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Climate Change Needs Behavior Change

Making the Case for Behavioral Solutions to Reduce Global Warming

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Sharing learnings, lessons and insights from behavioral science and conservation around the world

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Photo: Jason Houston

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Solving the global climate change crisis is going to rely on, in one way or another, changing human behavior.

Photo: Jason Houston

Foreword

Climate change is the defining global challenge of our time. Rapid changes to the global climate over the past several decades have already resulted in widespread impacts across human societies and natural systems. Continued changes of this magnitude will have severe and irreversible planetary impacts lasting hundreds of thousands of years, further threatening people and communities everywhere.

Lessening the worst of climate impacts requires a substantial push to limit global temperature changes over the course of this century. This in turn depends on humankind's ability to achieve rapid and sustained reductions in greenhouse gas emissions over the next several decades. Doing so demands a transformation of our economy and our systems of production and consumption, from changing how we generate energy and produce food to how we consume goods and services. While the focus for most of this change often rests at the scale of government and industry, changes at the level of individuals, households, and communities are of profoundly greater importance than most people appreciate.

As individuals, people often report feeling hopeless that they can effect change on a scale that matters for something as big as climate change. **But individual behavior change when taken up by billions of people makes a decisive difference.** Nearly two-thirds of global emissions are linked to both direct and indirect forms of human consumption; despite what the headlines suggest, even conservative estimates for the potential of changing behaviors to reduce natural resource consumption represent an enormous contribution to reducing global emissions. Achieving this potential, however, is a daunting challenge. It requires finding innovative ways of engaging individuals, households, and communities, and changing patterns of production and consumption that are ingrained in routine ways of life.

The movement to mitigate climate change has tended to rely heavily on categories of solutions that include: sweeping global policy reform, offsets and economic incentives to influence industry, and information-based messaging. Without a doubt, each of these is an important component to the worldwide effort to stop global warming. But we know that people are more complicated than the narrow solutions we often design to influence them.

New insights across the science of human of behavior have transformed our understanding of what motivates people. From this research, we have learned that emotions play an important role in our decision-making processes. As neuroscientist Antonio Damasio writes, "[Humans] are not thinking machines that feel; rather we are feeling machines that think."[1] Advances in evolutionary biology tell us also that people are inherently social animals and that 'self-interest' is far more complex than once assumed. Under the right conditions, we excel at cooperation, seek reciprocity, and act on the basis of social cues. And we have learned that our decision-making process is strongly influenced by the contextual environment in which we make decisions and the way choices are presented to us. **To get people to change, we need to design innovative solutions that meet them where they are, using the power of emotional appeals, social incentives, and choice architecture as expertly as we apply economics and policy.**

Scientists agree that humans are the primary driver of global warming, and that this process is happening at an unprecedented pace; we need increased political will to act and deliver on agreed global temperature targets to avoid the most catastrophic consequences. However, climate change needs to become everyone's business. This is evidenced by efforts such as *Drawdown*,[2] a recently published guide to the 80[i] most substantive solutions to address global warming, which has quantified the emissions impact (and conversely, the mitigation potential) across dozens of domains and solution categories. Our analysis in this report builds on *Drawdown's* work to specifically evaluate the role of individual behavior and its potential to reduce emissions. **Through this process, we identified 30 behavioral solutions that can mitigate 19.9-36.8 percent of global emissions from 2020-2050.** Indeed, the adoption of sustainable behaviors is a key component of solving the climate change challenge, especially if scaled up through collective action across communities and countries.

In 2017, Rare launched the Center for Behavior & the Environment to bring the best insights from behavioral science and design to tackle globally significant and 'wicked' environmental challenges. Among environmental and conservation programs, there remains an immense need to apply behavioral insights to develop effective approaches and spotlight what solutions are already being deployed at a small-scale around the world.

Identifying these solutions, creating a detailed evidence base of their effectiveness, and providing support to organizations that are speeding up their global adoption are critical if we are to address the most pressing global environmental challenges, especially those that are exacerbated by human consumption of natural resources. The following report makes that case by presenting a short summary of how human consumption is driving climate change. Next, it identifies the most promising categories of behavioral solutions at the individual and household level. Finally, it highlights how behaviorally-informed solutions can be scaled to make a transformative contribution to solving the climate crisis.

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i Drawdown sought to identify the top 100 solutions, but 20 of these are still in development, so we focus on the top 80 proven solutions in this report.


Photo: Jason Houston

Foundations of climate change and the role for human behavior

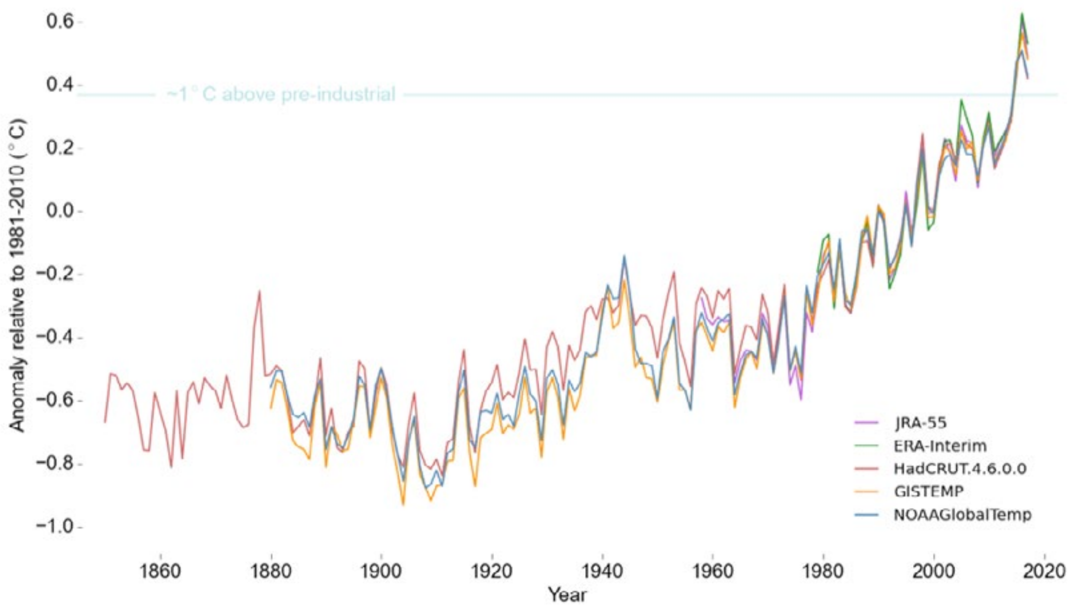


Figure 1. Global mean surface temperature anomaly 1850-2017 relative to 1981-2010. Source: WMO, 2017.

LATEST OUTLOOK ON CLIMATE CHANGE

In 2017, the Earth's climate set alarming records for surface and ocean temperature as well as sea ice extent. Recent analyses by the National Aeronautics and Space Administration (NASA) and the National Oceanic Atmospheric Administration (NOAA) showed that 2017 ranked as either the second or third warmest year for global surface temperature on record since 1880, depending on the analysis method used.[3] Despite evidence of global temperatures reaching a plateau from 2014-2016, in 2017, global warming has continued at an upwards trajectory. In the 136-year record of average near-surface temperatures, 16 of the 18 warmest years have occurred since 2001, and the average global surface temperature has now risen about 1.1°C above pre-industrial levels, averaged over the period 1850-1900.[4] Figure 1 shows the global mean surface temperature anomaly since pre-industrial times.

2017 was also the warmest year on record for ocean heat content.[5] Heat content of the ocean is a more reliable indicator of climate change because oceans take up more than 90 percent of heat trapped by increasing greenhouse gas (GHG) concentrations, and ocean heat content increases more smoothly than surface temperatures.[6] In addition to both of these records, 2017 also saw record-low sea ice in both the Arctic and Antarctic, continuing a long-term downward trend in global sea ice extent since the late 1970s.[7] These trends are just some of the sobering signs of accelerating climate change.

The fuel for global warming is GHG concentrations that reached record levels by the end of 2017. The global annual average atmospheric concentration of carbon dioxide (CO_2) was measured as more than 405 parts per million (ppm) in 2017.[8, 9]
The record surpassed 400 ppm in 2016 for the first time in modern atmospheric measurements and in ice core records of the past 800,000 years. While these latest data are still preliminary, they confirm that cumulative GHG concentrations are increasing and are projected to reach a level roughly two to three times the highest level occurring over the last 800,000 years unless decisive and rapid measures are undertaken to sharply reduce emissions.[10]

HUMAN CONTRIBUTIONS TO WARMING

Numerous comprehensive assessments of the climate system conclude that increasing concentrations of anthropogenic GHGs have been the primary driver of global warming since the mid-20th century.[11, 12] While concentrations of GHGs in Earth's atmosphere have changed throughout history, resulting in seven cycles of glacial advance and retreat in the last 650,000 years alone, the rapid increase in both GHG concentrations and global temperature observed today are incomparable to any rate observed over time periods ranging from decades to millennia.

The ebb and flow of GHG emissions in the atmosphere is directly related to their sources and sinks. Sources of GHGs include anything that leads to an increase in GHG emissions, such as decomposition, fossil fuel burning, and the application of chemical fertilizers. On the other hand, sinks include anything that stores GHGs, such as forests, the ocean, and soils.[13] By changing the balance of sources and sinks, we can reduce GHGs in the atmosphere that contribute to global warming. A commonly used metaphor for GHG emissions entering and leaving the atmosphere is a bathtub.[14] In this metaphor, water flowing into the tub would be sources of greenhouse gases entering the atmosphere, and the bathtub's drain would be the sinks that remove emissions. The challenge we are facing today is the result of our greenhouse gas sources overpowering our sinks, as we have turned on the faucet "at full blast." Delays in reducing or turning off the stream altogether means the bathtub will fill faster than we can drain it, causing the bathtub to "overflow." In real terms, this will translate into the utter breakdown of natural systems that support life on our planet. Even if we were to turn off the faucet tomorrow, we would still have to deal with the water already in the bathtub that is contributing to a warming world. A key takeaway is that we need to be mindful of both the rate of emissions as well as the total cumulative emissions that accrue over time.[15]

These total cumulative emissions of GHG emissions, which are rapidly increasing, will lock in the impacts of climate change for centuries and possibly millennia. Effective responses to the climate crises demand a robust understanding of how each sector (e.g., transport, energy, agriculture) contributes to projected warming. The need to tackle emissions from the various sectors is well understood, and new technologies are generating opportunities for faster decarbonization. What is often lacking is the political will to do so, which in turn often responds to a weak understanding across societies of the cost of inaction and of the fact that climate action can deliver multiple development benefits.[16] Another key ingredient is a full-fledged bottom-up commitment across societies, starting at individual level, to bring about the deep and rapid shifts needed. Climate change presents an immense challenge to human behavior, given that its abstract, large-scale, distant, and impersonal characteristics do not trigger the brain to action in the way other, more concrete and immediate problems might.[17] We need to share effective and actionable strategies to inspire and empower individuals to do their part in order to reduce the worst of the impacts of this global phenomenon and to demand more action by governments.

CLIMATE CHANGE MITIGATION

Climate change mitigation refers to human intervention to either reduce sources of GHGs or enhance sinks that absorb these emissions.[18] **The 2015 Paris Agreement signaled a major breakthrough for tackling the climate crisis, as it established for the first time global targets for reducing emissions and stemming the rise of global temperatures.** The principal objective of the Paris Agreement is to keep global temperature rise this century to well below 2˚C above pre-industrial levels and to pursue best efforts to limit this rise to 1.5˚C.[19] Under the Paris Agreement, all countries commit to reducing national emissions as detailed in their respective Nationally Determined Contributions (NDCs). Importantly, formal pledges made in the Agreement sets in place a five-year cycle of progressive ambition with a view to ensuring that continued efforts are made by all countries to reduce emissions in line with the agreed temperature targets. This so-called "ambition mechanism" is core to delivering on this Agreement. At present, even if countries fully deliver on both conditional and unconditional pledges for climate action in their respective NDCs, estimates indicate that this will result in temperature increases of between 2.7°C and 3.7°C.[20] More is needed, and Figure 2 shows the gravity of projected impacts of climate change at different degrees of warming.

Meeting the objectives of the Paris Agreement will require significant mitigation efforts across the entire global economy, and especially by high-emitting countries. Mitigation scenarios that achieve the Agreement's temperature target of "well below 2˚C" require that global CO_2 emissions peak between 2020-2030 and then decrease rapidly, reaching net-zero in the second half of the century.[21] Crucially, the longer the delay before our emissions peak and decline, the more rapid and significant decreases in emissions will then need to be, which will be both technologically and economically challenging (See Figure 3). The decarbonization rates implied under these scenarios, and which would have to be sustained over decades, have historically only been observed for short periods, such as during the Great Depression and the Second World War.[22]

In view of these daunting challenges, it is clear that rapid, sustained, and ambitious efforts are required to drastically reduce emissions over the short term, which requires active engagement across societies. Encouraging signs in recent years, such as the decoupling of economic growth from emissions in some countries, the rapid decline in the cost of renewable energy technologies, and the shift away from coal in several major economies, suggest that peaking global GHG emissions over the next several decades could be

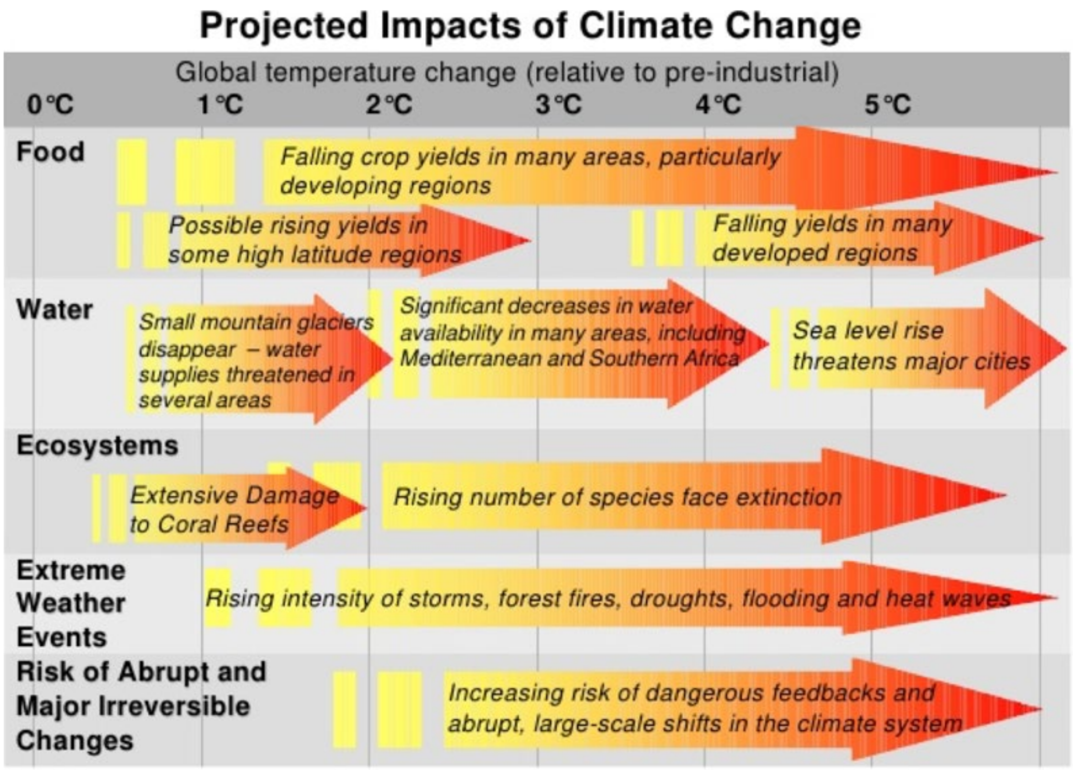


Figure 2. Projected impacts of climate change. Each row describes different threats associated with increased levels of global temperature change. Source: Stern Review, 2008.

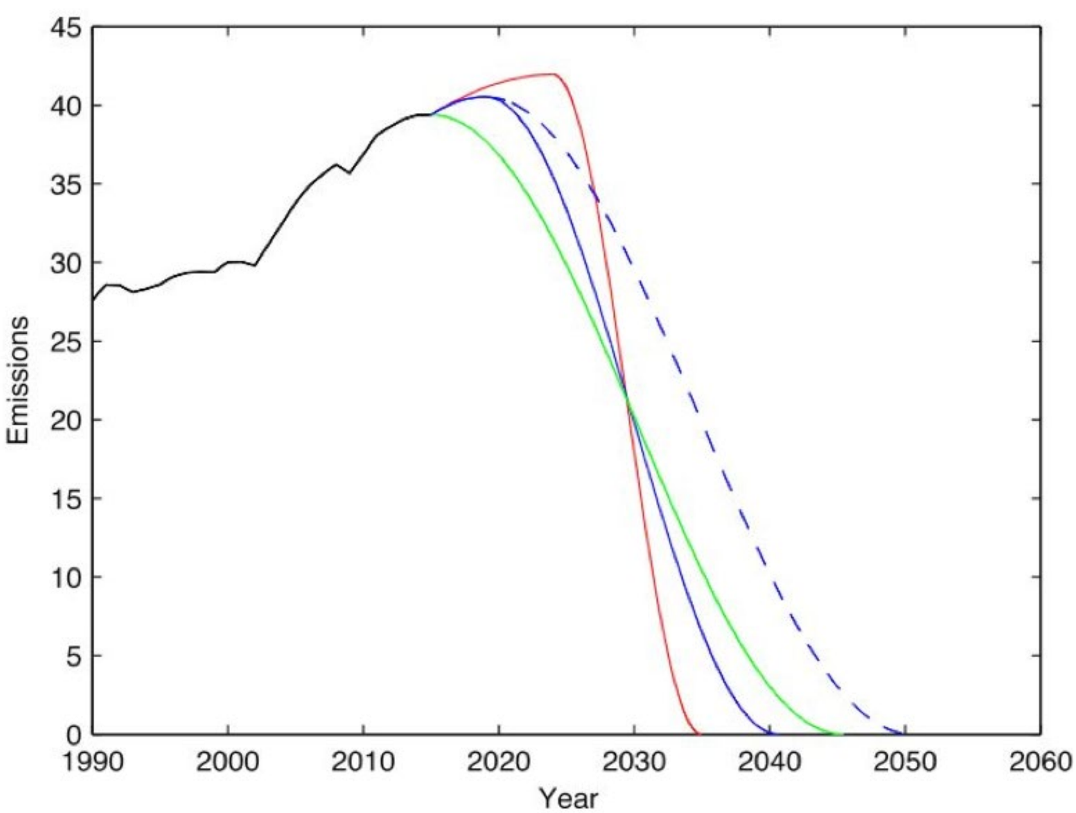


Figure 3. Three scenarios for achieving net-zero emissions while emitting a fixed budget of CO_2. The green line indicates emissions peaking in 2016, the blue line in 2020, and the red line in 2025 with 600 Gt CO_2. The dashed line indicates a scenario of achieving net-zero emissions by 2050 and emitting 800 Gt CO_2. As indicated by each line's slope, with each year we delay, the greater the decarbonization efforts that will be needed. Source: Mission 2020, 2017.

achievable. But very significant changes to our economic systems, especially in how energy and goods are produced and consumed, how land is used, and what lifestyles are privileged, are required to meet the temperature goals agreed to in Paris.

THE OPPORTUNITY OF HUMAN CONSUMPTION FOR REDUCING GLOBAL EMISSIONS

Human consumption of raw natural resources is at the center of the global economy and therefore an ideal place for actionable interventions. Nearly everything we do involves consumption of resources such as trees, water, fertile land, metal ores, and fossil fuels. And the global rate of consumption is increasing unabated, with economic growth coupled with increased resource use. According to the United Nations Environment Programme's (UNEP) latest report from the International Resource Panel (IRP), human consumption of global materials in 2017 reached 88.6 billion tons, more than triple the amount of consumption in 1970. High-income countries consumed ten times more per person than low-income countries.[23] In 2018, global consumption of natural resources, also called the "global ecological footprint," surpassed the amount the planet can sustainably renew in one year by August 1, with total consumption at the end of the year equal to 1.7 times the Earth's annual resource availability.[24] The ecological "deficit" that results from overconsumption of natural resources is growing, as shown in Figure 4, and its effects are being felt across natural and human systems, especially the global climate system. However impacts will be unevenly experienced across the globe, such as among poor and marginalized communities that suffer the most from climate change despite having contributed the least emissions.[25]

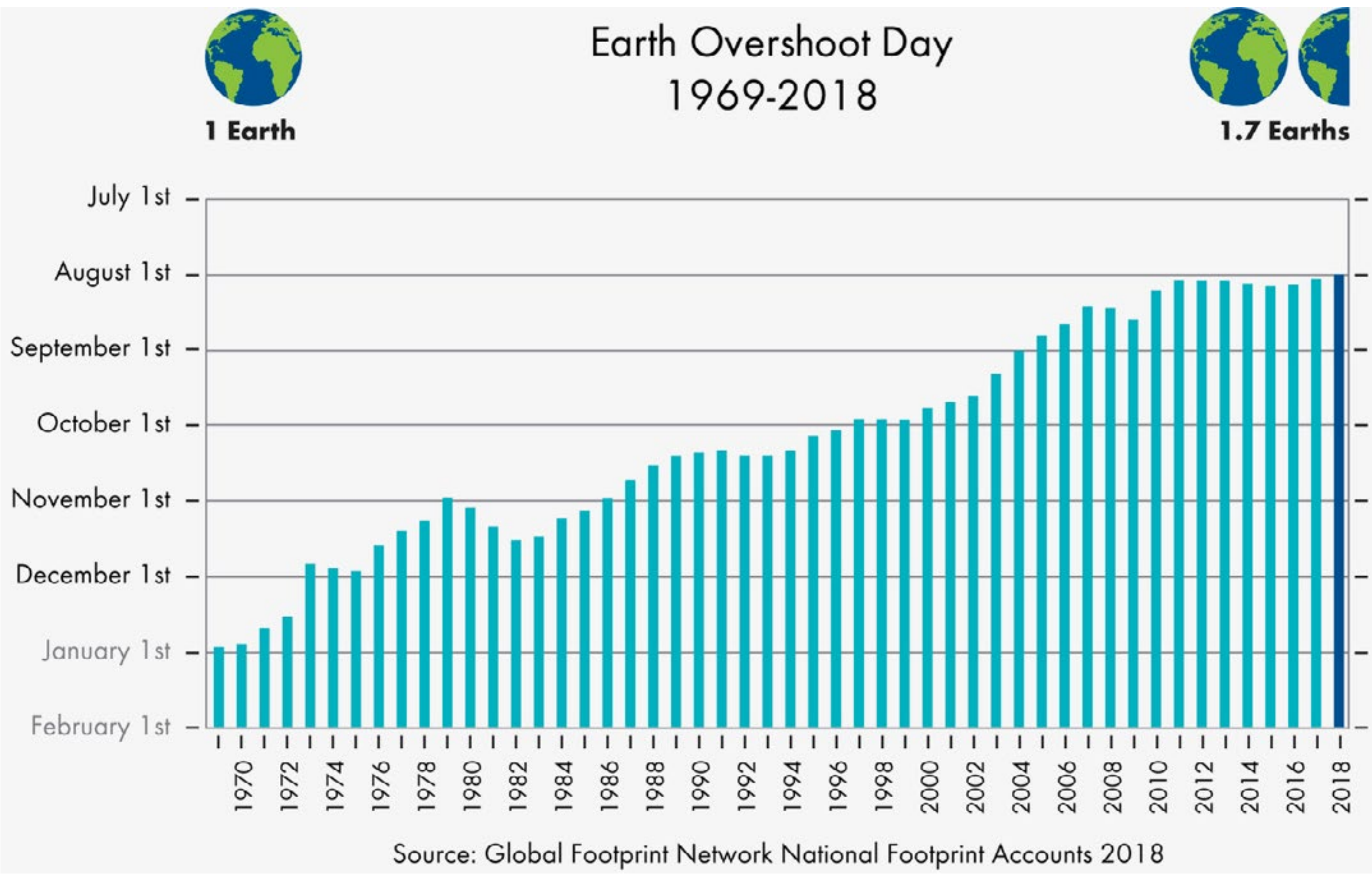


Figure 4. Earth overshoot day and days living over budget, 1971-2018. By August 1, 2018, we used more natural resources than the Earth could regenerate in that year. Source: GFN, 2018.

A landmark study of global supply chains in 2007 assessed the direct and indirect contributions of household consumption to greenhouse gas emissions.[26] According to the study, household purchases accounted for 70 percent of global land use, primarily for food and shelter, 48 percent of total raw material use, again mainly for food consumption as well as services and manufactured products, and 81 percent of total freshwater resources, of which less than 5 percent was in the form of direct consumption of water resources.[27] Consumption of agriculture and livestock was responsible for 74 percent of the global indirect water footprint and 80 percent of deforestation worldwide.[28,29] Across these sectors, household consumption was found to be responsible for between 50-80 percent of total natural resource use, with the vast majority of this consumption occurring in developed and emerging economies, such as the BRICS countries (Brazil, Russia, India, China, and South Africa).

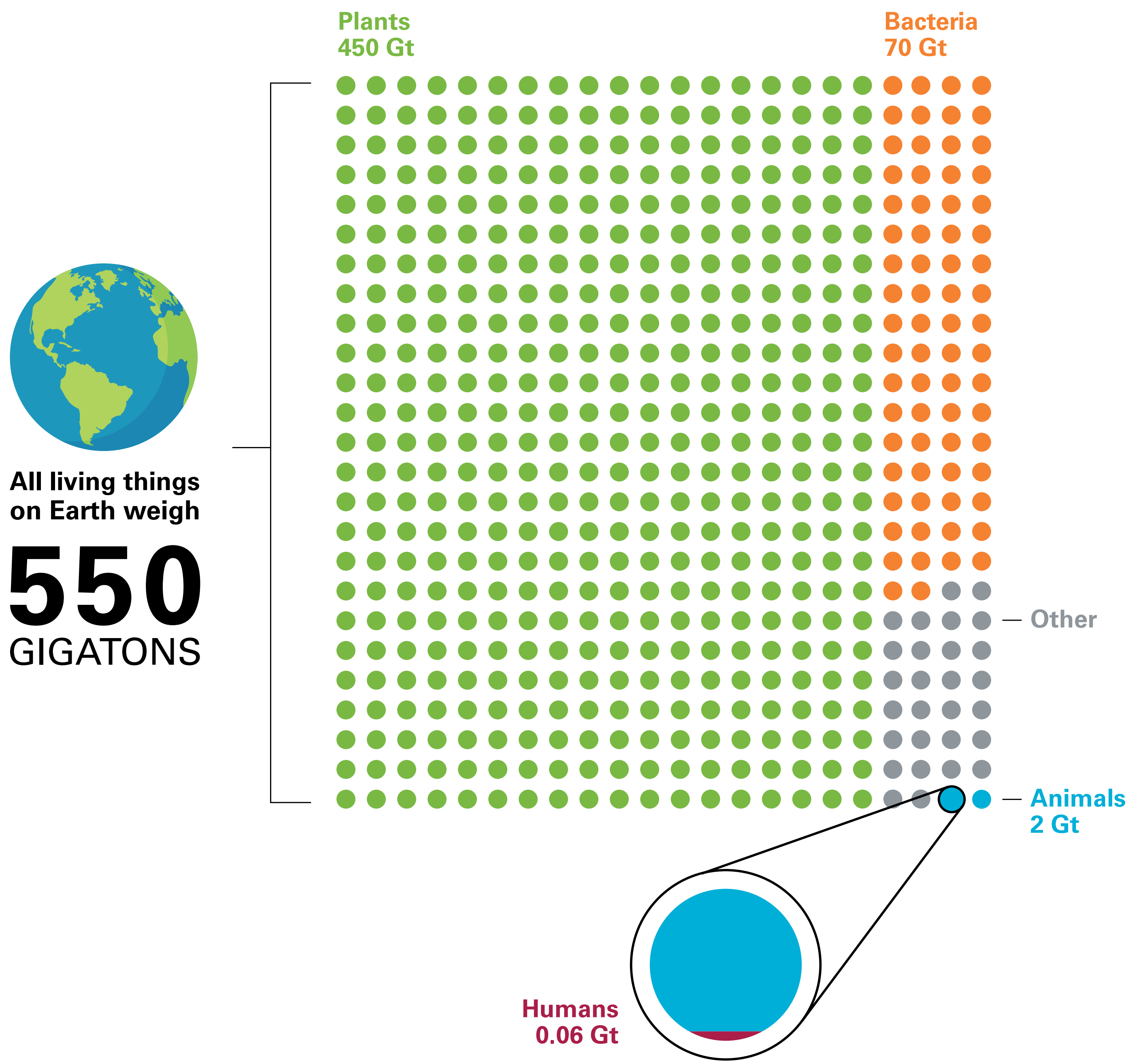
Clearly, enormous changes in behavior related to the consumption of natural resources are needed to effectively mitigate climate change. Building on the Paris Agreement's temperature targets that are country-determined, arguments promoting a "human-scale perspective" on climate change have proliferated in recent years.[30,31] These connect personal behavior with global GHG emissions, suggesting how individual actions that affect emissions and consumption of natural resources must be shifted to align with necessary GHG emissions reductions. It can also be argued that if people feel empowered to contribute to tackling the climate crisis they will, in turn, demand more action from governments and the private sector. Some authors have advocated for personal emissions quotas so that the tandem goals of emissions reductions and equity on a per capita basis can be achieved.[32] Even if such a system would be politically challenging to implement, it highlights the need for significant changes to human consumption patterns, especially for activities that cause overconsumption of food, water, and natural resources. In other words, **solving the global climate change crisis is going to rely on, in one way or another, changing human behavior.**

HUMANS ARE A TINY FRACTION OF THE WEIGHT OF LIVING THINGS AND HAVE A DISPROPORTIONATELY LARGE IMPACT ON OUR ENVIRONMENT

WHAT IS A GIGATON?

A gigaton is a billion metric tons, but what does that look like?

Source: Pennisi, 2018.



Behavioral solutions to reduce emissions

INTRODUCTION

By changing how humans around the world consume the products and services that come from natural resources, we can measurably reduce GHG emissions. The recently published bestseller, *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming,* measures, models, and describes the 80 most substantive existing solutions to address climate change mitigation (See Appendix).[33] Many of the solutions identified in the book exist at the level of the individual or household and rely directly on changing patterns of human consumption. Other researchers refer to such individual actions as "behavioral wedges" of a larger pie of necessary steps to reduce emissions.[34, 35] *Drawdown's* approach was to consider solutions across the entire global economy, from food and materials to energy and transport, and then to create scenarios that show the mitigation potential of rapidly scaling up these solutions from 2020-2050. The book presented three scenarios that range in ambition from a realistically rigorous rate of solutions adoption (Plausible scenario) to a rate where solutions achieve their maximum potential, fully replacing conventional technologies and practices, by 2050 (Optimum scenario). Each scenario is compared to a reference case, which assumes little change over the next 30 years and continued emissions growth in line with historical trends through 2050. The reference case is constructed based on a sensitivity analysis of a number of global systems models, including models from the International Institute of Applied Systems Analysis (IIASA), on which most of the IPCC's projections are based.[36]

Drawdown's methodology estimates the market potential for each solution and creates adoption trajectories for these based on published, peer-reviewed data and literature. A core assumption of *Drawdown* is that the infrastructure to manufacture and scale these solutions, as well as the policy and regulatory support needed enable their adoption, are already in place. In this way, *Drawdown* asks the question: if we rapidly scaled up the adoption of these promising solutions, what would be their global benefits in terms of financial savings and emissions reductions?

We then asked: how many of these solutions are particularly reliant on changes to people's behavior, whether that means changes to individual household consumption patterns, changes to farming practices, or changes that rely on community-scale shifts toward these solutions? And therefore, how much of the total emissions potential can be achieved by promoting their adoption on the individual scale? The solutions in the following sections are those that can be reasonably assumed to require more than just a technological shift or breakthrough but also a willingness among individuals and communities to adopt them. The list of these solutions is taken from *Drawdown* in order to provide consistent estimates for their potential, but that is not to say it is a comprehensive list of all behavior change solutions to reduce emissions. Undoubtedly, this list does demonstrate the massive potential that individuals and communities can have in terms of contributing to efforts to mitigate global warming. We believe that empowering individuals to make a difference can further help turn the tide in how businesses, governments, states, and countries choose to act on climate.

Table 1 presents our list of 30 solutions that we have grouped into four categories: food, agriculture and land management, transportation, and energy and materials. For each solution, we provide a definition, describe its impact on carbon emissions, as well as list its emission reduction for the Plausible and Optimum scenarios as calculated in *Drawdown*. In two cases (rice cultivation and recycling) we have combined similar solutions to consider their cumulative instead of individual impact. The total emissions reduction potential of these solutions is 393 (Plausible Scenario) to 729 (Optimum Scenario) gigatons of carbon dioxide-equivalent greenhouse gases ($GtCO_2$-eq). Based on *Drawdown's* modeling, the projected total greenhouse gas emissions from 2020-2050 is 1979 $GtCO_2$-eq.[37, 38] Therefore, large-scale adoption of these thirty behavioral solutions could mitigate 19.9-36.8 percent of emissions between 2020 and 2050, increasing the chances for us to achieve the necessary milestones to keep global temperatures well below 2°C.

THIRTY BEHAVIORAL SOLUTIONS FOR CLIMATE MITIGATION

Table 1. Thirty solutions to reduce emissions from human consumption across major economic sectors and solutions adoption scenarios. Numbered rankings were determined from the Optimum scenario emissions reduction estimates.
Note. Emissions potentials are based on varying assumptions about global levels of adoption.

Sector	Solution (Optimum scenario ranking)	Description	Plausible-Optimum Scenario Emissions Reduction ($GtCO_2$-eq)
FOOD	1. Reduced food waste	Minimizing food loss and wastage throughout the food supply chain from harvest to consumption	70.5-93.7
	2. Plant-rich diets	Eating more plant-based foods and fewer animal proteins and products (e.g., meat, dairy)	66.1-87.0
	13. Clean cookstoves	Using cookstoves that burn fuel more efficiently	15.8-24.3
	25. Composting	Converting biodegradable waste into a useful soil fertilizer instead of sending it to the landfill	2.3-3.6
AGRICULTURE AND LAND MANAGEMENT	3. Silvopasture	Adding trees to pastures to increase productivity	31.2-65.0
	5. Tropical staple trees	Growing trees and other perennial crops for staple protein, fats, and starch	20.2-47.2
	7. Tree intercropping	Growing trees together with annual crops in a given area at the same time	17.2-37.0
	8. Regenerative agriculture	Adopting at least four of the following six agricultural practices: compost application, cover crops, crop rotation, green manures, no-till or reduced tillage, and/or organic production	23.2-32.4
	9. Farmland restoration	Restoring degraded, abandoned farmland to grow crops or native vegetation	14.1-30.8
	10. Managed grazing	Adjusting stocking rates, timing, and intensity of grazing in grassland soils	16.3-27.9
	12. System of rice intensification and improved rice cultivation	Adopting low-methane rice production methods for small or large operations	14.5-26.1
	19. Conservation agriculture	Adopting crop rotation, cover crops, and reduced tillage practices on agricultural land	17.4-10.3
	28. Nutrient management	Reducing the use of fertilizer use on farmland	1.8-2.7
	29. Farmland irrigation	Installing water and energy saving irrigation systems, such as drip irrigation	1.3-2.3

TRANSPORTATION	4. Electric vehicles	Driving battery and plug-in vehicles instead of conventional vehicles	10.8-52.4
	26. Ridesharing	Using ride-sharing services and/or carpooling	6.9-29.5
	11. Mass transit	Using public transportation for commuting in cities instead of individual vehicles	6.6-26.3
	15. Telepresence	Using video-conferencing technologies in place of commercial flights	2.0-17.2
	16. Hybrid cars	Driving hybrid cars instead of conventional cars	4.0-15.7
	17. Bicycle infrastructure	Biking to destinations in cities instead of using cars	2.3-11.4
	18. Walkable cities	Walking to destinations in cities instead of using cars	2.9-11.1
	22. Electric bicycles	Using electric bikes for urban transport instead of using cars	1.0-7.1
ENERGY AND MATERIALS	6. Rooftop solar	Installing rooftop photovoltaic systems under one megawatt	24.6-40.3
	14. Solar water	Using solar radiation to pre-heat or heat water for building use	6.1-17.7
	20. Methane digesters	Adopting technologies that produce biogas for household heating through anaerobic digestion of organic waste	1.9-9.8
	21. LED lighting	Using energy efficient lighting in households	7.8-8.7
	23. Household water saving	Using water saving devices in homes such as low-flow showerheads	4.6-6.3
	24. Smart thermostats	Using devices that reduce heating and cooling demand through sensors and settings in the home	2.6-5.8
	27. Household recycling and recycled paper	Recycling paper, metal, plastic, and glass materials	3.7-5.5
	30. Micro wind	Installing small wind turbines to provide household electricity needs	0.2-0.1

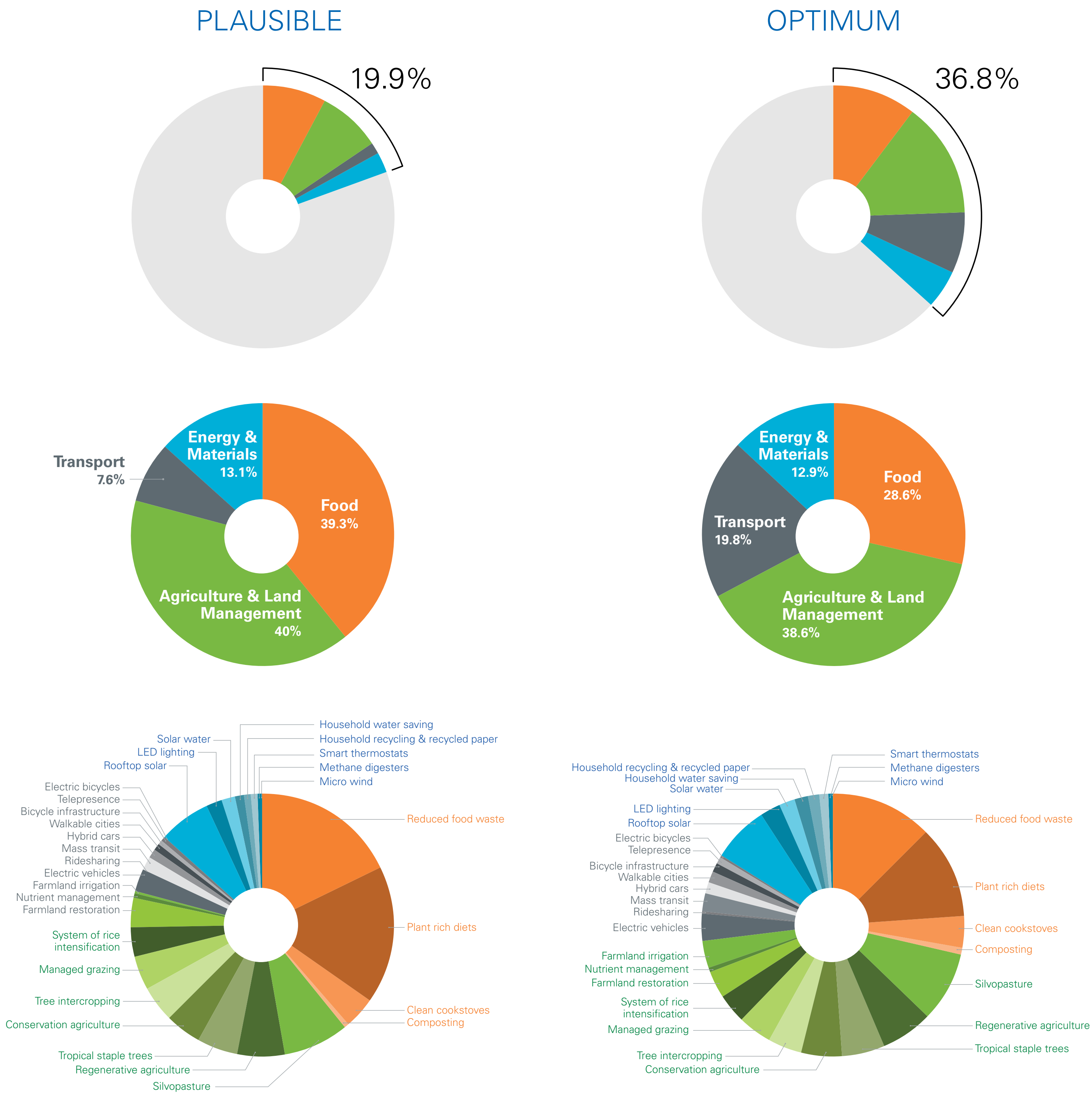
Total **393-729** $GtCO_2$-eq

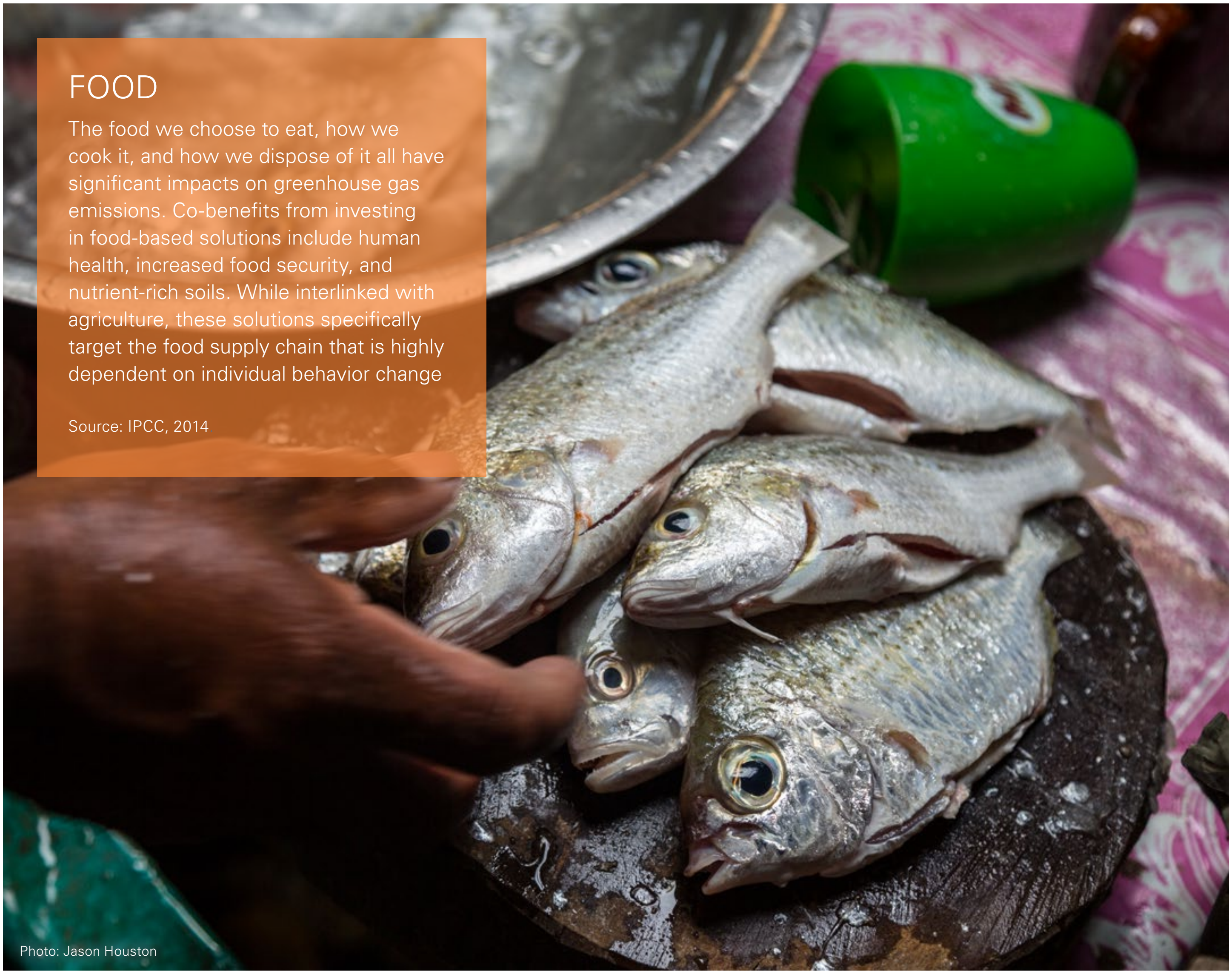
Emissions mitigated **19.9-36.8%**

It is important to highlight that many of these solutions are beneficial not only in terms of their mitigation potential but also in terms of economics, human health, and well-being. *Drawdown* is one of the first efforts to identify and rigorously evaluate readily actionable solutions by sector to slow and reduce global warming. While the initiative did not aim to focus on any specific type of solution, whether behavioral or not, it is telling that a number of the top solutions are those that specifically require changes to human behavior. Twelve of *Drawdown's* top 25 solutions are included in the table above, and two of these—reduced food waste and plant-rich diets—are in the top five most impactful solutions in terms of mitigation potential. The following sections further explain and provide examples of these solutions.

HOW MUCH CAN BEHAVIORAL SOLUTIONS CONTRIBUTE TO REDUCING EMISSIONS FROM 2020-2050?

Figure 4. Emissions reduction potential of 30 behavioral solutions, as projected in *Drawdown's* "Plausible" and "Optimum" scenarios, compared to a reference case of projected cumulative emissions from 2020-2050. The first row of pie charts shows the total emissions reduction potential of both scenarios using our 30 solutions colored by sector. The second row shows the emissions reduction potential of each of our four sectors of solutions. The third row shows the emissions reduction potential of each individual solution.





FOOD

The food we choose to eat, how we cook it, and how we dispose of it all have significant impacts on greenhouse gas emissions. Co-benefits from investing in food-based solutions include human health, increased food security, and nutrient-rich soils. While interlinked with agriculture, these solutions specifically target the food supply chain that is highly dependent on individual behavior change

Source: IPCC, 2014

Photo: Jason Houston

Reduced food waste

Solution: Minimizing food loss and wastage throughout the food supply chain from harvest to consumption.

Impact: The UN Food and Agriculture Organization (FAO) estimates that one-third of global food produced for human consumption does not reach end consumers, resulting in 4.4 $GtCO_2$-eq per year, or 8 percent of total anthropogenic GHG emissions.[39] This means that global emissions from food waste are nearly equivalent to those from global road transport. The FAO also estimates that the per capita footprint of emissions from food wastage in high income countries is more than double that of low income countries.[40] Food waste occurs throughout all phases of the supply chain; the highest carbon footprint of wastage occurs at end-consumption, which accounts for 22 percent of total food wastage but over 35 percent of total emissions, because food loss further along the supply chain is more carbon intensive.[41] While in developing regions most food waste occurs on-farm and during distribution, in developed countries, food is much more likely to be wasted because consumers do not like the "look" of certain foods or because foods have passed their use-by dates.[42] Estimates for the mitigation benefits of these solutions are substantial, with potential reductions between 1.3-4.5 $GtCO_2$-eq per year for a total of 70.5-93.7 $GtCO_2$-eq by 2050.[43, 44, 45]

Plant-rich diets

Solution: Individuals consuming more fruits, vegetables, grains, and legumes instead of animal protein and products (e.g., beef, chicken, milk), while also being mindful of local food sourcing and nutrition.

Impact: Animal proteins are a significant driver of climate change, with emissions from the livestock sector estimated at 7.1 $GtCO_2$-eq per year, equivalent to 14.5 percent of anthropogenic greenhouse gas emissions.[46] Beef and cattle milk production are responsible for over 60 percent of this sector's emissions, while pig and poultry products contribute another 15-20 percent. If the global stock of cattle was a country, it would rank as the third largest source of greenhouse gas emissions.[47] According to the World Resources Institute (WRI), global average per person protein consumption exceeded dietary requirements across all world regions in 2009, and the average person in the US could reduce their diet-related emissions by nearly one-half by reducing consumption of animal protein by 45 percent.[48] Livestock production has a large climate impact because of its consumption of natural resources across several sector activities: land clearing (often forests) for pastures, crop production for animal feed, required refrigeration during all stages of production, manure storage and processing, and fossil fuel consumption throughout the supply chain. Emissions savings globally from shifts to a plant-rich diet could total around 1.5 $GtCO_2$-eq per year by 2030, for a total of 66.1-87 $GtCO_2$-eq by 2050.[49, 50]

Clean cookstoves

Solution: Using efficient cookstoves and fuels in place of traditional cookstoves or cooking over open flames.

Impact: Today, there are approximately three billion people who rely on cookstoves and biomass fuels.[51] This method creates greenhouse gases not only through the cooking process but also through harvesting fuels from forests, the combination of which contributes 2-5 percent of global greenhouse gas emissions.[52] There are further health effects of long-term use of conventional cookstoves, especially due to exposure to black carbon. Global emissions could be reduced around 11-17 percent if 100 million improved cookstoves are adopted, as they decrease typical cookstove emissions by 95 percent.[53] Costs and social and cultural norms remain barriers to adoption,[54] but if adoption is able to reach 16 percent of the market by 2050, we can avoid 15.8-24.3 $GtCO_2$-eq.[55]

Composting

Solution: Converting biodegradable waste (e.g., food scraps, plant material) into a useful soil fertilizer instead of sending it to the landfill.

Impact: In urban areas around the world, nearly half of the 1.3 billion tons of municipal solid waste (MSW) generated every year is organic.[56] If organic waste goes to a landfill, it decomposes anaerobically and produces methane, which is a powerful greenhouse gas. Composting enables the conversion of organic waste into stable soil carbon without generating methane, which can then be used as fertilizer to improve soil health while also further sequestering carbon.[57] If all countries reached the composting rates common in the European Union, which are around 57 percent of all organic MSW, an estimated 2.3-3.6 $GtCO_2$-eq in total could be reduced globally by 2050. This accounts for just avoided landfill methane emissions and does not include additional sequestration gains from applying compost to soil.[58]

AGRICULTURE AND LAND MANAGEMENT

The IPCC has estimated the Agriculture, Forestry, and Other Land Use (AFOLU) sector accounts for around 10-12 $GtCO_2$-eq per year, or nearly a quarter of global anthropogenic GHG emissions. Solutions to reduce emissions include those that address unsustainable or high-emitting land use and farming practices. In both of these areas, changing behaviors has significant mitigation potential as well as ecosystem and economic co-benefits. The following solutions are those that are especially promising from a behavior change perspective.

Source: IPCC, 2014

Photo: Jason Houston

Silvopasture

Solution: Adding trees to pastures to increase productivity when raising livestock.

Impact: Pastures that contain trees sequester five to ten times as much carbon as those that are the same size but lack trees.[59] Silvopasture has additional benefits such as improving the health and productivity of both land and animals as well as providing marketable goods for farmers like nuts and fruit.[60] If global adoption expands from the current 351 million acres of land to 554 million acres by 2050, this solution could reduce emissions by 31.2-65 $GtCO_2$-eq.[61]

Tropical staple trees

Solution: Converting land from annuals to perennial tree crops to produce food.

Impact: The majority of agricultural crops planted each year are annuals. Perennials come back each year with similar yield and higher rates of carbon sequestration. Tropical staple tree crops require less fuel, fertilizer, and pesticides, if any at all.[62] If the current area where these staple crops were grown was expanded by 153 million acres by 2050 then the plants could sequester 20.2-47.2 $GtCO_2$-eq. This analysis assumes that the expansion occurs on existing cropland without any forest clearing.[63]

Tree intercropping

Solution: Deliberately planting trees in the same area as annual crops.

Impact: Tree intercropping increases the carbon content of the soil while improving productivity of the land.[64] There are many variations of tree intercropping, which provide different benefits.[65] Some systems use the trees to support crop production while others protect against erosion, flooding or wind damage. Growing 571 million acres globally could sequester a total of 17.2-37 $GtCO_2$-eq over 30 years.[66]

Regenerative agriculture

Solution: Adopting at least four of the following six agricultural practices: compost application, cover crops, crop rotation, green manures, no-till or reduced tillage, and/or organic production.

Impact: Like conservation agriculture, regenerative agriculture has many benefits and differs mainly in applying compost and organic matter to enhance soil rather than using pesticides or synthetic fertilizers.[67] Farms who have adopted this practice are finding that soil carbon levels increase from 1-2 percent to 5-8 percent over ten years, which can store 25-60 tons of carbon per acre. Ideally, conservation agriculture (solution #19) becomes regenerative agriculture over time for maximum results. The estimated mitigation potential of this type of agriculture is 23.2-32.4 $GtCO_2$-eq by 2050.[68]

Farmland restoration

Solution: Restoring degraded and abandoned farmland to grow crops or native vegetation.

Impact: There are an estimated 950 million to 1.1 billion acres of deserted farmland around the world.[69] This land was previously used for crops or pasture and is now deserted but has not been developed or restored as forest. Soils that are left to erode can be a source of emissions whereas converting abandoned lands back into productive ones can turn them into carbon sinks.[70] Restoration can mean including establishing tree plantations, encouraging the return of native vegetation, or introducing regenerative farming methods.[71] By 2050, 424 million acres of abandoned farmland could be restored for a combined emissions reduction of 14.1-30.8 $GtCO_2$-eq.[72]

Managed grazing

Solution: Changing grazing practices by adjusting stocking rates, timing, and intensity of grazing in grassland soils.

Impact: Grasslands benefit from the activity of migratory herds of grazing animals that move in tight groups, eat intensively, disturb the soil with their hooves, and then move on.[73] Managed grazing is a set of practices that imitates this herd behavior by controlling how long livestock graze on a specific area and then how long that land rests before it is grazed again.[74] Improved grazing could sequester one-half to three tons of carbon per acre.[75] In total, this solution can sequester 16.3-27.9 $GtCO_2$-eq by 2050.[76]

System of rice intensification and improved rice cultivation

Solution: Adopting low-methane rice production methods for small or large operations through a series of innovative techniques such as altering watering and planting patterns.

Impact: Globally, rice cultivation is responsible for at least ten percent of total agricultural emissions, primarily because flooded rice paddies create an environment where methane-producing microbes proliferate.[77] Improved rice cultivation and the System of Rice Intensification (SRI) are approaches that increase rice production while reducing emissions. These practices include several different techniques: reducing flooding conditions by draining the paddy mid-season and alternating wetting and drying; planting rice varieties that are less water-loving, while also planting single seedlings with more space between them; and seeding without tilling the ground while applying compost to improve soil health.[78] While four to five million farmers globally already practice these techniques, with benefits including 50-100 percent higher yields with reduced seed and water use, further adoption has the potential to reduce over 14-26.1 $GtCO_2$-eq in total by 2050.[79]

Conservation agriculture

Solution: Adopting crop rotation, cover crops, and reduced tillage practices on agricultural land.

Impact: The benefits of conservative agriculture include increased carbon-rich soil organic matter (SOM), which sequesters carbon from the atmosphere, improves crop productivity, and mitigates soil erosion and degradation.[80] The estimated mitigation potential of applying these practices to global agricultural land, which accounts for 37 percent of the earth's land surface, is significant: conservation agriculture can prevent up to 17.4 $GtCO_2$-eq by 2050.[81, 82] There are two important pathways for behavior change to highlight: through direct influences on producers (i.e., farmers) to adopt improved practices and influences on consumers to demand products that are farmed using those practices.

Nutrient management

Solution: Farmers more effectively managing nitrogen fertilizers that are used in agricultural systems.

Impact: Nitrogen fertilizers have significantly increased agricultural production since their introduction, but the application of fertilizers can lead to emissions of nitrous oxide - a potent greenhouse gas.[83] Fertilizer is routinely over-applied on farms in many countries and extra nitrogen not absorbed by plants leads to a number of adverse consequences.[84] Additionally, fertilizer production is an energy-intensive process that produces excess carbon dioxide emissions. Reducing the overuse of fertilizer by just 10 percent on 2.1 billion acres of farmland by 2050 could lead to avoided nitrous oxide emissions equaling 1.8-2.7 $GtCO_2$-eq.[85]

Farmland irrigation

Solution: Improving irrigation systems around the world, using technologies like sprinkler and drip irrigation.

Impact: Agriculture consumes 70 percent of the world's freshwater resources.[86] According to the World Water Assessment Program, irrigation is crucial for 40 percent of the world's food production. Irrigation systems require high energy inputs to pump and distribute water, thus making irrigation a source of carbon emissions. Improved irrigation technologies, like drip and sprinkler methods, help farmers use water more precisely and efficiently.[87] If the area of farmland with improved irrigation grows from 133 million acres in 2020 to 448 million acres in 2050, it would not only save water but also avoid 1.3-2.3 $GtCO_2$-eq.[88]

TRANSPORTATION

In 2010, the transport sector was responsible for over 25 percent of energy demand, with projections showing increased growth by 2050. The focus in reducing emissions from transportation is often the rapid deployment of low-carbon technologies, especially as the world continues to urbanize. While this is critically important for achieving mitigation targets, individual and household activities are some of the primary drivers of emissions growth, so changing behaviors can have considerable influence and high mitigation potential. Many of the requisite technologies already exist and simply require adoption at larger scale. The following behavioral solutions include zero to low carbon options for getting us to destinations. They are just several of the many that could have a large impact on reducing emissions from the transport sector if adopted at scale.

Source: IPCC, 2014

Electric vehicles

Solution: Driving battery and plug-in vehicles instead of conventional vehicles.

Impact: Electric vehicles are beginning to replace gas-powered vehicles on the road, with currently one million driven today.[89] They are powered through electric motors and high-capacity batteries that reduce emissions by 50-95 percent depending on the source of power. Electric vehicles and also are easier to make and maintain compared to conventional vehicles. These vehicles can travel 80-90 miles on a single charge, with some newer models approaching a range of 200. If the adoption rate of electric vehicles rises to 16 percent by 2050, they can mitigate 10.8-52.4 $GtCO_2$-eq.[90]

Ridesharing

Solution: Using ridesharing services and/or carpooling to get to destinations rather than personal vehicles.

Impact: Ridesharing can reduce the conventional practice of commuting in single-occupancy vehicles, which is the predominant form of transportation in many countries, especially in North America and Canada. Technology is essential for connecting passengers with drivers, such as mobile apps. And so is changing behaviors to make these forms of transport the norm in countries where reliance on single-occupancy vehicles is the fastest-growing source of emissions in the world.[91] Estimates of the potential of widespread adoption of these shifts in mobility are highly variable, but the reduction in passenger vehicle miles traveled (VMT) through an increase in carpooling from 10 percent to 15 percent can reduce 6.9-29.5 $GtCO_2$-eq in total by 2050.[92]

Mass transit

Solution: Choosing mass transit options for commuting in cities instead of personal vehicles.

Impact: Like ridesharing, mass transit (i.e., bus, metro, tram, commuter rail) reduces travel in personal vehicles, a rapidly growing source of emissions across the world. The use of mobile apps and increasingly efficient and reliable forms of mass transit are making public transportation an easier option for users. Mass transit also reduces traffic congestion by creating fewer vehicles on the road, while increasing safety and mobility for those traveling.[93] If mass transit use increases to 40 percent by 2050, carbon emissions can be mitigated by 6.6-26.3 $GtCO_2$-eq in total by 2050.[94]

Telepresence

Solution: Using video-conferencing technologies in the place of taking commercial flights to business meetings in distant locations.

Impact: In 2010, aviation accounted for around two percent of total global emissions and about 12 percent of transport sector emissions. Emissions forecast by the International Civil Aviation Organization are expected to grow 300-700 percent by 2050, making aviation one of the fastest-growing sources of GHG emissions.[95] The climate impacts of these projections also do not consider non CO_2 sources, such as water vapor, aerosols, and nitrogen oxides. These cause more radiative forcing at high altitudes and are estimated to have historical climate impacts two to four times higher than for CO_2 emissions alone.[96] More frequent use of telepresence and video conferencing technologies in businesses is a solution to reduce business travel-related emissions, while changing consumer behaviors to reduce their frequency of leisure air travel is a way to directly reduce aviation emissions. If over 140 million business trips are made using telepresence instead of flying, this could result in 2.0-17.2 $GtCO_2$-eq mitigated by 2050.[97]

Hybrid cars

Solution: Individuals switching from driving conventional internal combustion engine cars to driving hybrid cars.

Impact: Hybrid cars are hardwired to be more fuel efficient and lower emissions because they contain an electric motor, a battery, and an internal combustion engine. Increasing the fuel efficiency of passenger vehicles is a key strategy to reducing emissions from the transportation sector.[98] Hybrids are seen as a good mid-term solution while zero-carbon transportation methods are developed.[99] If hybrid vehicles reach six percent of the market by 2050, the additional 350 million cars could reduce carbon dioxide emissions by 4-15.7 GtCO_2-eq.[100]

Bicycle infrastructure

Solution: Biking to destinations in cities instead of using cars or other motorized transport and building a supportive biking environment.

Impact: As of 2014, biking in cities comprised 3-5.5 percent of urban trips around the world, with some cities having upwards of 20 percent.[101] Choosing to ride a bicycle can also decrease passenger vehicles miles traveled (VMT), thus reducing transport emissions. Co-benefits of these changes are improved air quality and health. While increasing biking relies on new urban designs and cycling infrastructure to facilitate shifts, it also requires changes to human behavior. In Denmark, 18 percent of local trips are via bicycle, while the rate in the Netherlands is 27 percent.[102] The same share is only one percent in the United States. A modest two percent increase from the existing 5.5 percent of total urban trips taken by bicycles could displace 2.2 trillion passenger VMT by 2050, resulting in 2.3-11.4 GtCO_2-eq in total avoided emissions by 2050.[103]

Walkable cities

Solution: Walking to destinations in cities instead of using cars or other motorized transport and building an environment suitable for walking.

Impact: Around the world, people walk an average of just seven minutes a day, and we choose to get in a vehicle seven times as much as we choose to walk.[104] Like bike riding, walking shares many of the same benefits in terms of carbon emissions, air quality, and personal health. It also is a simple, zero-cost mode of transport. Making a city walkable not only means increasing the ability to walk short distances to convenient locations, but also the enjoyment of that walk. If an additional five percent of vehicle trips are made by foot instead of by car, we can mitigate 2.9-11.1 $GtCO_2$-eq by 2050.[105]

Electric bicycles

Solution: Using electric bikes for urban transport instead of driving cars.

Impact: The most environmentally-friendly type of motorized transport in the world today is the electric bike.[106] Electric bikes have a small battery-powered motor that helps make bike travel faster and longer trips more manageable. Though electric bikes have higher emissions than a regular bicycle, they are still more efficient than cars, including electric ones.[107] If travel on electric bikes were to increase from 249 billion miles traveled in 2014 to 1.2 trillion miles per year by 2050, this solution could reduce 1-7.1 $GtCO_2$-eq.[108]

ENERGY AND MATERIALS

In a baseline scenario, the carbon emissions from the energy sector are expected to at least double by 2050 without changes to business as usual. Many of the impacts of energy and material consumption are linked to various economic sectors. For instance, the consumption of goods derived from palm oil, timber, and similar commodities drives deforestation and land-use change. Reducing demand for these products protects forests and ecosystems, which increases carbon sequestration rates. When demand for these products cannot be reduced, choosing to reuse and, as a last resort, recycle these products is a behavioral change that results in emissions reductions as well as financial savings. Increasingly affordable energy and technology solutions have helped to drive sustainable behavior that consumes and wastes less water, fuel, and natural resources.

Source: IPCC, 2014

Rooftop solar

Solution: Installing small-scale solar photovoltaic systems to provide energy for households.

Impact: Rooftop solar systems can have a huge impact on reducing greenhouse gas emissions by 2050 through their production of clean energy from the sun. As prices continue to be more affordable, there are estimates that rooftop solar could contribute 6.88 percent of total electricity generation worldwide by 2050, which is approximately 3,578 terawatt-hours. This could lead to the potential for avoiding 24.6-40.3 $GtCO_2$-eq from 2020-2050.[109]

Solar water

Solution: Using solar radiation to pre-heat or heat water for household and building use instead of using fossil fuels.

Impact: The need for hot water accounts for 25 percent of residential energy use worldwide. Heating water with solar energy can reduce the need for fuel by 50-70 percent.[110] These heaters can pay for themselves quickly based on the resulting high energy savings and continue to provide financial benefits for users in the long term. Countries such as Cyprus and Israel are currently at a 90 percent adoption rate due to solar water mandates starting in the 1980s, and solar water heaters have been successful in all countries and climates. If solar water heaters are used by 25 percent of the market by 2050, they can help reduce emissions by 6.1-17.7 $GtCO_2$-eq.[111]

Methane digesters

Solution: Using sealed tanks that produce biogas through the anaerobic digestion of organic waste (e.g., manure) to heat households instead of stoves that use wood, charcoal, or fossil fuels.

Impact: Methane digesters generate cleaner fuels and products for household tasks while also reducing methane and nitrous oxide emissions from the decomposition of manure. Methane is over 30 times more potent than carbon dioxide as a greenhouse gas, which increases the importance of managing manure. In addition to biogas, digesters also produce solids that can be used as fertilizer for crops. Each digester can mitigate 1.25-2.95 tons of carbon dioxide-equivalent emissions per year,[112, 113] for a total of 1.9-9.8 $GtCO_2$-eq reduced by 2050 if greater adoption occurs.[114] In the burning process, methane digesters contribute 0.02 kilograms of carbon dioxide per mega joule of cooking energy,[115] but they yield substantial health benefits through cleaner byproducts than conventional materials like wood or charcoal.

LED lighting

Solution: Using efficient light-emitting diodes (LEDs) in residential buildings instead of other conventional residential lighting solutions (e.g., compact fluorescent lamps, halogen lamps, incandescent lamps).

Impact: LEDs are efficient because they are designed to transmit most of their energy into light rather than heat, thereby requiring less power to operate. While currently LEDs represent a minority in the lighting sector, they are expected to capture 90-100 percent of the market by 2050, especially as prices continue to fall.[116] Each bulb lasts an average of five to ten years, which reduces costs over the long term. Residential LEDs can reduce emissions by 7.8-8.7 $GtCO_2$-eq over this time period.[117]

Household water saving

Solution: Installing and using water saving devices in homes such as low-flow showerheads and taps.

Impact: Household consumption of energy and water accounts for around 23 percent of total global energy demand.[118] Given that fossil fuels supply the majority of energy used in homes for powering lights and appliances, heating and cooling rooms, and heating water, this demand for energy and water services is responsible for 17 percent of global CO_2 emissions.[119] Worldwide, heating water can account for 25 percent of residential energy use, and encouraging voluntary reduction in household energy and water consumption has significant potential to reduce emissions.[120] Estimates vary widely, but household water saving measures, such as taking shorter showers and washing full loads of laundry, and energy saving behaviors, such as setting efficient thermostat set-points and turning off lights and appliances when not in use, can reduce home energy use by as much as 15-20 percent.[121] While this solution's mitigation estimates are just for low-flow showerheads and taps, alone they can prevent 4.6-6.3 $GtCO_2$-eq by 2050.[122]

Smart thermostats

Solution: Installing devices that control heating and cooling within the home to maximize energy savings in the place of conventional thermostats.

Impact: Current trends indicate that most homeowners who have thermostats do not apply settings for optimal energy use. Smart thermostats are able to store data of homeowners' preferences while also adjusting heating and cooling patterns during the day and night. This can create a 10-15 percent increase in energy savings while maintaining a comfortable home temperature. There is potential to reduce 2.6-5.8 $GtCO_2$-eq if there is growing adoption of smart thermostats to 46 percent of households with internet access by 2050.[123]

Household recycling and recycled paper

Solution: Recycling and reusing paper, metal, plastic, and glass materials.

Impact: Rapid urbanization around the world has resulted in runaway solid-waste generation. Wastes such as metals, plastic, glass, and other materials are now being generated faster than any other environmental pollutant, including greenhouse gases.[124] By 2000, the world's 2.9 billion people living in cities were creating three million tons of solid waste per day, and by 2025, that amount is expected to double.[125] Effective waste management strategies, such as waste reduction, diversion, and reuse can reduce emissions by saving energy that is needed to process waste and manufacture new materials. Raw aluminum production is very energy intensive, whereas manufacturing recycled aluminum reduces energy use and emissions by 95 percent.[126] Plastic production is especially wasteful, as over a million plastic bottles are bought around the world every minute, but fewer than half are collected for recycling, and only seven percent are turned into new bottles.[127] And since 2010, each year the world has produced over 400 million tons of pulp and paper.[128] The recycling of all materials in leading cities has reached rates of 65 percent or more, and if the global average reached this rate, 3.7-5.5 $GtCO_2$-eq in total could be avoided by 2050.[129]

Micro wind

Solution: Installing small wind turbines of under 100 kilowatts to provide household electricity needs instead of fossil fuels.

Impact: While less popular than utility-scale wind turbines, micro-wind allows for a household, small farm, or building to provide for its electricity needs in urban and rural locations. They can help pump water, provide lights, and charge batteries even in the most remote settings. If small wind turbines make up one percent of worldwide electricity generation by 2050, they can mitigate 0.2 $GtCO_2$-eq. The high cost of small wind turbines remains a large hurdle to bring these to scale, but if achieved, the presence of clean, renewable energy in areas without access to a central grid can have a significant impact.[130]

SUMMARY:
THIRTY BEHAVIORAL SOLUTIONS FOR REDUCING EMISSIONS

The 30 solutions highlighted in this section are only a subset of all the behavioral solutions one could imagine to reduce greenhouse gas emissions. ***Drawdown's*** **estimates for the adoption of these solutions alone could result in 393.3-728.9 $GtCO_2$ of avoided emissions by 2050, which is equivalent to 19.9-36.8 percent of projected cumulative global emissions.** If we compare our 30 solutions to *Drawdown's* full list of 80 solutions, we find that ours account for 37.4-45.2 percent of the total emissions reduction potential. These percentages are highly dependent on which scenario is used for projecting future emissions growth—for more ambitious scenarios that include faster decarbonization of global energy, building, and transport sectors, behavioral solutions will account for an increasingly large share of emissions abatement potential. Especially if the world aims to follow through on limiting temperatures to 1.5 or below 2°C, behavioral solutions are incredibly important for achieving these goals.

Behavioral solutions also in many cases accrue significant savings and additional co-benefits for human health and natural environments. Despite the availability of many enabling technologies and insights that support behavior change efforts, the emissions reduction potentials of many of these solutions are much greater than what is being achieved today. Reaching the true mitigation potential of these solutions will require novel approaches to changing human consumption patterns. The good news is that a revolution in the social and behavioral sciences is beginning to show how insights from disciplines as diversified as social psychology, behavioral economics, sociology, political science, evolutionary biology and more are informing new strategies for behavior change to reduce overconsumption of the planet's natural resources.


Photo: Jason Houston

Understanding human behavior

INTRODUCTION

While scientists have long studied the behavior of individuals and groups in human society, the science of human behavior has evolved quickly in the last few decades. New insights across economics, anthropology, political science, evolutionary biology, psychology, neuroscience, and more have transformed global understandings of human behavior and decision-making. Public, private, and nongovernmental sectors are changing as a result. **More than 100 governments and institutions are commissioning 'behavioral insights teams' or 'nudge units' to improve policy by applying novel insights about human decision making.[131, 132]** Product marketers are upgrading their approaches to pipeline development, advertising, and sales. And civil society, especially the public health and rural development sectors, is following suit. This shift is creating a growing demand for insights and expertise in human behavior change.

Behavior change is particularly relevant to environmental challenges and is a topic that has been studied extensively across disciplines. Theoretical models of human behavior, especially as it relates to consumption, are important for conceptualizing behavior while also signaling how behavior can be changed. These models help us understand how social and psychological influences affect behavior, which can further aid in identifying effective intervention strategies. The literature on theoretical models of consumer behavior is large and complex.[133] This section presents a brief introduction to several sets of these models as a kind of "behavior change theory toolkit," focusing on the shift away from rational choice models to those that underpin much of the advances in contemporary behavioral science.

A BRIEF OVERVIEW OF BEHAVIORAL SCIENCE

Rational choice theory

The theory of behavior that has guided much of existing policy is the well-known 'rational choice model,' which contends that behavior results from individuals acting to maximize the expected benefit of their individual decisions. Individuals make these decisions after weighing expected benefits and costs and choosing the action or behavior that offers the highest expected net benefit or lowest expected net cost.[134] This framework for understanding behavior resembles many of the theories foundational to classical economics, where cost-benefit analyses are central. The model makes several key assumptions about social action. First, it assumes that choice is purely rational; second, it assumes the individual is an appropriate focus for analyzing decision-making; and third, it assumes that choices are always made such that they maximize expected value and are thus always in the individual's self-interest.[135] Behavior change models that use an expectancy-value framework include the Theory of Reasoned Action and Theory of Planned Behavior.[136, 137, 138] Behavioral beliefs are multiplied by the evaluation of a behavioral outcome to form an attitude about a behavior, and normative beliefs are multiplied by a desire to comply with others to form a subjective norm about a behavior. Together these then shape a behavioral intention and ultimately behavior itself.

Unsurprisingly, the rational choice model has long been critiqued as a limited theory for explaining human behavior. Much of this criticism is pointed at the model's core assumptions about individuals' access to perfect information on which to base their cost-benefit analyses. This assumption often does not hold given both uncertainties about the future and the cost of information in the present. This critique gained prominence in Herbert Simon's work on the concept of 'bounded rationality,' which argues that individuals make decisions not by 'optimizing' between choices but by 'satisficing,' or choosing the action that meets a minimum level of benefit.[139] Furthermore, scholars as early as William James (1892) as well as current authors cite notions of attentional limits, where humans all have a finite amount of directed attention that they can devote to effortful activities as well as a limited number of cognitive channels to process information.[140, 141, 142] Other critiques show how emotion often plays a more important role in decision-making than does understanding expected costs and benefits. Still others argue that self-interest is not always the only factor that individuals take into consideration when making decisions, but that moral, social, and contextual dimensions of decisions are also highly influential. The Theory of Planned Behavior introduced a new variable to the Theory of Reasoned Action with perceived behavioral control to encompass the ways that perceived self-efficacy and supportive conditions also affect behavior.[143] Many of these critiques have grown out of psychological and sociological research and now underpin much of the thinking in the emergent fields of behavioral science and economics.

Advances in contemporary behavioral science

In 2002, psychologist Daniel Kahneman won the Nobel Prize in Economics for his work with Amos Tversky to develop *prospect theory*, which describes how people make decisions under uncertainty and how that deviates from what most rational choice, or 'normative,' models of rational behavior expect.[144] Prospect theory makes it clear that human decisions are not always optimized, because they are influenced by ways in which the decisions are framed. Kahneman and Tversky's research in heuristics and biases explored a number of the psychological factors at play in human behavior. As popularized in Kahneman's international best-seller, *Thinking, Fast and*

Slow, the brain's psychological forces can broadly be thought of as 'System 1' and 'System 2.' System 1 is fast, intuitive, automatic, and emotional, while System 2 is controlled, deliberative, and analytical. System 1 relies on heuristics or cognitive shortcuts and is also responsible for biases or variability in decision making.[145] Kahneman's dual-system theoretical framework is one explanation for how judgments do not often follow expected notions of rationality; instead they are often made by the impressionable and emotional System 1, even as System 2 unsuccessfully attempts to monitor this behavior. At the same time, it is worth considering the adaptive nature of our non-rational behavior rather than seeing it as less desirable than rational behavior.[146] Through humans' evolution, we needed to make fast decisions with limited information, and mental shortcuts were essential for our survival. Early humans also benefited from sampling widely from their environment to build strong mental maps of their surroundings, which would not have been possible if we pursued a strictly rational model of decision-making.[147] In this way, humans are capable of both rational and non-rational decisions, and both are valuable in different contexts.

In 2017, Richard Thaler, who collaborated closely with Kahneman and built on his and Tversky's work in prospect theory, was also awarded the Nobel Prize in Economics. Thaler's work and that of other behavioral economists emphasize how people defy economic theory with non-rational yet predictable behaviors.[148] There is a wealth of evidence that supports the idea that individuals consistently make non-rational decisions. Much of this evidence is reviewed in Thaler and Cass Sunstein's best-selling book, *Nudge: Improving Decisions about Health, Wealth, and Happiness*.[149] The experiments discussed in *Nudge* and *Thinking, Fast and Slow* consistently show that individuals make decisions not based on perfect information and rational choice but in much more nuanced ways that depend on psychological antecedents, such as values, beliefs, and social norms, and result from routines and habits that do not involve deliberative, cognitive processes. Late in 2017, new research emerged in favor of an alternative approach for influencing behavior, called "boosts" and explains several key distinctions between nudges and boosts in theory and practice. While nudges attempt to make the target behavior easier by influencing a person's environment, boosts also engage directly with human agency and cooperation by building competence, skills, and knowledge in the decision-making process.[150]

MODELS OF BEHAVIOR CHANGE

The behavioral science revolution has brought forward a range of models and heuristics to explain how behavior change occurs. Interventions to influence human behavior and choice often draw on these models to varying degrees. More such models exist than can be adequately detailed here, but below we highlight several archetypes that appear in most mainstream behavior change models. After each model's description, we also summarize its core logic using the following symbols:

Change

Increase

Activation

Education models

Like rational-actor models, environmental education emerged as one of the primary strategies to effect behavior change. Ramsey and Rickson's (1976) model of environmental knowledge and attitudes was one of the first to propose that education will lead to awareness and attitude change, which will create behavior change.[151] Hines, Hungerford, and Volk (1987) later put forth a model leveraging knowledge, psycho-social variables, intentions, and situational factors to determine behavior.[152] **Moreover, education remains an important strategy in environmental campaigns, although evidence suggests that it is less effective alone than paired with other techniques.** Within educational approaches, it is important to distinguish between different types of knowledge that may be useful in an intervention, such as the what, why, and how related to a behavior.[153]

Knowledge = Attitudes = Behavior

Extrinsic motivation models

There was a period of time in behavioral science and psychology when extrinsic or external motivations for behavior change were the norm for experiments. As expressed through today's "carrot or stick" approach, external motivation suggests that human behavior can be influenced through providing incentives and/or punishments. While it remains a common approach today, researchers have shown that external motivation's primary weakness is that is rarely leads to long-lasting behavior and requires continual or larger interventions to maintain the same outcomes.

Rewards or punishments = Behavior

Intrinsic motivation models

There is a growing body of literature on the role of intrinsic or internal motivation in guiding behavior change. Edward Deci and Richard Ryan, creators of the concept of Self-Determination Theory, argue that there are certain behaviors and goals that humans are inclined to do because they are enjoyable.[154, 155] Specifically, they say that building competence, autonomy or self-efficacy, and a sense of connectedness are self-motivated and can be leveraged in the behavior change process. While extrinsic and intrinsic forms of motivation are often put in contrast to one another, each serves an important function when thinking about causes of behavior.

Satisfaction + Autonomy = Behavior

Information-processing based models

There are also models that center around the needs of humans as information processors. These emphasize the cognitive workings and affective nature of behavior and decision-making, although they were not explicitly designed to create behavior change. Two models that use this approach are clarity-based decision making[156] and the Reasonable Person Model.[157, 158] Both models suggest that there are fundamental informational needs of humans at the core of motivation and action. The Reasonable Person Model is built upon concepts of model building, being effective, and meaningful action. Model building involves the innate desire to understand and explore the world around us, thereby building mental maps of our environment as we learn information. Being effective recognizes the attentional limits of humans and our need to be clear-headed in order to function well. We are also motivated to expand our competence through growing and refining our skill-base to know how to act in a given situation. Finally, meaningful action describes how humans want to feel needed and like to participate in problem-solving. When combined, these three aspects serve as a powerful framework for creating supportive environments for decision-making.

Supportive environments = Attitudes/knowledge + Ability + Meaningfulness = Behavior

Social models

Social models draw mostly on sociological theories and differ from individualist theories by putting much more emphasis on the context and structures that interact with and determine the ways in which individuals behave.[159] They focus more specifically on *actions* rather than *actors* and seek to understand how differing social and infrastructural contexts might make these actions inevitable.

Notable social models include the Norm Activation Model as well as the Value-Belief-Norm model.[160, 161] Both of these models rely on the activation or formation of personal norms that in turn lead to personal feelings of responsibility and ultimately behavior change. The Norm Activation Model theorizes that personal norms are the result of internalized social norms, and therefore this model helps people to act in accordance with generally believed norms in society about caring for the environment. The Value-Belief-Norm model proposes that personal value and belief systems crystalize into personal norms and shape behavior due to our desire for value-consistent actions in a number of different contexts. Discussions of norms also involve the important distinction between descriptive norms and injunctive norms. Descriptive norms are people's current behavior and what is commonly done, while injunctive norms are the behavior of what people should do. Robert Cialdini's work on norms and persuasion provides some of the clearest evidence for why aligning descriptive and injunctive norms for a behavior, such as with littering or towel reuse in hotels, is important in behavior interventions.[162, 163] Since people tend to be tuned into their environment and social norms, demonstrating that others' behavior is both common and responsible is very effective in altering behavior. Finally, new research on dynamic norms suggests that humans are also perceptive of changes in norms over time and will adjust their behavior accordingly.[164]

Finally, there are social-support and team-based approaches to behavior change. These techniques facilitate a social setting where individuals work together to learn about a problem, motivate one another to address it, and reflect on their progress. Psychologist Kurt Lewin was one of the pioneers of understanding social group dynamics and how individual participation towards solving a problem can result in new behaviors.[165] Since then, groups of researchers have explored team-based methods of influencing pro-environmental behavior and found them to be more successful and durable than traditional models of behavior change.[166, 167] While the application of social practice and other socially-oriented approaches to policy issues is relatively new, the approach does prove useful in understanding the complex social structures that give rise to various behaviors. **By identifying the key structural elements that perpetuate unsustainable behaviors, social theorists believe we can actively shape these elements to enable more sustainable behavior across varying social and cultural contexts.**

Social norm = Personal values = Behavior

ASSESSING THE EFFECTIVENESS OF BEHAVIORAL INTERVENTIONS

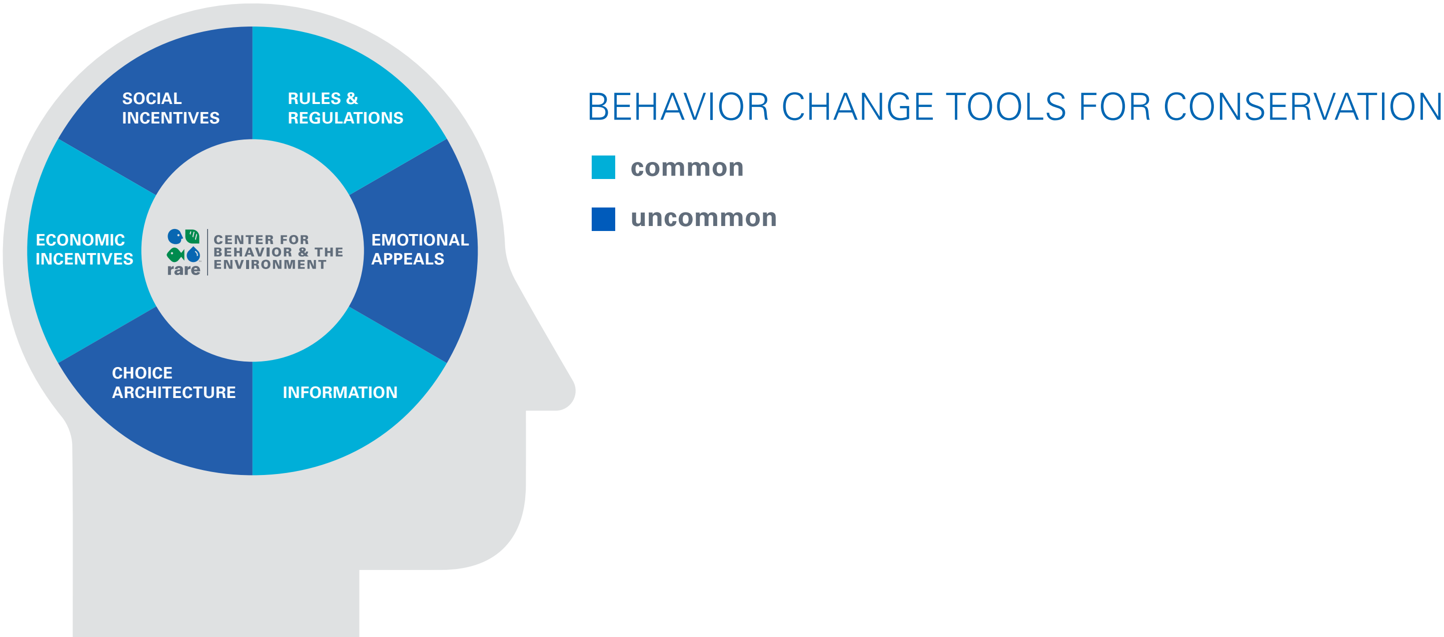
For any behavior change model and intervention strategy, we should examine its overall effectiveness and applicability. De Young (1993) provides a useful set of evaluation metrics that we can use for this purpose:

- **Speed of change:** how quickly a behavior is adopted during an intervention
- **Reliability:** whether behavior changes the first time during an intervention and in subsequent interventions over time
- **Particularism:** the level of specificity or tailoring of an intervention to subgroups as opposed to a universal application
- **Generalizability:** whether an intervention causes someone to become a change-agent for that behavior and/or adopt non-target behaviors through a "spill over" effect
- **Durability:** whether a behavior is maintained without continual intervention and is adopted as a common practice

Additional metrics include considering an individual's attentional state, emotional state, and sense of meaningfulness that result from an intervention.

SUMMARY

Human behavior and decision-making are complex. While our understanding of this complexity has evolved from purist 'rational choice' models of human behavior to much more nuanced theories of behavior that capture psychological and sociological insights, there are still many questions that remain about the most effective and sustainable approaches to behavior change, especially if we are to change ingrained patterns of natural resource consumption that are so central to developed, consumption-driven economies. The recent trend of applying innovative research in behavioral science to public challenges has highlighted how powerful psychological tendencies can be directed toward behavior that provides social and planetary benefit. The environmental field has arguably undervalued the behavioral and social sciences in contrast to the revolution unfolding in other sectors,[168, 169] but some recent efforts have begun to translate theory into practice in novel and pragmatic ways.[170, 171, 172, 173] **We do not argue that there is likely to be a single unifying theory upon which all design will rest, or even that such a theory would be ideal. Rather we suggest that more effort is needed to translate the growing number of insights, models, and theories into applicable tools made easily accessible and comprehensible to practitioners around the world.** The final section below outlines one way of beginning to do that and provides some compelling examples of how these tools are being applied to change human behavior to mitigate global warming.



Applying behavior change tools to natural resource conservation and climate action

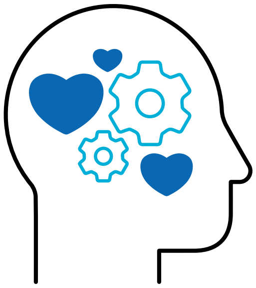
INTRODUCTION

Changing behavior to solve environmental challenges is not in and of itself a new idea. Indeed, if most environmental problems are rooted in human behavior, then most any tool we have deployed to solve them is fundamentally a behavior change tool. The fact is simply that the most common approaches thus far applied to addressing climate change and any number of other challenges have depended on a fairly narrow set of tools that can be summarized largely by the following:

- Providing **information** to improve knowledge-based decision-making;
- Setting **rules and regulations** (or what is commonly known as *command-and-control*) to set limits on what is allowed and what is not; and
- Introducing **economic or market incentives** (e.g., subsidies, payments, rewards) or disincentives (e.g., taxes, fines).

Climate change is a thoroughly imposing challenge to address by changing human behavior. Each of the above tools has a key contribution to make. But we know that facts do not necessarily change minds, that people do not necessarily follow rules just because they exist (especially when enforcement is problematic), and that people are not always perfect economic "maximizers." To make things more complicated, behaviors that perpetuate global warming are arguably much more difficult to change than those such as smoking or seatbelt usage, in part because the benefits of shifting those behaviors usually accrue more quickly and directly to the individual. **The climate benefits of changing behaviors are often delayed, mostly invisible, and require collective action to bring about.**

Yet there are many benefits that do accrue to individuals for shifted behaviors, such as physical health benefits from changing diets or yield benefits for farmers who shift cultivation practices. Highlighting how behavioral insights can change behaviors that have immediate benefits for individuals and groups as well as larger benefits for cities, countries, and the global climate is critically important given the need for rapid action to reduce emissions and slow global warming. To achieve full-scale adoption of the 30 behavioral solutions to climate change mitigation we have outlined above (in addition to the many others needed to achieve 2050 targets), we will need to draw as much as possible on the science of human behavior and the behavior change tools available to us. The good news is that these tools exist, and solutions around the world are already beginning to deploy them. We have identified three additional "levers" to influence behavior that the social and behavioral sciences tell us are particularly promising to inspire and enable behavior change for climate change: **emotional appeals, social incentives, and choice architecture**.

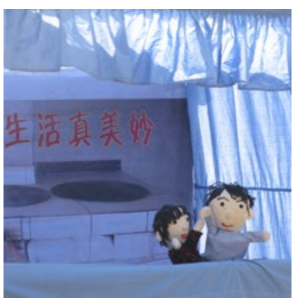


APPEALING TO EMOTION

Emotions are often much more powerful than reason. An emerging body of research provides evidence that the anticipation of future emotional or 'affective' states plays a powerful role in shaping behavior, especially when these emotional states involve feelings of pride and guilt.[174] For example, much of the messaging on environmental and climate change has taken a negative tone and focused on invoking fear and other negative emotions to promote sustainable behavior. But a history of evidence points to different tactics, such as highlighting one's feelings of pride or joy as a result of sustainable behavior, and shows that these can produce stronger pro-environmental behavioral intentions.[175, 176, 177] Barbara Fredrickson's popular "broaden and build" theory speaks to how positive emotions help humans in expanding and building their capacity to learn and gain skills, as opposed to negative emotions, which can narrow one's attention.[178] Setting positive goals for the future can also orient and shape behavior in the present.[179]

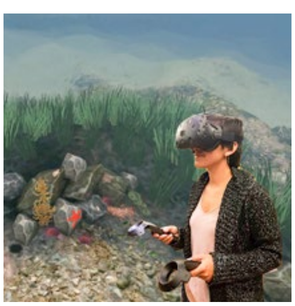
In many studies in psychology and neuroscience, it has been shown that when people evaluate products or brands, their limbic systems, the parts of the brain responsible for feelings, memory, and value judgments, are highly active, while much of the brain's centers for analysis are not.[180] **Messaging and other interventions that appeal to specific emotions and feelings (e.g., joy, autonomy, compassion) can engage the powerful centers of the brain that are often responsible for decisions.** Below are two examples of how using emotional appeals can speed up the adoption of behaviors and practices that yield benefits for both the consumer and the environment.

EXAMPLES OF BEHAVIOR CHANGE CAMPAIGNS THAT USE EMOTIONAL APPEALS TO SHIFT BEHAVIOR



Using pride to encourage the use of clean cookstoves in China

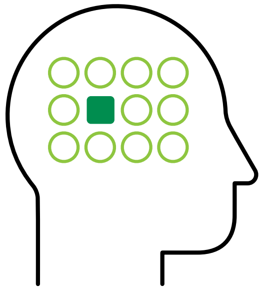
Emotions can be a powerful force for change. In China's Yunnan province, Rare led a campaign to increase adoption of cleaner, more efficient cookstoves to lower household emissions, reduce deforestation from fuelwood gathering, and conserve habitat for the Hoolock gibbon. A core activity in the campaign was a cooking contest among teams of women in the community to make the best versions of three local dishes using the efficient cookstoves. This contest not only helped the women familiarize themselves with the new stoves, but it also gave them a chance to feel mastery and pride in a valued skill while having fun and working towards the betterment of their community. The day's event was part of a large celebration, featuring a puppet show, traditional dancing, and a mascot of the Hoolock Gibbon.[181] This campaign leveraged key positive emotions to help individuals connect to their natural resources and wildlife. Adoption of clean cookstoves grew from 18 percent to 59 percent over the course of the campaign along with noticeable improvements to forest habitats.[182]



Source: Virtual Human Interaction Lab

Promoting awareness of climate impacts through immersive virtual reality experiences

Because climate impacts often feel so detached from individual actions and seem far-off or distant in the future, changing unsustainable behaviors is particularly challenging. The Virtual Human Interaction Lab at Stanford University is trying to change that by giving users a virtual reality simulation of how carbon emissions are directly causing ocean acidification. The simulation allows users to stand in heavy traffic and follow CO_2 molecules from car tailpipes to the ocean where they are absorbed. In the simulation, users move amid coral as it begins to feel the effects of acidification and loses its ability to support marine life.[183] A Stanford study showed that the simulation can cause a greater sense of empathy than a video-only experience because of embodied cognition, or how the body's actions affect the mind.[184] Immersive experiences appeal directly to human emotion by giving people a much deeper and embodied understanding of the effects of climate change, and these experiences can lead to lasting change to both perception and behavior.



PROVIDING SOCIAL INCENTIVES

Humans are social animals. Human nature has a propensity for cooperation because we like to be part of a group,[185] and many of our identities emerge from associating with others.[186] Because of this, we also care about our reputation and how it compares to the status of others in our group. **Social incentives and norms can thus be powerful motivators for behavior. They can provide cues for members of a group on how to behave, and they also add considerable pressure to change behavior and conform when behavior deviates from expected norms.** Similarly, research on modeling and social proof show us that we tend to follow the behavioral lead of those we feel are like us or we admire.[187]

Changing social norms around consumption behavior is a commonly employed intervention in environmental fields. Personalized Normative Feedback (PNF) is an approach that is used to provide individuals with information about themselves as well as their peers in an attempt to highlight how an individual or group's behavior deviates from the norm.[188] This approach works by making the behaviors of a particular social group more obvious, which then can promote opportunities for members of that group to cooperate and reciprocate rather than compete. Having individuals make written commitments towards a behavior can also work well in helping individuals compare their personal norms to group norms. Below are examples of how changing social norms and providing social incentives can encourage water and energy conservation.

EXAMPLES OF INTERVENTIONS THAT PROVIDE SOCIAL INCENTIVES FOR MAKING A DECISION OR HIGHLIGHT SOCIAL NORMS TO ENCOURAGE A DESIRED BEHAVIOR

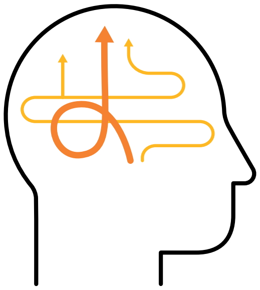
Source: Opower

Encouraging energy conservation with social norms

Another intervention relying on social norms that has gained popularity in sustainability circles is the practice of providing homeowners with information about how their consumption of utility services, such as electricity, water, and gas, differs from that of their neighbors.[189] The feedback in this case is designed to pressure high users to reduce their consumption and thereby greenhouse gas emissions. Evidence suggests this approach can be useful for reducing consumption by the order of one to two percent per year, though this reduction is shown to vary across households with different political ideologies.[190] In some cases, a 'boomerang' or 'rebound' effect has been observed, where households that are below the average increase their consumption after seeing the comparison. But adding an injunctive message, a smiley face emoticon for consuming less than average, eliminates this effect. This further indicates how social incentives, combined with emotions, encourage sustainable behavior.

Providing social proof for water conservation in Ecuador

In 2010, Rare supported an employee of Naturaleza y Cultura Internacional to establish reciprocal water agreements in the San Andrés watershed of Ecuador. The goal of the campaign was to conserve forested land under threat of being cleared for agriculture, which has major consequences for habitats and carbon emissions. What started with one landowner agreeing to conserve two hectares of land became a competition between two neighbors to designate as much as possible. In a week's time, the campaign had spread from zero to 14 acres of protected forest and jumpstarted adoption in the greater community. By demonstrating their commitment to conservation, the two farmers provided visual, social proof to others that there was a new norm to be followed.[191]

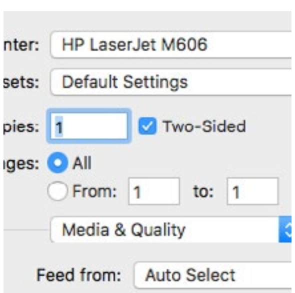


DESIGNING FOR CHOICE ARCHITECTURE

An understanding of the nuances of human decision-making and its tendency to defy expectations of rationality informs this behavior change strategy. As Kahneman and Tversky's research showed, people use heuristics that can lead to non-rational decisions. Humans also have limited and selective attention and can default to seeking information that confirms our existing beliefs while ignoring new information that contradicts it.[192, 193] Humans further process information best when it is engaging and presented in a limited number of options or units.[194]

Designing for choice architecture is one approach that acknowledges these insights about human behavior by creating an optimal decision-making environment. Related interventions take account of the fact that there are a multitude of forces at work when we decide how to behave in a situation. **Solutions that employ thoughtful choice architecture will simplify what we are asked to do, reduce the apparent number of choices we have, and frame decisions in a way that guide us towards desired behavior.**[195] This approach will also successfully capture our limited attention by prompting us and reminding us at the right time, which is often when we are in transition and more likely to break our habits.[196] We can draw on our earlier descriptions of nudging and boosting as two ways to help design environments and people's relationships with their environments to manage decision points. Below are examples of changing the choice architecture for printing and dining and how two simple insights can yield significant changes in human behavior that are beneficial for the environment.

EXAMPLES OF HOW SIMPLY CHANGING THE CHOICE ARCHITECTURE FOR A DECISION CAN HAVE SIGNIFICANT, POSITIVE OUTCOMES FOR CONSERVATION



Resetting the default behavior for paper conservation

This example rests on the behavioral science concept of default effects, which refers to the human tendency to choose the option that is automatically selected rather than choosing an alternate option. Setting the desired behavior as a default significantly increases adoption of that behavior. Rutgers University in New Jersey, USA, decided that the computer labs were wasting too much paper and changed the default option on the lab printers to double-sided. Simply by changing the default, the lab saved 7,391,065 sheets of paper in the first semester (equating to roughly 620 trees for the semester, and 1,280 trees for the academic year), while also reducing the emissions that would have resulted from deforestation and paper processing. They found that students frequently have no preference with printing. Those who did could manually change the settings to one-sided, but the majority of students simply accepted the default option, and thus paper conservation became the standard.[197]

Encouraging vegetarian diets by changing menu designs

Structuring the presentation and context of options such that eco-friendly choices are integrated within the other available options can improve their uptake. A London School of Economics and World Resources Institute study found that people will order significantly more vegetarian meals off menus when the options are mixed into the rest of the menu rather than called out in a separate "vegetarian" section. In the randomized control trial of 750 United Kingdom adults who usually ate meat and/or fish, researchers found that diners who received a menu with a separate "vegetarian" section were 56 percent less likely to order those dishes compared to those who received a mixed menu. In this example, providing diners with a choice architecture that did not stigmatize the vegetarian options but rather normalized them increased the choice of ordering plant-rich meals that have a lower carbon impact.[198]

SUMMARY

As we have seen, using emotion, social incentives, and choice architecture can be powerful ways of influencing behavior towards conservation goals. A growing number of organizations and research efforts are experimenting with interventions across a variety of behaviors from pollution, to energy use, to deforestation, to eating less meat. While these projects exemplify the kinds of consumer-focused approaches required to reduce global climate emissions, much more knowledge and evidence are needed to better understand effective approaches and codify proven strategies. Infrastructure (such as the government policy bodies), investment, and global support exist to implement change. The European Union alone has allocated over €180 billion to reduce emissions.[199] Unfortunately, nearly all of that funding is focused on regulation and financial incentives. With enough evidence of success, the field of behavioral science can begin to shift this distribution so that behavior change initiatives can scale up and begin to have a larger impact on emissions reductions at the global level.

CONCLUSION

The urgency of the climate crisis cannot be overstated. Impacts are already being felt around the world from longer heat waves, reductions in crop yields, depleted freshwater reserves, melting ice caps, and irreversible damage to much of the world's ecosystems. If swift action is not taken to reduce emissions over the next several decades, the planet will be locked in to increasingly higher temperatures, the impacts of which will gain in intensity and severity, threatening much of the world's people and natural systems. Most of the world's governments are aware of the existential threat posed by climate change, but their current ambition to mitigate this threat is not nearly enough.

If all nations follow through on climate targets pledged in the Paris Agreement, this would limit the global average temperature rise to 2.6-3.2˚C above preindustrial levels. Existing policies do not yet enable us to reach these levels.[200] With temperature changes in this range over the 21st century, the climate impacts are likely to be catastrophic for Earth's systems and much of the global population.[201] Though parties to the Paris Agreement will likely increase ambition in coming years, and though the 1.5˚C target is not yet a geophysical impossibility,[202] rapid decarbonization is needed across the entire economy to peak emissions in the next several years and reach net-zero by the mid-point of the century.

Global political efforts to achieve these rapid changes will benefit considerably from increased ambition from individuals and communities around the world to reduce overconsumption of natural resources and foster sustainable lifestyles that do not surpass the ecological limits of the planet. But changing behavior to prevent environmental harm and slow global warming is notably difficult because of the often-distant link between individual behaviors and these challenges, many of which develop over decades.

Emerging evidence from new and innovative approaches to changing human behavior give reason for hope. These approaches leverage insights from behavioral science, among other disciplines, to reshape unsustainable patterns of behavior, such as through the 30 solutions presented here. With this list of solutions comes the challenge to encourage adoption using what we know from behavioral insights in order to maximize emissions mitigation. This presents an opportunity to draw on new conceptions and models of why humans behave the way they do and use this knowledge to direct humans toward more sustainable decisions that have numerous additional benefits. We need more evidence on the applicability and effectiveness of these approaches to continue building the case.

As such, a systematic review is needed to identify organizations and their approaches to apply behavioral science for the purpose of changing unsustainable patterns of consumption. Developing this knowledge base and leader network is the best opportunity to support ongoing efforts to rapidly reduce global emissions and thus limit the devastating impacts that will result from global temperature rise. It is imperative that we act now to preserve the planet's rich natural resources for generations to come. Behavioral science offers us a promising path forward.

Appendix: A ranked list of all 80 Drawdown Solutions

Note: Our 30 behavioral solutions are highlighted in blue.

Rank	Solution	Sector	$GtCO_2$-eq (Plausible Scenario)	Net Cost (Billions US $)	Savings (Billions US $)
1	Refrigerant Management	Materials	89.74	N/A	$-902.77
2	Wind Turbines (Onshore)	Electricity Generation	84.60	$1,225.37	$7,425.00
3	Reduced Food Waste	Food	70.53	N/A	N/A
4	Plant-Rich Diet	Food	66.11	N/A	N/A
5	Tropical Forests	Land Use	61.23	N/A	N/A
6	Educating Girls	Women and Girls	59.60	N/A	N/A
7	Family Planning	Women and Girls	59.60	N/A	N/A
8	Solar Farms	Electricity Generation	36.90	$-80.60	$5,023.84
9	Silvopasture	Food	31.19	$41.59	$699.37
10	Rooftop Solar	Electricity Generation	24.60	$453.14	$3,457.63
11	Regenerative Agriculture	Food	23.15	$57.22	$1,928.10
12	Temperate Forests	Land Use	22.61	N/A	N/A
13	Peatlands	Land Use	21.57	N/A	N/A
14	Tropical Staple Trees	Food	20.19	$120.07	$626.97
15	Afforestation	Land Use	18.06	$29.44	$392.33
16	Conservation Agriculture	Food	17.35	$37.53	$2,119.07
17	Tree Intercropping	Food	17.20	$146.99	$22.10
18	Geothermal	Electricity Generation	16.60	$-155.48	$1,024.34
19	Managed Grazing	Food	16.34	$50.48	$735.27
20	Nuclear	Electricity Generation	16.09	$0.88	$1,713.40

21	Clean Cookstoves	Food	15.81	$72.16	$166.28
22	Wind Turbines (Offshore)	Electricity Generation	14.10	$545.30	$762.50
23	Farmland Restoration	Food	14.08	$72.24	$1,342.47
24	Improved Rice Cultivation	Food	11.34	N/A	$519.06
25	Concentrated Solar	Electricity Generation	10.90	$1,319.70	$413.85
26	Electric Vehicles	Transport	10.80	$14,148.00	$9,726.40
27	District Heating	Buildings and Cities	9.38	$457.10	$3,543.50
28	Multistrata Agroforestry	Food	9.28	$26.76	$709.75
29	Wave and Tidal	Electricity Generation	9.20	$411.84	$-1,004.70
30	Methane Digesters (Large)	Electricity Generation	8.40	$201.41	$148.83
31	Insulation	Buildings and Cities	8.27	$3,655.92	$2,513.33
32	Ships	Transport	7.87	$915.93	$424.38
33	LED Lighting (Household)	Buildings and Cities	7.81	$323.52	$1,729.54
34	Biomass	Electricity Generation	7.50	$402.31	$519.35
35	Bamboo	Land Use	7.22	$23.79	$264.80
36	Alternative Cement	Materials	6.69	$-273.90	N/A
37	Mass Transit	Transport	6.57	N/A	$2,379.73
38	Forest Protection	Land Use	6.20	N/A	N/A
39	Indigenous Peoples' Land Management	Land Use	6.19	N/A	N/A
40	Trucks	Transport	6.18	$543.54	$2,781.63

41	Solar Water	Electricity Generation	6.08	$2.99	$773.65
42	Heat Pumps	Buildings and Cities	5.20	$118.71	$1,546.66
43	Airplanes	Transport	5.05	$662.42	$3,187.80
44	LED Lighting (Commercial)	Buildings and Cities	5.04	$-205.05	$1,089.63
45	Building Automation	Buildings and Cities	4.62	$68.12	$880.55
46	Water Saving- Home	Materials	4.61	$72.44	$1,800.12
47	Bioplastic	Materials	4.30	$19.15	N/A
48	In-Stream Hydro	Electricity Generation	4.00	$202.53	$568.36
49	Cars	Transport	4.00	$-598.69	$1,761.72
50	Cogeneration	Electricity Generation	3.97	$279.25	$566.93
51	Perennial Biomass	Land Use	3.33	$77.94	$541.89
52	Coastal Wetlands	Land Use	3.19	N/A	N/A
53	System of Rice Intensification	Food	3.13	N/A	$677.83
54	Walkable Cities	Buildings and Cities	2.92	N/A	$3,278.24
55	Household Recycling	Materials	2.77	$366.92	$71.13
56	Industrial Recycling	Materials	2.77	$366.92	$71.13
57	Smart Thermostats	Buildings and Cities	2.62	$74.16	$640.10
58	Landfill Methane	Buildings and Cities	2.50	$-1.82	$67.57
59	Bike Infrastructure	Buildings and Cities	2.31	$-2,026.97	$400.47
60	Composting	Food	2.28	$-63.72	$-60.82

61	Smart Glass	Buildings and Cities	2.19	$932.30	$325.10
62	Women Smallholders	Women and Girls	2.06	N/A	$87.60
63	Telepresence	Transport	1.99	$127.72	$1,310.59
64	Methane Digesters (Small)	Electricity Generation	1.90	$15.50	$13.90
65	Nutrient Management	Food	1.81	N/A	$102.32
66	High-speed Rail	Transport	1.52	$1,038.42	$368.10
67	Farmland Irrigation	Food	1.33	$216.16	$429.67
68	Waste-to-Energy	Electricity Generation	1.10	$36.00	$19.82
69	Electric Bikes	Transport	0.96	$106.75	$226.07
70	Recycled Paper	Materials	0.90	$573.48	N/A
71	Water Distribution	Buildings and Cities	0.87	$137.37	$903.11
72	Biochar	Food	0.81	N/A	N/A
73	Green Roofs	Buildings and Cities	0.77	$1,393.29	$988.46
74	Trains	Transport	0.52	$808.64	$313.86
75	Ridesharing	Transport	0.32	N/A	$185.56
76	Micro Wind	Electricity Generation	0.20	$36.12	$19.90
77	Energy Storage (Distributed)	Electricity Generation	N/A	N/A	N/A
77	Energy Storage (Utilities)	Electricity Generation	N/A	N/A	N/A
77	Grid Flexibility	Electricity Generation	N/A	N/A	N/A
78	Microgrids	Electricity Generation	N/A	N/A	N/A
79	Net Zero Buildings	Buildings and Cities	N/A	N/A	N/A
80	Retrofitting	Buildings and Cities	N/A	N/A	N/A

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