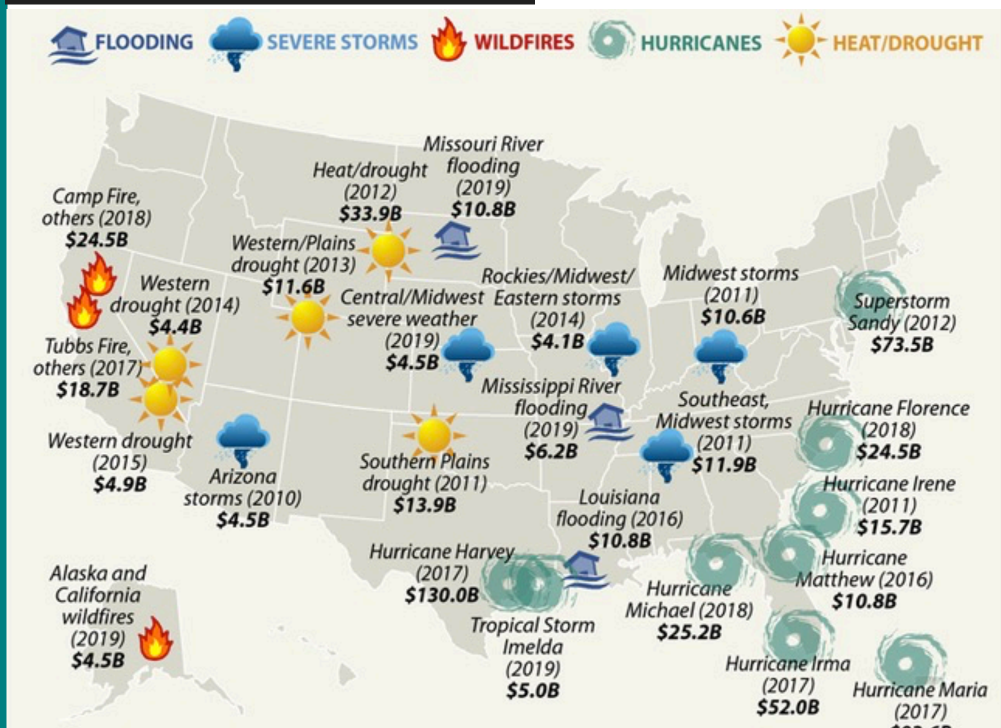
# Bigger than Expected:

## Climate-Change Costs & Emission-Reduction Benefits

### Costliest U.S. Disasters of the Decade




Source: NOAA, InsideClimateNews

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# Core Messages

**Recent research indicates the economic costs from climate disasters likely will be worse—perhaps much worse—than previously expected. For example:**

1. *More than* ***11,000 scientists*** *declared: "The climate crisis has arrived and is accelerating faster than most scientists expected…. It is more severe than anticipated, threatening natural ecosystems and the fate of humanity…."*
2. *As they worsen, climate disasters impose costs on communities, businesses, and families across the U.S. and the globe. The biggest U.S. disasters in 2018, for example, reduced South Carolina's economic output by perhaps $7,500 per household, and Oregon's households should expect to incur annual climate-related costs of at least* ***$15,000 per household*** *by mid-century.*
3. *In 2016, federal agencies expected GHG emissions in the next few years would cause climate-disaster damages of about $40–$50 per metric ton of $CO_2$ ($MtCO_2$). New research suggests that damages will be 2X–8X worse than expected:* ***$800–$3,300 per $MtCO_2$***.
4. *These risk-based estimates of the social costs of GHG emissions highlight the urgency of moving away from business-as-usual policies and practices. They show, for example, that climate-disaster damages from Oregon's emissions, for example, offset* 50%–200% *of the state's annual GDP. Such outcomes are not sustainable.*

**As the risks of climate disasters increase, so too do the potential benefits from acting now to reduce emissions. For example:**

1. *With the federal agencies' estimates, the expected climate benefit from not burning one gallon of gasoline or diesel was about 40 cents, but the heightened, 2X–8X risk of climate disasters raises the benefit to* ***$7–$29 per gallon***.
2. *Eliminating the emissions from 1,000 passenger vehicles for one year could reduce climate-disaster damages by* ***$4 million–$16 million***. *A 1 percent reduction in annual distance traveled by passenger vehicles in the U.S. would reduce climate-disaster damages by about* ***$45 billion– $180 billion***, *if climate disasters prove to be 2X–8X worse than expected.*
3. *Not burning one trainload of oil or coal could reduce future climate-disaster damages by* ***$29 million–$120 million***, *or* ***$18 million–$73 million***.
4. *Not burning natural gas would have similar benefits. For example, not burning gas that would be conveyed by the proposed Jordan Cove Pipeline, if operated at full capacity for one year, could reduce future climate-disaster damages by* ***$20 billion–$80 billion***.
5. *Allowing trees to grow longer before being logged will reduce future climate-disaster damages, because, as they grow older, the trees will remove $CO_2$ from the atmosphere. Permanently allowing trees on Oregon's industrial timberland to grow older by 15 years before logging could reduce climate damages by* ***$200 billion–$840 billion***, *or* ***$34,000–$140,000 per acre***.
6. *Halting logging altogether also would yield large economic benefits. The reduction in climate-disaster damages from not logging on forests managed by the Oregon Board of Forestry would exceed the board's forgone revenues by 13–53 times.*
7. *Planting one million urban-suburban trees would yield economic benefits of about $50 million–$200 million over the next ten years, and then $18 million–$73 million per year, if climate disasters prove to be 2X–8X worse than expected.*

# A. Climate disasters will be worse than expected

**Scientists are warning of imminent catastrophe.** Multiple scientific reports have demonstrated that models of GHG emissions and their impacts have underestimated the speed and runaway potential for climate disasters. More than 11,000 scientists have warned that we now are facing a climate emergency that threatens human existence.

> "[W]e declare, with more than 11,000 scientist signatories from around the world, clearly and unequivocally that planet Earth is facing a climate emergency. … The climate crisis has arrived and is accelerating faster than most scientists expected…. It is more severe than anticipated, threatening natural ecosystems and the fate of humanity…."[1]

**At least nine ecosystems are nearing "tipping points" that will threaten the existence of human civilizations.**

> "[E]vidence is mounting that these events [tipping points] could be more likely than was thought, have high impacts and are interconnected across different biophysical systems, potentially committing the world to long-term irreversible changes."[2]

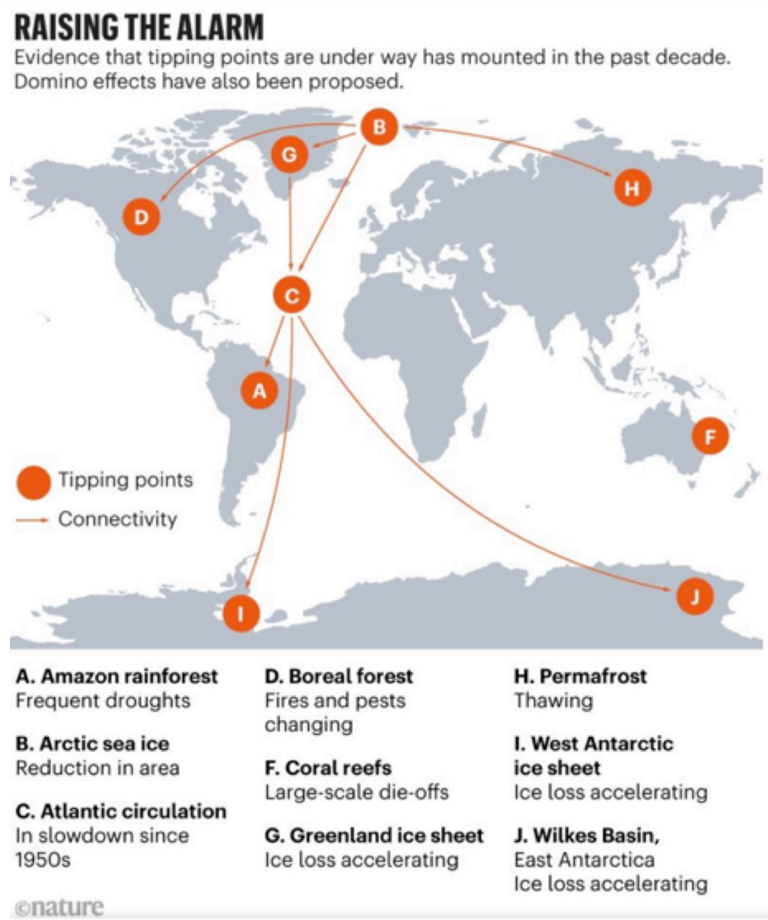


**Figure 1. Nine tipping points for the climate and ecosystems that, if crossed, would lead to large economic costs**

## Atmospheric greenhouse gases (GHGs) have grown to levels never seen before in human history, and current trends indicate these levels will greatly exceed "safe" limits by 2030.

"The concentration of carbon dioxide in the atmosphere hit…the highest level seen in some 3 million years, before humans existed, according to scientists at the Mauna Loa Observatory in Hawaii. $CO_2$ levels are now rising 3 ppm each year, up from an average 2.5 ppm over the last decade.… 'This increase is just not sustainable in terms of…what we are doing to the planet.'".[3]

## Although shifts away from activities that generate GHG emissions receive a lot attention, the reality is that these emissions have continued to grow.

"Emissions of heat-trapping carbon dioxide from fossil fuel and industry jumped from 6.06 billion metric tons of carbon in 1992 to 9.87 billion metric tons in 2017, according to the Global Carbon Project. That's a 63% increase in 25 years."[4]

"Emissions of planet-warming carbon dioxide from fossil fuels hit a record high in 2019, researchers said Tuesday, putting countries farther off course from their goal of halting global warming."[5]

## Risks are already materializing.

"The U.S. Climate Extremes Index has nearly doubled from 1992 to 2018, according to NOAA. The index takes into account far-from-normal temperatures, drought and overall dry spells, abnormal downpours."[6]

## Climate disasters slow the economy, making families and communities poorer.[7]

"The global economy will be at least 3% smaller by 2050 owed solely to the effects of unchecked climate change, including severe weather and rising sea levels. That's a figure laid out in a framework from data experts at The Economist Intelligence Unit…."

"Oxford Economics offers a more alarming estimate…. In the absence of efforts to curb greenhouse gas emissions, …2°C of warming expected by 2050 in a high-emissions scenario might shave between 2.5%-7.5% from global GDP…."

## Climate disasters harm millions of people every year.

"Climate fuelled disasters were the number one driver of internal displacement over the last decade, forcing more than 20 million people a year – one person every two seconds - to leave their homes, said Oxfam today."[8]

## Impacts on the oceans pose multiple, catastrophic threats.

"The U.N.'s…report released Sept. 25 makes crystal clear that the planet's oceans, snow, and ice are in dire trouble…. This most recent report on the ocean and cryosphere [the frozen regions of the planet] is among dozens released during the last 30 years by the IPCC, but its message is the boldest and urgent to date: If the world's nations do not act with urgency, we – and future generations – will suffer from these changes."[9]

## More emissions will cause hotter temperatures and greater disasters[10]

"Global carbon emissions from fossil fuel burning, which reached an all-time high in 2017 after being nearly constant during 2014- 2016, need to peak imminently and decline rapidly to have any possibility of achieving the Paris commitment of limiting warming to well below 2°C. The current pledges under the Paris agreement are insufficient to limit global mean temperature increases relative to pre-industrial levels to well below 2°C. Instead global mean surface temperatures will probably increase by around 3°C, or more.

"We…used a set of climate change impacts models to project the risks associated with these levels of warming, using both process based and empirical modelling approaches to assess risks to crop yields and the risks of human exposure to heat stress, disease vectors, water stress, fluvial and coastal flooding….

"Limiting warming to 1.5°C rather than 2°C would reduce the exposure of millions of people to drought, heat stress and water scarcity, fluvial flooding, and exposure to dengue infection. It would avoid the loss of thousands of square km to sea level rise and would avoid several reductions in crop yields of several percentage points….

"The economic benefits of limiting warming are also significant, with mean values of NPV [net present value] of climate change induced damages (including market, non-market impacts, impacts due to sea level rise and impacts associated with large scale discontinuities) of 551, 69, and 54 trillion $ for NPV."

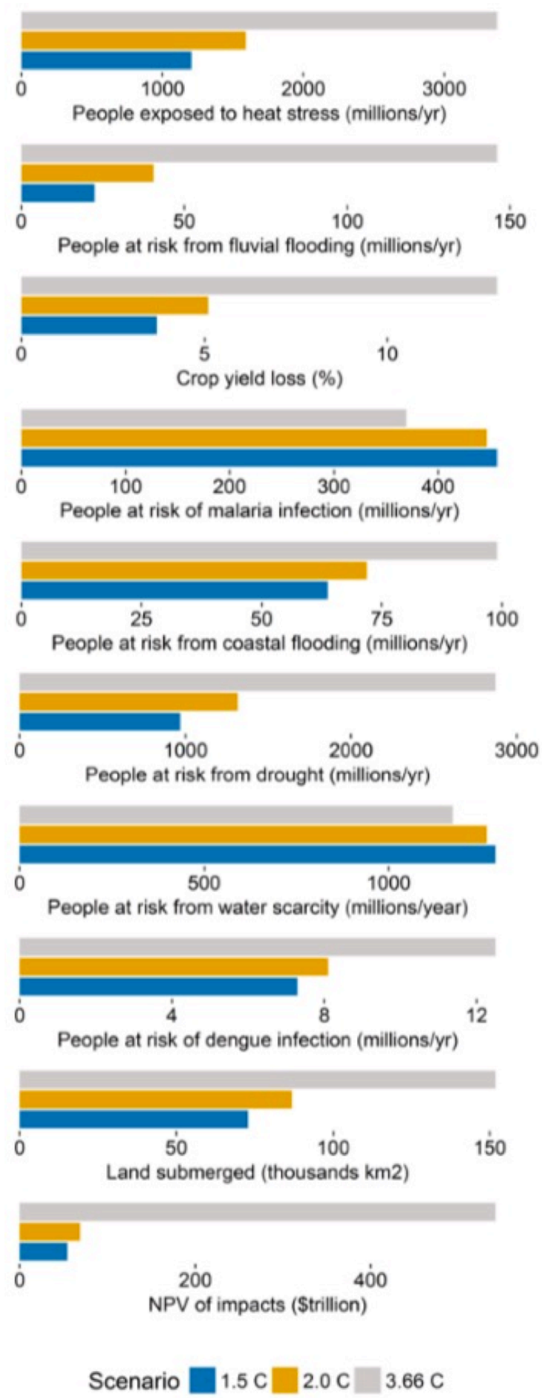


Figure 2. Risks increase with warming

## Without prompt, effective action, global temperatures could rise far beyond the targets of the Paris Agreement, with staggering impacts across the globe.

"[U]nder today's greenhouse-gas-driven climate change, warming and ice loss are happening in both [polar] regions at the same time. This means that if climate change continues unabated, Earth's past dramatic sea-level rise [about 10 meters] could be a small taste of what's to come."[11]

"Coral reefs, one of the world's most biodiverse ecosystems and home to critical global fisheries that feed billions—yes, billions—of people, are struggling to adapt to rapidly warming and acidifying oceans. In a roughly 4 degree Celsius world…Greenland's ice sheet would start to melt—if it hadn't already—nearly irreversibly, atmospheric scientist Dennis Hartmann of the University of Washington tells Popular Mechanics. 'That would mean something like seven meters (or 20 feet) of sea-level rise.'"[12]

## Climate leaders have begun sounding the alarm.[13]

"The point of no return is no longer over the horizon. It is in sight and hurtling toward us. … "What is still lacking is political will,' he said. "Political will to put a price on carbon. Political will to stop subsidies on fossil fuels. Political will to stop building coal power plants from 2020 onwards. Political will to shift taxation from income to carbon. Taxing pollution instead of people."

– U.N. Secretary-General Antonio Guterres.

## The IPCC just issued another, urgent warning.[14]

"The world is further off course than ever from meeting the goals of the Paris climate agreement and averting climate catastrophe…. This grim assessment comes from the latest United Nations Emissions Gap Report released [November 26].

"If the world had gotten its act together in 2010, countries would only have to reduce their emissions 3.3 percent per year to reach the 1.5 degree Celsius target. Now global emissions have to fall by 7.6 percent a year between 2020 and 2030.

"But according to the new gap report, the current trajectory puts the world's emissions to overshoot the 2030 target for 1.5 degrees Celsius by 38 percent. The current pace of emissions would lead to as much as 3.2 degrees Celsius (5.7 degrees Fahrenheit) of warming by 2100. This would be a world where millions more people would have to abandon coastal areas due to rising sea levels and vastly more dangerous periods of extreme heat."

## Financial institutions are recognizing the severity of climate-disaster risks.[15]

- "What do we do when an entire geographic region sees decades-long drought where rain was once present? Well, it's already happening.
- "What do we do when cities become increasingly inundated with ocean water from rising sea levels? Well, it's already happening.
- "What do we do when mosquitoes migrate farther north then they have ever been able to live? Well, it's already happening. …

"That is why scientists are concerned and increasingly sounding the alarm for where we are currently headed."

# B. Climate disasters will impose large costs on U.S. households, sooner than expected

Climate disasters will impose costs on everyone. The nature and severity will vary from place to place and over time, of course, but no one will evade costs completely.

An analysis of costs to households in Oregon illustrates several types of climate-disaster costs and their general magnitude.[16] Using research results published over the past several years, it quantified seven categories of climate disasters that will impose costs on Oregon's households in the near future, i.e., by somewhere near the middle of the century (Figure 3). These seven categories of costs will total about $15,000 per household, or more than 20 percent of the current median income for the state's households.

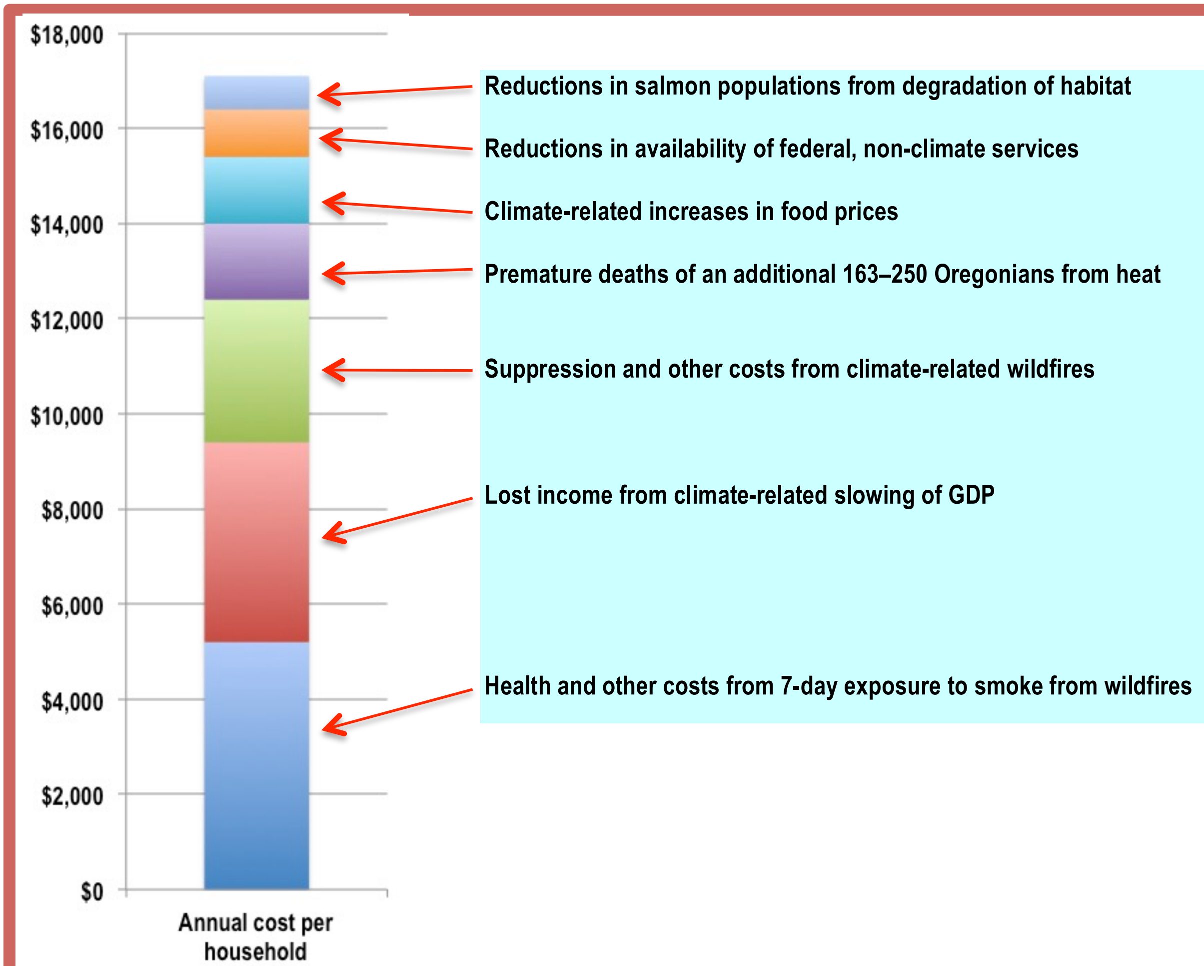


Figure 3. Potential annual cost per Oregon household from climate disasters[17]

The data in Table 1 provide more detail for the data underlying the chart in Figure 1. It is impossible at this time to know exactly when these costs will materialize. Some, such as the health and other costs from 7-day exposure to smoke from climate-related wildfires, could materialize in the coming summer and autumn. Others, such as reductions in salmon populations from climate-related degradation of habitat likely will emerge over several years.

### Table 1. Potential annual cost per Oregon household from climate disasters[18]

| | Potential cost in the near future[a] |
|---|---|
| Climate-related increases in food prices[19] | $1,000 – $1,400 |
| Lost income from climate-related slowing of GDP[20] | $2,400 – $4,200 |
| Suppression and other costs from climate-related wildfires[21] | $1,200 – $3,000 |
| Health and other costs from 7-day exposure to smoke from climate-related wildfires[22] | $5,200 |
| Premature deaths of an additional 163–250 Oregonians from climate-related heat[23] | $1,000 – $1,600 |
| Reductions in salmon populations from climate-related degradation of habitat[24] | $500 – $700 |
| Reductions in availability of federal, non-climate services[25] | $600 – $1,000 |

[a] Expressed as equivalent dollar estimates in today's economy. Does not include costs climate disasters already impose on households. Numbers rounded.

Insufficient information exists to estimate many other categories of climate-related costs (Table 2). Indeed, the quantified costs shown in Figure 1 and Table 1 represent just a small portion of the full list of ways in which GHG emissions already are imposing, or soon will impose costs costs on Oregonians and others.

The recent research described in Section A indicates that that all these costs, whether quantified or not, likely will materialize sooner than expected.

### Table 2. Additional, but not yet quantified costs that climate disasters will impose on Oregonians

| | |
|---|---|
| Increases in psycho-social trauma | Increased stress on threatened and endangered species |
| Changes in the productivity of Oregon's ecosystems | Accelerated spread of some undesirable invasive species |
| Increased cooling costs for homes | Increases in fish and wildlife diseases |
| Sea-level rise | Toxic algae blooms |
| Increased climate migration | Increased weather variability |
| Degradation of infrastructure from higher temperatures | Expanded range of tropical and sub-tropical diseases |
| Heat stress and water shortages for agricultural production | Reduced recreation due to decreased streamflows |
| Increases in agricultural pests and diseases | Increased incidence of water- and food-borne diseases |
| Increases in violence and suicides stimulated by unusually high temperatures | |

## C. The social costs of $CO_2$ provide a useful tool for measuring climate-disaster risks and costs

The many types of climate disasters make it difficult to combine them all into a coherent, easily understood yardstick for comparing the risks of one against those of another and for measuring the severity of the heightened, overall risks revealed by the recent research described above.

One readily available tool for evaluating the magnitude of climate risks is the ***social cost of carbon dioxide*** ($SCCO_2$).[26] It estimates the net global damages that will result from the emission of one metric ton of $CO_2$ ($MtCO_2$). Conversely, it also measures the social benefit from a decrease in emissions. This tool does not measure the overall potential harm that could result from all GHG emissions, past, present, and future. Nonetheless, the tool is useful because it provides insight into the magnitude of the damage that could result from future GHG emissions, and especially emissions in the next few years. Hence, many economists use the $SCCO_2$ to help describe the importance of taking different actions—or not—to reduce GHG emissions.

Within the U.S., there are two widely-used estimates of the $SCCO_2$ (Table 3). The first was developed in 2016 by an interagency working group of experts from U.S. federal agencies.[27] It says that, based on research available in 2013-2016, the agencies *expected* that, over the next few years, each additional $MtCO_2$ in the atmosphere will cause damages of about $40-50. The agencies' suspended their scientific estimation of the $SCCO_2$ in 2017, however, as the Obama administration came to an end. More recently, a peer-reviewed assessment by experts from outside the agencies (Ricke et al. 2018) updated the analysis and filled-in some of the gaps to re-estimate the *expected* $SCCO_2$.[28] The authors concluded that, for GHG emissions in the next few years, the *expected* $SCCO_2$ will be about $417/$MtCO_2$. Economists in other countries have produced similar estimates.[29]

**Table 3. Widely used *expected* values of the social costs of $CO_2$**

| | ***Expected* Cost/ $MtCO_2$** |
|---|---|
| Interagency Working Group (2013-2016) | $40– $50 |
| Ricke, et al. (2018) | $417 |

These values do not tell the whole story, however, for two reasons. One, they are incomplete, insofar as they fail to account for many potential harms, such as those related to acidification and warming of the oceans.[30] Two, they fail to account for the probability that climate disasters will arrive sooner and be more extreme than *expected*. With these two deficiencies, each of these estimates of $SCCO_2$ represents the average *expected* value supported by the science and assumptions that the economists recognized at the time they produced each value. The information in Section A, though, describes evidence indicating the risks that the disasters resulting from past and future GHG emissions will arrive sooner and be more severe than these *expected* levels. As a consequence, the *expected* values understate, perhaps to a large degree, the actual climate-related damages that will result from future GHG emissions.

To some extent, the economists and scientists who prepared the estimates anticipated this possibility. Hence, the interagency working group of experts from federal agencies that prepared the 2016 analysis reported that the actual $SCCO_2$ might be about 3 times the *expected* value and the authors of the 2018 study reported that the $SCCO_2$ might be about 2 times the *expected* value, if climate disasters exceed expectations. In addition, a 2016 analysis that focused on some of the most dangerous risks, i.e., the potential for GHG emissions to push the climate and ecosystems through one or more tipping points, concluded that these risks, alone, warrant multiplying the *expected* value of the $SCCO_2$ by a factor of about eight.[31]

Given the recent research findings indicating that climate disasters likely will occur sooner and with greater severity than previously *expected*, it would be reasonable to anticipate that future GHG emissions will cause damage greater than $417 per $MtCO_2$, the most recent estimate of the *expected* value for the $SCCO_2$. There is insufficient information to know exactly how much greater. The findings from the three studies, however, provide a first approximation of the $SCCO_2$ that might materialize if climate disasters prove to be 2X–8X higher than this *expected* value: a range of values from $800 to $3,300 per $MtCO_2$ (Table 4). This range represents the risks from GHG emissions over the next few years and, conversely, the benefits from reducing emissions, in light of the recent research findings discussed above.

**Table 4. The potential social costs of $CO_2$, given recent research indicating that climate disasters will be worse than *expected***

| Extent to which climate risks now exceed previous *expectations* | Cost/ $MtCO_2$ |
|---|---|
| 2 times | $800 |
| 8 times | $3,300 |

Using the risk-based range of estimates for the $SCCO_2$, rather than the *expected* value, to analyze the costs or benefits of increases or decreases in emissions is consistent not just with the new science that indicates climate disasters are likely to be worse than previously expected. Doing so also is consistent with research showing that, to avoid downplaying the uncertainties and risks associated with climate disasters—many of which lie beyond historical experience and potentially involve catastrophic outcomes—analyses conducted now should assume high cost levels, and future analyses should lower them only if resolution of the uncertainty demonstrates it is appropriate to do so.[32]

## D. Today's high climate-disaster risks increase the benefits of GHG reductions, relative to the costs

One common argument against taking decisive action to reduce GHG emissions asserts that these actions would harm the economy. Often, however, these arguments fail to give equal consideration to the economic harm that will result because *not* taking these decisive actions will accelerate and intensify future climate disasters.

Climate disasters, within and outside the U.S., are already disrupting economic activity and diminishing the productivity of communities, farms, and businesses. Domestic disasters in 2018, for example, diminished GDP by up to 0.5 percent in Oregon and 5 percent in South Carolina (Figure 4).[33] These reductions are eqivalent to about $750 perhousehold in Oregon and more than $7,500 per household in South Carolina.[34]

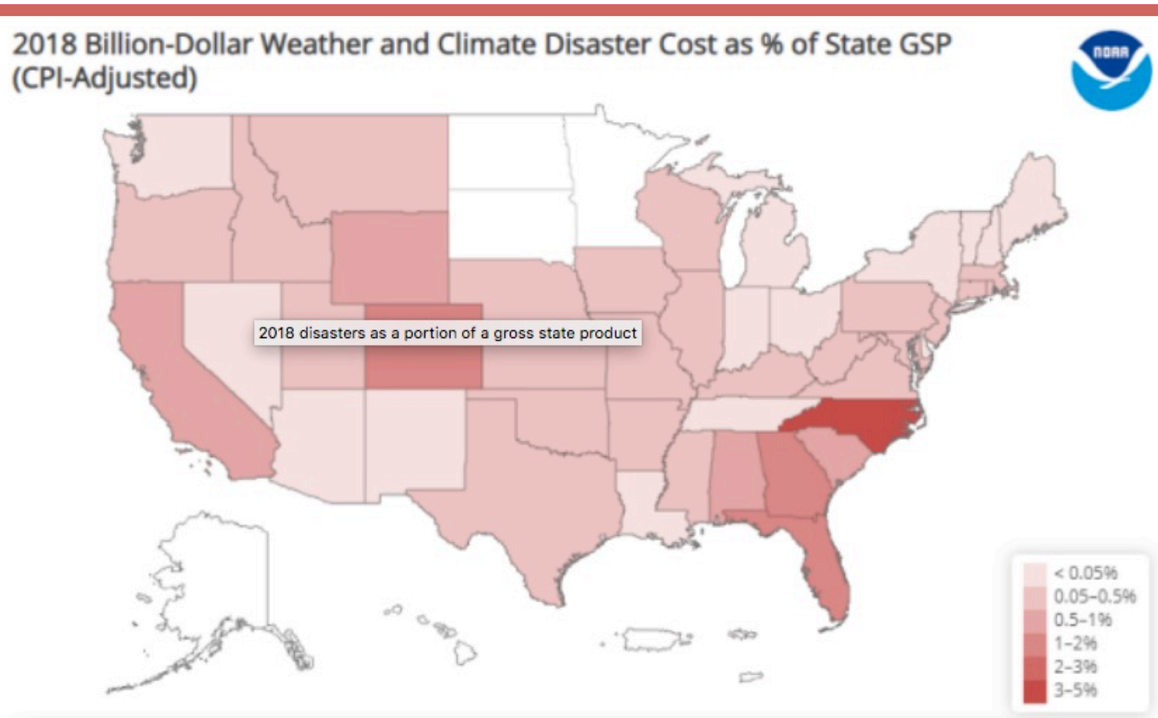


**Figure 4. Climate disasters within the U.S. are already reducing GDP**

Additional insights into the tradeoffs between the benefits of economic activity and the costs of climate disasters can come from comparing data for Oregon. On the one hand, the data show the value of the goods and services produced by Oregon's businesses, governments, and non-governmental organizations. This value is known as the state's gross domestic product, or GDP. On the other hand, the data show the GHG emissions that accompany the production of GDP. This amount, measured in metric tons of carbon dioxide, or $MtCO_2$, and multiplied by the estimates of the social cost per $MtCO_2$, from Table 4, reveals the climate-damage costs the emissions impose on society.

In 2016, Oregon produced goods and services with a value of about $200 billion.[35] The same year, the production of goods and services in five economic sectors directly emitted about 98 million $MtCO_2$ (Table 5). These emissions will cause climate-disaster damages of about $40 billion (Table 6), if they cause the *expected* level of climate-disaster damages estimated by Ricke et al. (2018). If climate disasters prove to be worse than expected, as indicated by the research summarized in Section A, the damage could be $80 billion–$320 billion.

Subtracting the *expected* climate-disaster costs indicates that the overall value of Oregon's GDP is reduced to $160 billion. If climate disasters prove to be 2 times worse than expected, the net value of Oregon's GDP falls to $120 billion. If they prove to be 8 times worse, the damages will exceed the gross value of the goods and services, reducing the net value of Oregon's GDP to negative $120 billion.

### Table 5. Oregon's GHG emissions in 2016

| | Emissions ($MtCO_2$) |
|---|---|
| **Direct emissions,[a] total, per year[36]** | 98 million |
| Timber sector[37] | 34 million |
| Transportation sector | 26 million |
| Residential/commercial sector | 21 million |
| Other Industrial sector | 12 million |
| Agricultural sector | 6 million |
| **Indirect emissions,[b] per year[38]** | **26 million** |
| **Total emissions, per year** | **124 million** |

[a] Direct emissions from in-state production of goods and services.
[b] Indirect emissions from the production of goods and services produced elsewhere and consumed in-state.

### Table 6. Climate-disaster costs resulting from the direct GHG emissions generated by Oregon's economic sectors may offset 20%–160% of the state's $200 billion GDP

| | Emissions ($MtCO_2$) | Cost to Society if Climate Disasters Prove To Be: | | |
|---|---|---|---|---|
| | | Expected | 2X Expected | 8X Expected |
| **Emissions from production of GDP[39]** | **98 million** | **$40 billion** | **$80 billion** | **$320 billion** |
| **Net benefit (cost)** | **- -** | **$160 billion** | **$120 billion** | **($120 billion)** |
| **GDP offset by climate-disaster costs** | **- -** | **20%** | **40%** | **160%** |

Numbers reflect rounding.

The data in Table 5 show that, in addition to directly generating 98 million $MtCO_2$ through their in-state production of good and services, Oregonians also generated 26 $MtCO_2$ through their consumption of goods and services produced elsewhere. If climate-disasters from these emissions materialize as *expected* by Ricke, et al. (2018), they will offset 25 percent of these benefits (Table 7). If, however, climate disasters prove to be worse than *expected*, as indicated by the scientists' warnings described above, they likely will offset at least 50 percent, and perhaps 200 percent of the gross value of the state's GDP.

### Table 7. Climate-disaster costs from Oregon's total (direct plus indirect) GHG emissions may offset 25%–200% of the state's $200 billion GDP

| | Emissions ($MtCO_2$) | Cost to Society if Climate Disasters Prove To Be: | | |
|---|---|---|---|---|
| | | Expected | 2X Expected | 8X Expected |
| Emissions from production of GDP[a] | 98 million | $40 billion | $80 billion | $320 billion |
| Indirect emissions[b] | 26 million | $11 billion | $21 billion | $86 billion |
| Total emissions | 124 million | $50 billion | $100 billion | $410 billion |
| Net benefit (cost) | - - | $150 billion | $100 billion | ($210 billion) |
| GDP offset by climate-disaster costs | - - | 25% | 50% | 200% |

[a] Direct emissions from in-state production of goods and services.
[b] Indirect emissions from the production of goods and services produced elsewhere and consumed in-state.
Numbers reflect rounding.

In other words, as Americans today enjoy extensive benefits from their current lifestyle, they do so only by imposing climate-disaster costs on those who will live in the future, and the data from Oregon indicate that these costs may be one-half-to-two-times the value of the benefits. If one looks at Oregonians' median income, the ratio of climate-disaster costs to economic benefits is even larger. The state's median household income was about $59,000 in 2016.[40] If climate-disasters from the state's emissions that year materialize as *expected* by Ricke, et al. (2018), they will total $62,000 per household, or 105 percent of the median income. If, instead, these costs prove to be 2X–8X worse than *expected*, they will total $94,000–$260,000 per household, and offset at least 160 percent, and perhaps 440 percent of the median income (Table 8).[41]

### Table 8. Climate-disaster costs from Oregon's total (direct plus indirect) GHG emissions may offset 105%–440% of the state's median household income ($59,000 in 2016)

| | Emissions ($MtCO_2$) | Cost to Society if Climate Disasters Prove To Be: | | |
|---|---|---|---|---|
| | | Expected | 2X Expected | 8X Expected |
| Direct emissions[a] | 61 | $49,000 | $73,000 | $200,000 |
| Indirect emissions[b] | 16 | $13,000 | $19,000 | $53,000 |
| Total emissions | 78 | $62,000 | $94,000 | $260,000 |
| Median income offset by climate-disaster costs | - - | 105% | 160% | 440% |

[a] Direct emissions from in-state activity.
[b] Indirect emissions from the production of goods and services produced elsewhere and consumed in-state.
Numbers reflect rounding.

# E. Higher risks climate disasters increase the benefits from reducing fossil-fuel emissions

The recent scientific findings highlighted in Section A indicate that future GHG emissions from the mining and combustion of fossil-fuels will cause climate-disaster damages far greater than what was expected from earlier research. This state of affairs also means, however, that the economic benefits from reducing fossil-fuel emissions are far greater than previously expected.

Eliminating the annual emissions produced by one passenger vehicle, for example, would reduce climate-disaster costs by $4,000–$16,000 if, as the recent research indicates, climate disasters prove to be 2X–8X worse than expected (Table 9). Every 1,000-mile reduction in miles traveled by passenger vehicles in the U.S. could reduce climate-disaster damages by $320–$1,300, if climate-disaster damages prove to be 2X–8X worse than expected. This amount indicates that a 1 percent reduction in annual distance traveled in the U.S.—about 14 billion miles—would reduce climate-disaster damages by about $45 billion–$180 billion, if climate-disaster damages prove to be 2X–8X worse than expected.[42]

**Table 9. Potential benefit (reduced climate damages) from reducing fossil-fuel emissions**

| | Emissions | Cost to Society if Climate Disasters Prove To Be: | | |
|---|---|---|---|---|
| | ($MtCO_2$) | Expected | 2X Expected | 8X Expected |
| **Reduction in fossil-fuel combustion** | | | | |
| Travel of one passenger vehicle (per year) | 5 | $2,000 | $4,000 | $16,000 |
| 1,000 miles by avg. passenger vehicle | 0.4 | $170 | $320 | $1,300 |
| 1,000 gallons gasoline | 9 | $4,000 | $7,000 | $29,000 |
| 1,000 gallons diesel | 10 | $4,000 | $8,000 | $34,000 |
| 1,000 cylinders propane for home bbq. | 24 | $10,000 | $19,000 | $79,000 |
| 1 billion cubic feet natural gas | 55,000 | $23 million | $44 million | $180 million |
| 1 trainload (120 railcars) oil[43] | 36,000 | $15 million | $29 million | $120 million |
| 1 trainload (120 railcars) coal[44] | 22,000 | $9 million | $18 million | $73 million |

Numbers reflect rounding.

The bottom three rows of Table 9 show the potential reductions in climate-disaster damages from reducing the combustion of fossil fuels—natural gas, oil, and coal—commonly shipped across the U.S. Reducing the combustion of natural gas by 1 billion cubic feet would reduce climate-disaster damages by $44 million–$180 million, if climate-disaster damages prove to be 2X–8X worse than expected. Reducing the combustion of oil and coal by one trainload would reduce the damages by $29 million–$120 million and $18 million–$73 million, respectively, if climate-disaster damages prove to be 2X–8X worse than expected.

# F. Higher risks of climate disasters increase the imperative for reducing forest emissions

The data in the preceding section are important because we can't avoid catastrophic climate disasters without reducing fossil-fuel emissions. They, alone, however, will not be enough. In addition, we must implement good forest- management practices that offer the "best climate solution available today."[45] Managing forests to remove and store $CO_2$ away from the atmosphere is especially important in those areas where forests have the greatest ability to do so. In the western states, these areas are concentrated in western Washington and Oregon, and dispersed through parts of the Rockies (Figure 5).[46] This section uses data from this region and across the U.S. to illustrate the benefits from managing forests to store more carbon by reducing logging, increasing the number of trees, and letting trees grow bigger.

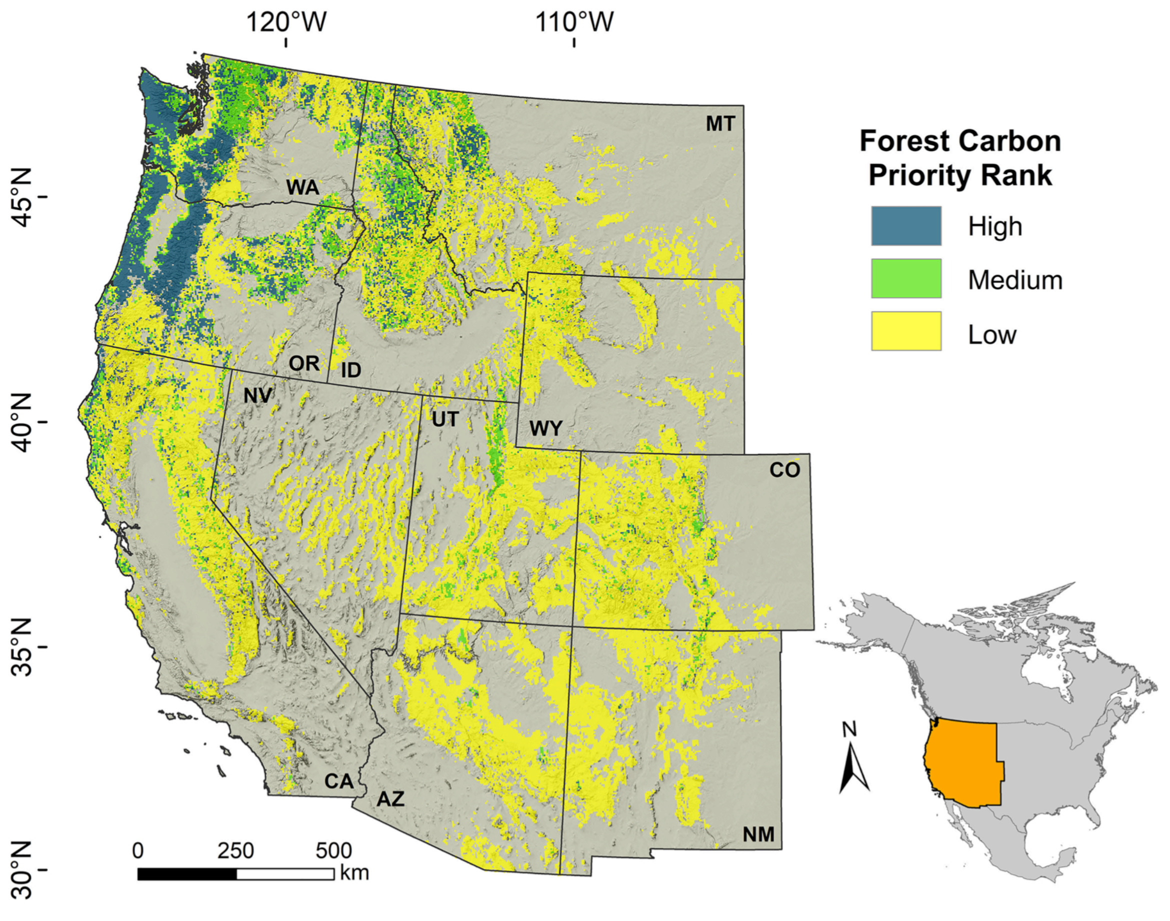


Figure 5. Forests ranked with the highest priority for preservation for carbon sequestration also have the highest current soil and aboveground carbon stocks

## A. Reduce logging-related emissions

Recent, cutting-edge research in Oregon reveals the importance of reducing logging-related emissions. The timber industry currently is Oregon's largest source of GHG emissions, generating about 34 $MtCO_2$ per year, or 38 percent of the state's total emissions (Table 5).[47] These emissions will generate climate-disaster costs of $14 billion–$27 billion–$110 billion if climate disasters prove to be *expected*, or 2X–8X worse (Table 10). Most of these costs (65 percent) come from logging on about 6 million acres of privately owned, industrial forest.

### Table 10. Potential benefit (reduced climate damages) from reducing the timber industry's GHG emissions in Oregon

| | Emissions ($MtCO_2$) | Cost to Society if Climate Disasters Prove To Be: | | |
|---|---|---|---|---|
| | | Expected | 2X Expected | 8X Expected |
| **Reduction in annual harvest:** | | | | |
| **Statewide, total**[48] | 34 million | $14 billion | $27 billion | $110 billion |
| Industry, total | 22 million | $9 billion | $17 billion | $71 billion |
| Non-industry private & tribal, total | 15 million | $6 billion | $4 billion | $18 billion |
| State, total | 2 million | $800 million | $1 billion | $5 billion |
| Forest Service, total | 3 million | $1 billion | $2 billion | $9 billion |
| BLM & other public, total | 20 million | $8 billion | $16 billion | $65 billion |
| **Reduction in harvest, per:** | | | | |
| Thousand board feet (mbf) | 8.5 | $3,500 | $6,800 | $28,000 |
| Million board feet (mmbf) | 8,500 | $4 million | $7 million | $28 million |
| Log truck | 42 | $18,000 | $34,000 | $140,000 |
| Acre logged (private, 20 mbf/ac) | 170 | $70,000 | $140,000 | $560,000 |
| Acre logged (BLM lands, 24 mbf/ac) | 220 | $90,000 | $180,000 | $730,000 |
| Acre logged (State lands, 26 mbf/ac) | 240 | $100,000 | $190,000 | $790,000 |
| $1 mil. stumpage revenue | | | | |
| BLM lands[49] | 34,000 | $14 million | $27 million | $110 million |
| State lands[50] | 16,000 | $7 million | $13 million | $53 million |

Numbers reflect rounding.

The bottom half of Table 10 shows the potential reduction in climate-disaster damages from reductions in logging. A reduction of one million board feet, for example, would reduce damages by $7 million-$28 million, one fewer log truck loaded with logs would reduce damages by $34,000–$140,000, and not logging one acre of state-owned land would reduce damages by $190,000–$790,000, if climate disasters prove to be 2X–8X worse than *expected*.

The last row of this table is especially revealing, insofar as it shows that the benefits (reduced climate damages) from curtailing logging can far exceed the costs (forgone log revenue for landowners). It shows that, if climate disasters materialize as *expected* by the most recent analysis of the social cost of carbon dioxide ($SCCO_2$),[51] the reduction in climate-disaster damages from curtailed logging on state-owned land will be seven times the state's forgone logging (stumpage) revenues. If, however, the climate disasters prove to be 2X–8X worse than *expected*, the reduction in damages could be 13–53 times the state's forgone revenues. The next-to-last row shows the ratio will be about twice as high for reduced logging on BLM lands. These ratios demonstrate that, although current logging practices generate short-term revenue for landowners, they do so only by imposing much greater costs on those who will live in the future. This behavior erodes the long-term sustainability of communities and economies in Oregon and around the globe, as well as the sustainability of these practices, themselves.

## B. increase the number of trees and let trees grow bigger

For many forests, logging reductions arguably offer the greatest opportunities to reduce future climate disasters. Complementary opportunities exist, though, through preventing the conversion of forests to other uses, reforestation (planting trees on lands that recently were forested), afforestation (planting trees on lands that have little or no legacy from being forested), and proforestation (allowing trees to grow bigger).[52]

One direct way to increase the number of trees is to prevent the conversion of forest to cropland, and the flip side of the coin is to convert cropland to forest. The former has a larger first-year impact on the amount of carbon in the atmosphere because forests hold a lot of carbon and much of this is released into the atmosphere when trees are logged and soils are plowed, but a much smaller amount of carbon is pulled out of the atmosphere during the first year after tree seedlings are planted on lands that formerly produced crops. Thus, the first-year benefits from preventing the conversion of 1,000 acres of forest to cropland could be as high as $400 million, if climate disasters prove to be 8X worse then *expected,* but the analogous benefits from planting 1,000 acres could be just $2.5 million (Table 11).

Increasing the number of trees in urban and suburban areas also can reduce future climate disasters by sequestering carbon dioxide from the atmosphere. By planting one million urban or suburban trees, the economic benefits over the next ten years would be about $25 million, if climate-disaster damages materialize as *expecte*d, and perhaps $200 million if they prove to be 8X worse than *expected*. As the trees mature, they may remove up to 22,000 $MtCO_2$ from the atmosphere per year, and reduce climate-disaster damages by $18 million–$73 million.

Letting trees grow bigger can substantially reduce future climate disasters. An analysis of private timberlands in southern states found that a long-term decision to allow trees to grow an additional 5, 10, or 15 years before being logged would respectively sequester 9, 14, or 17 $MtCO_2$ per acre.[53] Implementing the same options on private lands in the three West Coast states would sequester even more: 20, 33, or 43 $MtCO_2$ per acre. These increases in carbon dioxide stored in forests in the southern states could reduce climate-disaster damages by $11,000, $17,000, or $20,000 per acre, respectively, if climate-disaster risks are 2X worse than previous expectations, and by $30,000, $46,000, and $56,000 per acre if climate-disaster risks are 8X worse than previous expectations. Similarly, extending the harvest age in the West Coast states could reduce damages by $16,000, $26,000, or $34,000 per acre, if climate-disaster risks are 2X previous expectations, and by $66,000, $110,000, and $140,000 per acre if climate-disaster risks are 8X previous expectations.

These numbers provide the basis for estimating the potential reductions in climate-disaster damages from widespread efforts to extend the harvest rotation on industrial timberlands.

Extending the harvest age by 5, 10, or 15 years across 1 million acres in the southern states could reduce climate-disaster damages by $11 billion, $17 billion, or $20 billion, respectively, if the risk of climate disasters is 2X worse than *expected*, and by $30 billion, $46 billion or $56 billion, if the risk of climate disasters is 8X worse. Similarly, extending the harvest age across 1 million acres in the West Coast states could reduce damages by $16 billion, $26 billion, or $34 billion, if the risk of climate disasters is 2X worse than *expected*, and by $66 billion, $110 billion, or $140 billion, if the risk of climate disasters is 8X worse.

### Table 11. Potential benefit (reduced climate damages) from increasing the number of trees and letting trees grow bigger

| | Emissions | Cost to Society if Climate Disasters Prove To Be: | | |
|---|---|---|---|---|
| | ($MtCO_2$) | Expected | 2X Expected | 8X Expected |
| **Increase number of trees** | | | | |
| **Prevent conversion of forest to cropland[54]** | | | | |
| Per 1,000 acres ($MtCO_2$ in 1st year) | 150,000 | $62 million | $96 million | $400 million |
| **Convert land from other uses to forestry[55]** | | | | |
| Per 1,000 acres ($MtCO_2$ in 1st year) | 770 | $320,000 | $620,000 | $2.5 million |
| **Plant 1,000,000 urban tree seedlings** | | | | |
| First 10 years growth[56] | 58,000 | $24 million | $46 million | $190 million |
| Older trees, per year[57] | 22,000 | $18 million | $26 million | $73 million |
| **Let trees grow longer, bigger** | | | | |
| **Extend harvest rotation ($MtCO_2$ per acre)[58]** | | | | |
| Southern states[59] | | | | |
| 5 years | 9 | $7,000 | $11,000 | $30,000 |
| 10 years | 14 | $11,000 | $17,000 | $46,000 |
| 15 years | 17 | $14,000 | $20,000 | $56,000 |
| West Coast states[60] | | | | |
| 5 years | 20 | $8,000 | $16,000 | $66,000 |
| 10 years | 33 | $14,000 | $26,000 | $110,000 |
| 15 years | 43 | $18,000 | $34,000 | $140,000 |

Numbers reflect rounding.

# G. Heightened risks of climate disasters intensify the imperative to reduce emissions quickly

The preceding sections make clear that all of us now face climate-disaster risks and costs higher than most of us previously expected. Although the nature and severity of the disasters will vary from place to place and over time, we all will bear higher risks and costs directly, indirectly, or both. As the risks of future climate disasters increase, so too does the imperative for acting now to reduce GHG emissions. Here are a few examples:

1. **Households face direct costs from climate disasters**

   *If recent trends in GHG emissions continue unabated, the seven categories of climate-related costs described in Section B will grow until, sometime in the near future, they impose costs on Oregonians totaling about* **$15,000 per household per year**. *This amount is* **more than 20 percent of the current, median income**.[61] *Some costs, like those from exposure to climate-related wildfire smoke, could materialize immediately, but others, such as increases in food prices may take longer to materialize. Actual costs will be higher than these numbers suggest, insofar as many costs have not yet been quantified. Diminishing or deferring these costs can occur only through decisive actions to reduce GHG emissions or to pull GHGs from the atmosphere.*

2. **Households also face indirect costs from climate disasters**

   *Climate disasters don't have to occur locally to impose economic costs on households. For example, recent research found that river-flooding in China has a greater negative effect on the U.S. economy than does river-flooding in the U.S.*[62] *Other types of climate disasters in China will have a similar, negative effect on the U.S. economy, reducing incomes for some Americans, as will climate disasters in other countries. Much of the negative effect will impinge on future incomes for U.S. households, especially those with closer links to international trade.*

   *The combination of risks from climate disasters that strike here or elsewhere means that it would be incorrect for Americans to believe they will not be harmed when they emit GHGs, expecting that the resulting climate disasters will occur elsewhere. Somehow, sooner or later, all U.S. households will bear climate-disaster damages, regardless of where the disasters occur.*

3. **Combustion of fossil fuel by passenger vehicles**

   *The emissions and costs from passenger vehicles could be reduced through several mechanisms: reducing the number of miles driven per vehicle, increasing the miles per gallon, or replacing vehicles that burn fossil fuels with vehicles that don't.* A 1 percent reduction in annual distance traveled in the U.S. would reduce climate-disaster damages by about ***$45 billion–$180 billion per year***, if climate-disaster damages prove to be 2X–8X worse than expected.[63] A similar reduction in Oregon *would yield climate-disaster benefits of* ***$110 million–$460 million per year***, *or* ***$70–$290 per household***, *if the risks of climate-disaster damages are 2X–8X the expected level.*[64]

4. **Combustion of coal, oil, natural gas**

   *Many communities are resisting pipelines and trains that carry coal, oil, or natural gas. This infrastructure, often subsidized, encourages the combustion of these fossil fuels whenever it lowers the price of these fuels to consumers below levels that otherwise would exist and when it enables producers and consumers to disregard the heightened climate-disaster risks that result from burning the fuels. Successful efforts to reduce or stop the transshipment of fossil fuels through a community or* *state have to potential to correct these biases and prevent the combustion of the fuel. If totally successful, stopping the transshipment of a given amount of fossil fuel would reduce the amount of fuel burned by the same amount. In many instances, though, supplies from other sources might seek to fill-in the gap, but at a higher price, so that the amount burned would decline by less than the full amount. Stopping the transshipment of a 120-railcar train carrying coal has the potential to reduce climate-disaster damages by* ***$18 million–$73 million****, if the risks of climate-disaster damages are 2X–8X the expected level.*[65] *Stopping a similar train carrying oil has the potential to reduce damages by* ***$29 million–$120 million****.*[66]

*In Oregon, resistance to the transshipment of fossil fuels focuses on natural gas that would be carried by the Jordan Cove Pipeline Project. Preventing the combustion of the gas that would be carried by the proposed Jordan Cove, operating at full capacity, has the potential to reduce damages by* ***$20 billion–$80 billion*** *for each year that the pipeline remains closed.*[67] *Similar benefits likely would result from resistance to transshipments in other states.*

5. **Store more carbon in forests and trees on private lands**

*Timber production is a major source of $CO_2$ emissions, especially in Oregon, where it is the state's largest source, larger even than the combustion of fossil fuels by motor vehicles.*[68] *These emissions occur primarily as those who own most of Oregon's 6 million acres of industrial forestland manage the lands to extract maximum, short-term profit. Current methods of industrial timber production, with clearcut logging of trees on short rotations—perhaps only 30 years—contribute to climate disasters in two ways. One occurs as logging and related activities directly release $CO_2$ into the atmosphere. The other occurs as the logging of young trees prevents them from pulling $CO_2$ out of the atmosphere as they grow bigger. The overall result can have a massive effect on climate disasters. Permanently managing the 6 million acres of industrial lands so that trees would grow an additional 15 years before being logged, for example, would reduce climate-disaster damages by perhaps* ***$200 billion–$840 billion****, or* ***$34,000–$140,000 per acre****, if the risks of climate disasters are 2X–8X the expected level.*[69]

*Additional increases in carbon storage can be accomplished by planting more trees on private lands, perhaps through an initiative akin to the promotion of "victory gardens" that encouraged households to grow food in their backyards to support the war efforts during WWI and WWII. Planting 1 million hardwood trees in suburban backyards and horse pastures, and along the fringes of commercial croplands and pastures, for example, could reduce climate-disaster damages* ***by $46 million–$190 million over the first 10 years****, if climate-disaster damages prove to be 2X–8X the expected level, and later by perhaps* ***$18 million–$73 million per year*** *(Table 11).*

6. **Store more carbon in forests on public lands**

*Many public entities log trees on their lands to generate revenues, but the climate-disaster damages from this logging exceeds the stumpage revenues. For example, halting logging on the 729,859 acres of state-owned forests managed by the Oregon Board of Forestry for one year would reduce future climate-disaster damages by* ***$1–$5 billion****, or about* ***$1,400–6,800 per acre****, if the risks of climate-disaster damages are 2X–8X the expected level (Table 10). These benefits would be* ***7–53 times*** *the state's forgone timber (stumpage) revenue. Halting logging on BLM and other public lands in Oregon would reduce future climate-disaster damages by* ***$8 billion–$65 billion****, and the cost savings would be about* ***14–110 times*** *the BLM's forgone timber (stumpage) revenue (Table 10).*

Ernie Niemi prepared this report for Natural Resource Economics, a consultancy in Eugene, Oregon USA, which remains solely responsible for its contents. The report draws extensively from his earlier efforts to describe the costs climate change will impose on households and communities. In particular, it draws on the work of a team of economists, which he directed, that, in 2009, developed the first detailed estimates of potential climate-related costs for Oregon, Washington, and New Mexico. It also draws on his assessment, prepared in 2015 on behalf of Lebanon's Ministry of Environment and the United Nations Development Programme, that describes the costs climate change potentially will impose on Lebanon.

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1 Ripple, W.J., et al. 2019. World scientisis' warning of a climate emergency. *See* also:Yokohata, T., et al. 2019. Visualizing the interconnections among climate risks:

> "While a substantial number of climate risks are identified in the Intergovernmental Panel on Climate Change Fifth Assessment Report, there have been few attempts to explore the interconnections between them in a comprehensive way. To fill this gap, we developed a methodology for visualizing climate risks and their interconnections based on a literature survey. Our visualizations highlight the need to address climate risk interconnections in impact and vulnerability studies. Our risk maps and flowcharts show how changes in climate impact natural and socioeconomic systems, ultimately affecting human security, health, and well-being."

2 Lenton, T.M., et al. 2019. Climate tipping points—too risky to bet against.

3 Yale Environment 360. 2019. CO2 concentrations hit highest levels in3 million years. "While a substantial number of climate risks are identified in the Intergovernmental Panel on Climate Change Fifth Assessment Report, there have been few attempts to explore the interconnections between them in a comprehensive way. To fill this gap, we developed a methodology for visualizing climate risks and their interconnections based on a literature survey. Our visualizations highlight the need to address climate risk interconnections in impact and vulnerability studies. Our risk maps and flowcharts show how changes in climate impact natural and socioeconomic systems, ultimately affecting human security, health, and well-being."

2 Lenton, T.M., et al. 2019. Climate tipping points—too risky to bet against.

3 Yale Environment 360. 2019. CO2 concentrations hit highest levels in3 million years.

4 Borenstein, S. 2019. Warming toll: 1 degree hotter, trillions of tons of ice gone.

5 Plumer, B. 2019. Carbon dioxide emissions hit a record in 2019, even as coal fades. New York Times. December 3.

6 Borenstein, S. 2019. Warming toll: 1 degree hotter, trillions of tons of ice gone.

7 Beals, R.K. 2019. Global GDP will suffer at least a 3% hit by 2050 from unchecked climate change, say economists.

8 Oxfam International. 2019. Climate fuelled disasters number one driver of internal displacement globally forcing more than 20 million people a year from their homes.

9 Brooks, C. 2019. Another grim climate report on oceans: what will it take to address the compounding problems?

10 Tyndall° Centre for Climate Change Research. 2018. Risks associated with global warming of 1.5°C or 2°C.

11 Hibbert, F., and K. Grant. 2019. Sea levels are rising more than expected, according to scientists.

12 Leman, J. 2019. Welp, the latest UN Climate change report sure is bleak.

13 Ibbetson, R. 2019. UN chief warns the climate change 'point of no return is hurtling toward us' and the current response has been utterly inadequate.'

14 Irfan, U. 2019. UN: the world has backed itself into a treacherous corner on climate change.

15 Nace, T. 2019. Carbon dioxide reached highest recorded levels in human history. Forbes.

16 *See* Niemi, E. 2018. Paying for Oregon's future: costs climate change will impose on Oregon's households for data, assumptions, and calculations.

17 *See* Niemi, E. 2018. Paying for Oregon's future: costs climate change will impose on Oregon's households for data, assumptions, and calculations.

18 *See* Niemi, E. 2018. Paying for Oregon's future: costs climate change will impose on Oregon's households for data, assumptions, and calculations.

19 Americans currently spend about $7,200 per year per household on food. [Bureau of Labor Statistics. 2017. "Consumer Expenditures—2016".] If recent trends in GHG emissions continue, food prices will likely rise by 15 – 20 percent in the near future, but the higher prices would induce consumers to reduce their purchases by 3 percent. [Wiebe, Keith, Hermann Lotze-Campen, Ronald Sand, Andrzej Tabeau, Dominique van der Mensbrugghe, Anne Biewald, Benjamin Bodirsky, Shahnila Islam, Aikaterini Kavallari, Daniel Mason-D'Croz, Christoph Müller, Alexander Popp, Richard Robertson, Sherman Robinson, Hans van Meijl, and Dirk Willenbockel. 2015 . "Climate change impacts on agriculture in 2050 under a range of plausible socioeconomic and emissions scenarios."].

20 Climate-related effects will reduce annual federal revenues per household (17 percent of GDP) by $500 – $900 in the near future and per household GDP growth by $3,000 – $5,300. [Reduction in federal revenue: Office of Management and Budget. 2016. *Climate Change: The Fiscal Risks Facing the Federal Government*. Federal receipts as percent of GDP: Federal Reserve Bank of St. Louis. 2018.] Personal income is about 80 percent of Oregon's GDP. [Economic data for personal income as percent of GDP (Oregon): Federal Reserve Bank of St. Louis. 2018.]

21 Assume that federal/state/local fire-suppression costs of $454 million are 9 percent of the total costs, so that the total costs per year currently are about $5 billion. [Headwaters Economics. 2018. *Full Community Costs of Wildfire*.] Subtracting the federal portion of these costs leaves about $4.6 billion of other costs. If costs correlate with acres burned, [Oregon Climate Change Research Institute. 2017. *The Third Oregon Climate Assessment Report*. January.] then these costs will increase 40–100 percent in the near future, or $1.8–$4.6 billion. Dividing by Oregon's 1.6 million households reveals the additional cost of future climate-related wildfires, relative to today.

[22] Assumes exposure to a 7-day smoke intrusion per year and that the costs from exposure to dense wildfire smoke can total about $370 per adult per day, or $740 per day for a household with two adults. [Jones, Benjamin A. 2017. "Willingness To pay Estimates for Wildfire Smoke Health Impacts in the US Using the Life Satisfaction Approach."]
[23] A "large and robust" literature on the economic value of an increased risk of death, across society as a whole, indicates this cost is about $10 million per potential death. [Oregon Health Authority. 2014. "Climate Smart Strategy: Heath Impact Assessment."] This cost, multiplied times the risk that climate-related heat will cause 163-250 premature deaths, yields the total costs to Oregon's households. Dividing by the number of Oregon households, 1.55 million yields the cost per household per year.
[24] The value of the harm to all Oregonians from climate-related declines in salmon populations in the near future is about $0.7 – $1.0 billion per year. [ECONorthwest and Natural Resource Economics. 2012. Yakima River Basin integrated water resources management plan: four accounts analysis of the integrated plan.] This range, divided by the number of Oregon households, 1.55 million, yields the potential costs per household.
[25] Climate-related effects will reduce annual federal revenues per household (17 percent of GDP) by $500 – $900 in the near future. [Reduction in federal revenue: Office of Management and Budget. 2016. *Climate Change: The Fiscal Risks Facing the Federal Government*.]
[26] Niemi, E.G. 2017. The social cost of carbon.
[27] EPA Fact Sheet: Social Cost of Carbon.
[28] Ricke, K., et al. 2018. Country-level social cost of carbon.
[29] Smith, S. and N. A. Braathen. 2015. "Monetary Carbon Values in Policy Appraisal: An Overview of Current Practice and Key Issues."
[30] Howard, P. 2014. Omitted damages: what's missing from the social cost of carbon.; and Revesz, R.L. 2014. Global warming: improve economic models of climate change.
[31] Cai, Yongyang, Timothy M. Lenton, and Thomas S. Lontzek. 2016. Risk of multiple interacting tipping points should encourage rapid CO2 emission reduction.
[32] Daniel, K.D., R.B. Litterman, and G. Wagner. 2019. Declining $CO_2$ price paths.
[33] National Oceanic and Atmospheric Administration
[34] Data on GDP from Federal Reserve Bank of St. Louis. Data on number of households from U.S. Bureau of the Census.
[35] Oregon Global Warming Commission. 2018. 2018 biennial report to the legislature for the 2019 legislative session.
[36] Oregon Global Warming Commission. 2018. 2018 biennial report to the legislature for the 2019 legislative session.
[37] Law, B.E., et al. 2018. Land use strategies to mitigate climate change in carbon dense temperate forests; CSE. 2017. Oregon forest carbon policy: scientific and technical brief to guide legislative interventions.
[38] Oregon Global Warming Commission. 2018. 2018 biennial report to the legislature for the 2019 legislative session.
[39] Oregon Global Warming Commission. 2018. 2018 biennial report to the legislature for the 2019 legislative session. Tables 2, 3, 5. Assume 1.6 million households (OR Employment Dept.).
[40] Oregon has about 1.6 million households.
[41] Federal Reserve Bank of St. Louis. 2019. Median household income in Oregon.
[42] Total miles traveled by passenger vehicles in the U.S. is about 14 trillion miles per year. [Statista. 2019. Passenger miles traveled in the U.S. 2017.] Passenger vehicles, driven 1 million miles, emit 403 $MtCO_2$. National average. EPA. 2019. Greenhouse gases equivalencies calculator – calculations and references.] Reducing the total mileage by one percent, or 140 billion miles, would reduce emissions by 56 million $MtCO_2$. This reduction in emissions would reduce climate-disaster damages by $45 billion–$180 billion, if disasters prove to be 2X–8X worse than *expected*.
[43] Assume 700 barrels per railcar. [Conca, J. 2018. Which is safer for transporting crude oil: rail, truck, pipeline, or boat?] Assume 700 barrels of oil, when burned, generate 302 $MtCO_2$. [National average. EPA. 2019. Greenhouse gases equivalencies calculator – calculations and references.] A train with 120 oil railcars represents 36,000 $MtCO_2$.
[44] National average. [EPA. 2019. Greenhouse gases equivalencies calculator – calculations and references.]
[45] ETH Zurich. 2019. How trees could save the climate.
[46] Buotte, P.C., B.E. Law, W.J. Ripple, and L.T. Berner. 2019. Carbon sequestration and biodiversity co-benefits of preserving forests in the western USA.
[47] Law, B.E., et al. 2018. Land use strategies to mitigate climate change in carbon dense temperate forests; Center for Sustainable Economy (CSE). 2017. Oregon forest carbon policy: scientific and technical brief to guide legislative interventions.
[48] Harvest levels, 2018. [University of Montana, Bureau of Business and Economic Research. 2019. Oregon timber harvest.] Assume 8.5 $MtCO_2$ per thousand board feet (mbf), from total state emissions, 34 M $MtCO_2$, estimated by Law et al. (2018) divided by annual state harvest, ~4 billion board feet (bbf).
[49] Assumes stumpage price of $250/mbf. BLM. 2016. Resource management plan/final environmental impact statement: western Oregon.

[50] Assumes stumpage price of $536/mbf, the average for FY2018. Association of Oregon Counties and Oregon Department of Forestry. 2019. Council of Forest Trust Land Counties annual report.
[51] Ricke, K., et al. 2018. Country-level social cost of carbon.
[52] *See*, for example, Bastin, J-F, et al. 2019. The global tree restoration potential, and Moomaw, W.R., S.A. Masino, and E.K. Faison. 2019. Intact forests in the United States: proforestation mitigates climate change and serves the greatest good.
[53] Sohngen, B., and S. Brown. 2008. Extending timber rotations: Carbon and cost implications.
[54] National average. EPA. 2019. Greenhouse gases equivalencies calculator – calculations and references.
[55] National average. EPA. 2019. Greenhouse gases equivalencies calculator – calculations and references.
[56] Planting 17.3 tree seedlings will sequester 1 $MtCO_2$ over 10 years. National average. EPA. 2019. Greenhouse gases equivalencies calculator – calculations and references.
[57] USDA. The power of one tree – the very air we breathe.
[58] Average for West Coast states, calculated as the present value of future increases in forest carbon from long-term implementation of longer harvest rotations, using a discount rate of 6 percent per year. Sohngen, B., and S. Brown. 2008. Extending timber rotations: Carbon and cost implications.
[59] Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee.
[60] Washington, Oregon, and California.
[61] Oregon Employment Department. 2019. A closer look at Oregon's median household income; and Statisticalatlas.com. 2019. Household income in the Portland area.
[62] Willner, Sven Norman, Christian Otto, and Anders Levermann. 2018. "Global Economic Response to River Floods."
[63] Total miles traveled by passenger vehicles in the U.S. is about 14 trillion miles per year. [Statista. 2019. Passenger miles traveled in the U.S. 2017.] Passenger vehicles, driven 1 million miles, emit 403 $MtCO_2$. National average. EPA. 2019. Greenhouse gases equivalencies calculator – calculations and references.] Reducing the total mileage by one percent, or 140 billion miles, would reduce emissions by 56 million $MtCO_2$. This reduction in emissions would reduce climate-disaster damages by $45 billion–$180 billion, if disasters prove to be 2X–8X worse than *expected*.
[64] Oregon has about 3.2 million passenger vehicles. [ODOT. 2019. DMV facts and statistics.] A typical passenger vehicle emits about 4.6 MtCO2 per year. [EPA. 2-019. Greenhouse gas emissions from a typical passenger vehicle.
[65] National average. [EPA. 2019. Greenhouse gases equivalencies calculator – calculations and references.]
[66] Assume 700 barrels per railcar. [Conca, J. 2018. Which is safer for transporting crude oil: rail, truck, pipeline, or boat?] Assume 700 barrels of oil, when burned, generate 302 $MtCO_2$. [National average. EPA. 2019. Greenhouse gases equivalencies calculator – calculations and references.] A train with 120 oil railcars represents 36,000 $MtCO_2$.
[67] The Jordan Cove Pipeline's capacity would be "up to 1.2 billion cubic feet of natural gas per day." [Federal Energy Regulatory Commission. 2019. FERC staff issues the final EIS for the Jordan Cove Energy Project (CP17-494-000 and CP17-495-000)] Combustion of 1 billion cu. ct. of natural gas emits 56,000 $MtCO_2$. [National average. EPA. 2019. Greenhouse gases equivalencies calculator – calculations and references.] Damages = perhaps $3,300 per $MtCO_2$. [*See* endnote 8.] 1.2 bil cu. ft./day X 365 days X 56,000 $MtCO_2$/bil cu. ft. X $3,300/$MtCO_2$ ~ $81 billion.
[68] Non-timber estimates from Oregon Global Warming Commission. 2018. 2018 biennial report to the legislature for the 2019 legislative session. and timber estimates from Law, B.E., et al. 2018. Land use strategies to mitigate climate change in carbon dense temperate forests and Center for Sustainable Economy. 2017. Oregon forest carbon policy: scientific and technical brief to guide legislative interventions.
[69] These amounts are approximations, derived primarily from Sohngen, B., and S. Brown. 2008. Extending timber rotations: carbon and cost implications. They likely overstate the potential reductions in climate-disaster damages insofar as the authors estimated the potential carbon sequestration focusing on trees 40–60 years of age, which they deemed to be the harvestable age, the 6 million acres of industrial land in Oregon includes younger trees, and these trees will not exhibit the same level of sequestration until they reach this age. The amounts likely understate the potential reductions in climate-disaster damages insofar as they reflect the authors' application of a 6 percent discount rate, which they deemed appropriate from the landowners' perspective, and this rate downplays the significance to society as a whole of reductions in future disasters. [Howard, P., and D. Sylvan. 2015. *Expert Consensus on the Economics of Climate Change*.]