GLOBAL CLIMATE CHANGE
Vital Signs of the Planet

The Causes of Climate Change

A simplified animation of the greenhouse effect. Credit: NASA/JPL-Caltech

Scientists attribute the global warming trend observed since the mid-20th century to the human expansion of the "greenhouse effect"[1] — warming that results when the atmosphere traps heat radiating from Earth toward space.

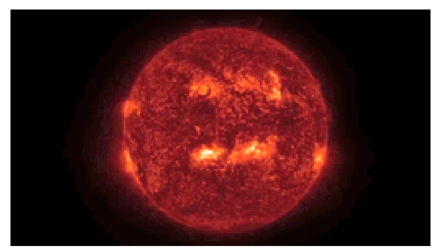
Certain gases in the atmosphere block heat from escaping. Long-lived gases that remain semi-permanently in the atmosphere and do not respond physically or chemically to changes in temperature are described as "forcing" climate change. Gases, such as water vapor, which respond physically or chemically to changes in temperature are seen as "feedbacks."

Gases that contribute to the greenhouse effect include:

We Live in a Greenhouse

Life on Earth depends on energy coming from the Sun. About half the light reaching Earth's atmosphere passes through the air and clouds to the surface, where it is absorbed and then radiated upward in the form of infrared heat. About 90 percent of this heat is then absorbed by the greenhouse gases and radiated back toward the surface, which is warmed to a life-supporting average of 59 degrees Fahrenheit (15 degrees Celsius).

Is the Sun to Blame?

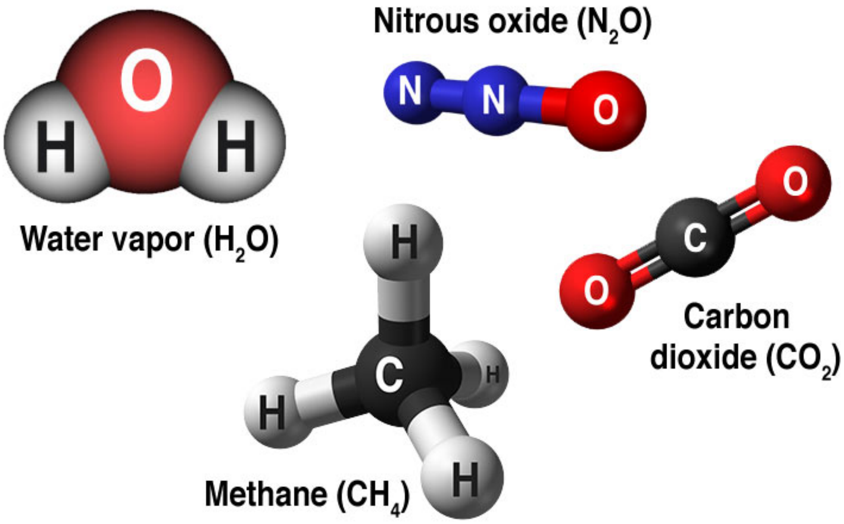


The Sun as seen from NASA's STEREO-B mission. Credit: NASA's Scientific Visualization Studio.

How do we know that changes in the Sun aren't to blame for current global warming trends?

Since 1978, a series of satellite instruments have measured the energy output of the Sun directly. The satellite data show a very slight drop in solar irradiance (which is a measure of the amount of energy the Sun gives off) over this time period. So the Sun doesn't appear to be responsible for the warming trend observed over the past several decades.

Longer-term estimates of solar irradiance have been made using sunspot records and other so-called



- Water vapor. The most abundant greenhouse gas, but importantly, it acts as a feedback to the climate. Water vapor increases as the Earth's atmosphere warms, but so does the possibility of clouds and precipitation, making these some of the most important feedback mechanisms to the greenhouse effect.

- Carbon dioxide (CO_2). A minor but very important component of the atmosphere, carbon dioxide is released through natural processes such as respiration and volcano eruptions and through human activities such as deforestation, land use changes, and burning fossil fuels. Humans have increased atmospheric CO_2 concentration by more than a third since the Industrial Revolution began. This is the most important long-lived "forcing" of climate change.

- Methane. A hydrocarbon gas produced both through natural sources and human activities, including the decomposition of wastes in landfills, agriculture, and especially rice cultivation, as well as ruminant digestion and manure management associated with domestic livestock. On a molecule-for-molecule basis, methane is a far more active greenhouse gas than carbon dioxide, but also one which is much less abundant in the atmosphere.

- Nitrous oxide. A powerful greenhouse gas produced by soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.

- Chlorofluorocarbons (CFCs). Synthetic compounds entirely of industrial origin used in a number of applications, but now

"proxy indicators," such as the amount of carbon in tree rings. The most recent analyses of these proxies indicate that solar irradiance changes cannot plausibly account for more than 10 percent of the 20th century's warming.[2]

Latest resources

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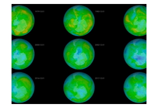

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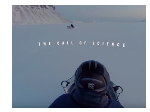

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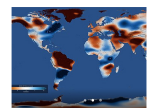


largely regulated in production and release to the atmosphere by international agreement for their ability to contribute to destruction of the ozone layer. They are also greenhouse gases.

On Earth, human activities are changing the natural greenhouse. Over the last century the burning of fossil fuels like coal and oil has increased the concentration of atmospheric carbon dioxide (CO_2). This happens because the coal or oil burning process combines carbon with oxygen in the air to make CO_2. To a lesser extent, the clearing of land for agriculture, industry, and other human activities has increased concentrations of greenhouse gases.

Not enough greenhouse effect: The planet Mars has a very thin atmosphere, nearly all carbon dioxide. Because of the low atmospheric pressure, and with little to no methane or water vapor to reinforce the weak greenhouse effect, Mars has a largely frozen surface that shows no evidence of life.

The consequences of changing the natural atmospheric greenhouse are difficult to predict, but certain effects seem likely:

- On average, Earth will become warmer. Some regions may welcome warmer temperatures, but others may not.

- Warmer conditions will probably lead to more evaporation and precipitation overall, but individual regions will vary, some becoming wetter and others dryer.

Too much greenhouse effect: The atmosphere of Venus, like Mars, is nearly all carbon dioxide. But Venus has about 154,000 times as much carbon dioxide in its atmosphere as Earth (and about 19,000 times as much as Mars does), producing a runaway greenhouse effect and a surface temperature hot enough to melt lead.

- A stronger greenhouse effect will warm the oceans and partially melt glaciers and other ice, increasing sea level. Ocean water also will expand if it warms, contributing further to sea level rise.

- Meanwhile, some crops and other plants may respond favorably to increased atmospheric CO_2, growing more vigorously and using water more efficiently. At the same time, higher temperatures and shifting climate patterns may change the areas where crops grow best and affect the makeup of natural plant communities.

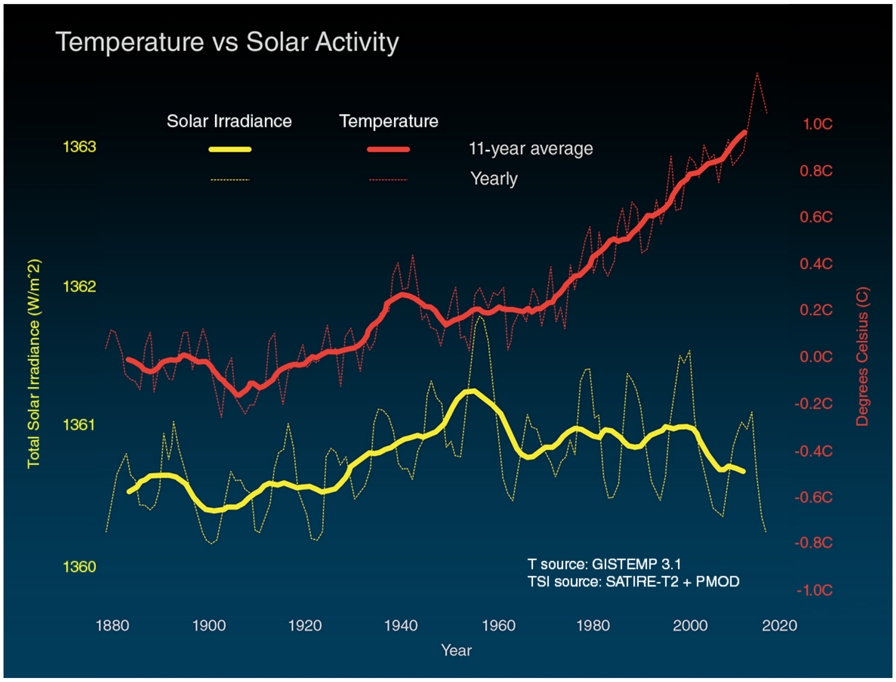
The Role of Human Activity

In its Fifth Assessment Report, the Intergovernmental Panel on Climate Change, a group of 1,300 independent scientific experts from countries all over the world under the auspices of the United Nations, concluded there's a more than 95 percent probability that human activities over the past 50 years have warmed our planet.

The industrial activities that our modern civilization depends upon have raised atmospheric carbon dioxide levels from 280 parts per million to 400 parts per million in the last 150 years. The panel also concluded there's a better than 95 percent probability that human-produced greenhouse gases such as carbon dioxide, methane and nitrous oxide have caused much of the observed increase in Earth's temperatures over the past 50 years.

The panel's full Summary for Policymakers report is online at **https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_summary-for-policymakers.pdf**.

Solar Irradiance



The above graph compares global surface temperature changes (red line) and the Sun's energy received by the Earth (yellow line) in watts (units of energy) per square meter since 1880. The lighter/thinner lines show the yearly levels while the heavier/thicker lines show the 11-year average trends. Eleven-year averages are used to reduce the year-to-year natural noise in the data, making the underlying trends more obvious.

The amount of solar energy received by the Earth has followed the Sun's natural 11-year cycle of small ups and downs with no net increase since the 1950s. Over the same period, global temperature has risen markedly. It is therefore extremely unlikely that the Sun has caused the observed global temperature warming trend over the past half-century. Credit: NASA/JPL-Caltech

It's reasonable to assume that changes in the Sun's energy output would cause the climate to change, since the Sun is the fundamental source of energy that drives our climate system.

Indeed, studies show that solar variability has played a role in past climate changes. For example, a decrease in solar activity coupled with an increase in volcanic activity is thought to have helped trigger the Little Ice Age between approximately 1650 and 1850, when Greenland cooled from 1410 to the 1720s and glaciers advanced in the Alps.

But several lines of evidence show that current global warming cannot be explained by changes in energy from the Sun:

- Since 1750, the average amount of energy coming from the Sun either remained constant or increased slightly.

- If the warming were caused by a more active Sun, then scientists would expect to see warmer temperatures in all layers of the atmosphere. Instead, they have observed a cooling in the upper atmosphere, and a warming at the surface and in the lower parts of the atmosphere. That's because greenhouse gases are trapping heat in the lower atmosphere.

- Climate models that include solar irradiance changes can’t reproduce the observed temperature trend over the past century or more without including a rise in greenhouse gases.

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This website is produced by the Earth Science Communications Team at

NASA's Jet Propulsion Laboratory | California Institute of Technology

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Site last updated: July 12, 2019

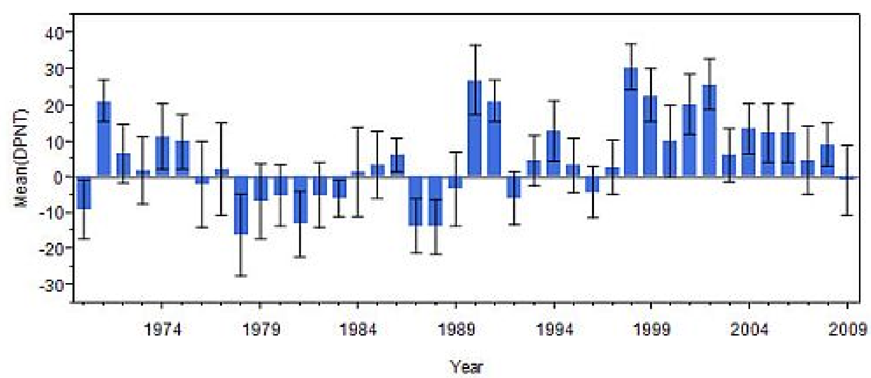
Climate Change Impacts in Virginia: A natural resource database

Environmental conditions

Climate data can tell an interesting story about changes in environmental conditions. Since climate change is a long-term process, long-term datasets are necessary to separate annual variation in temperature, precipitation, etc from climate-related trends. Multiple decades worth of data are necessary, centuries worth of data would be ideal.

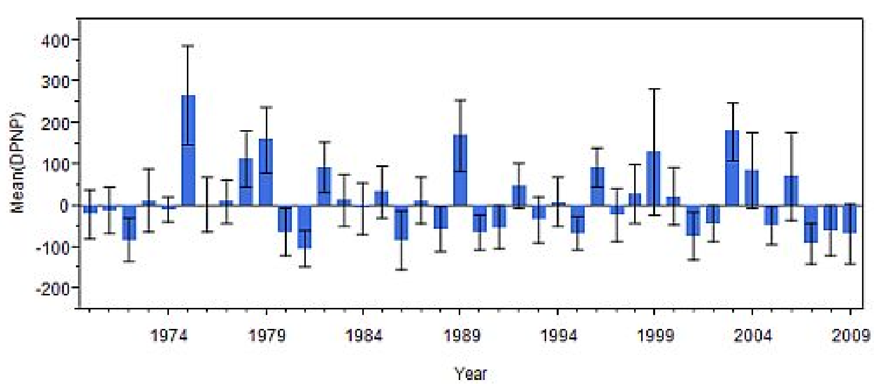
Examining the mean (average) departures from normal precipitation and temperature are one way to look for trends. The graphs below depict how the air temperature or precipitation in a given year differs from the norm, in Williamsburg VA. Positive values indicate extra rainfall or higher temperatures, while negative values indicate the opposite. No obvious trend is apparent in the graphs below. Possibly there is no trend, or there may be a trend which is not apparent because the time frame is too short, or trends have been hidden by climatic events, such as El Nino or La Nina years.

Mean Annual Departures from Normal Temperature



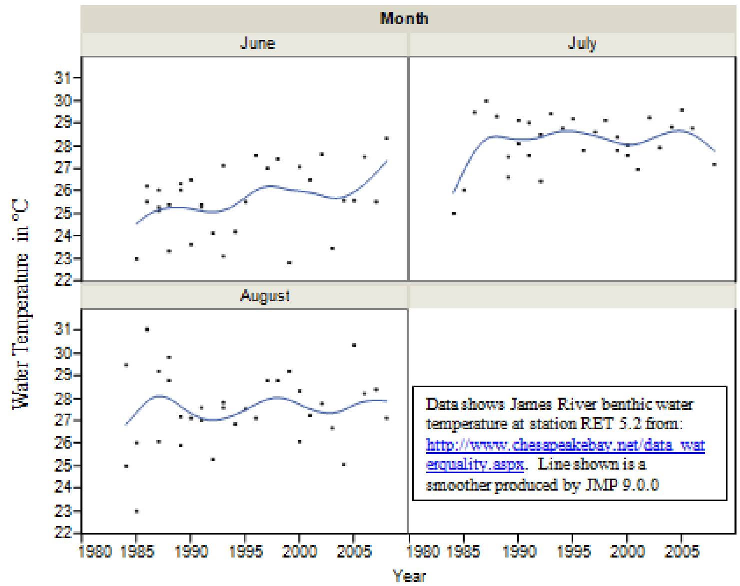
Data from: http://cdo.ncdc.noaa.gov Error bars are 1 SEM.

Mean Annual Departures from Normal Precipitation



Data from: http://cdo.ncdc.noaa.gov Error bars are 1 SEM.

Water temperature is another environmental factor expected to be impacted by climate change. The example below shows benthic (bottom) water temperature at a station on the James River. Early summer (June) benthic water temperature at this station appears to be showing an upward trend over time. This trend is not evident in the later summer months, suggesting that maximum water temperature is not increasing; however the river may be warming up earlier in the season. This can contribute to shifts in the timing of temperature-related events, such as spawning and phytoplankton blooms.



M. arenaria are temperature sensitive and the southern limit of their range is controlled by the upper water temperatures. Temperature influences growth and reproduction. In the Chesapeake Bay, *M. arenaria* does not usually survive temperatures above 28 degrees C. High temperatures during the fall spawning season may be particularly harmful to the population. Ideal spawning temperatures range from around 10-14 degrees C in the spring (May-mid June) and 12-15 degrees C in the fall (late August-December). Data for populations are from Chesapeake Bay Baywide Benthic Datasets; data for water temperature are from Chesapeake Bay Institute Water Quality (1985-1982) and Chesapeake Bay Program Water Quality (1984-present).

The example above shows the importance of data selection for determining climate-related changes. Since the trend does not show an increase in the maximum summer water temperature, no trend would be seen at all if the three summer months had been analyzed together. Similarly, different areas of the Chesapeake Bay have different processes at work. Stations near the mouth of the Bay, where cold ocean water enters, may not show such an obvious trend. Shallow water areas are more likely to reflect a change in air temperature with a concurrent change in water temperature.

Environmental factors expected to reflect shifts in climate include:

- CO2 concentrations
- Air temperature (Maximum and minimum temperatures and annual temperature distributions)
- Water temperature (Maximum and minimum temperatures and annual temperature distributions)
- Freshwater flows (volume and timing of high flow events)
- Sea level
- Salinity (distributions)

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SPEECHES & TRANSCRIPTS

Climate Change Is a Challenge For Sustainable Development

January 15, 2014

Rachel Kyte
Gaidar Forum
Moscow, Russian Federation

As Prepared for Delivery

Climate change is the most significant challenge to achieving sustainable development, and it threatens to drag millions of people into grinding poverty.

At the same time, we have never had better know-how and solutions available to avert the crisis and create opportunities for a better life for people all over the world.

Climate change is not just a long-term issue. It is happening today, and it entails uncertainties for policy makers trying to shape the future.

EFFECTS ON RUSSIA

In 2008, the Russian National Hydrometeorological Service (Roshydromet) found that winter temperatures had increased by 2 to 3 degrees Celsius in Siberia over the previous 120-150 years, while average global temperature rose about 0.7 degrees during the same period.

Russia is projected to cross the 2°C threshold earlier than the world on average if significant and effective mitigation is not forthcoming. By 2100, the northern half of Asia, including Russia, is likely to experience a temperature increase of 6 to 16°C, compared to approximately 4°C global mean temperature increase.

While warming might have some potential gains for Russia, the adverse effects include more floods, windstorms, heat waves, forest fires, and the melting of permafrost.

Globally, permafrost is thought to hold about 1,700 gigatons of carbon – and near-shore seabeds in the Eastern Siberian Sea hold a similar amount in methane hydrates that could potentially be destabilized in a warmer world, as well. This is compared to 850 gigatons of carbon currently in the Earth's atmosphere. Of this, 190 gigatons are stored just in the upper 30 cm of permafrost, the layers that area most vulnerable to melting and the irreversible release of methane. The release of even a small portion into the atmosphere could dramatically compound the challenge already presented from anthropogenic sources, potentially wiping out any hard-won mitigation gains.

Russia hosts perhaps 70 percent of methane in circumpolar permafrost, as well as the methane hydrates in the East Siberian Sea. Permafrost warming of up to 2°C in parts of the European Russia has already been observed.

Russia will be front and center for any efforts to deal with thawing permafrost and Russian leadership is much needed to better understand its effects for the global climate as well as finding solutions for effective adaptation. There is no time to lose.

In Yakutsk, collapsing ground caused by melting permafrost has damaged buildings, airport runways, and other infrastructure. In 2010, the Ministry of Emergency Situations estimated that a quarter of the housing stock in Russia's Far North would be destroyed by 2030.

Analyses indicate that about 60 percent of infrastructure in the Usa Basin in Northeast European Russia is located in the "high risk" permafrost area, which is projected to thaw in the future. This region is an area of high industrial and urban development, like coal mines, hydrocarbon extraction sites, railways, and pipelines. Yet the timing of this thaw remains uncertain – potentially a few decades or as long off as a century away.

DECISION MAKING UNDER UNCERTAINTY

Policy makers all over the world are facing similar challenges. While we certainly know that the climate will change, there is great uncertainty as to what the local or regional impacts will be and what will be the impacts on societies and economies. Coupled with this is often great disagreement among policy makers about underlying assumptions and priorities for action.

Many decisions to be made today have long-term consequences and are sensitive to climate conditions – water, energy, agriculture, fisheries and forests, and disasters risk management. We simply can't afford to get it wrong.

However, sound decision making is possible if we use a different approach. Rather than making decisions that are optimized to a prediction of the future, decision makers should seek to identify decisions that are sound no matter what the future brings. Such decisions are called "robust."

For example, Metropolitan Lima already has major water challenges: shortages and a rapidly growing population with 2 million underserved urban poor. Climate models suggest that precipitation could decrease by as much as 15 percent, or increase by as much as 23 percent. The World Bank is partnering with Lima to apply tested, state-of-the-art methodologies like Robust Decision Making to help Lima identify no-regret, robust investments. These include, for example, multi-year water storage systems to manage droughts and better management of demand for water. This can help increase Lima's long-term water security, despite an increasingly unpredictable future.

WORKING WHERE IT MATTERS MOST

Each country will need to find its own ways to deal with uncertainties and find its best options for low-carbon growth and emissions reduction. While they vary, every country has them.

One example: Russia has made remarkable progress since 2005 in reducing the flaring of gas from oil production, but it is still the world's largest gas flarer. And it is situated in a region from where black carbon from the flares reaches the Arctic snow and ice cap, which diminishes the cap's reflective power (albedo). The World Bank Group is appreciative of the successful cooperation with Russia's Khanty-Mansiysk region in the Global Gas Flaring Reduction partnership (GGFR). With more Russian partners, in particular from Russian state oil companies, the impact could be even greater.

Russia's forests provide the largest land-based carbon storage in the world. Better forest management and improving forest fire response – a long-standing field of cooperation between Russia and the World Bank Group – are another example to reconcile growth and emissions reductions.

Options for countries all over the world include a mix of technology development that lowers air pollution; increasing investment in renewable energy and energy efficiency, expanding urban public transport; improving waste and water management; and better planning for when disasters strike.

Each of these climate actions can be designed to bring short-term benefits and lower current and future emissions.

To move forward on the global level at the required scale, we must drive mitigation action in top-emitting countries, get prices and incentives right, get finance flowing towards low-carbon green growth, and work where it matters most.

Prices: Putting a price on carbon and removing harmful fossil fuel subsidies are necessary steps towards directing investment to low-carbon growth and avoiding a 4°C warmer world. We are working with others to help lay the groundwork for a robust price on carbon and supporting the removal of harmful fossil fuel subsidies. An ambitious global agreement could help establish stronger carbon prices and should include commitments to accelerate fossil fuel subsidy reform and other fiscal or tax policy measures in support of low carbon and climate resilient development.

Finance flowing: Progress on the provision of climate finance is critical. Governments must deliver a clear strategy for mobilizing the promised $100 billion in climate finance. This $100 billion is doubly important in that it must be used to mobilize effectively private investment and other finance.

Climate change increases the costs of development in the poorest countries by between 25 and 30 percent. For developing countries, the annual cost of infrastructure that is resilient to climate change is around $1.2 trillion to $1.5 trillion, resulting in a yearly $700 billion gap in financing. It will take combining efforts of development banks, financial institutions, export credit agencies, institutional investors, and public budgets to meet the climate and development challenge.

All public finance should be used to leverage private capital and fill gaps in the market where private finance is not flowing. Also, it must be deployed in a way that the least amount leverages the maximum amount from public and/or private sources. We are not dealing with how to jump start something in which the private sector is not interested, but how we create the framework within which the now small but significant momentum is captured, disseminated, and accelerated and the speed-bumps are removed and setbacks avoided.

At the World Bank Group we are committed to working where it matters most:

By 2050 two-thirds of the world's population will be living in cities. Helping developing country cities access private financing and achieve low-carbon, climate-resilient growth and avoid locking in carbon intensive infrastructure is one of the smartest investments we can make. Every dollar invested in building creditworthiness of a developing country city will mobilize $100 dollars in private financing for low-carbon and climate-resilient infrastructure.

To feed 9 billion people nutritiously by 2050 we need to make agriculture resilient, more productive in changing landscapes, and aggressively reduce food waste. Making agriculture work for the people and the environment is one of the most pressing tasks at hand. We need climate-smart agriculture that increases yields and incomes, builds resilience, and reduces emissions while potentially capturing carbon.

The World Bank Group supports the Sustainable Energy for All goals of doubling both the rate of improvement of energy efficiency and the share of renewable energy in the global energy mix from 18 percent to 36 percent by 2030. Reaching these goals is key to low-carbon growth.

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