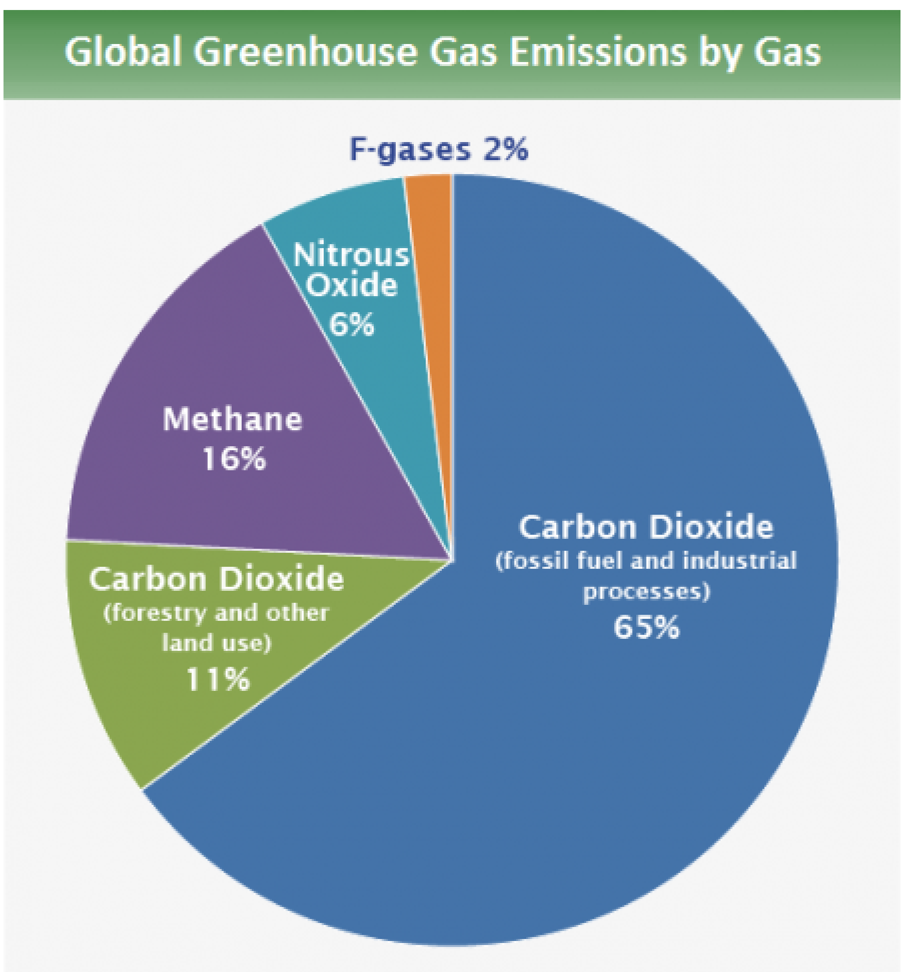
EPA United States Environmental Protection Agency

Global Greenhouse Gas Emissions Data

On This Page:

Global Emissions by Gas

At the global scale, the key greenhouse gases emitted by human activities are:



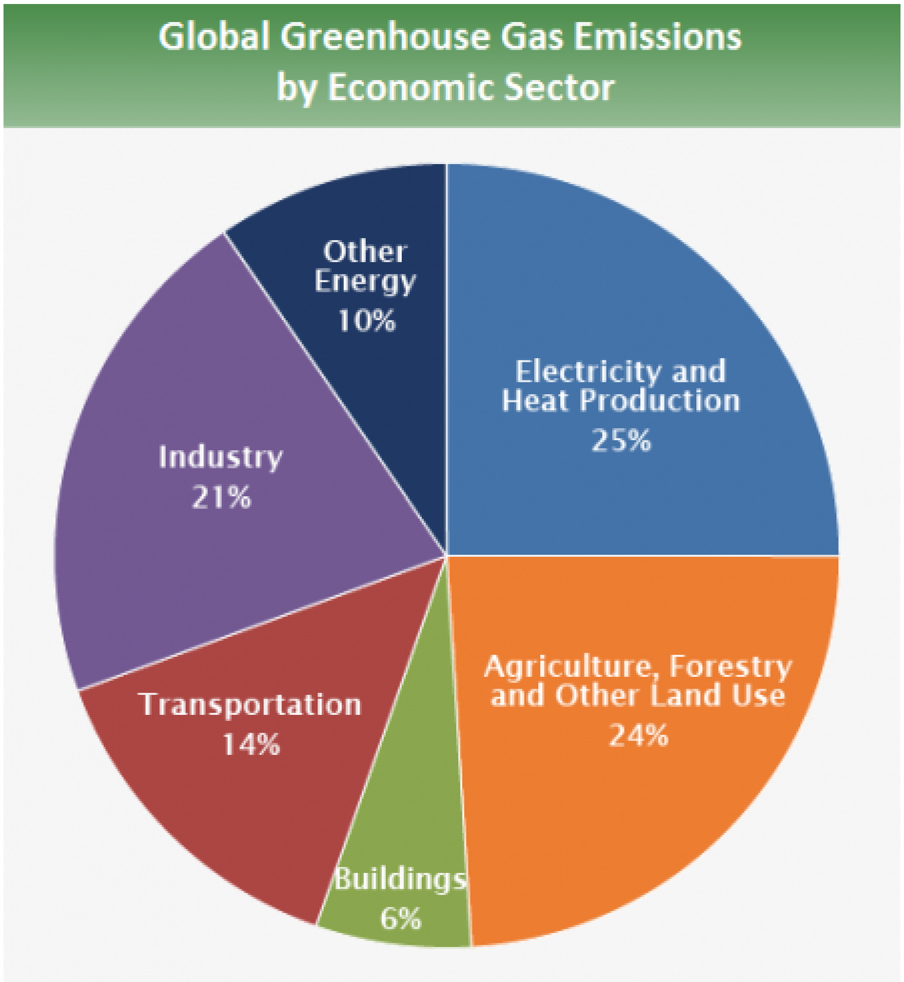
Source: IPCC (2014) EXIT based on global emissions from 2010. Details about the sources included in these estimates can be found in the *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. EXIT

- **Carbon dioxide (CO_2)**: Fossil fuel use is the primary source of CO_2. CO_2 can also be emitted from direct human-induced impacts on forestry and other land use, such as through deforestation, land clearing for agriculture, and degradation of soils. Likewise, land can also remove CO_2 from the atmosphere through reforestation, improvement of soils, and other activities.
- **Methane (CH_4)**: Agricultural activities, waste management, energy use, and biomass burning all contribute to CH_4 emissions.
- **Nitrous oxide (N_2O)**: Agricultural activities, such as fertilizer use, are the primary source of N_2O emissions. Fossil fuel combustion also generates N_2O.
- **Fluorinated gases (F-gases)**: Industrial processes, refrigeration, and the use of a variety of consumer products contribute to emissions of F-gases, which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Black carbon is a solid particle or aerosol, not a gas, but it also contributes to warming of the atmosphere. Learn more about black carbon and climate change on our Causes of Climate Change page.

Global Emissions by Economic Sector

Global greenhouse gas emissions can also be broken down by the economic activities that lead to their production.[1]



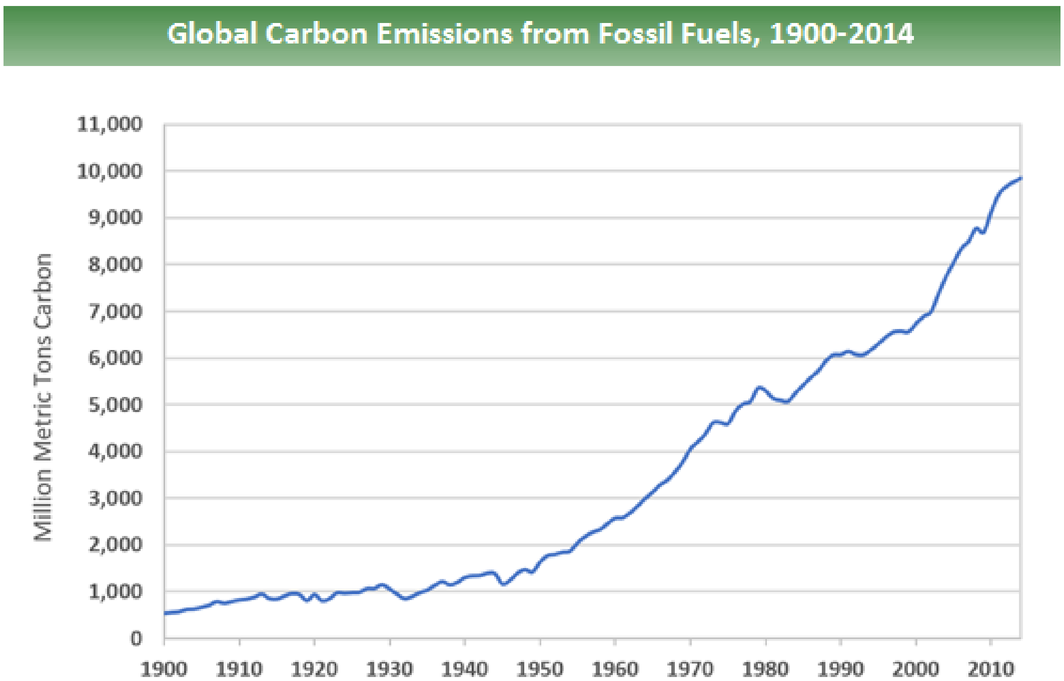
Source: IPCC (2014); EXIT based on global emissions from 2010. Details about the sources included in these estimates can be found in the *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. EXIT

- **Electricity and Heat Production** (25% of 2010 global greenhouse gas emissions): The burning of coal, natural gas, and oil for electricity and heat is the largest single source of global greenhouse gas emissions.
- **Industry** (21% of 2010 global greenhouse gas emissions): Greenhouse gas emissions from industry primarily involve fossil fuels burned on site at facilities for energy. This sector also includes emissions from chemical, metallurgical, and mineral transformation processes not associated with energy consumption and emissions from waste management activities. (Note: Emissions from industrial electricity use are excluded and are instead covered in the Electricity and Heat Production sector.)
- **Agriculture, Forestry, and Other Land Use** (24% of 2010 global greenhouse gas emissions): Greenhouse gas emissions from this sector come mostly from agriculture (cultivation of crops and livestock) and deforestation. This estimate does not include the CO_2 that ecosystems remove from the atmosphere by sequestering carbon in biomass, dead organic matter, and soils, which offset approximately 20% of emissions from this sector.[2]
- **Transportation** (14% of 2010 global greenhouse gas emissions): Greenhouse gas emissions from this sector primarily involve fossil fuels burned for road, rail, air, and marine transportation. Almost all (95%) of the

world's transportation energy comes from petroleum-based fuels, largely gasoline and diesel.
- **Buildings** (6% of 2010 global greenhouse gas emissions): Greenhouse gas emissions from this sector arise from onsite energy generation and burning fuels for heat in buildings or cooking in homes. (Note: Emissions from electricity use in buildings are excluded and are instead covered in the Electricity and Heat Production sector.)
- **Other Energy** (10% of 2010 global greenhouse gas emissions): This source of greenhouse gas emissions refers to all emissions from the Energy sector which are not directly associated with electricity or heat production, such as fuel extraction, refining, processing, and transportation.

Note on emissions sector categories.

Trends in Global Emissions

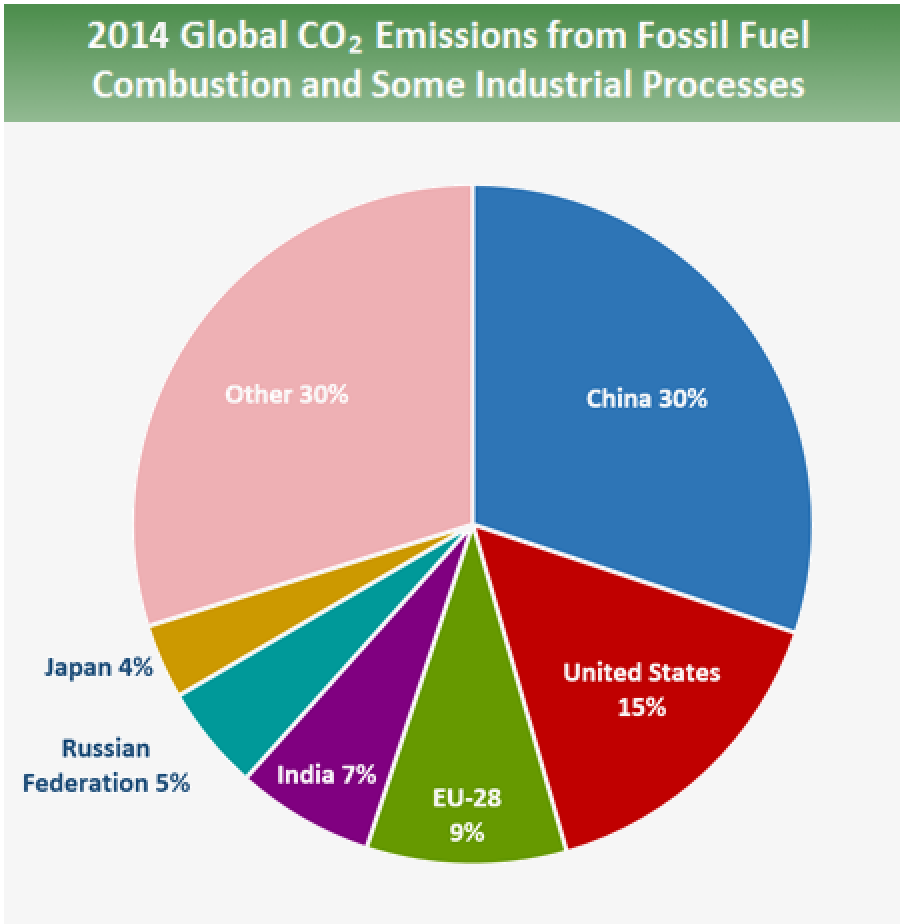


Source: Boden, T.A., Marland, G., and Andres, R.J. (2017). Global, Regional, and National Fossil-Fuel CO2Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2017.

Global carbon emissions from fossil fuels have significantly increased since 1900. Since 1970, CO_2 emissions have increased by about 90%, with emissions from fossil fuel combustion and industrial processes contributing about 78% of the total greenhouse gas emissions increase from 1970 to 2011. Agriculture, deforestation, and other land-use changes have been the second-largest contributors.[1]

Emissions of non-CO_2 greenhouse gases have also increased significantly since 1900. To learn more about past and projected global emissions of non-CO_2 gases, please see the EPA report, *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2020*.

Emissions by Country



Source: Boden, T.A., Marland, G., and Andres, R.J. (2017). National CO2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2014, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, doi 10.3334/CDIAC/00001_V2017.

In 2014, the top carbon dioxide (CO_2) emitters were China, the United States, the European Union, India, the Russian Federation, and Japan. These data include CO_2 emissions from fossil fuel combustion, as well as cement manufacturing and gas flaring. Together, these sources represent a large proportion of total global CO_2 emissions.

Emissions and sinks related to changes in land use are not included in these estimates. However, changes in land use can be important: estimates indicate that net global greenhouse gas emissions from agriculture, forestry, and other land use were over 8 billion metric tons of CO_2 equivalent,[2] or about 24% of total global greenhouse gas emissions.[3] In areas such as the United States and Europe, changes in land use associated with human activities have the net effect of absorbing CO_2, partially offsetting the emissions from deforestation in other regions.

Related Links

EPA resources

- Greenhouse Gas Emissions
- Sources of Greenhouse Gas Emissions (in the United States)
- Non-CO_2 Greenhouse Gases: Emissions and Trends

Other resources

- Carbon Dioxide Information Analysis Center
- European Commission Emission Database for Global Atmospheric Research EXIT
- National Inventory Submissions EXIT
- World Development Indicators EXIT
- World Resources Institute's Climate Analysis Indicators Tool (CAIT) EXIT

References

1. IPCC (2014). *Climate Change 2014: Mitigation of Climate Change* . EXIT Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

2. FAO (2014). Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks. (89 pp, 3.5 M, About PDF) EXIT Climate, Energy and Tenure Division, FAO.

3. IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (80 pp, 4.2 M, About PDF) EXIT [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

LAST UPDATED ON APRIL 13, 2017

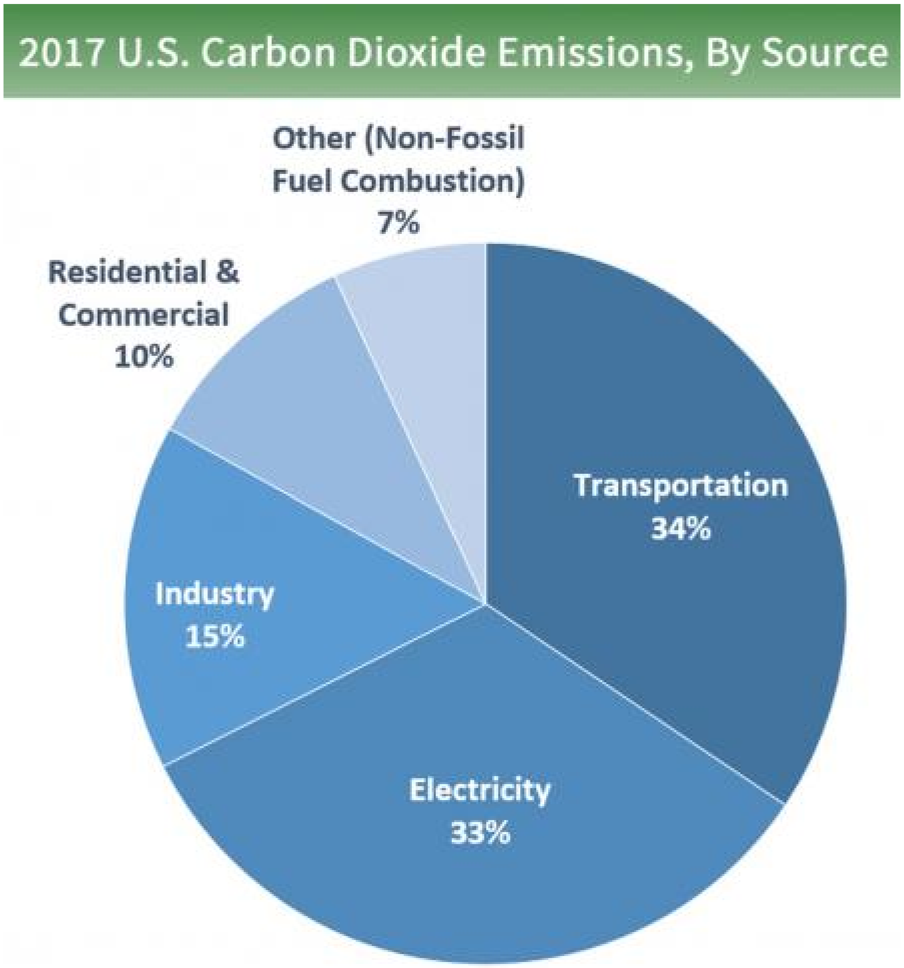
Overview of Greenhouse Gases

Carbon Dioxide Emissions

Properties of Carbon Dioxide

Chemical Formula: CO_2
Lifetime in Atmosphere: See below*
Global Warming Potential (100-year): 1

Carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities. In 2017, CO_2 accounted for about 81.6 percent of all U.S. greenhouse gas emissions from human activities. Carbon dioxide is naturally present in the atmosphere as part of the Earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities are altering the carbon cycle–both by adding more CO_2 to the atmosphere, by influencing the ability of natural sinks, like forests, to remove CO_2 from the atmosphere, and by influencing the ability of soils to store carbon. While CO_2 emissions come from a variety of natural sources, human-related emissions are responsible for the increase that has occurred in the atmosphere since the industrial revolution.[1]



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2017*.

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The main human activity that emits CO_2 is the combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation, although certain industrial processes and land-use changes also emit CO_2. The main sources of CO_2 emissions in the United States are described below.

- **Transportation.** The combustion of fossil fuels such as gasoline and diesel to transport people and goods was the largest source of CO_2 emissions in 2017, accounting for about 34.2 percent of total U.S. CO_2 emissions and 27.7 percent of total U.S. greenhouse gas emissions. This category includes transportation sources such as highway vehicles, air travel, marine transportation, and rail.
- **Electricity.** Electricity is a significant source of energy in the United States and is used to power homes, business, and industry. In 2017 the combustion of fossil fuels to generate electricity was the second largest source of CO_2 emissions in the nation, accounting for about 32.9 percent of total U.S. CO_2 emissions and 26.7 percent of total U.S. greenhouse gas emissions. The type of fossil fuel used to generate electricity will emit different amounts of CO_2. To produce a given amount of electricity, burning coal will produce more CO_2 than oil or natural gas.

- **Industry.** Many industrial processes emit CO_2 through fossil fuel consumption. Several processes also produce CO_2 emissions through chemical reactions that do not involve combustion; for example, the production and consumption of mineral products such as cement, the production of metals such as iron and steel, and the production of chemicals. Fossil fuel combustion from various industrial processes accounted for about 15.4 percent of total U.S. CO_2 emissions and 12.5 percent of total U.S. greenhouse gas emissions in 2017. Note that many industrial processes also use electricity and therefore indirectly cause the emissions from the electricity production.

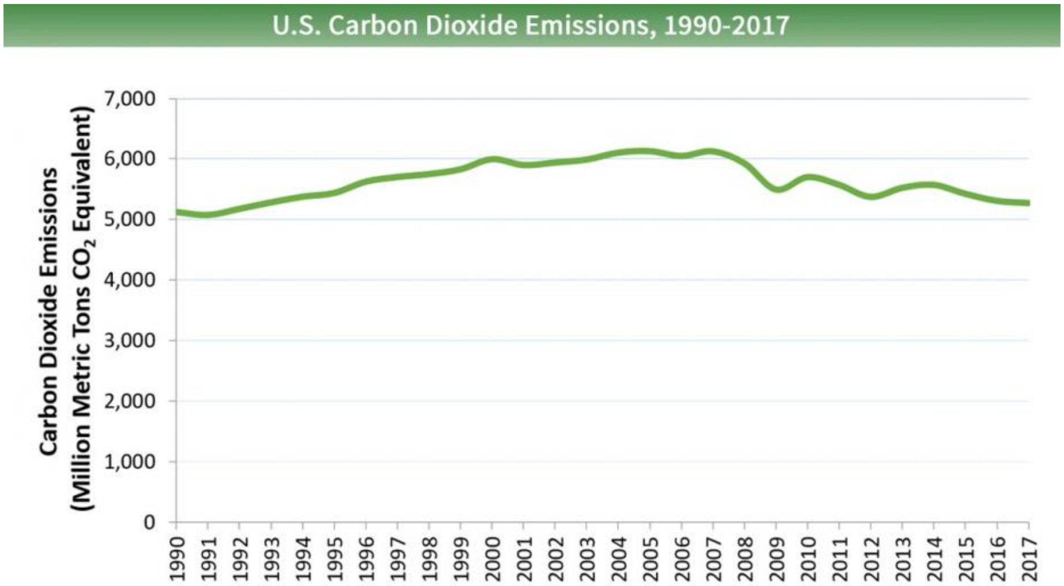
Carbon dioxide is constantly being exchanged among the atmosphere, ocean, and land surface as it is both produced and absorbed by many microorganisms, plants, and animals. However, emissions and removal of CO_2 by these natural processes tend to balance, absent anthopogenic impacts. Since the Industrial Revolution began around 1750, human activities have contributed substantially to climate change by adding CO_2 and other heat-trapping gases to the atmosphere.

In the United States, since 1990, the management of forests and other land has acted as a net sink of CO_2, which means that more CO_2 is removed from the atmosphere, and stored in plants and trees, than is emitted. This carbon sink offset is about 11 percent of total emissions in 2017 and is discussed in more detail in the Land Use, Land-Use Change, and Forestry section.

To find out more about the role of CO_2 warming the atmosphere and its sources, visit the Climate Change Indicators page.

Emissions and Trends

Carbon dioxide emissions in the United States increased by about 2.9 percent between 1990 and 2017. Since the combustion of fossil fuel is the largest source of greenhouse gas emissions in the United States, changes in emissions from fossil fuel combustion have historically been the dominant factor affecting total U.S. emission trends. Changes in CO_2 emissions from fossil fuel combustion are influenced by many long-term and short-term factors, including population growth, economic growth, changing energy prices, new technologies, changing behavior, and seasonal temperatures. Between 1990 and 2017, the increase in CO_2 emissions corresponded with increased energy use by an expanding economy and population, including overall growth in emissions from increased demand for travel.



Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2017*.

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Reducing Carbon Dioxide Emissions

The most effective way to reduce CO_2 emissions is to reduce fossil fuel consumption. Many strategies for reducing CO_2 emissions from energy are cross-cutting and apply to homes, businesses, industry, and transportation.

EPA is taking common sense regulatory actions to reduce greenhouse gas emissions.

- Learn about EPA's motor vehicle standards.

Examples of Reduction Opportunities for Carbon Dioxide	
Strategy	**Examples of How Emissions Can be Reduced**
Energy Efficiency	Improving the insulation of buildings, traveling in more fuel-efficient vehicles, and using more efficient electrical appliances are all ways to reduce energy consumption, and thus CO_2 emissions. • See EPA's ENERGY STAR® program for more information on energy-efficient appliances. • See EPA's and DOE's fueleconomy.gov site for more information on fuel-efficient vehicles. • Learn about EPA's motor vehicle standards that improve vehicle efficiency and save drivers money.

Examples of Reduction Opportunities for Carbon Dioxide	
Strategy	**Examples of How Emissions Can be Reduced**
Energy Conservation	Reducing personal energy use by turning off lights and electronics when not in use reduces electricity demand. Reducing distance traveled in vehicles reduces petroleum consumption. Both are ways to reduce energy CO_2 emissions through conservation. Learn more about What You Can Do at Home, at School, in the Office, and on the Road to save energy and reduce your carbon footprint.
Fuel Switching	Producing more energy from renewable sources and using fuels with lower carbon contents are ways to reduce carbon emissions.
Carbon Capture and Sequestration (CCS)	Carbon dioxide capture and sequestration is a set of technologies that can potentially greatly reduce CO_2 emissions from new and existing coal- and gas-fired power plants, industrial processes, and other stationary sources of CO_2. For example, capturing CO_2 from the stacks of a coal-fired power plant before it enters the atmosphere, transporting the CO_2 via pipeline, and injecting the CO_2 deep underground at a carefully selected and suitable subsurface geologic formation, such as a nearby abandoned oil field, where it is securely stored. Learn more about CCS.

* Atmospheric CO_2 is part of the global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. Some of the excess carbon dioxide will be absorbed quickly (for example, by the ocean surface), but some will remain in the atmosphere for thousands of years, due in part to the very slow process by which carbon is transferred to ocean sediments.

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ISSUE BRIEF

CLIMATE CHANGE AND HEALTH IN VIRGINIA

Have you noticed that Virginia summers have gotten hotter and stickier? Does it seem like allergy season is more intense? Is your home flooding more often than it used to?

It's not your imagination. Climate change is altering seasonal patterns, making our summers hotter, and fueling increased flooding from coastal storms, like Hurricane Sandy in 2012.[1] As a result, we face more heat-related illnesses, air quality issues, food and water contamination, traumatic injuries, threats to our mental health, and infectious diseases.[2] These threats will only get worse as big polluters continue to pump carbon from coal, oil, and natural gas into the air.

The good news is that we can protect ourselves from these impacts by moving to cleaner energy strategies and preparing more effectively for future disasters.[3]

EXTREME HEAT IS BAD FOR VIRGINIANS' HEALTH—AND COULD BECOME MORE DEADLY

Virginia summers are getting hotter—and could become downright dangerous in just a few decades. One way to define extreme heat is to look at maximum temperatures, which have climbed about 1 degree Fahrenheit in Virginia since 1895.[4] The average national risk of death increases about 2.5 percent for every 1°F increase in the intensity of heat waves, according to one study of 43 American cities from 1987 to 2005.[5]

Daily summer highs at Richmond International Airport averaged 88.6°F in the past decade, compared with 85.6°F in the 1960s.[6] From 2007 to 2016, 36 percent of Virginians lived in counties that experienced more than nine extreme heat days per year, more days than expected on the basis of local historical averages (Figure 1).[7]

Heat and humidity already pose a range of threats to Virginia residents, from minor illnesses like heat cramps to deadly conditions like heatstroke or heat-related heart attacks.[8] In the summer of 2017, Virginia's emergency departments and urgent care clinics recorded 498 visits for heat-related issues over 10 days.[9]

The risk of heat-related illnesses and deaths in Virginia will grow as climate change fuels more intense and frequent heat waves.[10] For example, from 1975 to 2010, the Virginia Beach metropolitan area experienced an average of approximately 20 excess deaths per year on dangerously hot summer days.[11] ("Excess deaths" are the number of deaths above the daily standardized summertime average for a given area.) Without action to dramatically cut global carbon emissions from current levels, this could increase to an annual average of 170 excess deaths on dangerously hot days by the 2040s.

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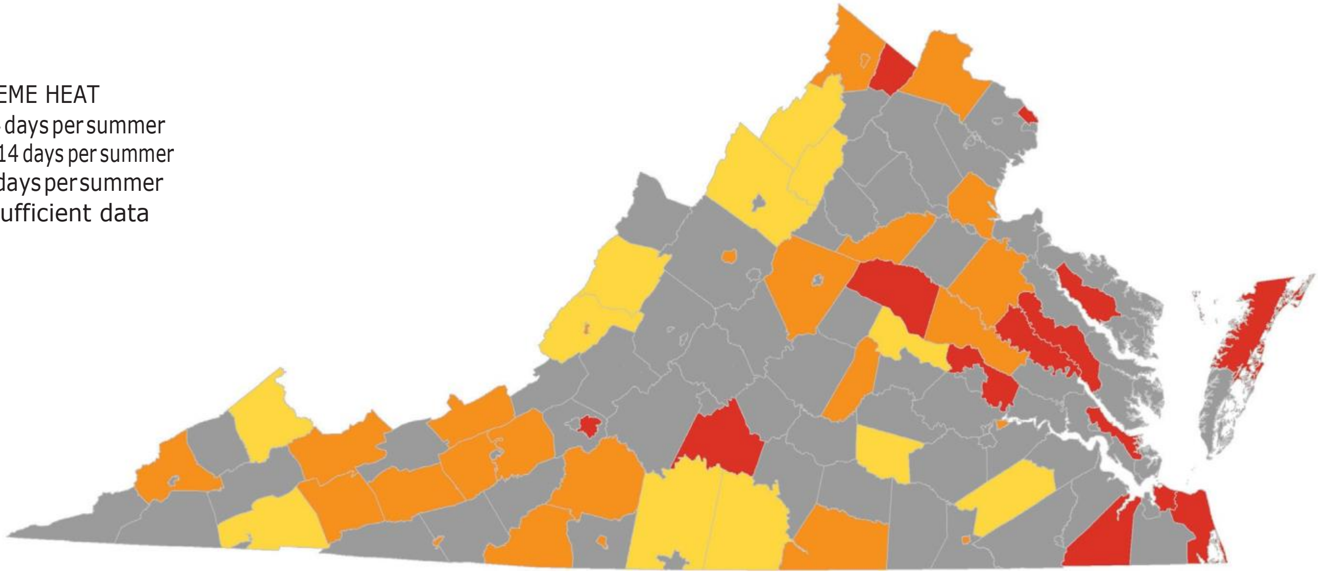
FIGURE 1. AVERAGE NUMBER OF EXTREME SUMMER HEAT DAYS PER YEAR IN VIRGINIA, BY COUNTY, 2007 TO 2016

“Extreme heat days” are defined as June, July, and August days from 2007 to 2016 on which the maximum temperature at a given weather station exceeded the local 90th-percentile value for that station. We used June, July, and August days from 1961 to 1990 to calculate the 90th percentile for each station.



Source: NRDC.[12]

Anyone can get sick from extreme heat, but outdoor workers, young children, older adults, people with chronic diseases like diabetes, and people experiencing poverty are particularly vulnerable.[13] This is especially pronounced in cities, where climate warming driven by carbon pollution is amplified by tall buildings that block airflow and by heat-absorbing surfaces like asphalt.[14] In Richmond, for instance, daily summer temperatures from 2004 to 2013 were 3.1°F higher, on average, than in nearby rural areas.[15]

Heat-related illnesses impact low-income households, many of which are concentrated in city neighborhoods that have a high density of buildings and parking lots and are devoid of shade and vegetation.[16] These households may lack access to official cooling centers or be unable to afford life-saving air-conditioning.[17] More than 22 percent of the children in Virginia’s 20 most urban counties experience poverty, compared with 15 percent in the state overall.[18]

COASTAL FLOODS ARE GETTING WORSE—AND COULD DISRUPT EMERGENCY HEALTH SERVICES

Coastal Virginia is experiencing one of the more challenging symptoms of a warming climate: sea level rise. The Sewells Point tide gauge in Norfolk has experienced the equivalent of 18.2 inches of relative sea level rise in the past 100 years, compared with the global average of 7 to 8 inches since 1890.[19] Because of global sea level rise and local land sinking, the low-lying Hampton Roads region in the southeast part of the state is experiencing an increase in minor tidal floods (also called “nuisance” or “sunny day” floods) that can block roads and damage homes.[20] Norfolk had 11 minor flood days in 2016, compared with 4 minor flood days in 1995.[21] In 2015, nearly half of Portsmouth residents reported they were unable to get in and out of their neighborhoods on at least one occasion that year because of repeated sunny day flooding.[22] And more than 60 percent of Hampton Roads residents worry that the effects of sea level rise already put their health at risk.[23]

The combination of sea level rise and coastal storms can make evacuation dangerous or impossible and disrupt emergency health services like ambulances, potentially delaying care and leading to loss of life.[24] Southern Virginia Beach has a dearth of potential evacuation routes, and

© Yaakov Wilson/NOAA Weather in Focus Photo Contest 2015 hospitals and emergency shelters are already difficult to access.[25] By 2080, 4 feet of relative sea level rise could flood about 10 percent of the interstate highways and arterial and primary roads in Virginia Beach and Norfolk during exceptionally high tides known as "king tides." [26] If a 100-year storm surge (floods with a 1 percent chance of occurring in a given year) coincided with a king tide, flooding could cover more than 50 percent of roadways in the same area. Note that more than one 100-year flood can occur in a given century.[27]

Flood-related damage or blocked roadways aren't good for anyone but can be especially difficult for those with low incomes, who may have trouble paying for rent, food, or doctors' bills if they can't get to work.[28] Parts of Norfolk and Portsmouth have some of the highest poverty rates in the state.[29] Furthermore, 52 percent of area renters spend more than 30 percent of their household income on rent—a marker of housing instability.[30]

CLIMATE CHANGE COULD CONTAMINATE VIRGINIA'S DRINKING WATER

Sea level rise will affect something many of us take for granted: safe drinking water. More than 5.5 million people lived in Virginia's coastal watershed counties in 2010, and the coastal population is expected to grow.[31] Coastal Virginians get their drinking water from a combination of surface water sources and groundwater sources that are largely below sea level.[32]

The combination of sea level rise and well pumping (which can allow saltwater under aquifers to flow upward) threatens to make coastal groundwater saltier. Excess salt concentrations in drinking water may increase blood pressure in sensitive individuals and can contribute to strokes and heart attacks.[33] Salt can also corrode water distribution pipes, which increases the likelihood of unhealthy lead or copper contamination.[34]

Increases in extreme precipitation will likely lead to more contaminated runoff in water and more failures of drinking water systems and wastewater treatment facilities across the country.[35] Nearly 70 percent of waterborne disease outbreaks in the United States between 1948 and 1994 were preceded by heavy precipitation.[36] In the Southeast, the amount of rain falling in the heaviest one-day storms increased 27 percent from 1958 to 2016.[37] In Virginia, the number of days with more than 2 inches of precipitation increased from 1995 to 2014, and that trend is expected to continue as the climate warms.[38] This poses a problem for cities, like Richmond, that have combined sewer overflow systems.[39] During heavy rains, these combined systems dump untreated sewage and other contaminants into rivers, lakes, and coastal waters. Combined sewer overflows were a major source of *Escherichia coli*—an indicator of fecal contamination—in Richmond's James River Basin in 2012.[40]

© Will Parson/Chesapeake Bay Program

RISING TEMPERATURES COULD MAKE VIRGINIA'S SEAFOOD DANGEROUS TO EAT

Virginia is home to a multitude of fishable streams and lakes and more than 3,300 miles of marine coastline.[41] But rising temperatures threaten the safety of the fish and shellfish those waters provide—including oysters, the pride of coastal Virginia.[42]

Vibriosis, which is spread by bacteria-laden seawater or seafood, can cause symptoms ranging from nausea to skin infections.[43] The illness affects an estimated 80,000 people and causes about 100 deaths in the United States every year. Anyone can get vibriosis, but severe complications are more likely for people with weakened immune systems or chronic diseases like cancer or liver disease, or for those who take medications to reduce stomach acid.[44]

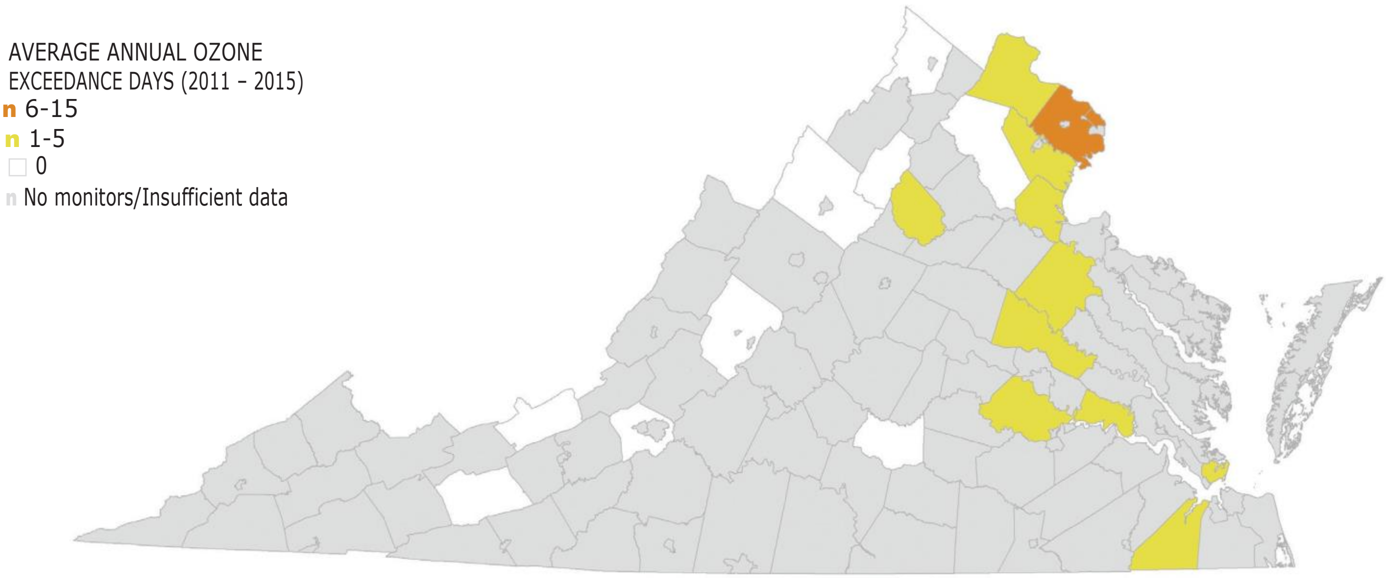
Vibrio bacteria concentrations in the temperate North Atlantic have risen over the last half century, and researchers have linked this rise to warming sea surface temperatures.[45] As the Chesapeake Bay area gets warmer, the likelihood of *Vibrio vulnificus* bacteria, which can cause symptoms like bloody diarrhea and vomiting, is expected to increase in bay water.[46] Warmer temperatures could also increase the concentration of *V. parahaemolyticus* bacteria, which can cause deadly bloodstream infections, in the area's oysters.

CLIMATE CHANGE PUTS VIRGINIA'S PROGRESS TOWARD CLEANER SKIES AT RISK

Virginia's air quality has improved since 2004 largely because of federal pollution limits.[47] However, climate change could undermine the state's progress toward cleaner air and make it harder to meet future air quality standards.[48] This is especially pertinent in the 12 Virginia counties that already experience an average of 2 to 9.7 unhealthy smog days per year (Figure 2).[49] Smog forms when pollution from power plants, vehicles, and other sources reacts with sunlight to create ground-level ozone.[50] Rising temperatures can speed up this process and lead to more smog. In the southeastern United States, warmer and drier fall weather could also extend the summer smog season into fall.[51]

FIGURE 2. VIRGINIA COUNTIES AVERAGING ONE OR MORE UNHEALTHY GROUND-LEVEL OZONE DAYS PER YEAR, 2011 TO 2015

Ozone exceedances are days when an eight-hour average concentration of ozone exceeds the EPA's 2015 Ozone National Ambient Air Quality Standard of 0.070 parts per million.



Source: NRDC.[55]

Smog and small particulate matter, another type of pollution from burning fossil fuels, are powerful triggers for asthma, threatening the health of Virginia's estimated 159,000 children and 518,000 adults with the condition.[52] These forms of air pollution have also been linked to preterm births, birth defects, developmental delays in children, strokes, heart attacks, dementia in older adults, lung cancer, and other health problems.[53] Smog and particle pollution from Virginia power plants cause an estimated 400 premature deaths per year from asthma and other causes in Virginia and nearby states.[54]

Climate-fueled increases in smog will increase health care costs for asthma, which is already an expensive disease to treat.[56] In 2012, for example, asthma generated an estimated $2,208 in medical costs per patient in Virginia and a cumulative cost of $76.7 million in lost work and school days.[57] The burden of worsening air quality will fall heavily on low-income families and children of color. For example, in the Washington-Arlington-Alexandria metropolitan area, there are nearly twice as many African-American and Hispanic households in severely or moderately inadequate housing as there are white households.[58] Children who live in poor-quality housing are 45 percent more likely to be diagnosed with asthma and 59 percent more likely to be treated in an emergency room for it.[59]

ALLERGY SEASONS ARE GETTING LONGER AND MORE SEVERE

Seasonal pollen allergies, also known as hay fever, are common across Virginia. In 2016, Richmond was the 14th most challenging city in the nation in terms of spring allergies.[60] Hay fever symptoms, such as congestion and headache, can range from mildly annoying to downright disruptive, affecting sleep, mood, and quality of life.[61]

Rising temperatures are leading to earlier spring allergy seasons across the United States.[62] The carbon dioxide driving climate change is also stimulating plant growth, boosting pollen production. From 2001 to 2010, the oak pollen season started nearly four days earlier, on average, than in the previous decade, according to a study of six monitoring sites in the southeastern United States.[63] Peak pollen counts averaged 117 percent higher in that same period. In 2017, Allergy Partners of Richmond reported its fourth-highest tree pollen count since the group began recording data outside its clinic in 1989.[64]

Asthma threats increase when there's more pollen in the air. In 2010, asthma triggered by oak pollen led to an estimated 8,800 emergency room visits in the Southeast. By the 2050s, emergency room visits for oak-related asthma attacks could increase 4 percent under continued high levels of carbon pollution.[65]

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Blacklegged ticks, which can carry the bacteria that cause Lyme disease, are expanding to new counties in Virginia at an explosive rate. In 1996, the ticks were reported or established in only 12 of Virginia's 95 counties; this had increased to 72 counties by 2016.

MOSQUITO- AND TICK-BORNE INFECTIONS ARE INCREASING

Climate change helps make it possible for ticks and mosquitoes to live in new places and be active earlier in the year.[66] That's bad news for the more than 49,260 Virginians who work in outdoor occupations such as farming, landscaping, and highway construction.[67] It also affects millions of Virginia residents who enjoy visiting natural areas, gardening, and other outdoor recreation every year.[68]

Virginia is one of 14 hot-spot states for Lyme disease, the most common tick-borne illness in the United States.[69] In its early stages, Lyme disease causes flulike symptoms. Later on—weeks or months after a bite by an infected tick—people with Lyme disease can suffer debilitating muscle and joint pain, headaches, memory problems, and even fatal heart damage.[70] In Virginia, there were 10,761 confirmed or probable cases of Lyme disease reported between 2008 and 2015.[71]

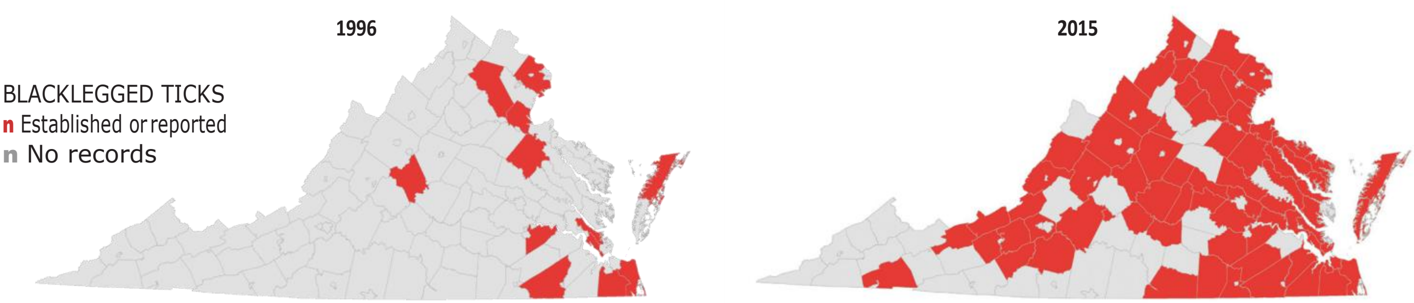
Blacklegged ticks, which can carry the bacteria that cause Lyme disease, are expanding to new counties in Virginia at an explosive rate. In 1996, the ticks were reported or established in only 12 of Virginia's 95 counties; this had increased to 72 counties by 2016 (Figure 3).[72] Lyme disease cases are also spreading to new areas of the state, potentially due to a combination of climate change, habitat change, and local increases in the population of deer and mice that carry ticks.[73] In addition, warmer springs will likely encourage an earlier start to Lyme disease season. By the 2060s, the season could begin three weeks earlier in Virginia than it did from 1992 to 2007.[74]

West Nile virus was first reported in Virginia in 2002, and a total of 163 cases have been reported in the state since then.[75] The disease, which is typically spread by mosquitoes, causes symptoms like vomiting and fatigue in about 1 in 5 people who are infected.[76] More rarely, infected patients develop severe neurological illnesses that can be fatal. Extremely hot and dry years projected from 2036 to 2049 could increase the average annual number of neuroinvasive West Nile cases more than 20-fold (compared to 1999 to 2013).[77]

Rising temperatures and humidity are also extending the mosquito season in Virginia cities, increasing the possibility of transmission of Zika, dengue, and other viruses.[78] In the state's largest cities, there was an average of 131 suitable days each year for Asian tiger mosquito activity from 2006 to 2015, compared with 113 such days annually from 1980 to 1989.[79]

FIGURE 3. DISTRIBUTION OF BLACKLEGGED TICKS IN VIRGINIA, 1996 AND 2015

Counties in Virginia where blacklegged ticks were reported (fewer than six ticks of a single life stage) or established (six or more ticks or two tick life stages) in 1996 and 2015.



Source: Modified from Eisen et al., *Journal of Medical Entomology* 53 (2016).

ACTING ON CLIMATE CAN PROTECT OUR HEALTH

The good news is that cleaning up power plants, vehicles, and other big sources of pollution will help protect our health by limiting the dangerous effects of climate change and by cutting unhealthy smog, particulate matter, and other air pollution.

Virginia has already made progress to address climate change, reducing total carbon dioxide emissions by more than 20 percent from 2005 to 2015.[80] Those efforts have also helped clean up the air Virginians breathe. For example, Arlington County's efforts to make traffic flow more efficiently and to enhance public transportation, cycling, and walking avoided the emission of more than 511,000 tons of carbon dioxide (equivalent to the emissions from more than 1.1 billion passenger vehicle miles) from 2008 to 2014. These efforts also eliminated more than 950,000 pounds of nitrogen oxides, a building block of smog and particle pollution, in the same period.[81] And from 2007 to 2017, Virginia's wind and solar power plants averted the emission of more than 1.6 million metric tons of carbon dioxide, more than 4,000 metric tons of sulfur dioxide, and more than 2,000 metric tons of nitrogen oxides.[82]

In March 2018, the Virginia state legislature passed a bill that mandates the investment of more than $1 billion in energy efficiency (including programs targeting low-income households), solar and wind energy, and electric grid modernization.[83] But there's a lot more to do. For instance, the state took a big step forward in November 2017 by approving a proposal to cut carbon pollution by 30 percent between 2020 and 2030.[84] As part of that plan, Virginia intends to join the Regional Greenhouse Gas Initiative (RGGI), a multistate program to limit carbon pollution from power plants. The air pollution reduced through the program from 2009 to 2014 generated an estimated $5.7 billion in health benefits in RGGI states and neighboring states—including Virginia.[85] Over that period, RGGI helped Virginia residents avoid a total of up to 53 premature adult deaths, an estimated 761 asthma attacks, and about 3,621 missed work days.[86] If Virginia joins RGGI, it will further boost air quality benefits to RGGI states and to their neighbors.

The health benefits of cutting carbon pollution aren't limited to reducing climate-related threats and improving air quality. Transportation is Virginia's largest source of carbon dioxide pollution.[87] A smarter and cleaner transportation system (for example, one that incentivizes more efficient vehicles and alternatives to cars) could help limit emissions and reduce the stress associated with traffic jams, improve access to health care among those who can't drive or don't own a car, and reduce premature mortality thanks to increased physical activity.[88]

Virginia also needs to create and implement more detailed plans to address the health impacts of climate change that are already being felt today. The state's 2008 climate action plan recommended several health initiatives—including tracking temperature-driven increases in the incidence of allergic diseases—but there has been little progress since then.[89] As of March 2018, the Virginia Department of Health website did not even mention climate change. In the near term, the Department of Health should develop a climate vulnerability assessment that combines data on socioeconomic and other health-risk factors with information about the ability of communities, health providers, and other key institutions to cope with the health consequences of climate threats. Such an assessment would help the state make evidence-based choices about which climate impacts to prioritize and how best to help the people most vulnerable to those impacts.[90]

The bottom line is that Virginia residents have much to gain from climate action—and lives to lose if we fail to clean up climate-changing pollution and build resilience to the shifts that have already occurred.

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