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Climate Change in 2017: Implications for Business

[The Department of Defense] recognizes the reality of climate change and the significant risk it poses to U.S. interests globally. The National Security Strategy, issued in February 2015, is clear that climate change is an urgent and growing threat to our national security, contributing to increased natural disasters, refugee flows, and conflicts over basic resources such as food and water. These impacts are already occurring, and the scope, scale, and intensity of these impacts are projected to increase over time.

— United States Department of Defense, July 2015[1]

The risk of large-scale climate change is one of the central issues facing the world. There is widespread consensus among the scientific community that the Earth is warming, that this warming is caused by human emissions of greenhouse gases (GHGs), and that the consequences of continued warming are likely to be severe. There is also global concern about the issue: in a recent Pew poll, majorities in all 40 nations polled said that climate change was a serious problem, and a global median of 54% said that it was a very serious problem.

But there is widespread disagreement about what—if anything—should be done in response. While many economists believe that the benefits of reducing global emissions greatly exceed the costs, there is only partial agreement as to what exactly should be done, how quickly it is appropriate to act, and who should pay the costs. Some people, particularly in the United States, reject the scientific consensus altogether. Others fear that many of the proposed solutions will be expensive and inefficient, or that the free riding problems inherent in reducing emissions—namely, that everyone benefits while particular nations, firms, or individuals must bear the costs—will make it impossible to substantially reduce the risk of significant global climate change.

As a result, the risks of climate change—and the costs and regulatory changes that these risks may drive—are emerging as central issues for the private sector. Some business leaders see climate change as a threat to their firms' viability. Others see opportunity in promoting technologies that will mitigate the risk of climate change by reducing GHG emissions or by helping the world in adapting to its effects. Some are actively lobbying against government action, while others are lobbying for industry, state, and global carbon policies. This note attempts to summarize what is known about the causes, current impacts, and likely future consequences of climate change; to outline the current debate about what should be done; and to explore the implications for the private sector.

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An Introduction to Climate Change

The Earth's average temperature has been increasing since the Industrial Revolution. Between 1880 and 2015, average global surface temperatures rose by 0.9°C (1.5°F) (**Exhibit 1**).[2] In 2016, the Earth experienced its third consecutive hottest year since recordkeeping began.[3] There is broad consensus in the scientific community that this warming has been largely driven by increases in atmospheric GHGs, particularly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). (Emissions of GHGs are often measured in equivalent units of CO_2 emissions, or CO_2eq, by indexing the 100-year global warming potential of each gas to that of CO_2.)[4] GHG emissions have been growing since the Industrial Revolution and were 60% higher in 2014 than they were in 1990 (**Exhibit 2**).[5] Since 1880, atmospheric CO_2eq concentrations have risen from around 290 ppm to 430 ppm.[6]

The primary sources of year-on-year GHG emissions are the "burning of fossil fuels (coal, oil, and gas), with important contributions from the clearing of forests, agricultural practices, and other activities."[7] Specifically, fossil fuel consumption for electricity and heat production generates about 25% of total GHG emissions; industry 21%; transportation 14%; other energy 10%; and buildings 6%; while agriculture, forestry, and other land uses (AFOLU) contribute the remaining 24% of total GHG emissions (**Exhibit 3**).[8,9] In 2016, fossil fuels provided 81% of global energy supply—a trend that is expected to continue (**Exhibit 4**).[10] Emissions vary widely across countries, and developing countries are predicted to drive emissions increases going forward (**Exhibit 5**).

Higher levels of atmospheric GHGs raise temperatures by increasing *radiative forcing*, or the amount of energy arriving on Earth's surface (**Exhibit 6**).[11] Higher GHG concentrations increase the amount of radiation caught by the atmosphere and redirected back toward the surface. The difference between the rate at which energy arrives on the Earth's surface and the rate at which it radiates back is the net heating, with this heat accumulating at and below the surface of Earth's oceans, land, and ice. Currently the Earth retains approximately 816 terawatts of excess heat per year, or more than 50 times the world's entire energy consumption.[12,13] Evidence of this retained heat is discernible in observations that document Earth's rising surface temperatures, warming oceans, and melting ice.[14]

Nearly 200 nations have formally acknowledged in joint statements and international agreements that human activity is responsible for global climate change, including the national academies of Brazil, Canada, China, France, Germany, India, Italy, Japan, Russia, the United Kingdom, and the U.S.[15] About 97% of climate scientists agree that human activity is causing climate change.[16,17] Some observers claim that climate change is not a man-made phenomenon, blaming factors such as solar cycles (variations in the amount of energy reaching the Earth from the sun) or volcanic activity for recent increases in temperature.[18] Others allege that scientists lack consensus or that global temperatures have cooled.[19] However, variations in the sun's radiation are small relative to surface forcing associated with GHGs, and the dominant 11-year cycle in solar output barely registers in global temperatures. In addition to the changes in ocean, ice, and surface temperatures, the pattern of warming as a function of latitude and elevation in the atmosphere allows for fingerprinting human-caused effects.[20] Climate skepticism, in the sense of raising doubt about the fundamentals of the science, is more prevalent in the U.S. than in other developed nations (**Exhibit 7**).[21] There is little debate about the reality of global warming beyond U.S. boundaries, even amongst conservative political parties in nations such as Sweden (Moderaterna), Canada (Conservative Party), the U.K. (Conservative Party), and Germany (CDU).[22]

Predicting how GHG emissions are likely to evolve and the resulting changes in Earth's temperature is a complex undertaking, fraught with uncertainty. In response, the United Nations (UN) Environmental Program and the World Meteorological Organization created the Intergovernmental Panel on Climate Change (IPCC) in 1988 "to prepare, based on available scientific information, assessments on all aspects of climate change and its impacts, with a view of formulating realistic response strategies."[23,24] Scientists are independently nominated for participation by their own governments, and in 2016 over 2,000 scientists from 154 countries participated in the IPCC process.[25]

By 2016, CO_2 concentrations in the atmosphere were 404 parts per million (ppm), the highest levels in 400,000 years and up almost 7% since 2007 (**Exhibit 8**).[26] The IPCC's states that, if no additional efforts are taken to mitigate the effects of climate change, CO_2eq concentrations are likely to increase to approximately 450 ppm by 2030 and between 750 ppm and 1,300 ppm by 2100.[27] If this occurs, by 2100 the planet may experience global mean surface temperature increases of 3.7°C to 7.8°C (6.7°F to 14°F) compared to pre-industrial levels.[28,29] (See **Exhibit 9**.)

However, many scientists stress that such estimates are probabilistic and that temperature increases could be either much greater or—perhaps—smaller **(Exhibit 10)**. Most of the uncertainty involves the upper estimates of possible warming, because temperature changes in response to increased radiative forcing are bounded near zero on the low end but are essentially unbounded on the high end. The reason for this asymmetric uncertainty is the presence of positive feedback loops. For example, global warming reduces the amount of snow and ice covering Earth's surface. Since snow and ice reflect more sunlight back into space than does exposed land, this reduction further accelerates the rate of global warming.[30,31] Similarly, higher temperatures are causing the melting of the permafrost that covers 24% of the Earth's Northern Hemisphere. The permafrost contains an estimated 1,400 gigatons[a] (Gt) of trapped carbon, between 33 and 114 Gt of which could be released by 2100 if the rate of thawing continues, compared to a total of 850 Gt of carbon already in the atmosphere and anthropogenic carbon emissions of about 10 Gt per year.[32,33,34,35]

One issue that concerns many scientists is that many of global warming's impacts have unfolded significantly faster than expected. For example, in 2007 the IPCC projected that global average sea levels would rise 0.6 meters (2 feet) by 2100, but in 2013 the prediction was revised to as much as 0.98 meters (3.2 feet), and then in 2016 revised again to up to 2 meters (6.6 feet).[36] Similarly, the IPCC has historically underestimated the pace of Arctic sea ice decline. In 2007, models predicted the first ice-free Arctic summers could arrive nearly a century later, in 2100; but in 2012, the estimate was that this would occur in only 20 to 30 years.[37] The actual pace of sea ice decline has turned out to be far quicker, "exceeding the worst worst-case scenario predicted in the 2007 IPCC report."[38] As of 2016, "[the] Arctic is on track to be free of sea ice this year or next for the first time in more than 100,000 years."[39]

The Impacts of Climate Change

Rising GHG concentrations are expected to have a wide range of effects, including:

Rising sea levels As the world warms, sea levels rise, both because increasing temperatures cause ice fields to melt and because the oceans themselves are warming (and therefore expanding). Since around 1870, rates of global sea level rise (GSLR) have accelerated and are now about 3.5 mm (0.15 inches) per year.[40] By 2100, sea levels are projected to rise by up to 2 meters (6.6 feet), depending on GHG emissions and the effects of warming air and ocean water on ice (**Exhibit 11**).[41]

Two thirds of the world's largest cities are located in low-lying coastal areas, and increasing sea levels could submerge the land on which an estimated 470 million to 760 million people are living.[42,43] A number of island nations—including 11 of the Solomon Islands—are already submerged or at risk

[a] A Gt is 1 trillion metric tons (t), equivalent to 1,000 kilograms.

of total destruction. By 2050, between 665,000 and 1.7 million people in the Pacific are expected to be forced to migrate due to rising sea levels, including the entire populations of islands such as Fiji, the Marshall Islands, and Tuvalu.[44,45,46] In larger countries, such as Bangladesh and the Netherlands, a very large proportion of the population will probably be forced to relocate (46% and over 70%, respectively).[47] By 2100, in the U.S. alone, barring a concerted mitigation effort, $238 billion to $507 billion worth of coastal property will likely be below sea level.[48] Some U.S. cities, including Miami, Florida and Norfolk, Virginia, are in particular danger of inundation and increased flooding.[49]

Changing weather patterns and extreme weather Although it is difficult to link any single event directly to climate change, rising temperatures means that the atmosphere can hold more water vapor, allowing both for greater rates of rainfall and runoff when the air is saturated and for drier (more under-saturated) conditions otherwise.[50,51] In other words, though overall rates of evaporation are not changing greatly, extremes in precipitation are becoming less frequent but more intense, and as a result rainfall patterns are shifting across the world.[52] Since 2013, extreme drought has affected the Western U.S. In California, 2015 was the driest year on record, supplanting 2013; and 2014 had been the third-driest.[53,54] Somalia, Kenya, and other East African countries have experienced below-average rainfall since the late 1990s, contributing to a 30% reduction in crop yields and famines in 2010, 2011, and 2016.[55,56] There has also been an increase in the prevalence of hurricanes and other destructive weather events.[57] For example, in 2013 the Philippines was hit by one of the worst typhoons in recorded history (Typhoon Haiyan), which led to over 6,000 deaths, displaced nearly 4 million people, and caused billions of dollars in damages.[58]

Pressure on water and food Food production is tightly coupled with water availability. As recently as 2014, just 16% of the Earth's croplands were irrigated (as opposed to rainfed), but irrigated lands produced 36% of global harvest.[59] As the Earth warms, the combination of shrinking glaciers, reduced snowpack, and increasingly erratic rainfall raises fears of shortages, particularly in the world's most vulnerable regions.[60] Water shortages in Pakistan and India, for example, threaten the viability of agriculture in the region.[61,62] By 2030, overall demand for water may outstrip supply by 40%.[63] And by the 2090s, without significant reductions in GHG emissions, the proportion of the global land surface in extreme drought could increase from 1% to 3% today to 30%.[64] Global food production is also affected by warmer temperatures, increased CO_2 levels, and extreme weather events.[65] In some cases, increased CO_2 or warmer weather may accelerate crop growth or increase yields; however, yields decline above an optimal temperature that varies by crop, and crops grown under high levels of CO_2 yield less of nutrients such as zinc, iron, and protein.[66] Furthermore, warmer weather allows pests, weeds, and parasites to thrive; extreme weather can be destructive to farmland, crops, and livestock; and rising sea levels can erode and salinize croplands.[67,68]

Political and security risks Climate change has been linked to increased political instability worldwide.[69] When food prices rose sharply in 2007-2008, dozens of so-called "food riots" caused casualties in Argentina, Cameroon, Haiti, and India.[70] Both the Somalian civil war and the Syrian civil war have been linked to drought and famine exacerbated by climate change.[71] The U.S. military has suggested that climate change is "a salient national security concern," which could redraw maps and spheres of engagement while compounding conflicts and resource constraints in some of the world's already vulnerable countries, leading to further instability and even war.[72,73] (See **Exhibit 12** for a map of major disaster-related displacements in 2014.**)**

Human health risks Higher temperatures increase the possibility of heat-related injury and death.[74] As many as 70,000 people died in the 2003 European heat wave, and more than 50,000 died in a 2010 heat wave in Russia.[75,76] Thousands more have perished in increasing and increasingly severe heat waves in India (2015), Europe (2006), and around the world.[77] Water- and vector-borne diseases are also projected to increase as insects and other carriers move into higher latitudes.[78] For example, between 2000 and 2013, instances of Lyme disease in the U.S. doubled.[79] A warmer atmosphere also increases the concentrations of smog (a lung irritant), while continuing to burn fossil fuels—particularly coal—can lead to millions of premature deaths. The burning of coal has been linked to tens of thousands of premature deaths in the U.S. annually, and the World Health Organization found that, in 2012, 7 million people worldwide died due to air pollution (**Exhibit 13**).[80]

Studies conducted to quantify economically the health impacts of climate change have suggested that the costs are substantial. According to research conducted by the Harvard T.H. Chan School of Public Health, the extraction, transportation, processing, and combustion of coal in the U.S. cause 24,000 excess lives lost annually due to lung and heart disease (evaluated at $187.5 billion per year) and 11,000 excess lives lost annually due to high health burdens in coal-mining regions (evaluated at $74.6 billion per year).[81] Another study conducted by the EPA found that the health impacts of fossil fuel electricity in the U.S. totaled between $362 billion and $887 billion per year (representing 2.5% to 6.0% of GDP) due to premature mortality, workdays lost, and other direct healthcare costs.[82]

Impact on wildlife and ecosystems Climate change also significantly affects many natural habitats and puts many species at higher risk of extinction in the coming century.[83] Observing that current extinction rates are 100 times the normal rate, some scientists predict that the Earth is headed for the sixth mass extinction event in its history.[84,85] By 2100, 30% to 50% of the world's land and marine animal species may be extinct.[86,87] Climate change is also having significant effects on the oceans. Over the last 100 years, it has raised near-surface ocean temperatures by about 0.74° C (1.3° F) and made the sea significantly more acidic, likely affecting marine animals' reproduction and survival.[88,89,90] (**Exhibits 14** and **15**.) In some places, live coral coverage is only half of what it was in the 1960s, and scientists predict that the world's coral reefs could be entirely extinct by 2050.[91,92] As many as 1 billion people rely on the fish that live in coral reefs as their primary protein source.[93]

Responding to Climate Change: The Ongoing Debate

The discussion of what should be done in response to climate change is complicated by two distinct but interrelated problems. The first is the sheer magnitude of the changes required to mitigate and/or adapt successfully to climate change, and the second is the global free riding problem that impedes consensus on who should pay for those changes.

There is general agreement in the scientific community that global warming needs to be limited to 2°C (3.6°F) above pre-industrial levels by the end of the 21st century in order to avoid potentially dangerous impacts.[94] This probably requires atmospheric concentrations of CO_2eq, which in 2016 were estimated to be around 430 ppm, to remain below 450 ppm.[95,96] Keeping the Earth within the 2°C limit thus requires urgent action (**Exhibit 16**).[b]

In general, reducing emissions requires action on three fronts: greatly increasing the efficiency with which energy is used; "decarbonizing" the world's energy system through the use of renewable energy

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[b] For all the comforting predictability implied by the graphs, charts, and proposals of international climate assessment reports, if climate change unfolded as forecast under some CO_2 emissions scenarios, no one really knows what would happen. Harvard economist Martin L. Weitzman has argued that "the most striking feature of the economics of climate change is that its extreme downside is non-negligible. Deep structural uncertainty about the unknown unknowns of what might go very wrong is coupled with essentially unlimited downside liability on possible planetary damages." See his "Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change," *Review of Environmental Economics and Policy*, vol. 5, issue 2, 2011, pp. 275, http://reep.oxfordjournals.org/content/5/2/275.abstract, accessed September 2016.

or carbon capture; and changing land use and management. The Carbon Mitigation Initiative at Princeton University suggests that it is useful to think about the magnitude of the changes that are required in terms of "wedges," where each wedge represents a carbon-cutting strategy that has the potential to avoid 1 billion tons of carbon emissions per year by 2060, or about one eighth of what is required to stabilize global emissions. The Carbon Mitigation Initiative presents a menu of 15 wedges, including "cutting emissions by 25% in all new and existing residential and commercial buildings" and "adding new nuclear electric plants to triple the world's current nuclear capacity," that if taken together would keep emissions at or below levels seen in 2000 (**Exhibit 17**).[97]

Improvements in energy efficiency Reducing energy demand through conservation and innovation appears to be a particularly promising means of reducing GHG emissions. For example, between the mid-1980s and 2015, energy efficiency standards and labeling for appliances and a broad range of products in the U.S., U.K., Australia, and other nations reduced the energy consumption of these products by 10% to 25%.[98] In 2015, such measures saved consumers and businesses in the U.S. about $40 billion.[99] A National Academies study concluded that while using LEED-Silver or equivalent standards in the construction of new buildings increased the costs of initial construction by up to 8%, energy costs would be reduced by between 5% and 30% over the life of the building.[100] A report from the UN Foundation estimated that an investment of $3.2 trillion worldwide in energy conservation would avoid new supply investments of $3 trillion and would pay for itself within three to five years.[101] Since most energy use occurs in cities with rising populations, policies that encourage residential density, localized employment opportunities, diversified urban land use, and public transportation are particularly important.[102] Behavioral changes can also have a tangible impact. For instance, McKinsey estimates that changes such as driving smaller cars could reduce fuel demand by about 10% in 2030.[103] The International Energy Agency (IEA) estimates that around 40% of the reductions required by 2050 could potentially come from increased energy efficiency.[104]

Moving away from fossil fuels Keeping GHG concentrations in the atmosphere below 450 ppm requires either the development of the ability to capture CO_2 directly from the atmosphere at scale and/or moving away from coal, natural gas, and oil toward hydro, nuclear, solar, and wind power.[105] In 2014, the world used an average of 16 to 18 terawatts (TW) of power at a given moment.[c] About 28.6% of this energy was supplied from coal, 31.1% from oil, 21.2% from natural gas, and 4.8% from nuclear.[106] Biofuels and waste made up 10.3%, hydro 2.4%, and "other" renewables—geothermal, solar, wind, etc.—made up 1.4%.[107] Despite its tiny market share, solar energy has been frequently cited as a promising contender to fossil fuels. A key reason is that the experience curve (or learning curve) of solar photovoltaic (PV) modules has been shown to be about 20%, meaning that the price per module drops by about 20% every time the cumulative production of PV modules doubles.[108]

Are solar and wind energy already competitive against fossil fuels today? In some parts of the world, at some times of day, the answer is almost certainly yes. In 2015, the average retail price of electricity was $0.1267 per kWh for residential, $0.1059 per kWh for commercial, and $0.689 per kWh for industrial customers.[109] In areas such as the Southwest U.S. and North Africa, unsubsidized utility-scale solar PV can cost between $0.05 per kWh and $0.07 per kWh.[110] The cost of land-based wind power declined from $0.55 per kWh in 1990 to between $0.04 and $0.06 per kWh in 2016 (**Exhibits 18** and **19**).[111] Some analysts believe that wind is currently the cheapest source of power in about one third

[c] A note about "watts" (W) versus "watt hours" (Wh): The watt is a measure of power, or the *rate* at which energy is generated or consumed. For example, the Three Gorges Dam has a power-generating capacity of 22,500 megawatts (MW). The watt hour is a measure of the *amount* of energy. The annual energy output of power stations is given in this measurement. For example, in 2014 the Three Gorges Dam generated 98.8 terawatt-hours (TWh) of electricity. When a light bulb with a power rating of 100 W is turned on for one hour, the energy used is 100 Wh or 0.1 kilowatt hours (kWh).

of the US.[112] Moves toward increased use of solar and wind are complicated by the fact that, as of 2016, neither solar nor wind can provide baseload (or continuous) power.[113] Deploying wind and solar at scale thus requires significant advances in energy storage and the development of a *smart grid* to redirect excess power over long distances.[114] Opinions differ as to how soon this will be feasible and how much it will cost, but some analysts believe that it is likely the U.S. will be able to decarbonize its energy system by 2050 (**Exhibit 20**).[d]

Expanding nuclear power is another option, in particular through the accelerated diffusion of so called "fourth generation" nuclear power: recent developments hold the promise of significantly reducing the capital costs associated with building nuclear power reactors while also making them safer and reducing their waste production.[115] In addition, transportation is responsible for 26% of U.S. CO_2 emissions, making it the second largest source behind electricity (30%).[116] Efforts to reduce emissions from the sector include substantial investments in both biofuels and electric vehicles.

Changes in agricultural, forestry, and other land use practices Changes in land use also have the potential to be an important factor in reducing carbon emissions.[117] For example, from 2000 to 2005, the burning of tropical forests accounted for 7% to 14% of all anthropogenic CO_2 emissions.[118] Because forests act as sinks that remove carbon from the atmosphere and place it in the ground, the destruction of those forests accelerates the pace of climate change.[119] Biochar—charcoal added to soil to enhance crop yields and nutrition—is one potential means of reducing GHG emissions while simultaneously improving soil health.[120] Rather than burning agricultural and forestry waste, a source of enormous GHG emissions, waste biomass could be converted to biochar, which stores carbon in soil for thousands of years.[121] Other changes in agricultural practices aim to reduce methane emissions from livestock, which account for 14.5% of global CO_2eq emissions.[122] One possible solution is the use of feed additives, which could reduce these emissions by 25% to 30%.[123] The U.N. Food and Agriculture Organization estimates that changes in practices "within existing [livestock agriculture] production systems could cut agricultural emission by about 30%."[124]

Geoengineering Some scientists claim that geoengineering, or intentionally interfering in the world's climate systems, is a possible solution to mitigating climate change.[125] They suggest exploring possibilities like injecting sulfates into the atmosphere, where their high reflectivity would stop up to 1% of the sun's radiation from reaching the Earth's surface.[126] One plan in the U.K. involves pumping "water nearly a kilometer up into the atmosphere, by way of a suspended hose" attached to a "stadium-size hydrogen balloon" in the stratosphere, 20 km above the Earth.[127] The plan, called Stratospheric Particle Injection for Climate Change (SPICE), is meant to test the feasibility of one day spraying sulfate particles in place of water.[128] SPICE and other geoengineering ideas were inspired by studying the atmosphere-cooling effects of volcanic eruptions, such as the Mount Pinatubo, Philippines eruption of 1991, which "spewed 20 million tons of sulfate particles into the atmosphere, cooling Earth by 0.5 degree Celsius for 18 months."[129,130] Preliminary estimates suggest that geoengineering could be relatively cheap, although it would have to be maintained continuously in order to control the Earth's temperature.[131] However, this suggestion is hugely controversial. There are concerns that we have very little understanding of what the widespread distribution of sulfates might do and fear that they will damage the ozone layer, lead to drought, and possibly "disrupt the Asian and African summer monsoons, reducing precipitation to the food supply to billions."[132]

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[d] See Chris Goodall, *The Switch* (London: Profile Books, 2016).

The Debate: Who Should Pay and How Much Should Be Spent

At the highest level, several studies suggest that the costs of mitigating the effects of climate change are likely to be much lower than the costs of leaving it unchecked. For example, the IPCC estimated that keeping GHG emissions to a level that offers a 66% chance of not exceeding 2°C warming would cost 3% to 11% of world GDP by 2100, while leaving global warming unchecked might cost 23% to 74% of global per capita GDP by 2100 in lost agricultural production, health risks, flooded cities, and other major disruptions.[133,134]

One approach to this question is through attempts to calculate the "social cost of carbon" (SCC), a measure designed to capture the economic damages caused by carbon emissions and usually expressed as an estimate of the damages caused by burning one ton of carbon. SCC values project the impact of carbon emissions far into the future, so they are sensitive to discount rates and to assumptions about how climate damages are likely to unfold. In 2015, the U.S. government estimated that the SCC was $36 per metric ton of CO_2., using a discount rate of 3%(**Exhibit 21**).[135] This value suggests, for example, that the social costs of burning coal are significantly greater than the entire coal industry's revenues. The two most common types of coal in the U.S. cost $14.72 and $55.99 per ton at the mine, respectively; and each ton of burnt coal emits 1.7 t and 2.2 t of CO_2, respectively.[136,137,138]

The International Monetary Fund concluded that in 2013, fossil fuels caused $1.1 trillion in environmental and economic damages from climate change (1.5% of world GDP) and $2.2 trillion in health damages from pollution (3% of world GDP).[139] In the U.S. alone, fossil fuels led to $186 billion in climate change damages and $180 billion in pollution damages (each 1.1% of U.S. GDP).[140,141] (In 2010, the U.S. spent over $800 billion on coal, natural gas, and petroleum.)[e,142]

The fact that the benefits of addressing the problem of climate change almost certainly outweigh the costs—and that the effects of increased emissions are likely to last for thousands of years and affect the wellbeing of billions of people yet to be born—does not make concerted global action to address the problem easy. Indeed climate change is a difficult problem because addressing it requires dealing with (at least) three thorny issues: discount rates, free riding, and global geopolitics.

Discount rates How much do we value GDP 100 years in the future? If we apply a discount rate based on the conventional cost of capital of 7% to 8% the answer is "not very much." For example, $1,000 discounted at 7% for 100 years is worth only $1.15 in 2016 dollars. Many have argued that this is the wrong calculation and that it cannot be correct to place essentially no value on the wellbeing of our children's children, but there is enormous debate about how fast it makes sense to attempt to respond to climate change.[143] Analysis is complicated by the potential for technologies to become much cheaper in the future, just as solar panels have, and by the fact that climate change is already having major economic impacts. Hurricane Irene, for example, the storm system that hit New York City in 2011, caused around $15 billion or more in damage.[144] The costs of the Syrian conflict are plausibly many times that, not to mention the loss of life of hundreds of thousands of people.

Free riding Even given general agreement among nations that the costs of inaction outweigh the costs of action, addressing climate change still requires solving the free riding problem, or the fact that while the costs of reducing emissions must be incurred by particular firms, cities, or nations, the benefits will be experienced by everyone on the planet. GHG emissions are a classic "externality": their

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[e] This estimate included expenditures in the residential, commercial, industrial, and transportation sectors but did not include expenditures on retail electricity or biomass.

emission imposes harm on the entire community, but the emitters themselves—absent some form of cooperative agreement or global regulation—have no incentive to reduce them.[145]

Global geopolitics This issue is further complicated by the fact that many of the countries that are most vulnerable to climate change—primarily poorer developing nations—are those with relatively small historical carbon footprints. Many of them argue that the countries whose cumulative actions have contributed most to climate change, the developed nations, should bear most of the responsibility for cutting emissions.[146] This has proved to be a controversial idea, particularly as developing countries' emissions have increased rapidly in line with their economic growth. Many developing countries have chosen to pursue cheaper but more GHG-intensive energy sources such as coal-fired power plants to foster development.[147] Some experts believe that some developing countries may be able to "leapfrog" traditional energy-intensive development paths.[148]

Despite these formidable difficulties, the global community has been experimenting with a variety of mechanisms to address climate change. It is widely believed that the most effective way to reduce carbon emissions is to rely on market based mechanisms such as carbon taxes and/or cap and trade regimes.[149,150] Cap and trade systems issue permits that allow companies to emit a certain amount of GHGs; those companies that emit less than their initial allotments are then allowed to sell their excess permits to companies that wish to emit more than their initial allotment. The U.S. Acid Rain program relied on a cap and trade mechanism and succeeded in reducing sulfur dioxide (SO_2) emissions by 40% and acid rain by 65%. The estimated benefits of the program were $56 billion compared to costs of just $558 million.[151,152,153] In contrast, a carbon tax places a predetermined price on every ton of CO_2eq emitted into the atmosphere.[154] An EIA study found that total U.S. emissions could fall by four fifths by 2040 if the U.S. imposed a $25 per ton carbon tax in 2014 and raised it by 5% every year.[155] Both cap and trade systems and carbon tax programs seek to shape behavior by presenting the "real" external cost of emissions to firms and consumers.[f,156]

The first attempt to implement a global cap and trade regime to reduce GHG emissions was embodied in the Kyoto Protocol, which was adopted in 1997 and took effect in 2005.[157] The agreement mandated that developed countries reduce their overall GHG emissions to 5% below their 1990 levels between 2008 and 2012.[158] The Kyoto Protocol appears to have contributed to significant emissions reduction in the European Union but was never ratified by the U.S. and did not impose any obligations on developing countries such as China and India.[159] More recently, annual UN climate change conferences have brought together world leaders to review and extend the Kyoto commitments, with varying results. In 2015, 195 countries signed an agreement at the Paris Climate Conference (also known as COP21). It was the first commitment by nearly all of the world's nations to take steps to curb GHG emissions and keep temperature increases "well below" 2°C.[160]

In the absence of binding global commitments, some states and regions have experimented by imposing their own carbon taxes and cap and trade regimes. Norway introduced a countrywide carbon tax in 1991.[161] Australia instituted a carbon tax in 2012 but repealed it the following year.[162,163] A consortium of states including Connecticut, New York, and Massachusetts set up a cap and trade regime titled the Regional Greenhouse Gas Initiative.[164] One study found that the program produced $1.6 billion in net value added and $16.1 billion in increased employment between 2009 and 2011.[165]

[f] Regulations that seek to directly shape behavior by mandating the use of energy efficient appliances can be effective tools for reducing energy consumption or supporting a shift to lower carbon fuels. Many studies have explored the conditions under which this is likely to be the case. Source: "Scientific Assessment of Ozone Depletion: 2006," World Meteorological Organization, pp. 19, available at http://www.esrl.noaa.gov/csd/assessments/ozone/2006/chapters/contentsprefaceexecutivesummary.pdf, accessed September 2014.

California introduced a cap and trade system in 2013.[166] The Canadian province of British Columbia instituted the only North American carbon tax in 2012.[167] The tax, which was designed to be revenue neutral, brought in $1.1 billion in 2013.[168] The tax has not had an adverse effect on the province's competitiveness in the agriculture sector, although industries like cement manufacturing may have lost business.[169] In December 2016, Prime Minister Justin Trudeau of Canada announced plans to introduce nationwide carbon pricing in 2018, which would set a minimum price of about $7.60 per metric ton on fossil fuels that would increase to $38 per metric ton in five years.[170]

A number of countries have experimented with a range of other policies designed to reduce emissions. Many have offered subsidies to offset the costs of developing and producing renewable energy, such as simple lump-sum rebates or grants typically provided at the beginning of a project. Such policies can help to level the playing field as many countries also continue to provide fossil fuel subsidies.[171] For example, in 2015 China led the world with $103 billion in renewable energy investments, 36% of the world's total,[172] and in the same year over 20% of China's energy generation came from renewable sources.[173] Many American states have imposed renewable portfolio standards, mandating that a certain proportion of electricity supply must be generated from renewable sources.[174] Congestion charging has led to significant reductions in car usage in places such as Singapore, London, and Stockholm. Tax credits have been used to incentivize investments such as renewable energy projects or residential efficiency improvements; and performance standards mandating the use of lower-energy technologies are found in many countries (**Exhibit 22**).[175]

Implications for the Private Sector

The challenge of climate change presents both wide-ranging threats and opportunities for the private sector. On the one hand, public support for some form of carbon regulation appears to be quite strong (**Exhibit 22**), and government action to mitigate climate change poses a significant threat for some firms. The immediate effects of climate change are already threatening the viability of existing business practices in agriculture, infrastructure, and construction. But climate change also opens up opportunities. For example, 45% of consumers are willing to pay more for a product "from a company known for being environmentally friendly," and the percentage of those willing to pay more for environmentally friendly products is highest among younger consumers.[176] Investment in sustainable energy technologies also is sometimes helping companies save on costs. For example, 25% of Wal-Mart operations are powered by renewables, and the company claims that from 2005 to 2016 its stores reduced energy use by 20% for a total savings of $1 billion.[177]

Climate change as a threat to business as usual

In the agricultural sector, widespread concern that climate change threatens the supply of key commodities such as tea, fish, and cocoa has led some of the largest firms to adopt sustainable farming and fishing practices. Many of the world's largest food companies believe this threat is compounded by the risk that being seen to contribute to climate change will increasingly become a public relations liability.[178] For example, in response to NGO accusations that they were contributing to deforestation, McDonald's spearheaded industry-wide efforts to preserve the Amazon rainforest; Unilever helped to found the Roundtable for Sustainable Palm Oil; and Kimberly Clark committed to sourcing 50% of wood fiber from natural growth forests by 2025.[179,180,181] In the insurance industry, some firms, such as Swiss Re and Prudential, have incorporated climate change into their product offerings, for example with "pricing plans that account for potential climate impacts like storms and fires" or by declining to offer policies for properties at risk of coastal erosion attributable to climate change.[182]

Some companies have responded by including a carbon price in calculations used to make investment decisions. In 2016, 437 large companies reported using "internal carbon prices" (up from 150 in 2014) and 583 more stated that they intend to implement internal carbon pricing by 2018.[183] For example, in 2012 Microsoft began charging individual business groups that used Microsoft services for their carbon use; by 2014, the internal carbon price completely offset Microsoft's energy consumption, reducing GHG emissions by 7.5 million tons and saving the company over $10 million. One sources suggested that "carbon is expected to converge at $140 per ton of CO2 by 2030 and $400 by 2050. In a 1.5-degree scenario, these costs would be considerably higher."[184]

The increasing likelihood that the world may adopt some form of global carbon regulation may also have significant implications for financial markets. Several observers have argued that current equity prices reflect a "carbon bubble," noting that if the world decides to keep atmospheric carbon concentrations below 450 ppm, the world's balance sheets hold energy reserves containing over twice the amount of carbon than would be burned. They suggest that this implies that current valuations do not take account of the threat that these assets and capital investments will be "stranded." One bank estimated that 40% to 60% of the current market value of the oil and gas sector may be at risk and noted that the top 200 companies in the sector have a total market value of $4 trillion.[185,186]

Some of the largest firms in conventional energy have reacted to the threat of regulation by attempting to discredit climate science. For example, between 2007 and 2015, ExxonMobil contributed $1.87 million to politicians who deny climate change and an additional $454,000 to the American Legislative Exchange Council, a corporate lobbying group that impedes efforts to fight climate change.[187] Some accounts suggest that Charles and David Koch, whose businesses generate $100 billion in annual revenues from fossil fuels and other related industries, have spent over $88 million to deny the science and block regulation.[188,189] Climate change denier organizations often follow a multi-pronged strategy that involves objecting to scientific data, funding seemingly academic front organizations, promoting "scientific spokespeople," declaring the need for more research regardless of the consensus, and lobbying government officials to prevent regulations.[190] A Union of Concerned Scientists report found that many of these tactics (and some of the people) were borrowed from the tobacco industry's earlier attempts to cast doubt on the scientific proof that smoking led to cancer.[191]

Mitigation and adaptation: the opportunities

Climate change also presents the private sector with a number of opportunities in mitigation and adaptation. According to data from Bloomberg New Energy Finance, in 2015 total investments in clean energy reached a global record of $286 billion, more than six times the 2004 total.[192] New solar and wind capacity composed about half of all new energy generation.[193]

In transportation, electric cars (both battery electric and plug-in hybrids) are projected to grow rapidly in the next 25 years. In 2015, only about 550,000 new electric cars were registered worldwide, less than 1% of the global total of 66 million passenger cars sold.[194] However, some estimates show that in 2040, sales of electric cars would hit 41 million units, making up 35% of all light duty vehicle sales. A key reason is that the price of electric vehicle batteries are expected to drop significantly (the learning curve of lithium-ion batteries is about 22%); and by 2022 electric vehicles are expected to be at price parity with conventional internal-combustion cars.[195,196] In 2015, Tesla Motors, the leading American electric vehicle company, had sales of only $4 billion, but its market capitalization in June of the same year was half that of General Motors—a firm whose 2015 sales were $152 billion.[197,198,199]

In urban planning and infrastructure, so-called "smart city" solutions might help urban centers reduce carbon emissions and be more energy-efficient. For example, Denmark operates district heating schemes—essentially large boilers that produce heat for whole neighborhoods through a networks of pipes—to reduce fuel consumption by capturing and redistributing heat that would have otherwise been dissipated. These underground pipes also combine heat transferred from industrial factories, incinerators, and transport systems. Such district heating solutions could help other cities significantly: One engineering firm estimated that in London, recapturing wasted heat could power 70% of the city's heating needs.[200] Other urban planning techniques to reduce fuel consumption include the preservation of green space (which would help sequester GHGs) and putting homes, shops, jobs, schools, and other destinations closer to public transportation.[201]

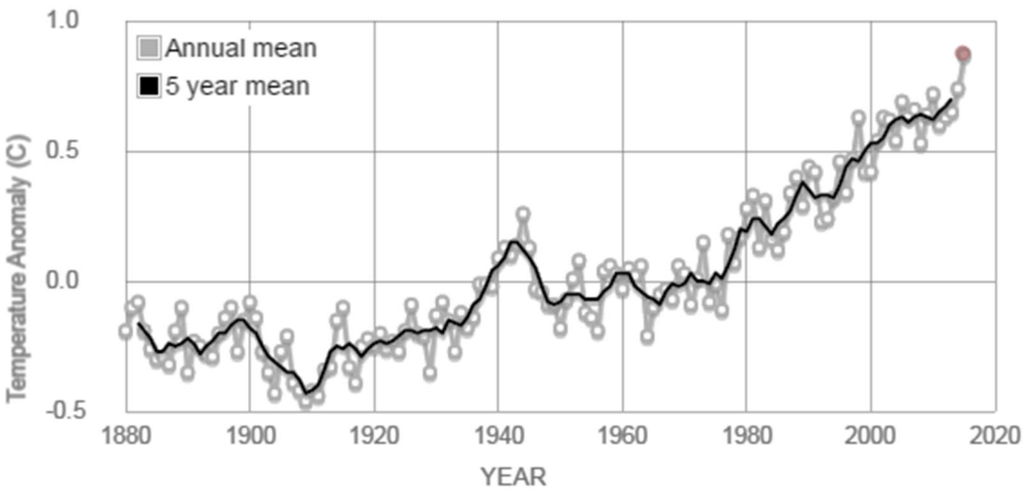
In industry and manufacturing, mitigation and adaptation opportunities can help firms save costs and reap competitive advantages. For example, technology companies can build new server centers in cold locations to lower cooling costs, and energy-intensive firms can consider relocating to locations where they can access cheap utility-scale solar energy.[202] Schneider Electric, a $29 billion revenue global energy giant, recently repositioned itself as the "global specialist in energy management," aiming for 75% of its product revenue to be derived from products featuring its "Green Premium"™ eco-label.[203,204]

In construction, new buildings are increasingly designed with better energy efficiency. LEED project registrations have grown by about 2,200 registrations each quarter, even during the 2008-2009 real estate crisis.[205] The energy efficient light bulb business is now a $170+ billion industry,[206] while Johnson Controls had 2015 revenues of over $10.5 billion in its building efficiency business.[207,208] In agriculture, firms that specialize in technologies to increase water supply or to increase its usage efficiency are expecting significant market expansion. The micro-irrigation market was valued at $1.9 billion in 2013 and is projected to grow at a CAGR of 17.2% from 2014 to 2019.[209]

Looking to the Future

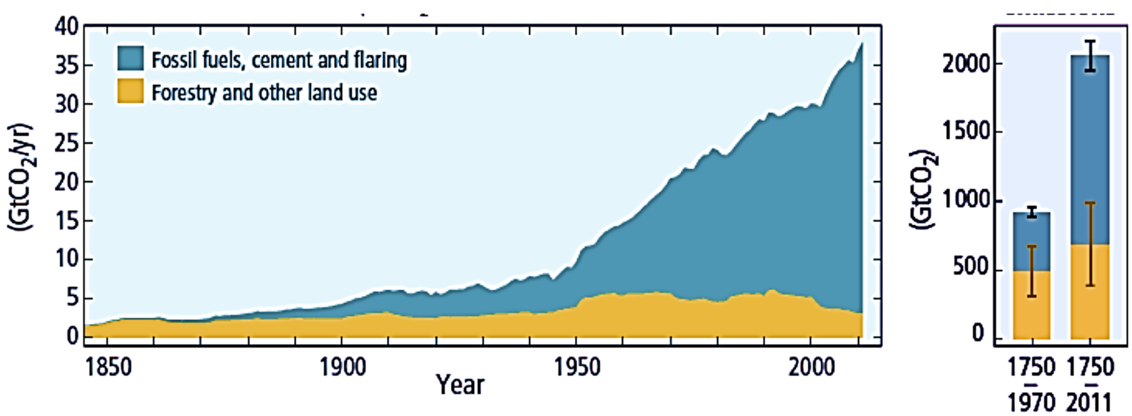
Climate change is a systemic issue that has far-reaching consequences for global health, security, and prosperity. But despite continued efforts, the world's emissions continue to increase, and 2016 was the hottest year on record for the third consecutive year.[210] Climate change mitigation will require a concerted global effort to enact systemic change, and many questions remain as to what shape such an effort should take. Should developed and developing nations be expected to participate equally in climate change reduction? How fast should such an effort move, and where should it focus? Will developing countries be able to leapfrog traditional energy-intensive development paths, or will they continue to face a trade-off between growth and low-carbon development? And what role should the private sector play in driving change?

Exhibit 1 Global Land-Ocean Temperature Index, 1880-2015



Source: NASA's Goddard Institute for Space (GISS), "Global Temperature," NASA website, http://climate.nasa.gov/vital-signs/global-temperature/, accessed August 2016.

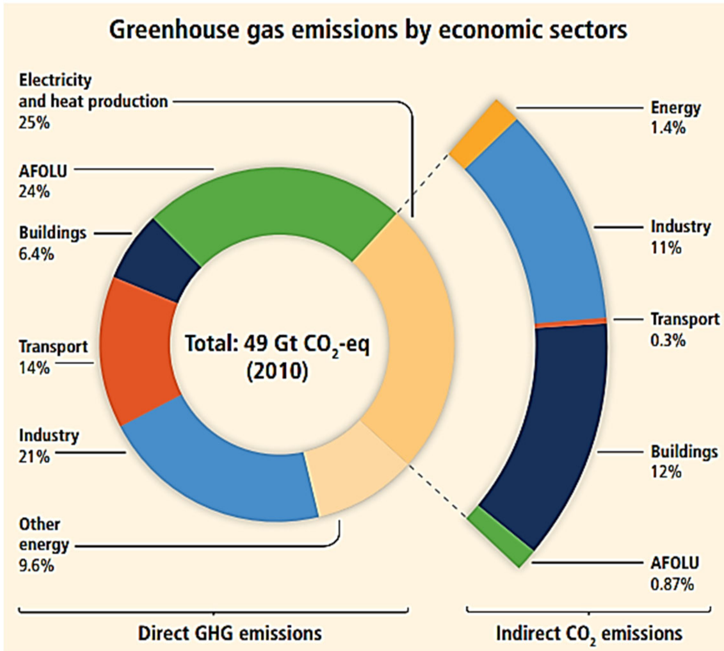
Exhibit 2 Atmospheric CO_2 emissions, gigatonnes CO_2 ($GtCO_2$), 1850-2011



Source: "Climate Change 2014: Synthesis Report," Intergovernmental Panel on Climate Change, 2014, p.3, https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf, accessed May 2016.

Note: Global anthropogenic CO2 emissions from forestry and other land use as well as from burning of fossil fuel, cement production and flaring. Cumulative emissions of CO2 from these sources and their uncertainties are shown as bars and whiskers, respectively, on the right hand side.

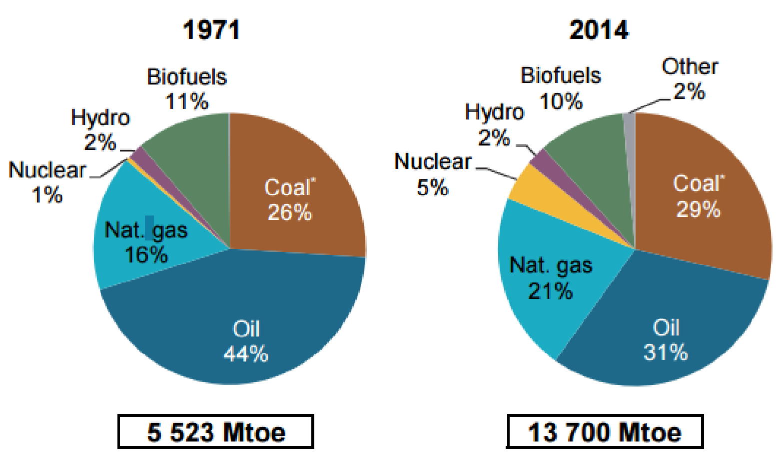
Exhibit 3 Global GHG Emissions by Economic Sector, 2010



Source: "Climate Change 2014: Synthesis Report," Intergovernmental Panel on Climate Change, 2014, pp. 47, https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_All_Topics.pdf, accessed June 2016.

Note: Indirect CO_2 emissions indicate distribution of electricity and heat production to sectors of final energy use. AFOLU was agriculture, forestry, and other land uses.

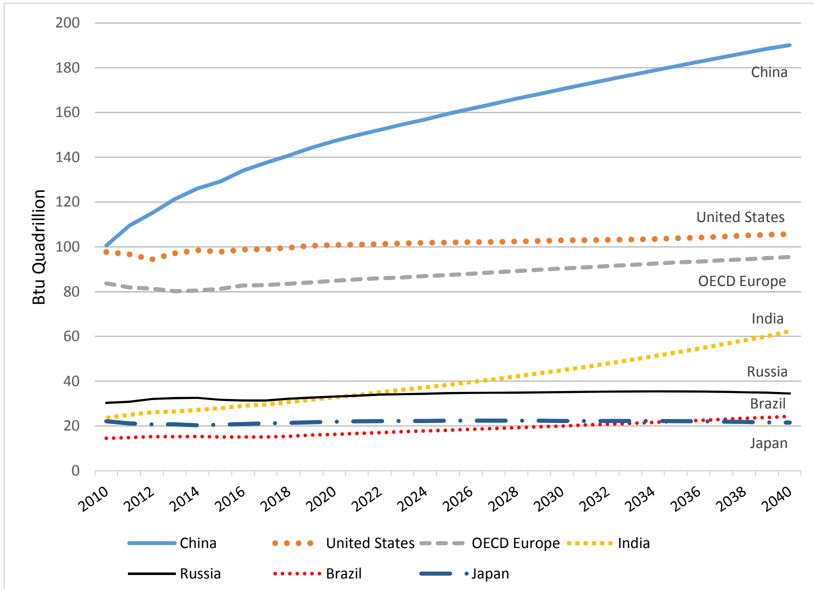
Exhibit 4 Global Total Primary Energy Supply by fuel, millions of metric tons CO2e (MtCO2e), 1971 and 2014



Source: International Energy Agency, "Key World Energy Trends. Excerpt from: World Energy Balances," 2016 using 2014 data, p. 4, https://www.iea.org/publications/freepublications/publication/KeyWorldEnergyTrends.pdf, accessed August 2016.

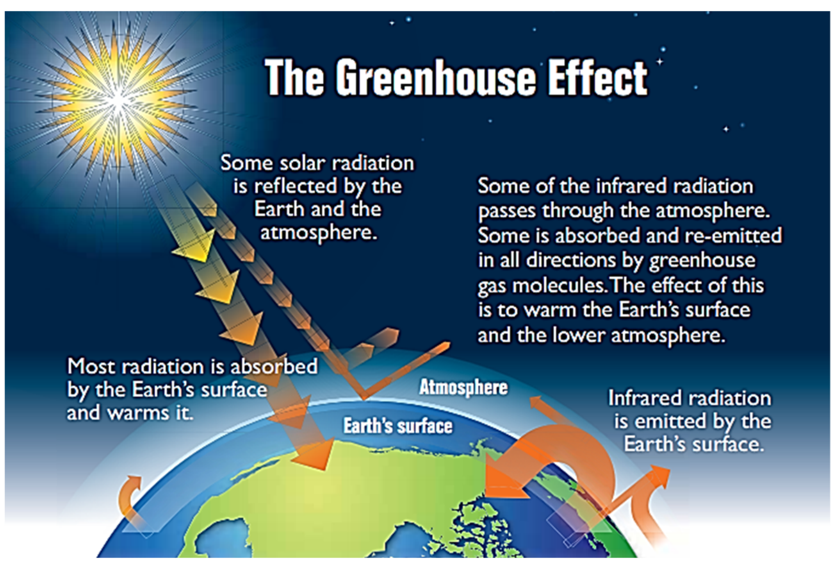
Note: In this graph peat and oil shale are aggregated with coal.

Exhibit 5 Projected World Energy Consumption by region, 2010-2040



Source: Adapted from International Energy Outlook 2016, World Total Primary Energy Consumption by Region, http://www.eia.gov/forecasts/aeo/data/browser/#/?id=1-IEO2016&region=0-0&cases=Reference&start=2010&end=2040&f=A&linechart=Reference-d021916a.3-1-IEO2016~Reference-d021916a.6-1-IEO2016~Reference-d021916a.8-1-IEO2016~Reference-d021916a.15-1-IEO2016~Reference-d021916a.18-1-IEO2016~Reference-d021916a.19-1-IEO2016~Reference-d021916a.24-1-IEO2016&ctype=linechart&sourcekey=0, accessed September 2016.

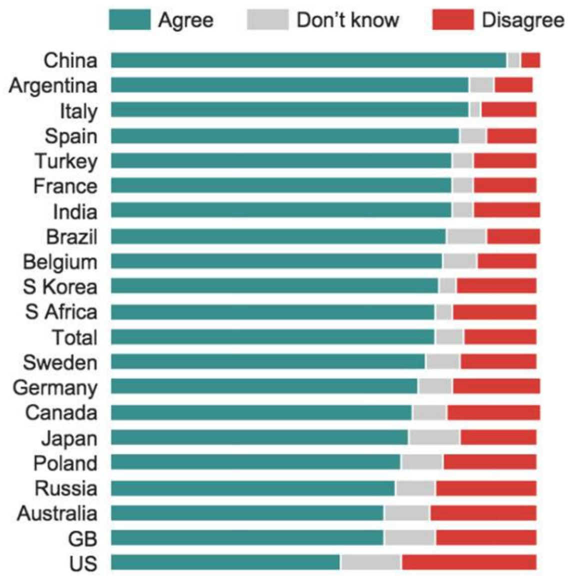
Exhibit 6 Radiative Forcing and the Greenhouse Gas Effect



Source: "Climate Change Indicators in the United States, 2014," U.S. Environmental Protection Agency, 3rd Ed., 2014, p. 4, https://www3.epa.gov/climatechange/pdfs/climateindicators-full-2014.pdf, accessed May 2016.

Exhibit 7 The General Public's Agreement with Climate Change Science Varies by Country, 2014

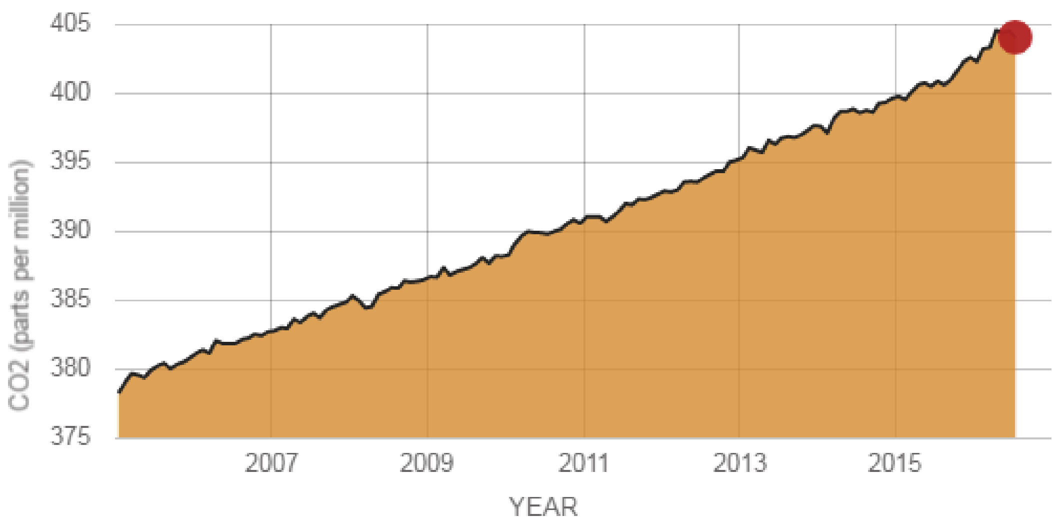
To what extend do you agree or disagree? The climate change we are currently seeing is largely the result of human activity



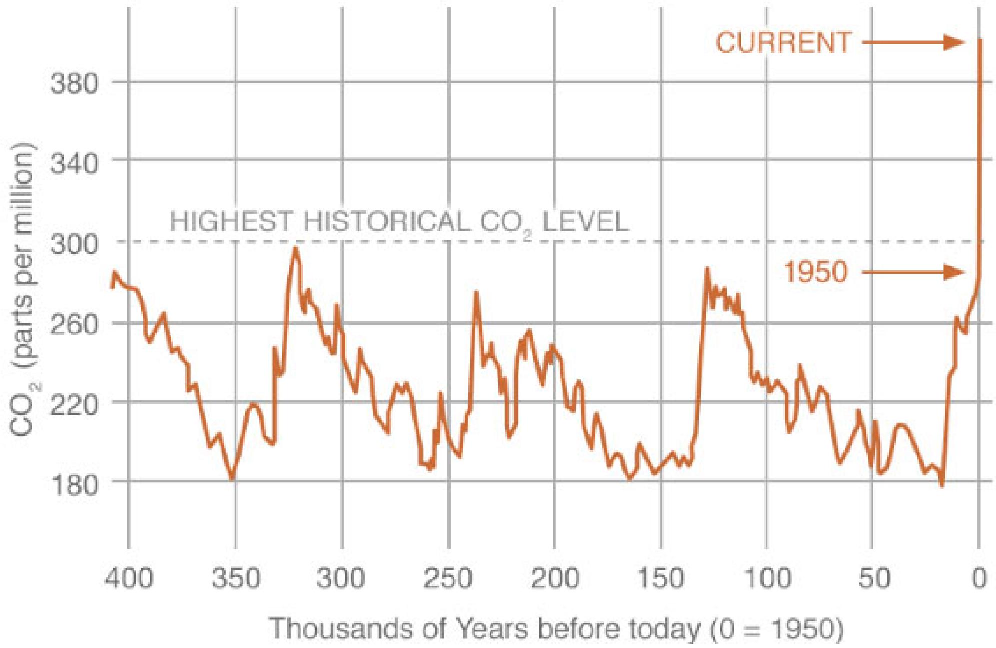
Source: "Where in the World Is Climate Change Denial Most Prevalent?" The New York Times, December 11, 2015, http://www.nytimes.com/interactive/projects/cp/climate/2015-paris-climate-talks/where-in-the-world-is-climate-denial-most-prevalent, accessed August 2016, citing "Global Trends 2014," Ipsos MORI, http://www.ipsosglobaltrends.com/environment.html, accessed August 2016.

Exhibit 8 Atmospheric CO_2 Levels, parts per million, direct and indirect measurements, 2005-2016 and historically

Direct Measurements, 2005-2016



Proxy (Indirect) Measurements



Source: "Carbon Dioxide," NASA website, http://climate.nasa.gov/vital-signs/carbon-dioxide/, accessed August 2016.

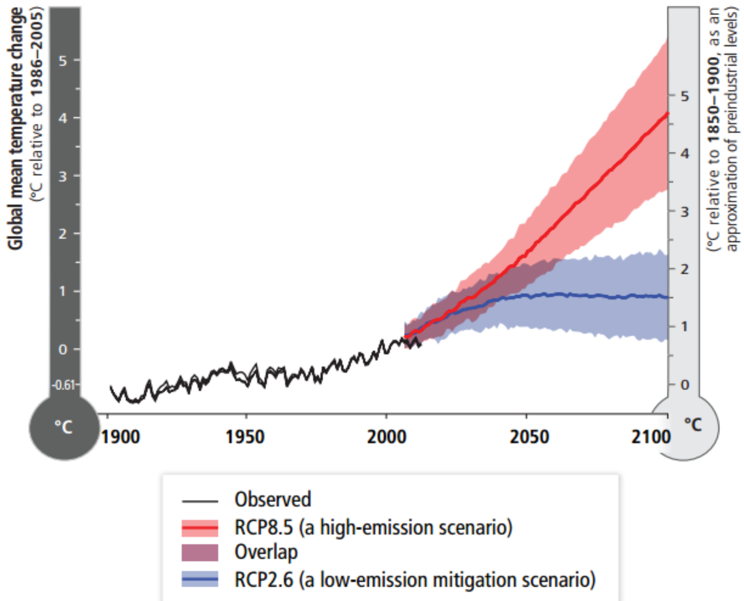
Note: Direct data source: Monthly measurements (average seasonal cycle removed). Proxy (indirect) data source: Reconstruction from ice cores.

Exhibit 9 Forecasted Temperatures Associated with Various GHG Concentration Scenarios, Collected and Assessed for IPCC Fifth Assessment Report (AR5)

CO_2eq Concentrations in 2100 [ppm CO_2eq] Category label (concentration range)[9]	Subcategories	Relative position of the RCPs[5]	Cumulative CO_2 emissions[3] [$GtCO_2$]		Change in CO_2eq emissions compared to 2010 in [%][4]		Temperature change (relative to 1850–1900)[5, 6]				
			2011–2050	2011–2100	2050	2100	2100 Temperature change [°C][7]	Likelihood of staying below temperature level over the 21st century[8]			
								1.5 °C	2.0 °C	3.0 °C	4.0 °C
< 430	Only a limited number of individual model studies have explored levels below 430 ppm CO_2eq										
450 (430–480)	Total range[1, 10]	RCP2.6	550–1300	630–1180	−72 to −41	−118 to −78	1.5–1.7 (1.0–2.8)	*More unlikely than likely*	*Likely*		
500 (480–530)	No overshoot of 530 ppm CO_2eq		860–1180	960–1430	−57 to −42	−107 to −73	1.7–1.9 (1.2–2.9)		*More likely than not*		
	Overshoot of 530 ppm CO_2eq		1130–1530	990–1550	−55 to −25	−114 to −90	1.8–2.0 (1.2–3.3)		*About as likely as not*	*Likely*	
550 (530–580)	No overshoot of 580 ppm CO_2eq		1070–1460	1240–2240	−47 to −19	−81 to −59	2.0–2.2 (1.4–3.6)	*Unlikely*			*Likely*
	Overshoot of 580 ppm CO_2eq		1420–1750	1170–2100	−16 to 7	−183 to −86	2.1–2.3 (1.4–3.6)		*More unlikely than likely*[12]		
(580–650)	Total range	RCP4.5	1260–1640	1870–2440	−38 to 24	−134 to −50	2.3–2.6 (1.5–4.2)				
(650–720)	Total range		1310–1750	2570–3340	−11 to 17	−54 to −21	2.6–2.9 (1.8–4.5)		*Unlikely*	*More likely than not*	
(720–1000)	Total range	RCP6.0	1570–1940	3620–4990	18 to 54	−7 to 72	3.1–3.7 (2.1–5.8)	*Unlikely*[11]		*More unlikely than likely*	
>1000	Total range	RCP8.5	1840–2310	5350–7010	52 to 95	74 to 178	4.1–4.8 (2.8–7.8)		*Unlikely*[11]	*Unlikely*	*More unlikely than likely*

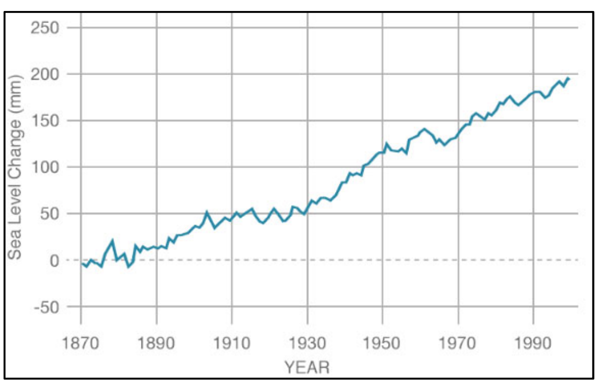
Source: Summary for Policymakers, In: Climate Change 2014, Mitigation of Climate Change," Intergovernmental Panel on Climate Change, 2014, p. 13, https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_summary-for-policymakers.pdf, accessed August 2016. See endnote.[211]

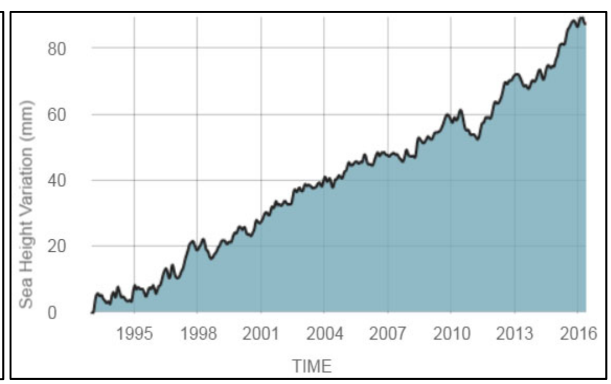
Exhibit 10 Global Mean Temperature Changes Measured in 1850-2012 and Forecasted Through 2100, 2014



Source: "Climate Change 2014: Impacts, Adaptation, and Vulnerability Top-Level Findings," Intergovernmental Panel on Climate Change, 2014, pp. 3, http://www.ipcc.ch/report/ar5/wg2/docs/WGIIAR5_SPM_Top_Level_Findings.pdf, accessed September 2016.

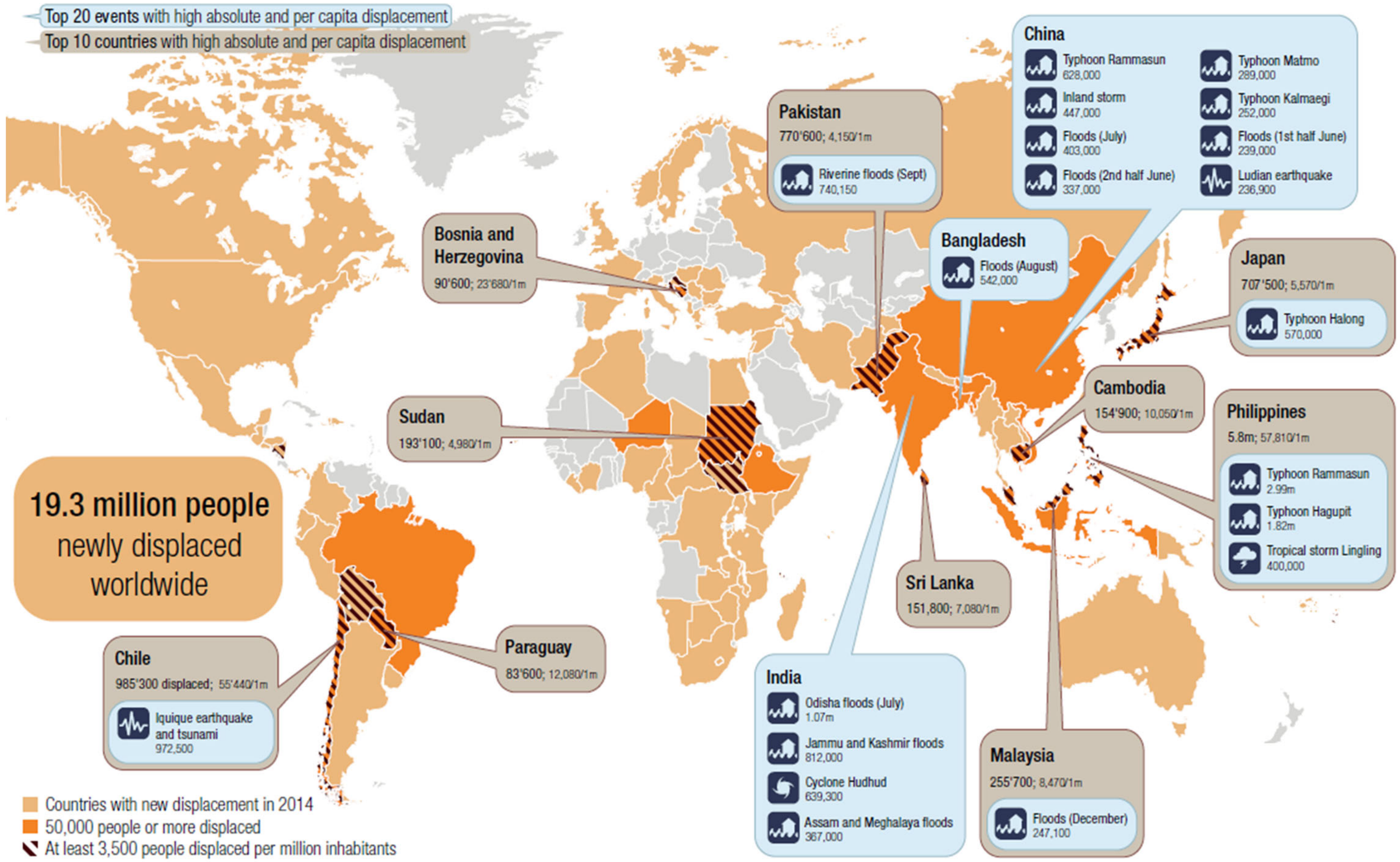
Exhibit 11 Sea Level Change, mm, 1870-2000 and Sea Height Variation, mm, 1993-present





Source: "Sea Level," NASA website, http://climate.nasa.gov/vital-signs/sea-level/, accessed August 2016.

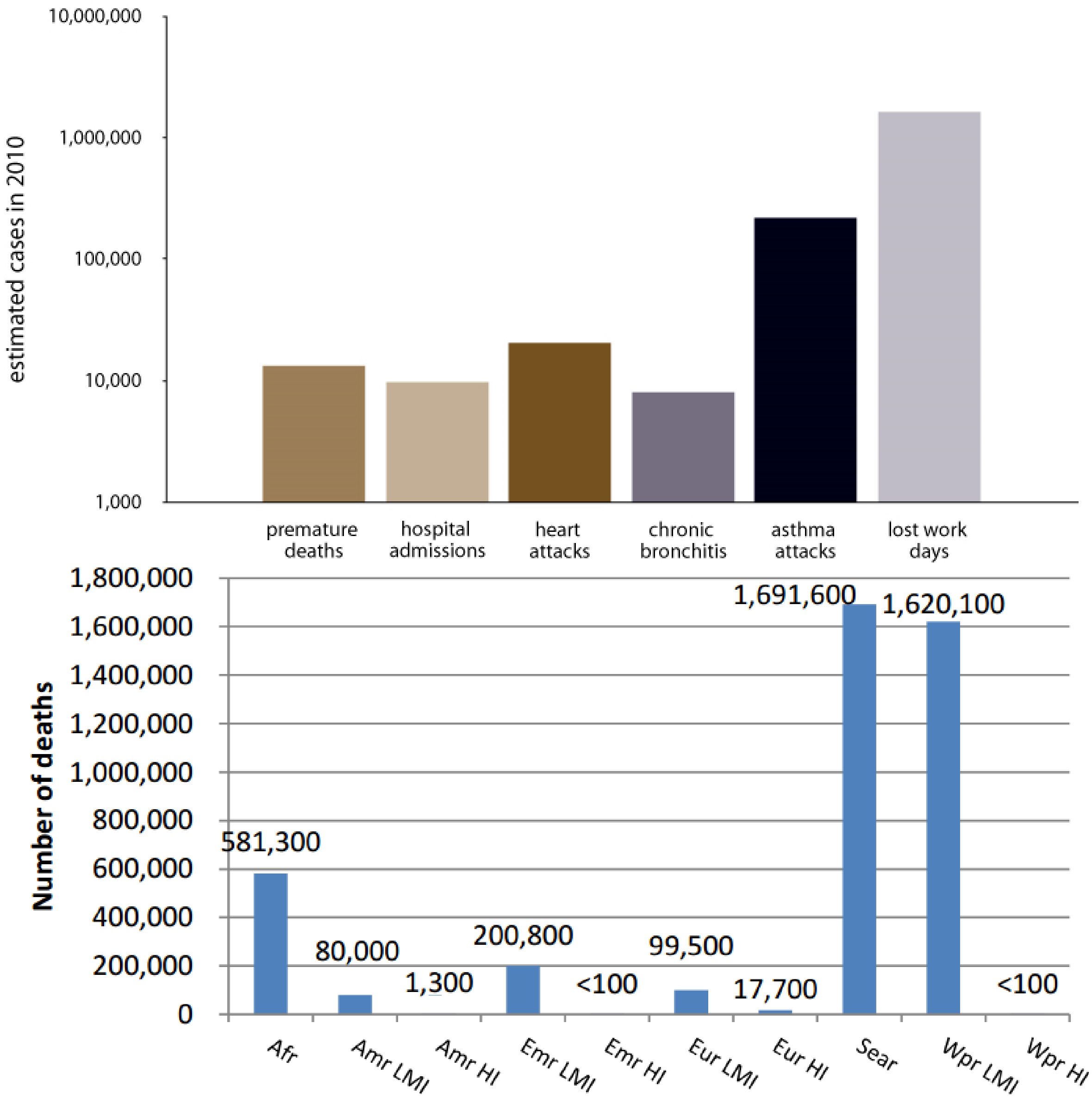
Exhibit 12 Population Displacement (People Leaving their Homes) due to Natural Disaster, Top 20 Events by Total Population Displacement and Top 10 Countries by Per Capita Displacement, 2014



Source: Michelle Yonetani, "Global Estimate 2015: People displaced by disasters," Internal Displacement Monitoring Centre (IDMC), July 20, 2015, http://www.internal-displacement.org/assets/library/Media/201507-globalEstimates-2015/20150713-global-estimates-2015-en-v1.pdf, accessed February 2017.

Note: 19.3 million people newly displaced worldwide. Bangladesh: Floods (August) 542,000; Bosnia and Herzegovina: 90'600, 23,680/1m; Cambodia: 154'900, 10,050/1m; Chile: 985'300 displaced, 55'440/1m; China: Typhoon Rammasun 628,000, Inland storm 447,000, Floods (July) 403,000, Floods (2nd half June) 337,000, Typhoon Matmo 289,000, Typhoon Kalmaegi 252,000, Floods (1st half June) 239,000, Ludian earthquake 236,900; India: Odisha floods (July) 1.07m, Jammu and Kashmir floods 812,000, Cyclone Hudhud 639,000, Assam and Meghalaya floods 367,000; Japan: 707'500, 5,570/1m, Typhoon Halong 570,000; Malaysia: 255'700, 8.470/1m, Floods (December) 247,100; Pakistan: 770'600, 4,150/1m, Riverine floods (September) 740,150; Paraguay: 83'600, 12,080/1m; Philippines: 5.8m, 57,810/1m, Typhoon Rammasun 2.99m, Typhoon Hagupit 1.82m, Tropical storm Lingling 400,000; Sri Lanka: 151,800, 7,080/1m; Sudan 193'100, 4,980/1m.

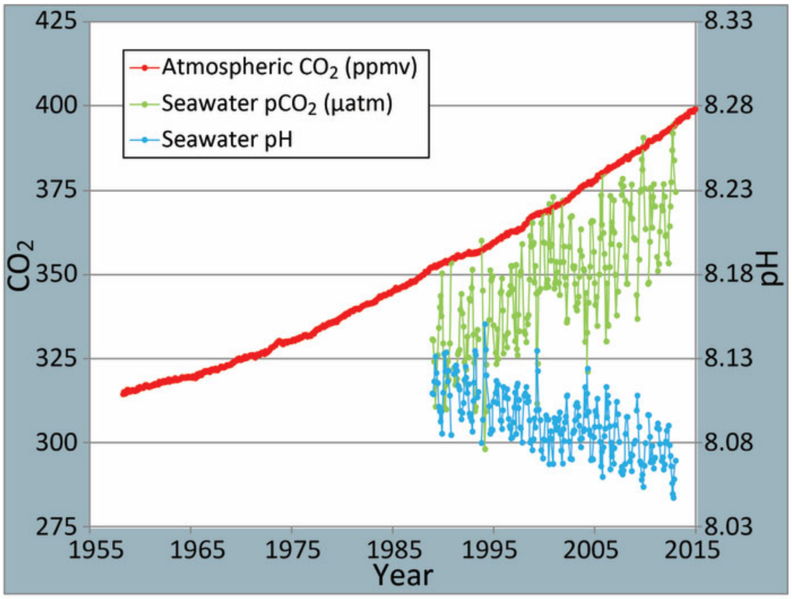
Exhibit 13 Estimated Health Effects from U.S. Coal-Fired Power Plant Emissions, 2010 and Total Deaths Attributable to Household Air Pollution, by region, 2012



Source: Conrad Schneider and Jonathan Banks, "The Toll From Coal," Clean Air Task Force, September 2010, http://www.catf.us/resources/publications/files/The_Toll_from_Coal.pdf, cited in "Estimated Health Effects from U.S. Coal-Fired Power Plant Emissions," Rocky Mountain Institute, http://www.rmi.org/RFGraph-health_effects_from_US_power_plant_emissions; World Health Organization, "Burden of Disease from Household Air Pollution for 2012," http://www.who.int/phe/health_topics/outdoorair/databases/FINAL_HAP_AAP_BoD_24March2014.pdf?ua=1, both accessed September 2016.

Note: Household air pollution; Amr: America, Afr: Africa; Emr: Eastern Mediterranean, Sear: South-East Asia, Wpr: Western Pacific; LMI: Low- and middle-income; HI: High-income.

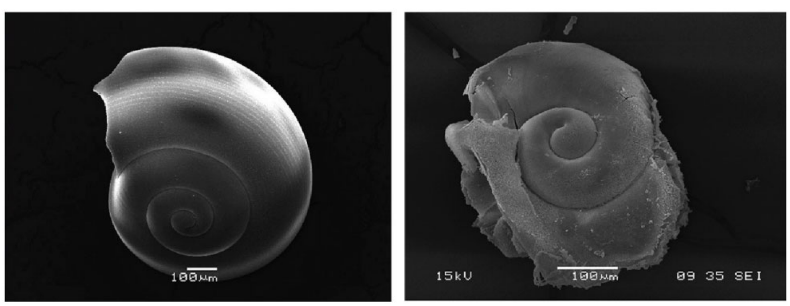
Exhibit 14 Increasing Atmospheric Concentrations of CO_2 Lead Oceans to Absorb More Carbon Dioxide, which Increases the Acidity of Oceans, Hawaii Carbon Dioxide Time-Series, 1958 to 2015



Source: "Ocean Acidification: The Other Carbon Dioxide Problem," NOAA PMEL Carbon Program website, http://www.pmel.noaa.gov/co2/story/Ocean+Acidification, accessed September 2016.

Note: This graph shows the correlation between rising levels of carbon dioxide (CO_2) in the atmosphere at Mauna Loa with rising CO_2 levels in the nearby ocean at Station Aloha. (Upward sloping data correspond to atmospheric and seawater CO_2 concentrations; downward sloping data correspond to seawater pH.)As more CO_2 accumulates in the ocean, the pH of the ocean decreases (modified after R.A. Feely, *Bulletin of the American Meteorological Society*, July 2008).

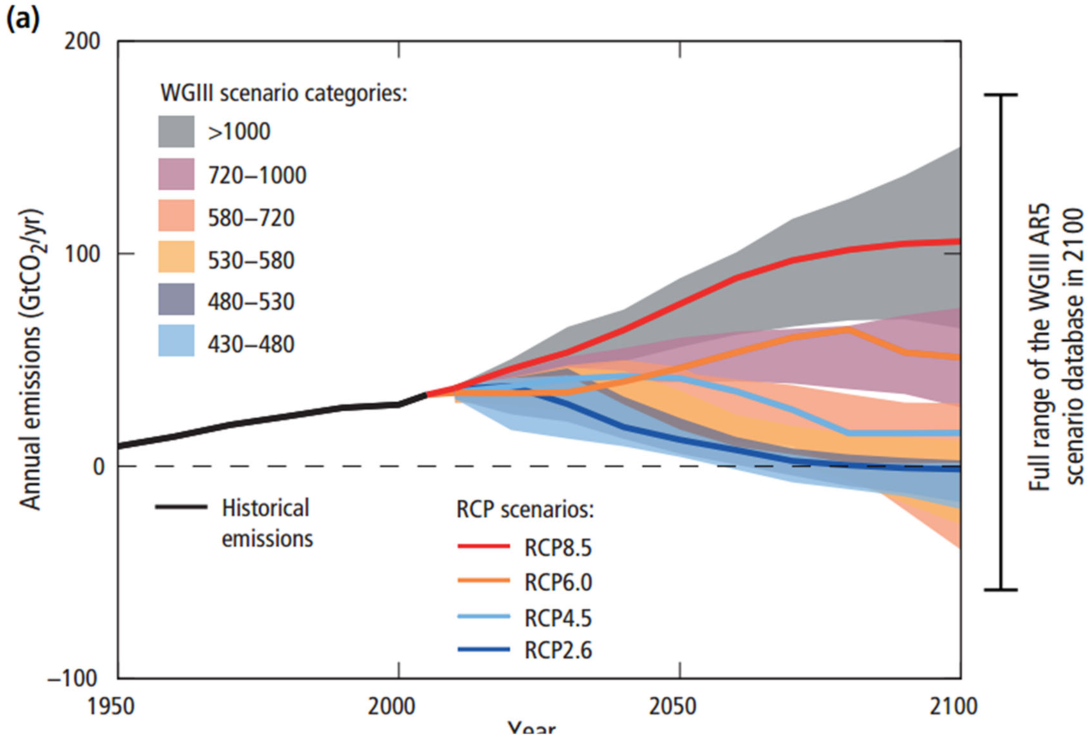
Exhibit 15 Climate Change and Ocean Acidification: Shells Dissolve in Acidified Ocean Water



Source: "Climate Change Impacts in the United States," U.S. Global Change Research Program National Climate Assessment and Development Advisory Committee, 2014, pp. 49, http://s3.amazonaws.com/nca2014/high/NCA3_Climate_Change_Impacts_in_the_United%20States_HighRes.pdf, accessed June 2016.

Note: Pteropods, or "sea butterflies," are free-swimming sea snails about the size of a small pea. Pteropods are eaten by marine species ranging in size from tiny krill to whales and are an important source of food for North Pacific juvenile salmon. The photos above show what happens to a pteropod's shell in seawater that is too acidic. The left panel shows a shell collected from a live pteropod from a region in the Southern Ocean where acidity is not too high. The shell on the right is from a pteropod collected in a region where the water is more acidic (Photo credits: (left) Bednaršek et al. 2012; (right) Nina Bednaršek).

Exhibit 16 Global Annual Anthropogenic CO_2 Emissions, 1950-2100 GtCO2 per year, 2014



Source: "Climate Change 2014: Synthesis Report," Intergovernmental Panel on Climate Change, 2014, p.9, https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf, accessed September 2016.

Exhibit 17 Stabilization Wedges

Stabilization wedges refer to a framework for preventing approximately 200 billion tons of carbon emissions by 2060 by keeping emissions flat for the next 50 years and then reducing emissions below today's levels in the second half of the twenty first century. "A wedge represents a carbon-cutting strategy that has the potential to grow from zero today to avoiding 1 billion tons of carbon emissions per year by 2060." There are 15 strategies to cut emissions in the electricity production, heating and direct fuel use, transportation, and biostorage sectors:

- Efficiency—Transportation: One wedge could come from doubling the efficiency of all the world's cars from 30 miles per gallon to 60 miles per gallon using hybrid and diesel technologies; increase aviation efficiency. Challenges include car size and power.
- Conservation—Transportation: One wedge could come from cutting miles traveled by all passenger and/or freight vehicles in half by increasing public transport and enhancing urban design.
- Efficiency—Buildings: One wedge could come from 25% emissions cuts in new and existing buildings by increasing insulation, furnace, and lighting efficiency. Challenges include house size and demand for appliances.
- Efficiency—Electricity: One wedge could come from increasing the efficiency of power generation by raising plant efficiency from 40% to 60%, although this would increase plant costs.
- Carbon Capture & Storage (CCS) Electricity: One wedge could come from injecting underground a volume of CO_2 every year equal to the volume extracted, or 90% of the CO_2 from 800 large coal or 1,600 natural gas power plants. The risk is the possibility of CO_2 leakage.
- CCS Hydrogen: One wedge could come from producing hydrogen at 10x current rates, displacing hydrocarbon with hydrogen fuel. Challenges include new infrastructure cost and hydrogen safety.
- CCS Synfuels (fuels made from non-petroleum synthetic feedstocks): One wedge could come from using CCS at 180 large synfuels plants to capture and store CO_2 emitted during production.
- Fuel Switching—Electricity: One wedge could come from replacing 1,400 coal plants with natural gas plants that would use natural gas equal to the amount used for all purposes today, making availability a challenge.
- Nuclear Electricity: One wedge could come from doubling the current capacity of nuclear power, requiring about three times the effort France put into expanding nuclear power in the 1980s, sustained for 50 years. Challenges include weapons proliferation, nuclear waste, safety, and local opposition.
- Wind Electricity: One wedge could come from using an area equal to about 3% of U.S. land area for wind farms, adding 10x current capacity. Local opposition is a challenge.
- Solar Electricity: One wedge could come from using the equivalent of a 100x 200 km PV arrays, 100x current capacity, to displace coal-based electricity, but the challenge is PV cell materials.
- Wind Hydrogen: One wedge could come from powering half the world's cars by 2050 with hydrogen produced using wind electricity. Challenges include local opposition, hydrogen infrastructure, and safety.
- Biofuels: One wedge could come from scaling up world ethanol production by a factor of 12 to replace petroleum fuels. However, maintaining biodiversity and competing land uses are challenges.
- Forest Storage: One wedge could come from halting deforestation for 50 years, storing carbon in new forests. However, maintaining biodiversity and competing land uses are challenges.
- Soil Storage: One wedge could come from practicing carbon management on all the world's agriculture by using farming techniques to increase carbon retention or storage in soil. However, the risk is that this could be reversed if the land is deep-plowed later.

Source: Compiled by casewriter from "Stabilization Wedges," Carbon Mitigation Initiative, Princeton Environmental Institute, Princeton University, https://cmi.princeton.edu/wedges, accessed September 2016.

Exhibit 18 Estimated LCOE (simple average of regional values) for new generation resources, for plants entering service in 2022

U.S. Average LCOE (2015 $/MWh) for Plants Entering Service in 2022

Plant Type	Capacity Factor (%)	Levelized Capital Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System LCOE	Levelized Tax Credit	Total LCOE including Tax Credit[1]
Dispatchable Technologies								
Advanced Coal with CCS[2]	85	97.2	9.2	31.9	1.2	139.5	N/A	139.5
Natural Gas-fired								
Conventional Combined Cycle	87	13.9	1.4	41.5	1.2	58.1	N/A	58.1
Advanced Combined Cycle	87	15.8	1.3	38.9	1.2	57.2	N/A	57.2
Advanced CC with CCS	87	29.2	4.3	50.1	1.2	84.8	N/A	84.8
Conventional Combustion Turbine	30	40.9	6.5	59.9	3.4	110.8	N/A	110.8
Advanced Combustion Turbine	30	25.8	2.5	63.0	3.4	94.7	N/A	94.7
Advanced Nuclear	90	78.0	12.4	11.3	1.1	102.8	N/A	102.8
Geothermal	91	30.9	12.6	0.0	1.4	45.0	-3.1	41.9
Biomass	83	44.9	14.9	35.0	1.2	96.1	N/A	96.1
Non-Dispatchable Technologies								
Wind	40	48.5	13.2	0.0	2.8	64.5	-7.6	56.9
Wind – Offshore	45	134.0	19.3	0.0	4.8	158.1	-11.4	146.7
Solar PV[3]	25	70.7	9.9	0.0	4.1	84.7	-18.4	66.3
Solar Thermal	20	186.6	43.3	0.0	6.0	235.9	-56.0	179.9
Hydroelectric[4]	58	57.5	3.6	4.9	1.9	67.8	N/A	67.8

Source: "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2016," US EIA, August 2016, http://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf, accessed December 2016.

Notes: 1 The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. The capacity additions for each region were based on additions in 2018 -2022. Technologies for which capacity additions are not expected do not have a capacity-weighted average, and are marked as "N/B."

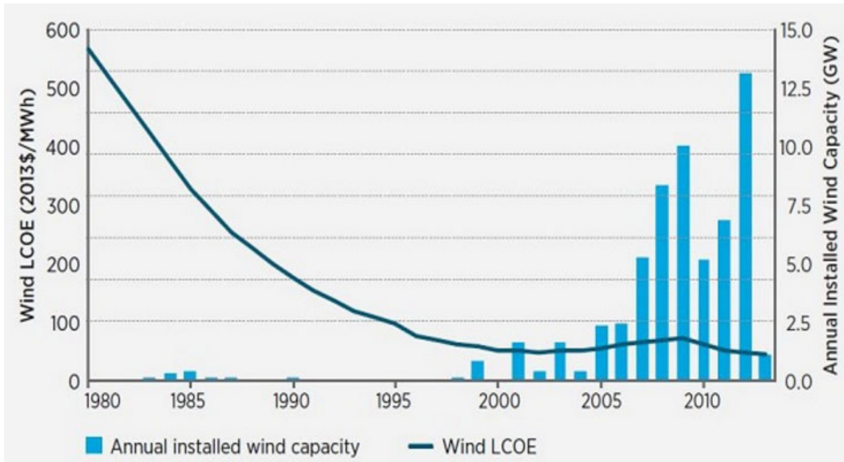
2 The tax credit component is based on targeted federal tax credits such as the production or investment tax credit available for some technologies. It only reflects tax credits available for plants entering service in 2022. EIA models renewable tax credits as follows: new solar thermal and PV plants are eligible to receive a 30% investment tax credit on capital expenditures if under construction before the end of 2019, and then tax credits taper off to 26% in 2020, 22% in 2021, and 10% thereafter. New wind, geothermal, and biomass plants receive a $23.0/MWh ($12.0/MWh for technologies other than wind, geothermal and closed-loop biomass) inflation-adjusted production tax credit over the plant's first ten years of service if they are under construction before the end of 2016, with the tax credit for wind declining by 20% in 2017, 40% in 2018, 60% in 2019, and expiring completely in 2020. Up to 6 GW of new nuclear plants are eligible to receive an $18/MWh production tax credit if in service by 2020. Not all technologies have tax credits, and are indicated as "N/A." The results are based on a regional model and state or local incentives are not included in LCOE calculations.

3 Due to new regulations (CAA 111b), conventional coal plants cannot be built without CCS because they are required to meet specific CO_2 emission standards. The coal with CCS technology modeled is assumed to remove 30% of the plant's CO_2 emissions. Coal plants have a 3 percentage-point adder to their cost-of-capital.

4 Costs are expressed in terms of net AC power available to the grid for the installed capacity.

5 As modeled, hydroelectric is assumed to have seasonal storage so that it can be dispatched within a season, but overall operation is limited by resources available by site and season.

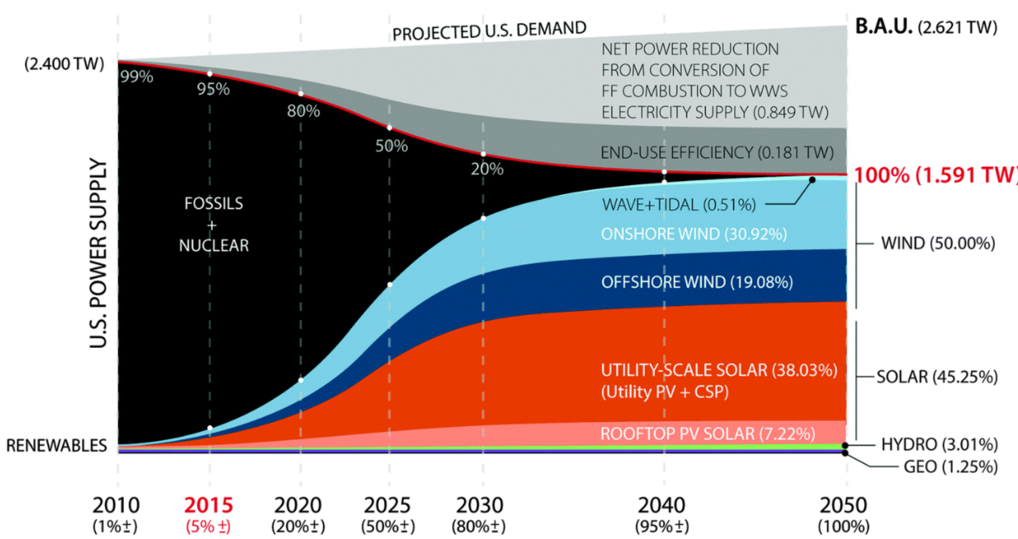
Exhibit 19 U.S. Annual Installed Wind Capacity (gigawatts) and Levelized Cost of Energy (LCOE) from Wind Generation (2013 USD per megawatt-hour), 2014



Source: "Wind Vision," U.S. Department of Energy, 2014, pp. 11, http://www.energy.gov/sites/prod/files/wv_chapter2_wind_power_in_the_united_states.pdf, accessed September 2016.

Note: In the *Wind Vision*, "good to excellent sites" are those with average wind speeds of 7.5 meters per second (m/s) or higher at hub height. LCOE estimates exclude the PTC.

Exhibit 20 Proposed Timeline for the Implementation of 100% Clean and Renewable Wind, Water, and Sunlight All-Sector Energy Roadmaps for the United States



Source: Mark Z. Jacobson, Mark A. Delucchi, Guillaume Bazouin, Zack A. F. Bauer, Christa C. Heavey, Emma Fisher, Sean B. Morris, Diniana J. Y. Piekutowski, Taylor A. Vencill, and Tim W. Yeskoo, "100% Clean and Renewable Wind, Water, and Sunlight (WWS) All-Sector Energy Roadmaps for the 50 United States," *Energy & Environmental Science*, issue 7, 2015, via Royal Society of Chemistry Journals, accessed September 2016.

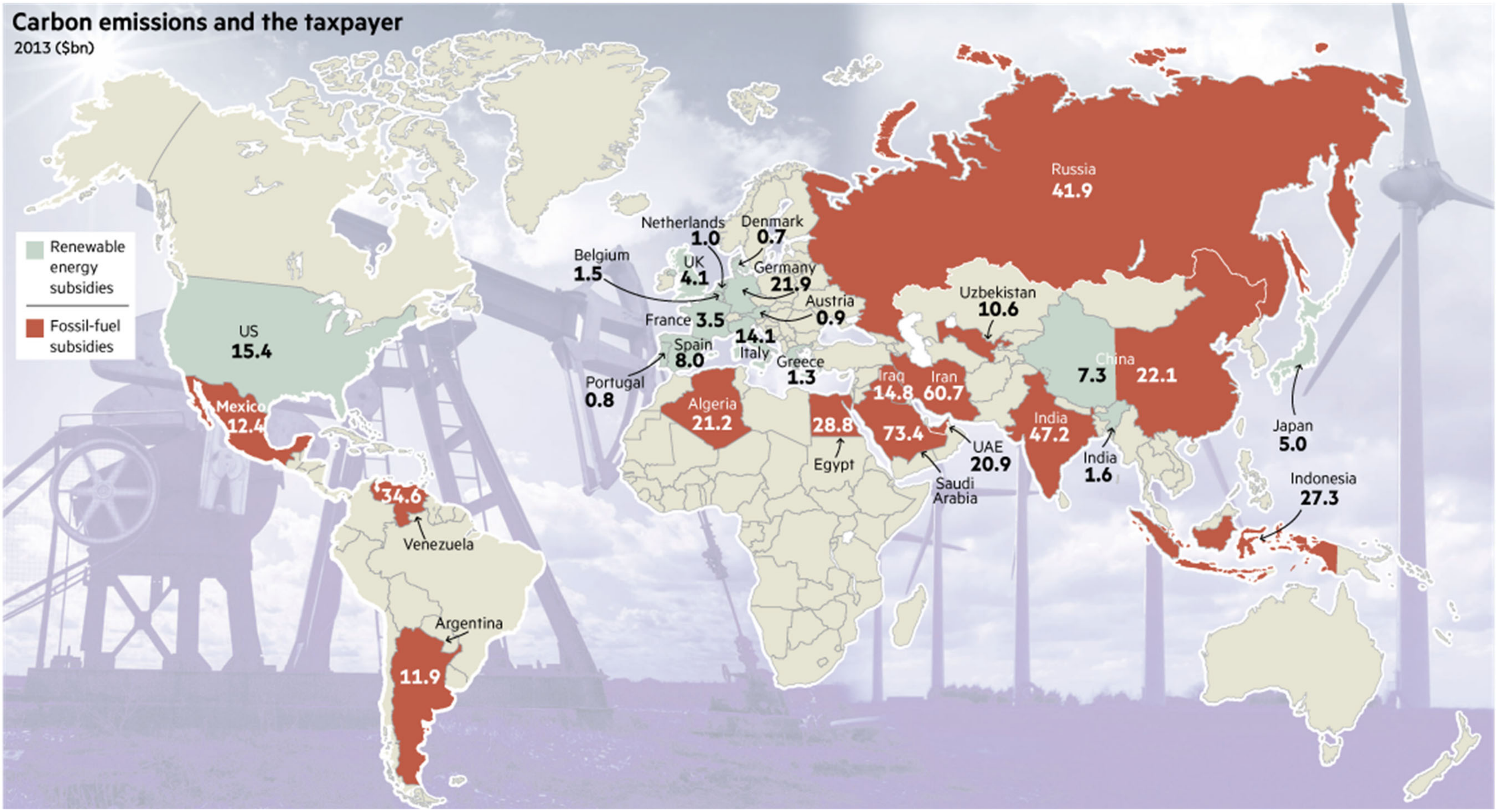
Note: Time-dependent change in U.S. end-use power demand for all purposes (electricity, transportation, heating/cooling, and industry) and its supply by conventional fuels and WWS generators based on state roadmaps proposed here. Total power demand decreases on conversion to WWS due to efficiency of electricity over combustion and end-use energy efficiency measures. Percentages on date axis are percent conversion to WWS by that year. The percentages next to each WWS source are final estimated penetration of the source. The 100% demarcation in 2050 indicates that 100% of all-purpose power is provided by WWS technologies by 2050, and the power demand by that time has decreased.

Exhibit 21 The Social Cost of Carbon

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

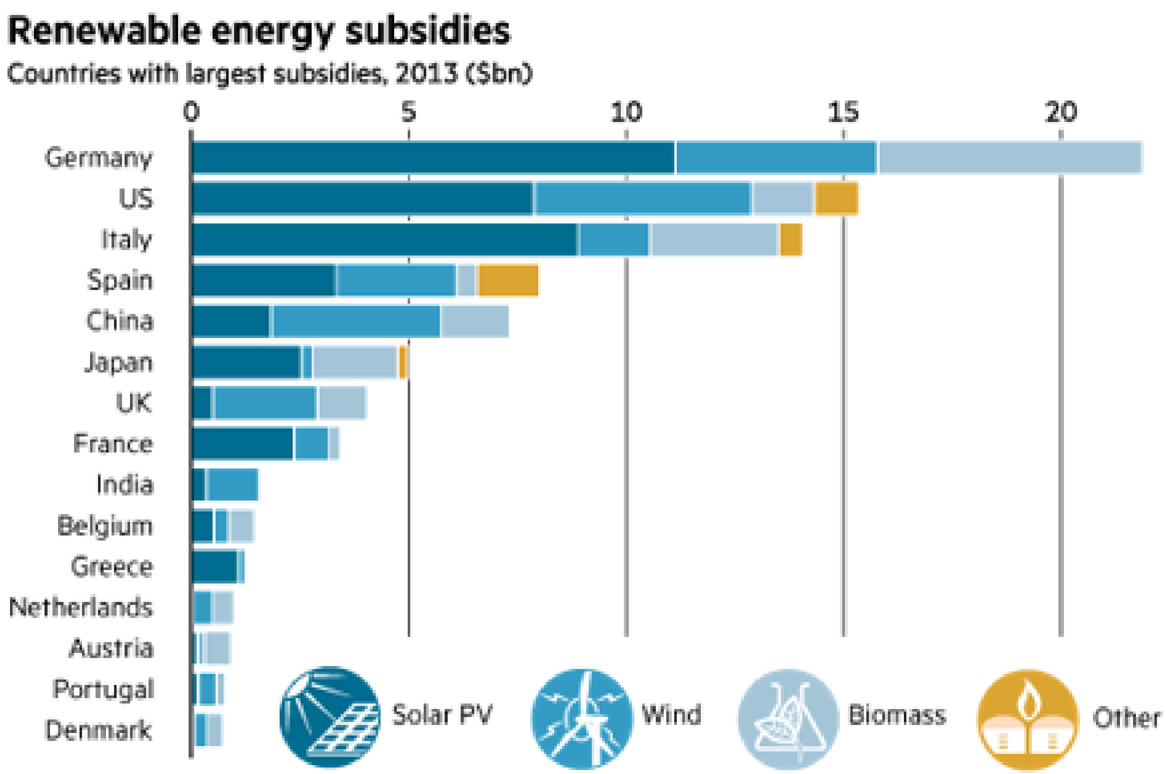
Source: "Technical Support Document: -Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis -Under Executive Order 12866," Interagency Working Group on Social Cost of Greenhouse Gases, United States Government, August 2016, https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf, accessed December 2016.

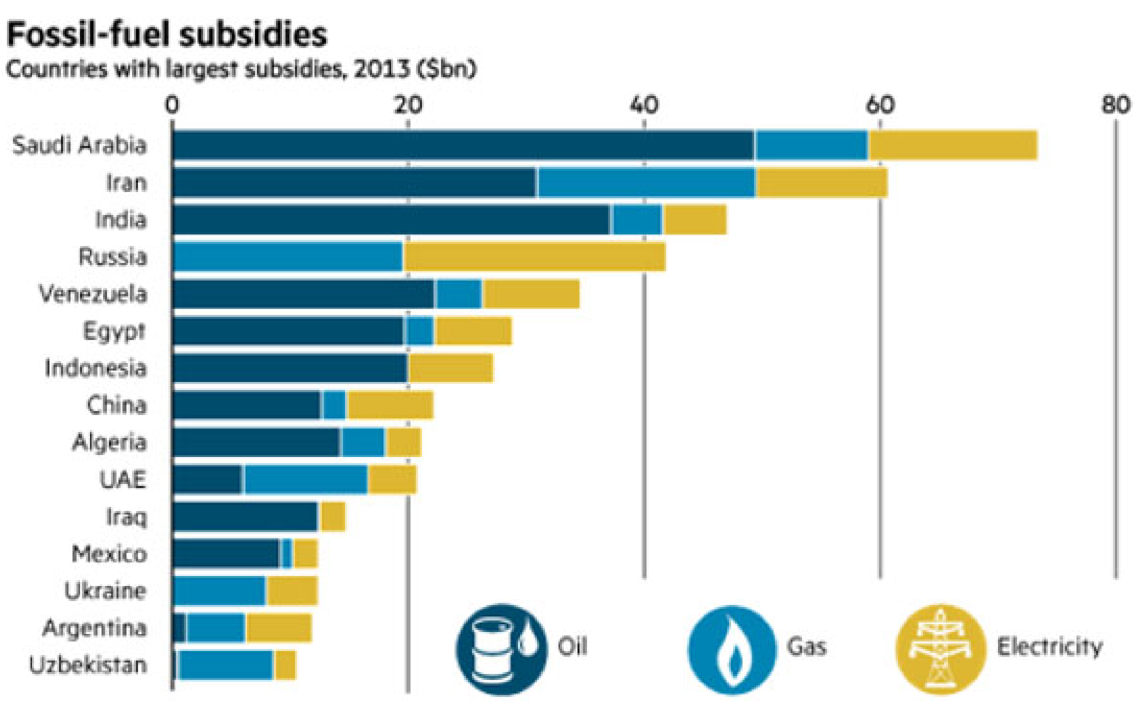
Exhibit 22 Fossil Fuel and Renewable Energy Subsidies Worldwide, 2013 ($ billions)



Source: "Carbon Emissions and the Taxpayer," *Financial Times*, 2013, http://blogs.ft.com/the-world/files/2016/07/GR262Xcarbon_tax_modern_energy_SR_CHART.png, accessed September 2016.

Exhibit 22 (con't) Renewable Energy and Fossil-Fuel Subsidies, by Country, 2013





Source: "Carbon Emissions and the Taxpayer," Financial Times, 2013, http://blogs.ft.com/the-world/files/2016/07/GR262Xcarbon_tax_modern_energy_SR_CHART.png, accessed September 2016.

Endnotes

[1] Department of Defense, "National Security Implications of Climate-Related Risks and a Changing Climate," July 23, 2015, http://archive.defense.gov/pubs/150724-congressional-report-on-national-implications-of-climate-change.pdf?source=govdelivery, accessed August 2016.

[2] NASA's Goddard Institute for Space (GISS), "Global Temperature," NASA website, http://climate.nasa.gov/vital-signs/global-temperature/, accessed August 2016.

[3] Nell Greenfieldboyce, "2016 Was The Hottest Year Yet, Scientists Declare," NPR, January 18, 2017, http://www.npr.org/sections/thetwo-way/2017/01/18/510405739/2016-was-the-hottest-year-yet-scientists-declare, accessed January 2017.

[4] "tCO2e," *The Dictionary of the Climate Debate (DCD)*, http://www.odlt.org/dcd/ballast/tco2e.html, accessed June 2016.

[5] "Turn Down the Heat: Confronting the New Climate Normal," World Bank, 2014, p.xviii, available at http://documents.worldbank.org/curated/en/2014/11/20404287/turn-down-heat-confronting-new-climate-normal-vol-2-2-main-report, accessed May 2016.

[6] "Climate Change 2014: Synthesis Report," Intergovernmental Panel on Climate Change, 2014, pp. 45, https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_All_Topics.pdf, accessed June 2016.

[7] U.S. Global Climate Change Research Program, "Climate Change Impacts in the United States," Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson (eds.), 2014, p. 9, https://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf, accessed August 2016.

[8] "Climate Change 2014: Synthesis Report," pp. 47.

[9] Pete Smith, Mercedes Bustamante, Helal Ahammad, Harry Clark, Hongmin Dong, Elnour A. Elsiddig, Helmut Haberl, Richard Harper, Joanna House, Mostafa Jafari, Omar Masera, Cheikh Mbow, Nijavalli H. Ravindranath, Charles W. Rice, Carmenza Robledo Abad, Anna Romanovskaya, Frank Sperling, Francesco N. Tubiello, "2014: Agriculture, Forestry and Other Land Use (AFOLU)," in *Climate Change 2014: Mitigation of Climate Change*, contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, eds. Ottmar Edenhofer, Ramón Pichs-Madruga, Youba Sokona, Ellie Farahani, Susanne Kadner, Kristin Seyboth, A. Adler, I. Baum, S. Brunner, Patrick Eickemeier, B. Kriemann, J. Savolainen, Steffen Schlömer, Christoph von Stechow, Timm Zwickel, and J.C. Minx (Cambridge, United Kingdom and New York, New York: Cambridge University Press, 2014), https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter11.pdf, accessed September 2016.[10] International Energy Agency, "Key World Energy Trends. Excerpt from: World Energy Balances," 2016 using 2014 data, p. 4, https://www.iea.org/publications/freepublications/publication/KeyWorldEnergyTrends.pdf, accessed August 2016.

[11] David L. Chandler, "Explained: Radiative Forcing," *MIT News Office*, March 10, 2012, http://newsoffice.mit.edu/2010/explained-radforce-0309, accessed August 2014.

[12] "Surface Area of the Earth,' Universe Today website, http://www.universetoday.com/25756/surface-area-of-the-earth/, accessed September 2014.

[13] Chandler, "Explained . . .."

[14] IPCC Fifth Assessment Report (AR5), Intergovernmental Panel on Climate Change, 2014, https://www.ipcc.ch/report/ar5/, accessed December 2016.

[15] "Scientific Consensus," National Wildlife Federation website, https://www.nwf.org/Wildlife/Threats-to-Wildlife/Global-Warming/Global-Warming-is-Well-Documented/Scientific-Consensus.aspx, accessed September 2016.

[16] William Anderegg, James W. Prall, Jacob Harold, and Stephen Schneider, "Expert Credibility in Climate Change," *Proceedings of the National Academy of Sciences of the United States of America*, April 9, 2010, p. 12107, http://www.pnas.org/content/107/27/12107.full.pdf+html~~
Preliminary, accessed December 2014.

[17] John Cook, Naomi Oreskes, Peter T. Doran, William R.L. Anderegg, Bart Verheggen,Ed W. Maibach, J. Stuart Carlton, Stephan Lewandowsky, Andrew G. Skuce, Sarah A. Green, Dana Nuccitelli, Peter Jacobs, Mark Richardson, Bärbel Winkler, Rob Painting, and Ken Rice, "Consensus on consensus: a synthesis of consensus estimates on human-caused global warming," IOP Science, April 13, 2016, http://iopscience.iop.org/article/10.1088/1748-9326/11/4/048002, accessed August 2016.

[18] "How to Talk to a Climate Skeptic: Responses to the Most Common Skeptical Arguments on Global Warming," *The Grist*, http://grist.org/series/skeptics/, August 2016.

[19] "How to Talk to a Climate Skeptic . . .."

[20] Benjamin D. Santer, Jeffrey F. Painter, Celine Bonfils, Carl A. Mears, Susan Solomon, Tom M. L. Wigley, Peter J. geckler, Gavin A. Schmidt, Charles Doutriaux, Nathan P. Gillett, Karl E. Taylor, Peter W. Thorne, and Frank J. Wentz, "Human and natural influences on the changing thermal structure of the atmosphere," *Proceedings of the National Academy of Sciences*, vol. 110, issue 43, 2013, pp. 17235-17240. http://www.pnas.org/content/110/43/17235.full.pdf, accessed December 2016.

[21] "Where in the World Is Climate Change Denial Most Prevalent?" *The New York Times*, December 11, 2015, http://www.nytimes.com/interactive/projects/cp/climate/2015-paris-climate-talks/where-in-the-world-is-climate-denial-most-prevalent, accessed August 2016.

[22] Sondre Båtstrand, "More than Markets: A Comparative Study of Nine Conservative Parties on Climate Change," *Politics & Policy*, vol. 43, issue 4, August 2015, pp. 538-561, http://onlinelibrary.wiley.com/doi/10.1111/polp.12122/full, accessed August 2016.

[23] "History," Intergovernmental Panel on Climate Change website, https://www.ipcc.ch/organization/organization_history.shtml, accessed August 2014.

[24] "History," Intergovernmental Panel on Climate Change website.

[25] "IPCC Participants," IPCC Facts website, http://www.ipccfacts.org/participants.html, accessed August 2014.

[26] NOAA, "Carbon Dioxide," NASA website, http://climate.nasa.gov/vital-signs/carbon-dioxide/, accessed August 2016.

[27] Summary for Policymakers, In: Climate Change 2014, Mitigation of Climate Change," Intergovernmental Panel on Climate Change, 2014, p. 9, https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_summary-for-policymakers.pdf, accessed August 2016.

[28] Summary for Policymakers . . .," p. 8.

[29] David L. Chandler, "Climate Change Odds Much Worse than Thought," MIT News Office, May 19, 2009, http://newsoffice.mit.edu/2009/roulette-0519, accessed October 2014.

[30] "What are Positive Feedbacks?" National Oceanic and Atmospheric Administration website, http://www.ncdc.noaa.gov/paleo/abrupt/story2.html, accessed August 2014.

[31] "What are Positive Feedbacks?"

[32] "Permafrost in a Warming World," Weather Underground, 2016, https://www.wunderground.com/resources/climate/melting_permafrost.asp, accessed August 2016.

[33] Kevin Schaefer, "Methane and Frozen Ground," National Snow & Ice Data Center, https://nsidc.org/cryosphere/frozenground/methane.html, accessed August 2016.

[34] T. Schneider von Deimling, M. Meinshausen, A. Levermann, V. Huber, K. Frieler, D. M. Lawrence, and V. Brovkin, "Estimating the near-surface permafrost-carbon feedback on global warming," *Biogeosciences*, 9, November 20, 2011, pp. 649-655, http://www.biogeosciences.net/9/649/2012/bg-9-649-2012.html, accessed September 2016.

[35] Quéré, C. Le, et al. "The global carbon budget 1959–2011." Earth System Science Data 5.1 (2013): 165-185, http://www.earth-syst-sci-data-discuss.net/5/1107/2012/essdd-5-1107-2012.pdf, accessed December 2016.

[36] Nicola Jones, "Rising Waters: How Fast and How Far Will Sea Levels Rise?" Yale Environment 360, October 21, 2013, http://e360.yale.edu/feature/rising_waters_how_fast_and_how_far_will_sea_levels_rise/2702/, accessed August 2016.

[37] "Arctic Sea Ice Decline," Weather Underground website, https://www.wunderground.com/climate/SeaIce.asp?MR=1, accessed September 2016.

[38] "Arctic Sea Ice Decline."

[39] Peter Wadhams in Ian Johnston, "Arctic could become ice-free for first time in more than 100,000 years, claims leading scientist," *Independent*, June 4, 2016, http://www.independent.co.uk/environment/climate-change/arctic-could-become-ice-free-for-first-time-in-more-than-100000-years-claims-leading-scientist-a7065781.html, accessed September 2016.

[40] "Sea Level," NASA website, http://climate.nasa.gov/vital-signs/sea-level/, accessed August 2016.

41 "Understanding Sea Level: Empirical Projections," NASA website, https://sealevel.nasa.gov/understanding-sea-level/projections/empirical-projections, accessed August 2016.

42 Nell Greenfieldboyce, "Study: 634 Million People at Risk from Rising Seas," *National Public Radio*, March 28, 2007, http://www.npr.org/templates/story/story.php?storyId=9162438, accessed August 2014.

43 "New Report and Maps: Rising Seas Threaten Land Home to Half a Billion," Surging Seas, November 8, 2015, http://sealevel.climatecentral.org/news/global-mapping-choices, accessed August 2016.

44 "Five Pacific Islands Lost to Rising Seas as Climate Change Hits," Reuters in *The Guardian*, May 10, 2016, https://www.theguardian.com/environment/2016/may/10/five-pacific-islands-lost-rising-seas-climate-change, accessed August 2016.

45 Oliver Milman, "Pacific Nations Beg for Help for Islanders Forced to Flee," Climate Central, *The Guardian*, October 17, 2015, http://www.climatecentral.org/news/pacific-nations-beg-for-climate-help-19558, accessed August 2016.

46 Kelly Wyett, "Escaping a Rising Tide: Sea Level Rise and Migration in Kiribati," *Asia & The Pacific Policy Studies*, vol. 1, no. 1, October 2013, http://onlinelibrary.wiley.com/doi/10.1002/app5.7/pdf, accessed August 2016.

47 Srabani Roy, "Climate Change: Coastal Mega-Cities in for a Bumpy Ride," *Common Dreams*, March 28, 2007, http://www.commondreams.org/news/2007/03/28/climate-change-coastal-mega-cities-bumpy-ride, accessed September 2014.

48 Kate Gordon, "Risky Business: The Economic Risks of Climate Change in the United States," The Risky Business Project, June 2014, p. 4, http://riskybusiness.org/site/assets/uploads/2015/09/RiskyBusiness_Report_WEB_09_08_14.pdf, accessed June 2016.

49 Gordon, p. 26.

50 John Carey, "Global Warming and the Science of Extreme Weather," *Scientific American*, June 29, 2011, http://www.scientificamerican.com/article/global-warming-and-the-science-of-extreme-weather/, accessed August 2014.

51 "Explaining Extreme Events of 2012 from a Climate Perspective," Bulletin of the American Meteorological Society, Vol. 94, No. 9, Eds. Thomas C. Peterson, Martin P. Hoerling, Peter A. Stott, and Stephanie C. Herring, September 2013, pp. 3.

52 Kate Marvel and Celine Bonfils, "Identifying External Influences on Global Precipitation," *Proceedings of the National Academy of Sciences of the Unites States of America*, October 18, 2013, http://www.pnas.org/content/110/48/19301.full.pdf+html, accessed September 2014.

53 Janet Zimmerman, "DROUGHT: 2015 water year is hottest and driest on record," *The Press Enterprise*, September 29, 2015, http://www.pe.com/articles/year-781907-average-percent.html, accessed September 2016.

54 "Water Year 2014 Ends as 3rd Driest in Precipitation," California Department of Water Resources website, http://www.water.ca.gov/waterconditions/, accessed December 2014.

55 "Explaining Extreme Events of 2012 from a Climate Perspective," Bulletin of the American Meteorological Society, Vol. 94, No. 9, Eds. Thomas C. Peterson, Martin P. Hoerling, Peter A. Stott, and Stephanie C. Herring, September 2013, p. 45.

56 John Vidal, "Across Africa, the Worst Food Crisis Since 1985 Looms for 50 Million," *The Guardian*, May 22, 2016, https://www.theguardian.com/global-development/2016/may/22/africa-worst-famine-since-1985-looms-for-50-million, accessed August 2016.

57 "Climate Change Indicators in the United States, 2014," U.S. Environmental Protection Agency, 3rd Ed., 2014. pp. 9.

58 "Typhoon Haiyan death toll tops 6,000 in the Philippines," CNN, December 13, 2013, http://www.cnn.com/2013/12/13/world/asia/philippines-typhoon-haiyan/, accessed September 2016.

59 "Water and Food Security," Food and Agriculture Organization of the United Nations website, http://www.fao.org/docrep/x0262e/x0262e01.htm, accessed September 2014.

60 "Water and Food Security."

61 "Climate Change Vulnerabilities in Agriculture in Pakistan," Government of Pakistan Ministry of the Environment, pp. 2 http://cmsdata.iucn.org/downloads/pk_cc_agr_vul.pdf, accessed September 2014.

62 "Warming Climate in India to Pose Significant Risk to Agriculture, Water Resources, Health, Says World Bank Report," World Bank press release, June 19, 2013, http://www.worldbank.org/en/news/press-release/2013/06/19/warming-climate-india-pose-significant-risk-agriculture-water-resources-health-says-world-bank-report, accessed September 2014.

[63] Giulio Boccaletti, Sudeep Maitra, and Martin Stuchtey, "Transforming Water Economies," McKinsey & Company, 2012, p. 1 https://www.mckinsey.com/~/media/McKinsey/dotcom/client_service/Sustainability/PDFs/McK%20on%20SRP/SRP_09_Water.ashx, accessed September 2014.

[64] "Floods and Droughts," Intergovernmental Panel on Climate Change website, http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch3s3-4-3.html, accessed December 2014.

[65] "Agriculture and Food Supply," U.S. Environmental Protection Agency website, https://www3.epa.gov/climatechange/impacts/agriculture.html, accessed April 2016.

[66] "CO2 Can Reduce Food Value," *Living on Earth*, August 22, 2014, http://www.loe.org/shows/segments.html?programID=14-P13-00034&segmentID=1, accessed August 2014.

[67] "Agriculture and Food Supply," accessed April 2016.

[68] Christoph Müller, Wolfgang Cramer, William L. Hare, and Hermann Lotze-Campen, "Climate Change Risks for African Agriculture," *Proceedings of the National Academy of Sciences*, vol. 108, no. 11, March 15, 2011, pp.4313-4315, available at http://www.pnas.org/content/108/11/4313.abstract, accessed June 2016.

[69] "Food Price Watch, May 2014: First Quarterly Increase Since August 2012; The Role of Food Prices in Food Riots," The World Bank website, May 2014, http://www.worldbank.org/en/topic/poverty/publication/food-price-watch-may-2014, accessed September 2014.

[70] "Food Price Watch, May 2014 . . .," accessed September 2014.

[71] Colin P. Kelley, Shahrzad Mohtadi, Mark A. Cane, Richard Seager, and Yochanan Kushnir, "Climate change in the Fertile Crescent and implications of the recent Syrian drought," *Proceedings of the National Academy of Sciences*, vol. 112, no. 11, January 30, 2015, http://m.pnas.org/content/112/11/3241.abstract%20and%20need%20Somalian%20reference, accessed September 2016.

[72] John F. Kerry, "Remarks by Secretary Kerry on Climate Change and National Security," Council on Foreign Relations website, November 11, 2015, http://www.state.gov/secretary/remarks/2015/11/249393.htm, accessed January 2017.

[73] "Climate Futures: Responses to Climate Change in 2030," Forum for the Future, October 2008, https://www.forumforthefuture.org/sites/default/files/project/downloads/climate-futures.pdf, accessed April 2016.

[74] "The Reality, Risks and Response to Climate Change," The AAAS Climate Science Panel, 2014, pp. 4, http://whatweknow.aaas.org/wp-content/uploads/2014/07/whatweknow_website.pdf, accessed June 2016.

[75] Jean-Marie Robine, Siu Lan K. Cheung, Sophie Le Roy, Herman Van Oyen, Clare Griffiths, Jean-Pierre Michel, Francois Richard Hermann, "Death Toll Exceeded 70,000 in Europe during the Summer of 2003," *Comptes Rendus Biologies*, http://www.sciencedirect.com/science/article/pii/S1631069107003770, accessed September 2014.

[76] Alok Jha, "Climate change increased likelihood of Russian 2010 heatwave—study," *The Guardian*, February 21, 2012, https://www.theguardian.com/environment/2012/feb/21/climate-change-russian-heatwave, accessed September 2016.

[77] Jeff Masters, "Earth's 5th Deadliest Heat Wave in Recorded History Kills 1,826 in India," WunderBlog, May 29, 2015, https://www.wunderground.com/blog/JeffMasters/earths-5th-deadliest-heat-wave-in-recorded-history-kills-1826-in-ind, accessed September 2016.

[78] "National Climate Assessment Report Executive Summary," National Climate Assessment and Development Advisory Committee, Draft for Public Comment, January 2013, pp. 6, http://www.globalchange.gov/sites/globalchange/files/NCAJan11-2013-publicreviewdraft-chap1-execsum.pdf, accessed June 2016.

[79] "Climate Change Indicators in the United States, 2014," U.S. Environmental Protection Agency, 3rd Ed., 2014. p. 73.

[80] "Climate Change Impacts," accessed March 2016.

[81] Paul R. Epstein, Jonathan J. Buonocore, Kevin Eckerle, Michael Hendryx, Benjamin M. Stout III, Richard Heinberg, Richard W. Clapp, Beverly May, Nancy L. Reinhart, Melissa M. Ahern, Samir K. Doshi, Leslie Glustrom, "Full cost accounting for the life cycle of coal," *Annals of the New York Academy of Sciences*, 1219(1), pp. 73-98, via Wiley Online Library, accessed February 2017.

[82] Ben Machol, Sarah Rizk, "Economic value of US fossil fuel electricity health impacts," *Environment International*, vol. 52, February 2013, pp. 75-80, via ScienceDirect, accessed February 2017.

[83] "Climate Change 2014: Synthesis Report," pp. 13, accessed June 2016.

84 "Will Humans Survive the Sixth Great Extinction?" *National Geographic*, June 23, 2015, http://news.nationalgeographic.com/2015/06/150623-sixth-extinction-kolbert-animals-conservation-science-world/, accessed April 2016.

85 Rob Jordan, "Stanford Researcher Declares that the Sixth Mass Extinction Is Here," *Stanford News*, June 19, 2015, https://news.stanford.edu/2015/06/19/mass-extinction-ehrlich-061915/, accessed April 2016.

86 "The Extinction Crisis," Center for Biological Diversity website, http://www.biologicaldiversity.org/programs/biodiversity/elements_of_biodiversity/extinction_crisis/, accessed September 2016.

87 "Mass Extinction: What Causes Animal Die-Offs?" *National Geographic* website, http://science.nationalgeographic.com/science/prehistoric-world/mass-extinction/, accessed September 2016.

88 "Threats: Climate Change," U.S. Department of Commerce National Oceanic and Atmospheric Administration NOAA Coral Reef Conservation Program website, http://coralreef.noaa.gov/threats/climate/, accessed June 2016.

89 "Ocean Acidification: Carbon Dioxide is Putting Shelled Animals at Risk," *National Geographic*, http://ocean.nationalgeographic.com/ocean/critical-issues-ocean-acidification/, accessed December 2014.

90 "Climate Change Indicators in the United States, 2014," U.S. Environmental Protection Agency, 3rd Ed., 2014. p. 45.

91 Caitlin Martin, "The Effects of Climate Change on Coral Reef Health," *Scientific American* Expeditions blog, June 5, 2013, http://blogs.scientificamerican.com/expeditions/the-effects-of-climate-change-on-coral-reef-health/, accessed June 2016.

92 Lauretta Burke, Kathleen Reytar, Mark Spalding, Allison Perry, "Reefs at Risk Revisited," World Research Institute (WRI) website, 2011, http://pdf.wri.org/reefs_at_risk_revisited.pdf, accessed September 2016.

93 "About Coral Reefs," International Society for Reef Studies website, http://coralreefs.org/about-coral-reefs/, accessed September 2016.

94 "Why 2 Degrees Celsius is Climate Change's Magic Number," *PBS Newshour* website, December 2, 2015, http://www.pbs.org/newshour/bb/why-2-degrees-celsius-is-climate-changes-magic-number/, accessed May 2016.

95 "Climate Change 2014: Synthesis Report," pp. 45.

96 "Summary for Policymakers . . .," pp. 8.

97 Roberta Hotinski, "Stabilization Wedges: A Concept & Game," Carbon Mitigation Initiative, Princeton Environmental Institute, Princeton University, March 16, 2015, https://cmi.princeton.edu/wedges/pdfs/teachers_guide.pdf, accessed September 2016.

98 "Achievements of appliance energy efficiency standards and labelling programs," Edition 2015, International Energy Agency, pp. 1-4, https://www.iea.org/publications/freepublications/publication/4E_S_L_Report_180915.pdf, accessed January 2016.

99 "Achievements of appliance energy efficiency standards and labelling programs."

100 "Energy-Efficiency Standards and Green Building Certification Systems Used by the Department of Defense for Military Construction and Major Renovations," National Research Council, The National Academies Press, 2013, available at https://www.nap.edu/catalog/18282/energy-efficiency-standards-and-green-building-certification-systems-used-by-the-department-of-defense-for-military-construction-and-major-renovations, accessed January 2017.

101 "Realizing the Potential of Energy Efficiency," United Nations Foundation, 2007, http://www.globalproblems-globalsolutions-files.org/unf_website/PDF/realizing_potential_energy_efficiency.pdf, accessed December 2014.

102 "Summary for Policymakers . . .," pp. 26.

103 Richard Dobbs, Jeremy Oppenheim, Fraser Thompson, Marcel Brinkman, Marc Zornes, "Resource Revolution: Meeting the World's Energy, Materials, Food, and Water Needs," McKinsey Global Institute, November 2011, pp. 72, http://riskybusiness.org/site/assets/uploads/2015/09/RiskyBusiness_Report_WEB_09_08_14.pdf, accessed June 2016.

104 "Energy Efficiency Market Report 2015," IEA website, 2015, pp. 3, https://www.iea.org/publications/freepublications/publication/MediumTermEnergyefficiencyMarketReport2015.pdf, accessed April 2016.

105 "Summary for Policymakers . . .," pp. 18, accessed July 2014.

106 International Energy Agency, "Key World Energy Trends. Excerpt from: World Energy Balances," 2016 using 2014 data, pp. 4, https://www.iea.org/publications/freepublications/publication/KeyWorldEnergyTrends.pdf, accessed August 2016.

[107] International Energy Agency, "Key World Energy Trends. Excerpt from: World Energy Balances," 2016 using 2014 data, pp. 4, https://www.iea.org/publications/freepublications/publication/KeyWorldEnergyTrends.pdf, accessed December 2016.

[108] "Photovoltaics Report," Fraunhofer Institute for Solar Energy Systems, ISE, November 17, 2016, available at https://issuu.com/kanagagnana/docs/2016-11-17_photovoltaics_report , accessed December 2016.

[109] "Electricity Data Browser: Average retail price of electricity, annual," U.S. Energy Information Administration, https://www.eia.gov/electricity/data/browser, accessed December 2016.

[110] "Lazard's Levelized Cost of Energy Analysis—Version 7.0," Lazard, August 2013, pp. 2, http://gallery.mailchimp.com/ce17780900c3d223633ecfa59/files/Lazard_Levelized_Cost_of_Energy_v7.0.1.pdf, accessed September 2014.

[111] "Revolution Now: The Future Arrives for Four Clean Energy Technologies," U.S. Department of Energy, September 17, 2013, pp. 2-4, http://energy.gov/sites/prod/files/2013/09/f2/200130917-revolution-now.pdf, accessed September 2014.

[112] "Why Clean Energy Can Withstand Changing Political Winds," *Forbes*, Nov 23, 2016, http://www.forbes.com/sites/morganstanley/2016/11/23/why-clean-energy-can-withstand-changing-political-winds/#6686e6543ef3, accessed January 2017.

[113] Stefan Pfenninger, Paul Gauche, Johan Lilliestam, Kerstin Damerau, Fabian Wagner, and Anthony Patt, "Potential for Concentrating Solar Power to Provide Baseload and Dispatchable Power," *Nature Climate Change*, June 22, 2014, pp. 689, http://www.nature.com/nclimate/journal/v4/n8/full/nclimate2276.html, accessed June 2016.

[114] Pfenninger, et al., pp. 690, accessed June 2016.

[115] William A. Sahlman, Ramana Nanda, Joseph B. Lassiter III, and James Mcquade, "TerraPower," HBS No. 813-108 (Boston: Harvard Business School Publishing, 2013), p. 7.

[116] "Sources of Greenhouse Gas Emissions," United States Environmental Protection Agency website, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions, accessed January 2017.

[117] "Redrawing the Energy-Climate Map," International Energy Agency, June 10, 2013, pp. 16, http://www.iea.org/publications/freepublications/publication/weo_special_report_2013_redrawing_the_energy_climate_map.pdf, accessed September 2016.

[118] Nancy L. Harris, Sandra Brown, Stephen C. Hagen, Sassan S. Saatchi, Silvia Pertova, William Salas, Matthew C. Hansen, Peter V. Potapov, and Alexander Lotsch, "Baseline Map of Carbon Emission from Deforestation in Tropical Regions," *Science Magazine*, May 3, 2012, p. 1573-1576, http://www.sciencemag.org/content/336/6088/1573.abstract, accessed September 2014.

[119] "Forests and Climate Change," Food and Agriculture Organization of the United Nations, http://www.fao.org/docrep/005/ac836e/AC836E03.htm, accessed September 2014.

[120] Dominic Woolf, James E. Amonette, F. Alayne Street-Perrott, Johannes Lehmann, and Stephen Joseph, "Sustainable Biochar to Mitigate Global Climate Change," *Nature Communications*, August 10, 2010, http://www.nature.com/articles/ncomms1053, accessed September 2016.

[121] Peter Winsley, "Biochar and Bioenergy Production for Climate Change Mitigation," *New Zealand Science Review*, vol. 64 (1), 2007, http://www.biochar-international.org/images/NZSR64_1_Winsley.pdf, accessed September 2016.

[122] "Key facts and findings: By the numbers: GHG emissions by livestock," Food and Agriculture Organization of the United Nations, http://www.fao.org/news/story/en/item/197623/icode/, accessed September 2016.

[123] "Mobilizing Bright Science for Project 'Clean Cow,'" DSM website, https://www.dsm.com/corporate/science/competences/chemical-sciences/project-clean-cow.html, accessed September 2016.

[124] "Key facts and findings . . .."

[125] Erin O'Donnell, "Buffering the Sun," *Harvard Magazine*, August 2013, http://harvardmagazine.com/2013/07/buffering-the-sun, accessed August 2014.

[126] O'Donnell.

[127] Sarah Fecht, "U.K. Researchers to Test 'Artificial Volcano' for Geoengineering the Climate," *Scientific American*, September 14, 2011, http://www.scientificamerican.com/article/uk-researchers-to-test-artificial-volcano-for-geoengineering-the-climate/, accessed September 2016.

[128] Fecht.

[129] Fecht.

[130] Damian Carrington, "Geoengineering could prevent climate effects caused by giant volcanic eruptions," *The Guardian*, November 6, 2016, https://www.theguardian.com/environment/2014/nov/06/geoengineering-could-prevent-climate-effects-caused-by-giant-volcanic-eruptions, accessed September 2016.

[131] O'Donnell.

[132] Alan Robock, Luke Oman, and Georgiy L. Stenchikov, "Regional Climate Responses to Geoengineering with Tropical and Artic SO2 Injections, *Journal of Geophysical Research*, August 16, 2008, p. 1, http://climate.envsci.rutgers.edu/pdf/2008JD010050small.pdf, accessed August 2014.

[133] Dimitri Zenghelis, "How much will it cost to cut global greenhouse gas emissions?," The London School of Economics and Political Science Grantham Research Institute on Climate Change and the Environment website, October 27, 2014, http://www.lse.ac.uk/GranthamInstitute/faqs/how-much-will-it-cost-to-cut-global-greenhouse-gas-emissions/, accessed April 2016.

[134] Marshall Burke, Solomon M. Hsiang, and Edward Miguel, "Global Non-Linear Effect of Temperature on Economic Production," *Nature*, November 12, 2015, 527, pp. 235–239, http://www.nature.com/nature/journal/v527/n7577/full/nature15725.html, accessed June 2016.

[135] "Technical Support Document: -Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis -Under Executive Order 12866," Interagency Working Group on Social Cost of Greenhouse Gases, United States Government, August 2016, https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf, accessed December 2016.

[136] "Coal Explained: Coal Prices and Outlook," U.S. Energy Information Administration, August 10, 2016, http://www.eia.gov/energyexplained/index.cfm?page=coal_prices, accessed January 2017.

[137] "Global Carbon Atlas," Global Carbon Project, http://www.globalcarbonatlas.org/en/CO2-emissions, accessed December 2016.

[138] "Carbon Dioxide Emissions Coefficients," U.S. Energy Information Administration, https://www.eia.gov/environment/emissions/co2_vol_mass.cfm, accessed January 2017.

[139] David Coady, Ian Parry, Louis Sears, and Baoping Shang, "How Large Are Global Fossil Fuel Subsidies?" *World Development*, vol. 91, March 2017, pp. 11-27, via ScienceDirect, accessed January 2017.

[140] Coady, et. al.

[141] "Country-level energy subsidy estimates," IMF and Reforming Energy Subsidies, International Monetary Fund, http://www.imf.org/external/np/fad/subsidies/#mes, accessed January 2017.

[142] "Table 3.6 Consumer Expenditure Estimates for Energy by End-Use Sector, 1970-2010," Annual Energy Review 2011, U.S. Energy Information Administration, September 2012, https://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf, pp. 79, accessed January 2017.

[143] Numerous sources include: David A. Weisbach and Cass R. Sunstein, "Climate Change and Discounting the Future: A Guide for the Perplexed," working paper, August 12, 2008, available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1223448; Lawrence H. Goulder and Roberton C. Williams III, "The Choice of Discount Rate for Climate Change Policy Evaluation," *Climate Change Economics*, vol. 3, no. 4, 2012, http://web.stanford.edu/~goulder/Papers/Published%20Papers/Choice%20of%20Discount%20Rate%20for%20Cl%20Ch%20Policy%20Evals%20(Goulder-Williams,%20CCE%202012).pdf; Hilary Greaves, "Discounting for climate change: A critical survey," working paper, 2015, http://users.ox.ac.uk/~mert2255/papers/discounting.pdf; Peter Howard and Derek Sylvan, "Expert Consensus on the Economics of Climate Change," Institute for Policy Integrity New York University School of Law, 2015, http://policyintegrity.org/files/publications/ExpertConsensusReport.pdf; all accessed September 2016.

[144] "Hurricane Irene one year later: Storm cost $15.8 in damage from Florida to New York to the Caribbean," *The Associated Press* in *NY Daily News*, August 27, 2012, http://www.nydailynews.com/new-york/hurricane-irene-year-storm-cost-15-8-damage-florida-new-york-caribbean-article-1.1145302, accessed September 2016.

[145] Joseph E. Aldy "Mobilizing Political Action on Behalf of Future Generations" *The Future of Children*, Vol. 26, No. 1, Spring 2016, 157-178.

[146] See, for an influential meditation on this issue, Henry Shue, *Climate Justice: Vulnerability and Protection* (Cambridge: Cambridge University Press, 2014).

147 Jeffrey Ball, "Climate Change is Now in the Developing World's Hands," *Slate*, November 29, 2013, http://www.slate.com/articles/health_and_science/energy_around_the_world/2013/11/warsaw_climate_talks_developing_countries_will_be_source_of_greenhouse_gas.single.html, accessed December 2014.

148 "Climate Futures."

149 "Economics of Climate Change," U.S. Environmental Protection Agency website, http://yosemite.epa.gov/EE%5Cepa%5Ceed.nsf/webpages/ClimateEconomics.html, accessed August 2014.

150 Winston Harrington and Richard D. Morgenstern, "Economic Incentives versus Command and Control," Resources for the Future, Fall/Winter 2004, pp. 15, http://www.rff.org/rff/Documents/RFF_Resources_152_ecoincentives.pdf, accessed August 2014.

151 Richard Schmalensee and Robert N. Stavins, "Lessons Learned from Three Decades of Experience with Cap-and-Trade," prepared for the Review of Environmental Economics and Policy and available as a discussion paper 15-51 for Resources for the Future, November 2015, http://www.rff.org/files/document/file/RFF-DP-15-51.pdf, accessed September 2016.

152 Roger Hinrichs and Merlin Kleinbach, *Energy: Its Use and the Environment*, Brooks/Cole, Cengage Learning, January 1, 2012, p. 255, http://books.google.com/books?id=Q-9dza3IOCsC&pg=PA255&lpg=PA255&dq=acid+rains+levels+drop+by+65%25&source=bl&ots=H8j13r5aqP&sig=T5u76g9rrs958xuwzTP0L9ugeX4&hl=en&sa=X&ei=uXqAVKOTLI6QyASflYHQDA&ved=0CEAQ6AEwBA#v=onepage&q=acid%20rains%20levels%20drop%20by%2065%25&f=false, accessed December 2014.

153 Ronald J. Shadbegian, Wayne B. Gray, and Cynthia L. Morgan, "Benefits and Costs from Sulfur Dioxide Trading: A Distributional Analysis," EPA National Center for Environmental Economics, Working Paper # 05-09, December 2005, https://www.epa.gov/sites/production/files/2014-12/documents/benefits_and_costs_from_sulfur_dioxide.pdf, accessed September 2016.

154 "What is a Carbon Tax?" British Columbia Ministry of Finance website, http://www.fin.gov.bc.ca/tbs/tp/climate/A1.htm, accessed August 2014.

155 Eduardo Porter, "A Carbon Tax Could Bolster Green Energy," *The New York Times*, November 18, 2014, http://www.nytimes.com/2014/11/19/business/economy/a-carbon-tax-could-bolster-wobbly-progress-in-renewable-energy.html?_r=0, accessed December 2014.

156 National Research Council of the National Academies, *Limiting the Magnitude of Future Climate Change* (Washington D.C.: The National Academies Press, 2010), p. 91.

157 "A Summary of the Kyoto Protocol," United National Framework Convention on Climate Change website, http://unfccc.int/kyoto_protocol/background/items/2879.php, accessed August 2014.

158 "A Summary of the Kyoto Protocol," United National Framework Convention on Climate Change website, http://unfccc.int/kyoto_protocol/background/items/2879.php, accessed August 2014.

159 Greg Kahn, "The Fate of the Kyoto Protocol Under the Bush Administration," *Berkeley Journal of International Law*, 2003, p. 3, http://scholarship.law.berkeley.edu/cgi/viewcontent.cgi?article=1248&context=bjil, accessed December 2014.

160 "Historic Paris Agreement on Climate Change—195 Nations Set Path to Keep Temperature Rise Well Below 2 Degrees Celsius," Press Release, United Nations Framework Convention on Climate Change, December 12, 2015, http://newsroom.unfccc.int/unfccc-newsroom/finale-cop21/, accessed May 2016.

161 Annegrete Bruvoll, "Greenhouse Gas Emission in Norway: Do Carbon Taxes Work?" Statistics Norway Research Department, December 2002, p. 10, http://www.ssb.no/a/publikasjoner/pdf/DP/dp337.pdf, accessed September 2014.

162 Rob Taylor and Rhiannon Hoyle, "Australia Becomes First Developed Nation to Repeal Carbon Tax," *The Wall Street Journal*, July 17, 2014, http://online.wsj.com/articles/australia-repeals-carbon-tax-1405560964, accessed August 2014.

163 "Australia Introduces Controversial Carbon Tax," *BBC*, July 1, 2012, http://www.bbc.com/news/world-asia-18662560, accessed August 2014.

164 "Memorandum of Understanding," Regional Greenhouse Gas Initiative website, http://rggi.org/design/history/mou, accessed August 2014.

165 "The Economic Impact of the Regional Greenhouse Gas Initiative on Ten Northeast and Mid-Atlantic States," Analysis Group, November 15, 2011, http://www.analysisgroup.com/uploadedfiles/publishing/articles/economic_impact_rggi_report.pdf, accessed December 2014.

166 Rory Carroll, "Analysis: Strong Start for California Carbon Market, but Challenges Loom," *Reuters*, December 20, 2013, http://www.reuters.com/article/2013/12/20/us-california-carbon-market-analysis-idUSBRE9BJ17U20131220, accessed August 2014.

167 "Carbon Tax," British Columbia Ministry of Finance website, http://www.fin.gov.bc.ca/tbs/tp/climate/carbon_tax.htm, accessed December 2014.

168 "Carbon Tax," British Columbia Ministry of Finance website, http://www.fin.gov.bc.ca/tbs/tp/climate/carbon_tax.htm, accessed December 2014.

169 "British Columbia's carbon tax: The evidence mounts," *The Economist*, July 31, 2014, http://www.economist.com/blogs/americasview/2014/07/british-columbias-carbon-tax, accessed September 2016.

170 Ian Austen, "Canada Strikes a Deal to Cut Carbon Emissions by Putting a Price on Them," *New York Times*, December 9, 2016, http://www.nytimes.com/2016/12/09/world/americas/canada-carbon-emissions-taxes-cap-and-trade.html, accessed December 2016.

171 Kate Gordon, "Why Renewable Energy Still Needs Subsidies," *The Wall Street Journal*, Sept. 14, 2015, http://blogs.wsj.com/experts/2015/09/14/why-renewable-energy-still-needs-subsidies/, accessed April 2016.

172 Emma Rumney, "China is world's largest investor in renewable energy," *Public Finance International*, March 31, 2016, http://www.publicfinanceinternational.org/news/2016/03/china-worlds-largest-investor-renewable-energy, accessed September 2016.

173 "China's Clean Energy Exceeds 20% of Power Generation in 2015," *Bloomberg News*, August 24, 2016, http://www.bloomberg.com/news/articles/2016-08-24/china-s-clean-energy-exceeds-20-of-power-generation-in-2015, accessed September 2016.

174 Jocelyn Durkay, "State Renewable Portfolio Standards and Goals," National Conference of State Legislatures website, July 27, 2016, http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx, accessed September 2016.

175 Michael Kavanagh, "A world map of subsidies for renewable energy and fossil fuels," *Financial Times*, July 26, 2016, http://www.ft.com/cms/s/2/fb264f96-5088-11e6-8172-e39ecd3b86fc.html#axzz4JbSJgjPI, accessed September 2016.

176 "Green Generation: Milennials Say Sustainability Is A Shopping Priority," Nielsen website, November 5, 2015, http://www.nielsen.com/us/en/insights/news/2015/green-generation-millennials-say-sustainability-is-a-shopping-priority.html, accessed September 2016.

177 Kelsey Lindsey, "Why Wal-Mart Is a Retail Sustainability Leader (but Doesn't Really Want to Talk About It," *Retail Dive*, August 9, 2016, http://www.retaildive.com/news/why-wal-mart-is-a-retail-sustainability-leader-but-doesnt-really-want-to/423713/, accessed September 2016.

178 "About Greenwashing," Greenwashing Index website, http://greenwashingindex.com/about-greenwashing/, accessed September 2016.

179 "Sustainability: Making a Difference," McDonald's website, http://corporate.mcdonalds.com/mcd/sustainability.html; "McVictory: Victory as Fast Food Giant Pledges to Help Protect the Amazon," Greenpeace International website, July 25, 2006, http://www.greenpeace.org/international/en/news/features/McVictory-200706/, both accessed September 2016.

180 Unilever, RSPO website, http://www.rspo.org/members/107/unilever, accessed September 2016.

181 "Kimberly-Clark Announces Ambitious Sustainable Development Goal for Forest Use," Kimberly-Clark press release, June 18, 2012, http://investor.kimberly-clark.com/releasedetail.cfm?ReleaseID=683471, accessed September 2016.

182 Tim McDonnell, "Climate Change Is Kicking the Insurance Industry's Butt," *Mother Jones*, October 22, 2014, http://www.motherjones.com/environment/2014/10/climate-insurance, accessed September 2016.

183 "What Is an Internal Carbon Price, and Should My Business Implement One?" Triple Pundit website, December 21, 2015, http://www.triplepundit.com/2015/12/what-is-an-internal-carbon-price-and-should-my-business-implement-one/, accessed September 2016.

184 "What Is an Internal Carbon Price, and Should My Business Implement One?" Triple Pundit website, December 21, 2015, http://www.triplepundit.com/2015/12/what-is-an-internal-carbon-price-and-should-my-business-implement-one/, accessed September 2016.

185 Paul Spedding, Kirtan Mehta, Nick Robins, "Oil & carbon revisited: Value at risk from 'unburnable' reserves," HSBC Global Research, January 25, 2013, available at http://dcdivest.org/wp-content/uploads/2015/10/HSBCOilJan13.pdf, accessed September 2016.

[186] Damian Carrington, "Carbon bubble will plunge the world into another financial crisis—report," *The Guardian*, April 18, 2013, https://www.theguardian.com/environment/2013/apr/19/carbon-bubble-financial-crash-crisis, accessed September 2016.

[187] Suzanne Goldenberg, "ExxonMobil gave millions to climate-denying lawmakers despite pledge," *The Guardian*, July 15, 2015, https://www.theguardian.com/environment/2015/jul/15/exxon-mobil-gave-millions-climate-denying-lawmakers, accessed September 2016.

[188] "Koch Industries," *Forbes*, http://www.forbes.com/companies/koch-industries/, accessed September 2016.

[189] "Koch Industries: Secretly Funding the Climate Denial Machine," Greenpeace website, http://www.greenpeace.org/usa/global-warming/climate-deniers/koch-industries/, accessed September 2016.

[190] "Smoke, Mirrors & Hot Air," Union of Concerned Scientists, January 2007, p. 1 http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/exxon_report.pdf, accessed December 2014.

[191] "Smoke, Mirrors & Hot Air," Union of Concerned Scientists, January 2007, p. 1 http://www.ucsusa.org/sites/default/files/legacy/assets/documents/global_warming/exxon_report.pdf, accessed December 2014.

[192] Frankfurt School of Finance & Management gGmbH 2016, "Global Trends in Renewable Energy Investment 2016," United Nations Environment Programme and Bloomberg New Energy Finance, available at http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2016lowres_0.pdf, accessed February 2017.

[193] "Clean Energy Defies Fossil Fuel Price Crash To Attract Record $329bn Global Investment In 2015,"Press Release, Bloomberg New Energy Finance, January 14, 2016, https://about.bnef.com/press-releases/clean-energy-defies-fossil-fuel-price-crash-to-attract-record-329bn-global-investment-in-2015/, accessed December 2016.

[194] "Global EV Outlook 2016," International Energy Agency, https://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf, accessed December 2016.

[195] Liebreich, Michael, "Bloomberg New Energy Finance Summit 2015," April 14, 2015, https://data.bloomberglp.com/bnef/sites/4/2015/04/bnef_2015-04-14-summit-keynote-11.pdf, accessed December 2016.

[196] Randall, Tom, "Here's How Electric Cars Will Cause the Next Oil Crisis," Bloomberg, February 25, 2016, http://www.bloomberg.com/features/2016-ev-oil-crisis/, accessed December 2016.

[197] "Tesla's Revenue from FY 2008 to FY 2015 (in million U.S. dollars)," via Statista, accessed September 2016.

[198] General Motors Company, Form 10-K, 2015, https://www.gm.com/content/dam/gm/en_us/english/Group4/InvestorsPDFDocuments/10-K.pdf, accessed September 2016.

[199] Douglas A. McIntyre, "Tesla Market Cap Hits Half of GM's," 247 Wall St., June 22, 2015, http://247wallst.com/autos/2015/06/22/tesla-market-cap-hits-half-of-gms/, accessed September 2016.

[200] Frederika Whitehead, "Lessons from Denmark: how district heating could improve energy security," *The Guardian*, August 20, 2014, https://www.theguardian.com/big-energy-debate/2014/aug/20/denmark-district-heating-uk-energy-security, accessed December 2016.

[201] "Smart Growth and Climate Change," U.S. Environmental Protection Agency, https://www.epa.gov/smartgrowth/smart-growth-and-climate-change, accessed December 2016.

[202] "A Roadmap For A Renewable Energy Future, 2016 Edition," International Renewable Energy Agency, http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_2016_edition_report.pdf, accessed December 2016.

[203] "Schneider Electric introduces Continuous Efficiency—a new approach to global energy management," PR Newswire, October 25, 2016, http://www.prnewswire.com/news-releases/schneider-electric-introduces-continuous-efficiency--a-new-approach-to-global-energy-management-300350078.html, accessed January 2017.

[204] "Eco-Design," Schneider Electric, http://www2.schneider-electric.com/sites/corporate/en/group/sustainable-development-and-foundation/environment-protection/eco-design.page, access January 2017.

[205] Cecilia Shutters and Robb Tufts, "LEED by the numbers: 16 years of steady growth," U.S. Green Building Council website, May 27, 2016, http://www.usgbc.org/articles/leed-numbers-16-years-steady-growth, accessed September 2016.

[206] "Energy efficient lighting market to reach market size of $173.4 billion by 2016," InterLumi website, October 22, 2015, http://www.inter-lumi.com/m_article/27-Energy-efficient-lighting-market-to-reach-market-size-of-1734-billion-by-2016.html, accessed September 2016.

207 "Winning on our Strengths," Johnson Controls website, http://www.johnsoncontrols.com/corporate-sustainability/reporting-and-policies/business-and-sustainability-report/message-to-stakeholders, accessed September 2016.

208 "Johnson Controls reports double digit increase in 2016 second quarter adjusted earnings per share; raises fiscal year 2016 earnings guidance," Johnson Controls press release, April 21, 2016, http://www.johnsoncontrols.com/media-center/news/press-releases/2016/04/21/johnson-controls-reports-double-digit-increase-in-2016-second-quarter-adjusted-earnings-per-share-raises-fiscal-year-2016-earnings-guidance, accessed September 2016.

209 "Micro Irrigation Systems Market 2015-2019 with Netafim, The Toro Company, Jain Irrigation Systems & Rain Bird Dominating the $2.22 Billion Market," PR Newswire, April 8, 2015, http://www.prnewswire.com/news-releases/micro-irrigation-systems-market-2015-2019-with-netafim-the-toro-company-jain-irrigation-systems--rain-bird-dominating-the-222-billion-market-300062943.html, accessed September 2016.

210 Nell Greenfieldboyce, "2016 Was The Hottest Year Yet, Scientists Declare," NPR, January 18, 2017, http://www.npr.org/sections/thetwo-way/2017/01/18/510405739/2016-was-the-hottest-year-yet-scientists-declare, accessed January 2017.

211 For all parameters, the 10th to 90th percentile of the scenarios is shown, 1, 2. 1 The 'total range' for the 430–480 ppm CO2eq scenarios corresponds to the range of the 10th–90th percentile of the subcategory of these scenarios shown in Table 6.3. 2 Baseline scenarios (see SPM.3) fall into the >1000 and 720–1000ppm CO2eq categories. The latter category also includes mitigation scenarios. The baseline scenarios in the latter category reach a temperature change of 2.5–5.8°C above preindustrial in 2100. Together with the baseline scenarios in the >1000ppm CO2eq category, this leads to an overall 2100 temperature range of 2.5–7.8°C (range based on median climate response: 3.7–4.8°C) for baseline scenarios across both concentration categories. 3 For comparison of the cumulative CO2 emissions estimates assessed here with those presented in WGI, an amount of 515 [445–585] GtC (1890 [1630–2150] GtCO2), was already emitted by 2011 since 1870 [Section WGI 12.5]. Note that cumulative emissions are presented here for different periods of time (2011–2050 and 2011–2100) while cumulative emissions in WGI are presented as total compatible emissions for the RCPs (2012–2100) or for total compatible emissions for remaining below a given temperature target with a given likelihood [WGI Table SPM.3, WGI SPM.E.8]. 4 The global 2010 emissions are 31% above the 1990 emissions (consistent with the historic GHG emission estimates presented in this report). CO2eq emissions include the basket of Kyoto gases (CO2, CH4, N2O as well as F-gases). 5 The assessment in WGIII involves a large number of scenarios published in the scientific literature and is thus not limited to the RCPs. To evaluate the CO2eq concentration and climate implications of these scenarios, the MAGICC model was used in a probabilistic mode (see Annex II). For a comparison between MAGICC model results and the outcomes of the models used in WGI, see Sections WGI 12.4.1.2 and WGI 12.4.8 and 6.3.2.6. Reasons for differences with WGI SPM Table.2 include the difference in reference year (1986–2005 vs. 1850–1900 here), difference in reporting year (2081–2100 vs 2100 here), set-up of simulation (CMIP5 concentration driven versus MAGICC emission-driven here), and the wider set of scenarios (RCPs versus the full set of scenarios in the WGIII AR5 scenario database here). 6 Temperature change is reported for the year 2100, which is not directly comparable to the equilibrium warming reported in WGIII AR4 [Table 3.5, Chapter 3]. For the 2100 temperature estimates, the transient climate response (TCR) is the most relevant system property. The assumed 90% range of the TCR for MAGICC is 1.2–2.6 °C (median 1.8 °C). This compares to the 90% range of TCR between 1.2–2.4 °C for CMIP5 [WGI 9.7] and an assessed likely range of 1–2.5 °C from multiple lines of evidence reported in the WGI AR5 [Box 12.2 in Section 12.5]. 7 Temperature change in 2100 is provided for a median estimate of the MAGICC calculations, which illustrates differences between the emissions pathways of the scenarios in each category. The range of temperature change in the parentheses includes in addition the carbon cycle and climate system uncertainties as represented by the MAGICC model [see 6.3.2.6 for further details]. The temperature data compared to the 1850–1900 reference year was calculated by taking all projected warming relative to 1986–2005, and adding 0.61 °C for 1986–2005 compared to 1850–1900, based on HadCRUT4 [see WGI Table SPM.2]. 8 The assessment in this table is based on the probabilities calculated for the full ensemble of scenarios in WGIII using MAGICC and the assessment in WGI of the uncertainty of the temperature projections not covered by climate models. The statements are therefore consistent with the statements in WGI, which are based on the CMIP5 runs of the RCPs and the assessed uncertainties. Hence, the likelihood statements reflect different lines of evidence from both WGs. This WGI method was also applied for scenarios with intermediate concentration levels where no CMIP5 runs are available. The likelihood statements are indicative only [6.3], and follow broadly the terms used by the WGI SPM for temperature projections: likely 66–100%, more likely than not >50–100%, about as likely as not 33–66%, and unlikely 0–33%. In addition the term more unlikely than likely 0– 0–33%. In addition the term more unlikely than likely 0–<50% is used. 9 The CO2-equivalent concentration includes the forcing of all GHGs including halogenated gases and tropospheric ozone, as well as aerosols and albedo change (calculated on the basis of the total forcing from a simple carbon cycle/climate model, MAGICC). 10 The vast majority of scenarios in this category overshoot the category boundary of 480 ppm CO2eq concentrations. 11 For scenarios in this category no CMIP5 run [WGI Chapter 12, Table 12.3] as well as no MAGICC realization [6.3] stays below the respective temperature level. Still, an unlikely assignment is given to reflect uncertainties that might not be reflected by the current climate models. 12 Scenarios in the 580–650 ppm CO2eq category include both overshoot scenarios and scenarios that do not exceed the concentration level at the high end of the category (like RCP4.5). The latter type of scenarios, in general, have an assessed probability of more unlikely than likely to stay below the 2 °C temperature level, while the former are mostly assessed to have an unlikely probability of staying below this level.