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THE

Drawdown Review

Climate Solutions for a New Decade

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2020

Climate Solutions for a New Decade

A PROJECT DRAWDOWN Publication

Project Drawdown is a highly collaborative effort, and the work presented here is the creation of many, not one. We gratefully acknowledge the many people who contributed and without whom this work would not have been possible.

The Drawdown Review

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This work also builds upon previous work published in *Drawdown* in 2017. Many other individuals contributed to that effort, as named in the book and at Drawdown.org.

Wild honey harvesting is a traditional practice of the Molo community, West Timor, Indonesia.

About Project Drawdown®

The World's Leading Resource for Climate Solutions

Founded in 2014, Project Drawdown is a nonprofit organization that seeks to help the world reach "Drawdown"—the future point in time when levels of greenhouse gases in the atmosphere stop climbing and start to steadily decline.

Since the 2017 publication of the New York Times bestseller, *Drawdown*, the organization has emerged as a leading resource for information and insight about climate solutions. We continue to develop that resource by conducting rigorous review and assessment of climate solutions, creating compelling and human communication across mediums, and partnering with efforts to accelerate climate solutions globally.

Cities, universities, corporations, philanthropies, policymakers, communities, and more turn to Project Drawdown, as they look to advance effective climate action. We aim to support the growing constellation of efforts to move climate solutions forward and move the world toward Drawdown—as quickly, safely, and equitably as possible.

A 501(c)(3) nonprofit organization, Project Drawdown is funded by individual and institutional donations.

Top Left: Tokyo, Japan, is home to one of the best rail transport systems in the world.

Middle Left: Forest restoration in the Democratic Republic of Congo multi-solves for climate, livelihoods, and biodiversity.

Bottom Left: India's Kaas Plateau is a UNESCO World Natural Heritage Site, celebrated for its annual wildflower bloom.

Foreword

In the spring of 2017, Project Drawdown released its inaugural body of work on climate solutions with the publication of the best-selling book Drawdown *and open-source digital resources on Drawdown.org.*

That material has influenced university curricula, city climate plans, commitments by businesses, community action, philanthropic strategy, and more. This Review represents the organization's second seminal publication and the first major update to our assessment of solutions to move the world toward "Drawdown"—the future point in time when levels of greenhouse gases in the atmosphere stop climbing and start to steadily decline.

Science has made clear the wholesale transformation needed to address the climate crisis. In its 2018 special report *Global Warming of 1.5ºC*, the Intergovernmental Panel on Climate Change (IPCC) calls for "rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems."[1] At present, global efforts come nowhere near the scale, speed, or scope required. Yet many of the means to achieve the necessary transformation already exist. Almost daily, there is promising evolution and acceleration of climate solutions, alongside growing efforts to sunset fossil fuel infrastructure and prevent expansion of these antiquated and dangerous energy sources.

Project Drawdown conducts an ongoing review and analysis of climate solutions—the practices and technologies that can stem and begin to reduce the excess of greenhouse gases in our atmosphere—to provide the world with a current and robust resource. (See more on research methods below.) *The Drawdown Review* is core to our efforts to respond nimbly to the rapidly

evolving landscape of solutions and the urgency of the challenge humanity faces. We anticipate regular publication going forward, including updates as well as new solutions, scenarios, and insights.

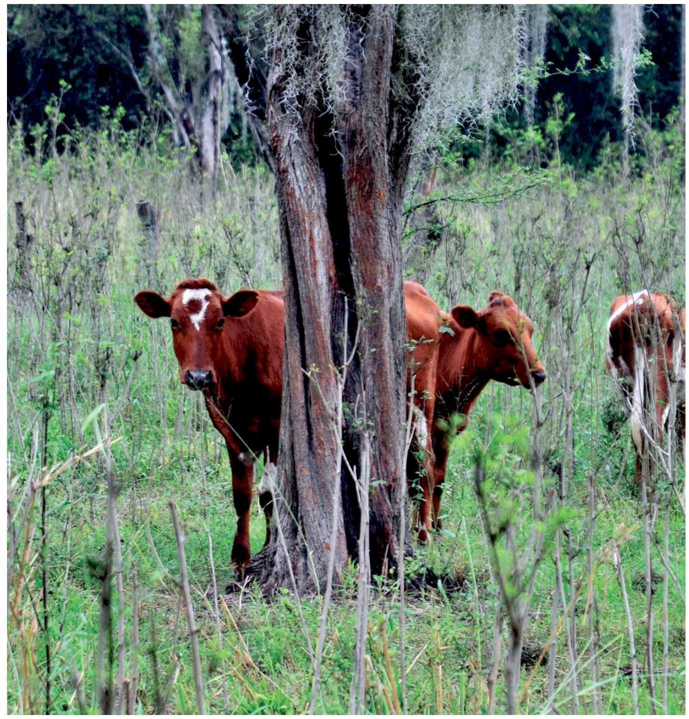
Drawdown is a critical turning point for life on Earth, and we must strive to reach it quickly, safely, and equitably. What follows is an overview of climate solutions in hand—now, today—to reach Drawdown and begin to come back into balance with the planet's living systems. These solutions are tools of possibility in the face of a seemingly impossible challenge. They must not remain the domain of specialists or select groups. Widespread awareness and understanding of climate solutions is vital to kindle agency and effect change worldwide, across individual, community, organizational, regional, national, and global scales. People and institutions of all kinds, in all places, have roles to play in this great transformation, and the solutions in these pages are a synthesis of collective wisdom and collective action unfolding around the globe.

NOTE: The results we share here represent our best assessment of climate solutions for the year 2020. Due to changes in methodology and data, it is not possible to directly compare current results to those released in 2017 and published in Drawdown*. The solutions content in the original book remains robust and relevant and its broader lessons still hold.*

NOTE: All unreferenced numbers are results from Project Drawdown analysis. All climate solutions are quantified in metric gigatons (Gt) of carbon dioxide avoided or sequestered. All general references to greenhouse gases are expressed in carbon dioxide equivalents (CO_2-eq), using a 100-year global warming potential. All financial results are expressed in current U.S. dollars.

Florida's coastal wetlands provide habitat, flood control, groundwater recharge, and storm protection.

10 Key Insights



Silvopasture in action at Reserva Natural El Hatico, a natural reserve near Palmira, Colombia.

Our first body of work in 2017 put a spotlight on a vast array of climate solutions, each with its own compelling story and possibility. As the saying goes, it can sometimes be a challenge to "see the forest for the trees," and that's certainly true with climate solutions.

Throughout this Review, we aim to illuminate what you might call the "groves" and "forests" beyond the individual trees, which are sometimes hiding in plain view. Here, we surface ten key insights to make essential messages of our work clear, direct, and easy for others to communicate. Project Drawdown is a living effort and a learning organization. These insights will continue to deepen, refine, and expand as the work itself does.

1 We can reach Drawdown by mid-century if we scale the climate solutions already in hand.

Drawdown is a bold goal but an absolutely necessary one, given that global emissions are still rising each year—not declining as they need to. Our new analysis shows the world can reach Drawdown by mid-century, if we make the best use of all existing climate solutions. Certainly, more solutions are needed and emerging, but there is no reason—or time—to wait on innovation. *Now* is better than *new*, and society is well equipped to begin that transformation today. If we pursue climate solutions with purpose and determination, our analysis shows we could reach Drawdown as early as the mid-2040s—or not until the 2060s, depending on our level of ambition. (See more on scenarios below.)

2 Climate solutions are interconnected as a system, and we need all of them.

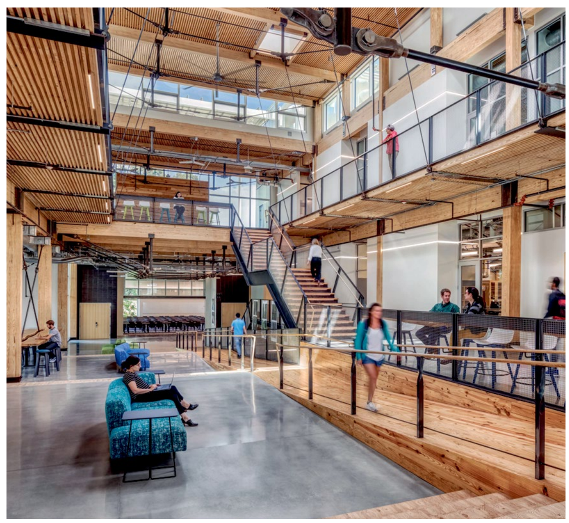
The notion of "silver bullets" has persistent appeal—"what's the *one big thing* we can do?"—but they simply don't exist for complex problems such as the climate crisis. A whole system of solutions is required. Many climate solutions combine and cooperate, leveraging or enabling others for the greatest impact. For example, efficient buildings make distributed, renewable electricity generation more viable. The food system requires interventions on both supply and demand sides—e.g., better farming practices *and* reduced meat consumption. For greatest benefit, electric vehicles need 100% clean power on which to run. We need many, interconnected solutions for a multi-faceted, systemic challenge.

3 Beyond addressing greenhouse gases, climate solutions can have "co-benefits" that contribute to a better, more equitable world.

Climate solutions are rarely just climate solutions. For example, those that curb air pollution are also health solutions. Others that protect and restore ecosystems are also biodiversity solutions. Many can create jobs, foster resilience to climate impacts such as storms and droughts, and bring other environmental benefits such as safeguarding water resources. Climate solutions can advance social and economic equity if utilized wisely and well—with attention to who decides, who benefits, and how any drawbacks are mitigated. The *how* really matters, as the same practice or technology can have very different outcomes depending on implementation. It takes intention and care to move solutions forward in ways that heal rather than deepen systemic injustices.

4 The financial case for climate solutions is crystal clear, as savings significantly outweigh costs.

Unfounded arguments about the economic inviability of climate action persist but are patently false. Project Drawdown analyzes the financial implications of solutions: How much money will a given solution cost, or save, when compared with the status quo technology or practice it replaces? That financial analysis looks at the initial implementation of a solution, as well as the use or operation of that solution over time. Overall, net operational savings exceed net implementation costs four to five times over: an initial cost of $23.4–26.2 trillion versus $96.4–143.5 trillion saved. If we consider the monetary value of co-benefits (e.g., healthcare savings from reduced air pollution) and avoided climate damages (e.g., agricultural losses), the financial case becomes even stronger. So long as we ensure a just transition for those in sunsetting or transitioning industries, such as coal, it's clear that there is no economic rationale for stalling on climate solutions—and every reason to forge boldly ahead.



Left: A woman and child travel by bicycle to retrieve water near Boromo, Burkina Faso.

Right: A Living Building at the Georgia Institute of Technology, designed to produce more energy than it uses.

Grasslands are one of the ecosystems found within Kilimanjaro National Park, Tanzania.

Top Left: A woman examines algae-based, compostable bioplastics, designed for a circular economy.

Right: Rice is a key crop of India's monsoon season. Here, a researcher gathers data during a farm visit in the state of Punjab.

Rooftop solar installation in upstate New York.

5 The majority of climate solutions reduce or replace the use of fossil fuels. We must accelerate these solutions, while actively stopping the use of coal, oil, and gas.

The use of fossil fuels for electricity, transport, and heat currently drives roughly two-thirds of heat-trapping emissions worldwide.[2] Of the 76 solutions included in this Review, roughly 30% reduce the use of fossil fuels by enhancing efficiency and almost 30% replace them entirely with alternatives. Together, they can deliver almost two-thirds of the emissions reductions needed to reach Drawdown. Alongside accelerating these vital solutions, such as solar and wind power, retrofitting buildings, and public transit, we must actively stop fossil fuel production and expansion—including ending billions of dollars in subsidies and financing and, ideally, directing those funds to climate solutions instead. Reaching Drawdown depends on concurrent "stop" and "start" paths of action. A similar stop-start dynamic exists within food, agriculture, and land use: ending harmful practices (e.g., deforestation) and advancing helpful ones (e.g., methods of regenerative agriculture).

6 We cannot reach Drawdown without simultaneously reducing emissions toward zero and supporting nature's carbon sinks.

Imagine the atmosphere as a bathtub overflowing, as the water continues to run. The primary intervention is clear: turn off the tap of greenhouse gases by bringing emissions to zero. In addition to curbing the source of the problem, we can also open the drain somewhat. That's where nature plays a vital role: absorbing and storing carbon through biological and chemical processes, effectively draining some of the excess out of the atmosphere. Human activities can support natural carbon sinks, and many ecosystem- or agriculture-related climate solutions have the double benefit of reducing emissions and absorbing carbon simultaneously. It takes stemming all sources and supporting all sinks to reach Drawdown. (See further exploration of sources and sinks below.)

7 Some of the most powerful climate solutions receive comparably little attention, reminding us to widen our lens.

Many climate solutions focus on reducing and eliminating fossil fuel emissions, but others are needed too. Among the top solutions assessed by Project Drawdown, we find some "eye-openers" that are on par with solutions that often get the spotlight, such as onshore wind turbines and utility-scale solar photovoltaics:

- Food waste reduction and plant-rich diets, which together curb demand, deforestation, and associated emissions;
- Preventing leaks and improving disposal of chemical refrigerants, which are potent greenhouse gases, the use of which is projected to grow significantly;
- Restoration of temperate and tropical forests, which are powerful, vast carbon sinks;
- Access to high-quality, voluntary reproductive healthcare and high-quality, inclusive education, the many ripple effects of which include climate benefits.

These results are a reminder to look beyond the obvious, to a broader suite of solutions, and beyond technology, to natural and social systems.

8 Accelerators are critical to move solutions forward at the scale, speed, and scope required.

It goes without saying: solutions do not scale themselves. We need means of removing barriers and accelerating their implementation and expansion. Key "accelerators" can create the conditions for solutions to move forward with greater speed and wider scope. Some, such as changing policy and shifting capital, are closer in and have more direct impacts; others, such as shaping culture and building political power, are further out and more indirect in their effect. Accelerators are heavily dependent on social and political contexts and work at different scales, from individuals to larger groups to entire nations. As with solutions, they intersect and interact; none are singularly effective, and we need them all. (See more on accelerators below.)

Community health workers in Nepal bring reproductive healthcare directly to villages.

9 Footholds of agency exist at every level, for all individuals and institutions to participate in advancing climate solutions.

The climate crisis requires systemic, structural change across our global society and economy. The reality of intervening in a complex system is that no one can do it all, and we all have an opening to show up as problem-solvers and change-agents and contribute in significant ways—even when we feel small. The range of climate solutions illuminates diverse intervention points across individual, community, organizational, regional, national, and global scales. The necessary accelerators expand that array of action opportunities even more. It will take a whole ecosystem of activities and actors to create the transformation that's required.

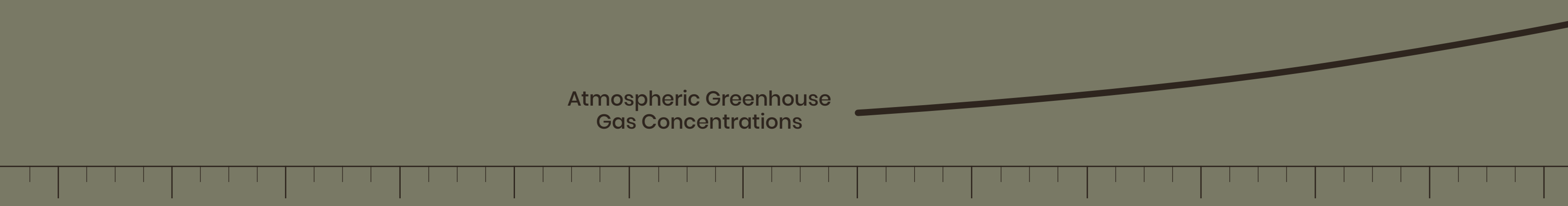
In Germany, 1.4 million people participated in the September 2019 climate strike.

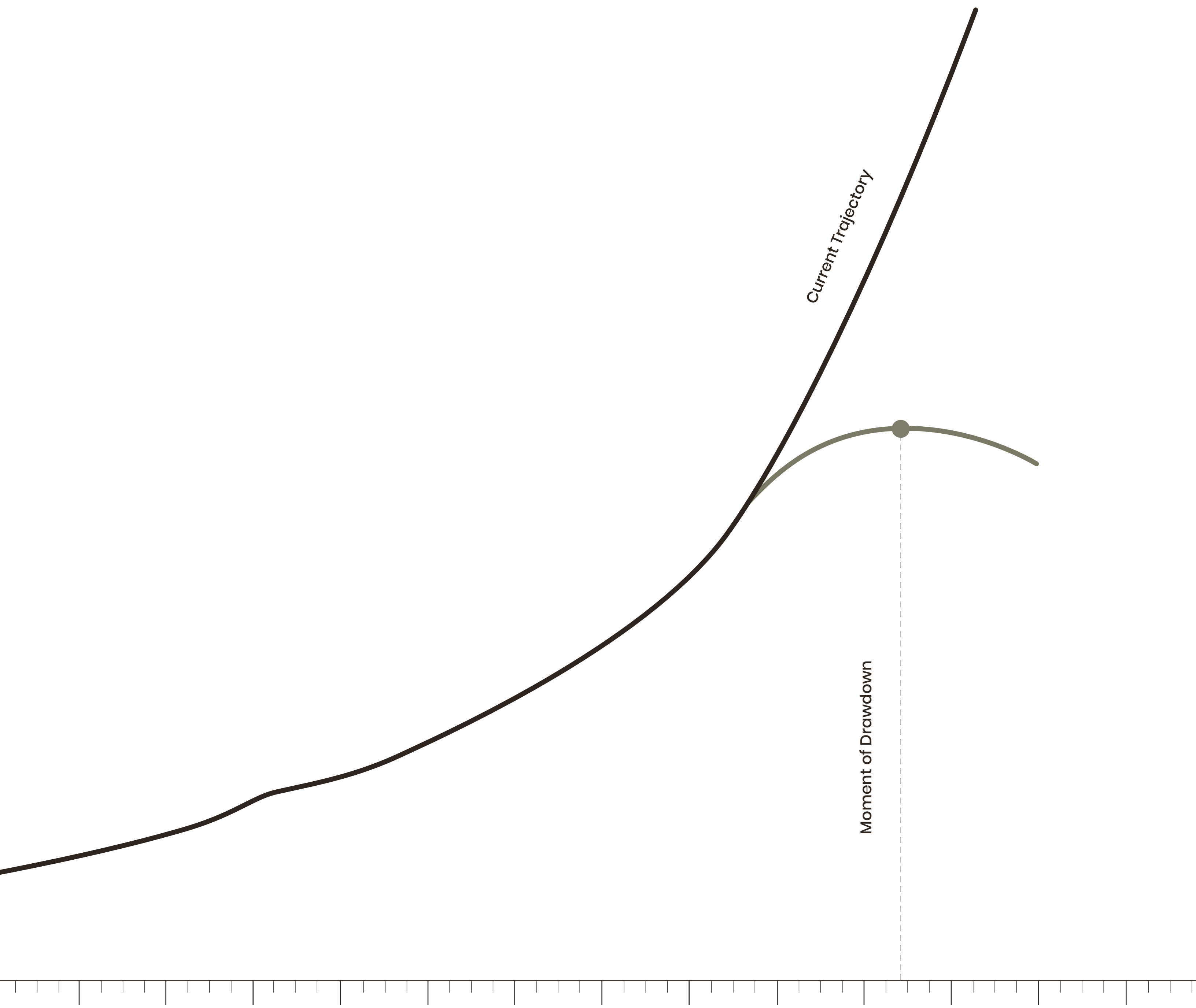
10 Immense commitment, collaboration, and ingenuity will be necessary to depart the perilous path we are on and realize the path that's possible. But the mission is clear: *make possibility reality*.

In September 2019, Swedish climate activist Greta Thunberg testified before the U.S. Congress. "You must unite behind the science," she urged. "You must take action. You must do the impossible. Because giving up can never ever be an option."[3] In four short sentences, she articulated exactly the task and challenge at hand. Project Drawdown's mission is to help the world reach Drawdown as quickly, safely, and equitably as possible. That could also be humanity's mission in this pivotal moment for life on Earth. The current path we are on is beyond dangerous, and it's easy to be paralyzed by that perilousness. Yet possibility remains to change it. Together, we can build a bridge from where we are today to the world we want for ourselves, for all of life, and, most importantly, for generations yet to come.

Drawdown Solutions Framework

Drawdown is the future point in time when levels of greenhouse gases in the atmosphere stop climbing and start to steadily decline. This is the point when we begin the process of stopping further climate change and averting potentially catastrophic warming. It is a critical turning point for life on Earth—one we must reach as quickly, safely, and equitably as possible.




Current Trajectory
Moment of Drawdown

The Challenge

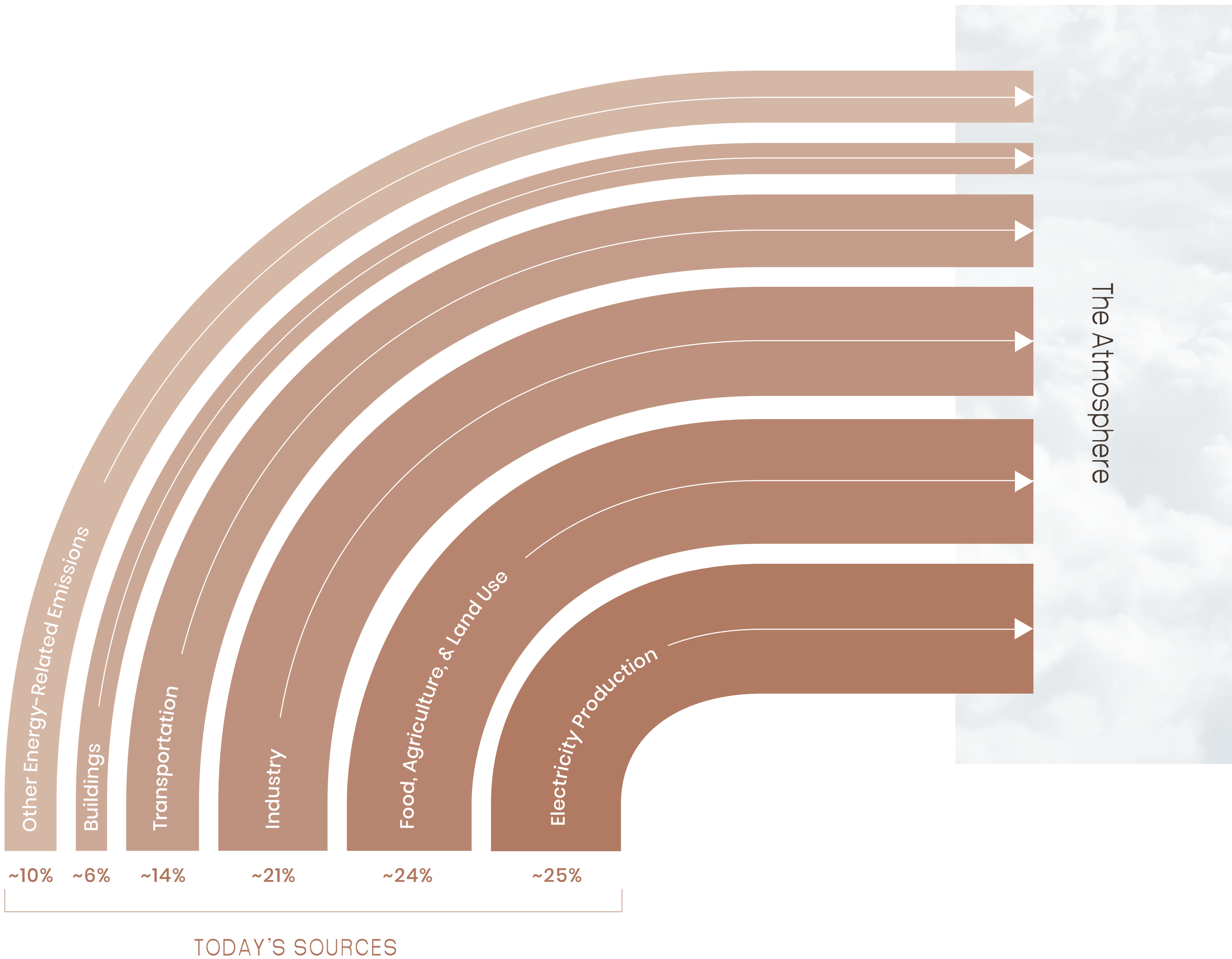
Burning fossil fuels for electricity, mobility, and heat. Manufacturing cement and steel. Plowing soils. Clearing forests and degrading other ecosystems. All these activities emit heat-trapping carbon dioxide into the air. Cattle, rice fields, landfills, and fossil fuel operations release methane—a gas that warms the planet even more.

Nitrous oxide and fluorinated gases seep out of agricultural lands, industrial sites, refrigeration systems, and urban areas, adding still more heat-trapping pollutants to Earth's atmosphere. Most of these greenhouse gases stay airborne, but not all. Natural biological and chemical processes—especially photosynthesis—bring some of that excess back to plants, soil, or sea. These "sinks" are nature's reservoirs for absorbing and storing carbon.

To understand and advance climate solutions, it's important to understand the sources of emissions and nature's means of rebalancing the climate system.

Heat-trapping greenhouse gases come from six sectors:[2]

- **~25%** Electricity Production
- **~24%** Food, Agriculture, & Land Use
- **~21%** Industry
- **~14%** Transportation
- **~6%** Buildings
- **~10%** Other Energy-Related Emissions



Greenhouse gas sinks are the counterpoint to these sources. While **~59%** of heat-trapping emissions stay in the atmosphere, **~24%** are quickly removed by plants on land and **~17%** are taken up by oceans.[4]

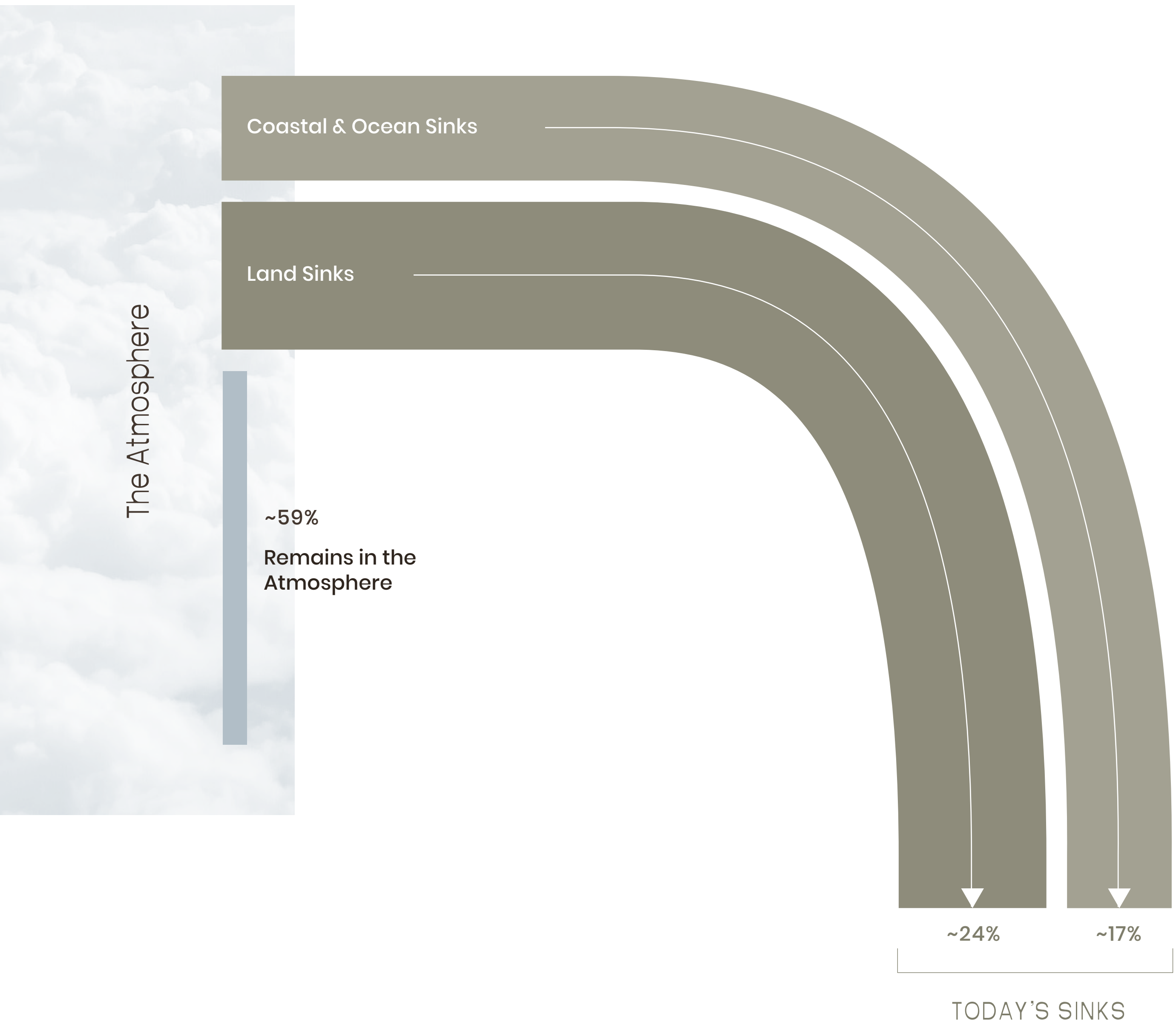
To reach Drawdown, we must work on all aspects of the climate equation—stopping sources and supporting sinks, as well as helping society achieve broader transformations. That is, three connected areas call for action, which we must pursue globally, simultaneously, and with determination.

1. Reduce Sources,
bringing emissions to zero.
2. Support Sinks,
uplifting nature's carbon cycle.
3. Improve Society,
fostering equality for all.

Nested within each area of action, there are sectors and subgroups of diverse solutions—practices and technologies that can help the world stabilize and then begin to lower greenhouse gas levels in the atmosphere. Together, they comprise the Drawdown Framework for climate solutions.

NOTE: These are the sectors where greenhouse gases are emitted directly into the atmosphere. A sector may also have indirect impacts on emissions. For example the 6% of emissions attributed to buildings only accounts for fuels burned on site (e.g., natural gas for cooking or heating); power plant emissions tied to buildings' electricity use are counted within the electricity sector. (See further exploration below.)

NOTE: Land sinks absorb roughly 29% of the carbon dioxide emissions pumped into the atmosphere each year, and oceans take up about 23%. When we consider other greenhouse gases, including methane, nitrous oxide, and fluorinated gases, land absorbs approximately 26% of the total emissions and oceans remove approximately 17%. (Global Carbon Project analysis adjusted to include all greenhouse gases at 100-year global warming potential.)



The Solutions

Minimum CO_2-eq (Gt) reduced/sequestered (2020-2050)

Maximum CO_2-eq (Gt) reduced/sequestered (2020-2050)

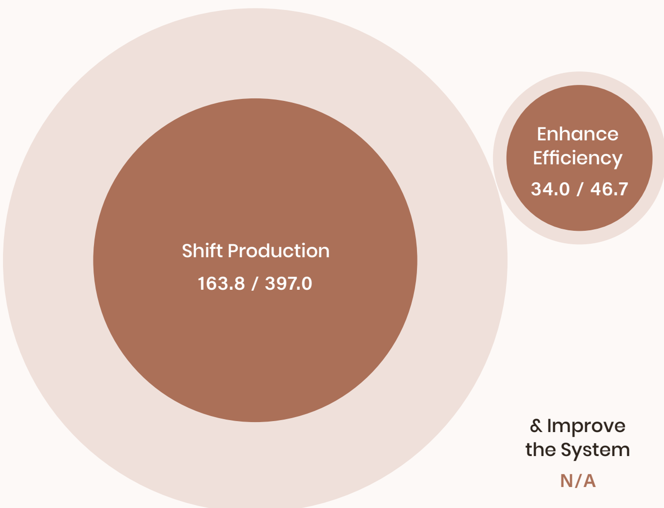
X / Y = Min / Max CO_2-eq (Gt) reduced/sequestered (2020-2050)

The Drawdown Solutions Framework organizes climate solutions by sector and by subgroup, within three overarching areas of action. Here, you see the potential emissions impact of each sector, as well as the solution subgroups therein. Using two different scenarios of solution implementation, we derived the minimum and maximum impact shown here. (See more on scenarios below.)

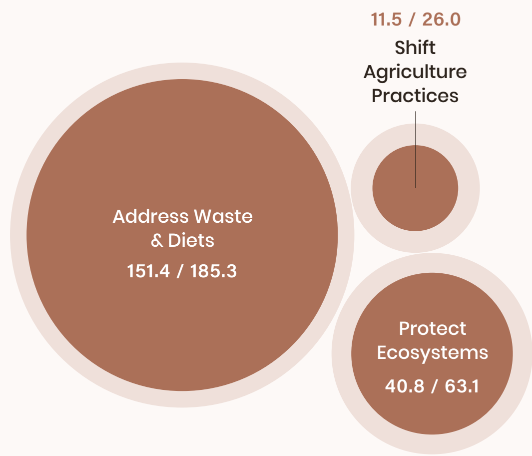
Reduce Sources

TOTAL: MIN **649.2** | MAX **1113.5**

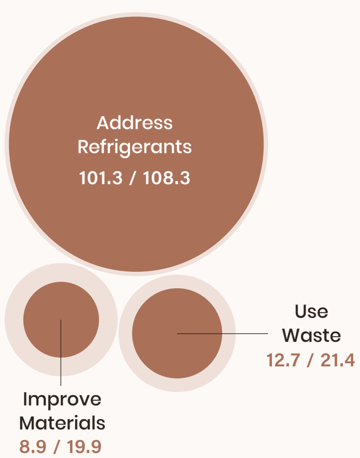
Electricity



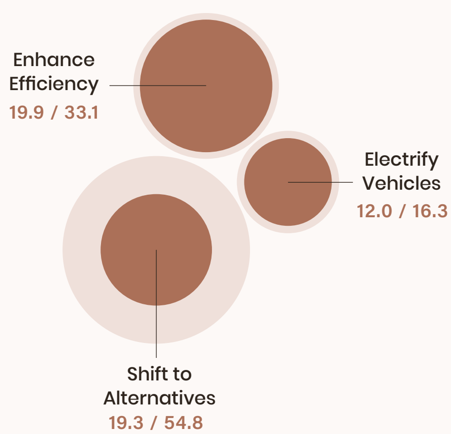
Food, Agriculture & Land Use



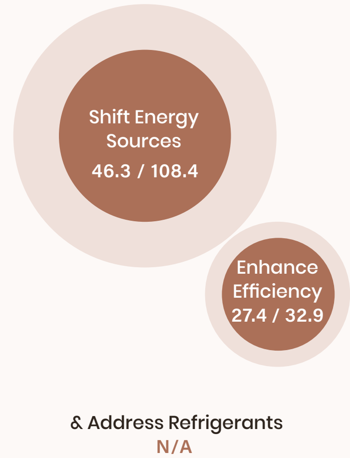
Industry

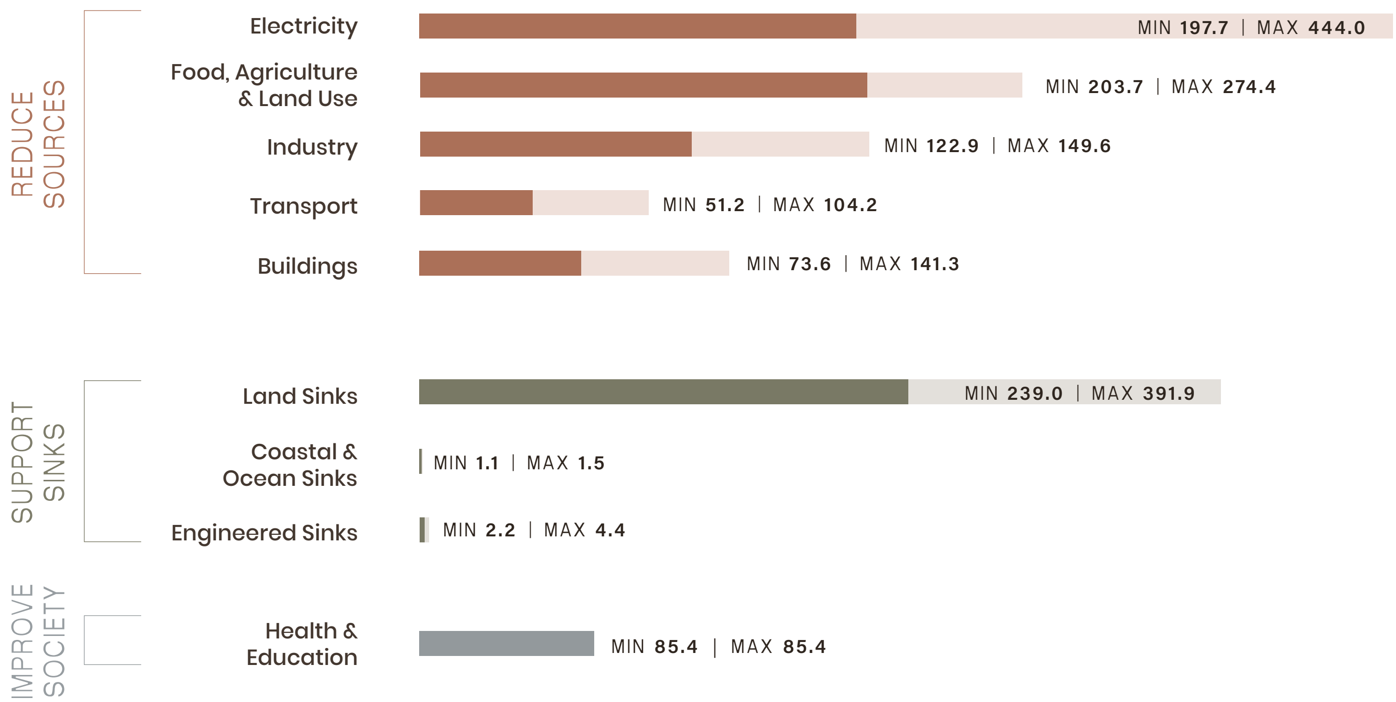


Transport



Buildings

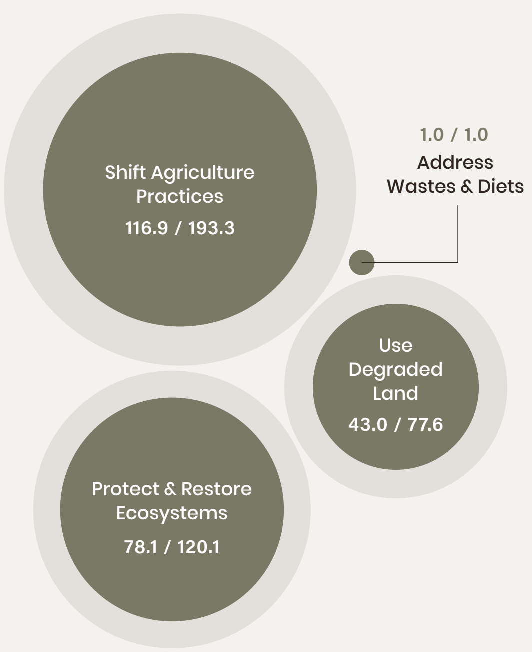




Support Sinks

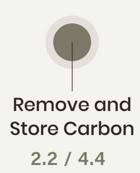
TOTAL: MIN **242.3** | MAX **397.8**

Land Sinks



Coastal & Ocean Sinks

Engineered Sinks



Improve Society

TOTAL: MIN **85.4** | MAX **85.4**

Health & Education

1 Reduce Sources

bringing emissions to zero

Electricity

Food, Agriculture & Land Use

Industry

Transportation

Buildings

1.1

Electricity

Electricity is particles in motion—a flow of electrons from one place to another that keeps air conditioners cooling, heaters heating, lights illuminating, computers computing, and all manner of motors humming. For much of the world, electricity powers the realities of daily life, yet 840 million people still lack access to electricity.[5]

Since the emergence of electrical systems in the late 1800s, society has created most of its electricity by using fossil fuels. The process? Burn coal, oil, or natural gas. Heat water to create steam. Steam turns a turbine. Turbine rotates a generator, to get electrons moving. The locked-up energy of long-buried plants and animals is transmuted into electricity, as carbon dioxide spills into the atmosphere as a byproduct. Today, electricity production gives rise to 25% of heat-trapping emissions globally.[2]

How can we generate electricity for the whole world without burning fossil fuels? How do the means of transmitting, storing, and using electricity need to evolve?

These questions are critical for addressing emissions, especially given the current push to "electrify everything," from cars to home heating, needing clean power on which to run. A mosaic of solutions is required, centered around electricity efficiency, production, and a more robust electrical system.

Windsurfers and wind turbines catch the breeze at Brazil's Icaraizinho de Amontada beach.

Enhance Efficiency

Electricity efficiency solutions include technologies and practices that reduce demand for electricity generation, literally lightening the load. The two biggest end-users of electricity are buildings and industry, in roughly equal measure.[2] While a home or factory may be the location of efficiency measures, these emissions get counted at the power plant where they are created or avoided, as part of the electricity sector. (See further exploration of buildings and industry below.)

Shift Production

Production of electricity must move away from fossil fuels, as quickly as possible. A spectrum of solutions can help, from small-scale/distributed to large-scale/centralized. Some solutions harvest photons from the sun. Others tap nature's generous kinetic energy—the movement of wind and water. Still others use an alternate source of heat, such as geothermal or nuclear, for the same basic steam-turbine process.

Improve the System

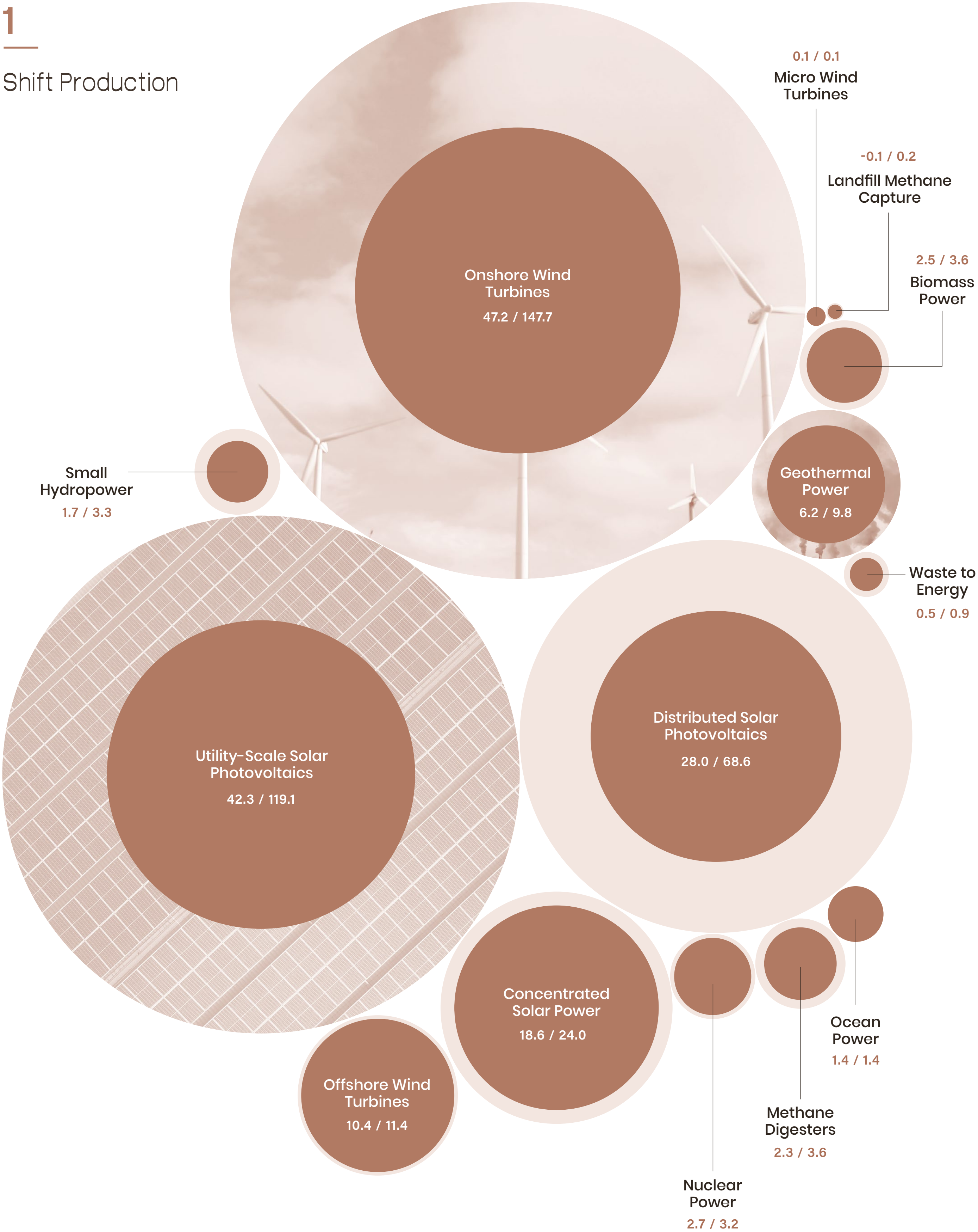
To enable the transition to renewable electricity production and use, the broader electricity system also needs to evolve and upgrade. Flexible grids for transmission and effective energy storage make it possible to better balance electricity supply with demand.

As we look forward, an electricity transformation is undeniably possible. Already, economics favor wind and sun over fossil fuels in many places. A shift away from coal-powered electricity is underway in the United States, the United Kingdom, and much of Europe, albeit not fast or widespread enough. The speed of transformation is the issue at hand. We must curtail and supplant 19th and 20th-century forms of production more rapidly—including the large pipeline of proposed new coal plants—while ensuring that the future of clean electricity is equitable and empowering for all.

In the village of Tinginaput, India, distributed solar panels are used for street lighting.

1

Shift Production



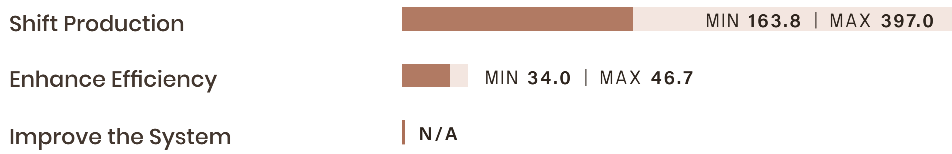
Here, you see the potential emissions impact of each subgroup for this sector, as well as the individual solutions therein. Solutions are scaled relative to one another within this sector. Each sector is individually scaled for legibility.

Minimum CO_2-eq (Gt) reduced/sequestered (2020-2050)

Maximum CO_2-eq (Gt) reduced/sequestered (2020-2050)

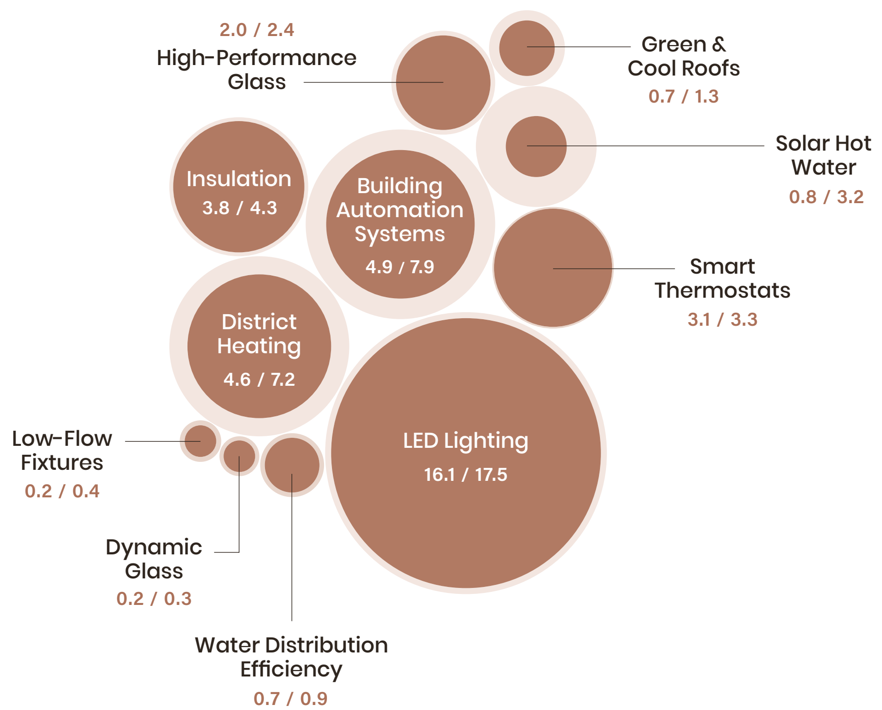
X / Y = Min / Max CO_2-eq (Gt) reduced/sequestered (2020-2050)

Overall Impact



2

Enhance Efficiency



Building Retrofitting N/A

Net-Zero Buildings N/A

High-Efficiency Heat Pumps -3.0 / -1.7

3

Improve the System

Grid Flexibility N/A

Microgrids N/A

Distributed Energy Storage N/A

Utility-Scale Energy Storage N/A

NOTE: Where a solution's impact is N/A, emissions reductions are allocated to other solutions. (See more below.)

SOLUTIONS

Enhance Efficiency

**also in Buildings*

Smart Thermostats*

Thermostats are mission control for space heating and cooling. Smart thermostats use algorithms and sensors to become more energy efficient over time, lowering emissions.

Building Automation Systems*

These systems can control heating, cooling, lighting, and appliances in commercial buildings. They cut emissions by maximizing energy efficiency and minimizing waste.

LED Lighting

LEDs (light emitting diodes) are the most energy-efficient bulbs available. Unlike older technologies, they transfer most of their energy use into light, rather than waste heat.

Insulation*

Insulation impedes unwanted airflow in or out of buildings. In new construction or retrofits, it makes heating and cooling more energy efficient, with lower emissions.

Dynamic Glass*

By responding to sunlight and weather, dynamic glass can reduce a building's energy load for heating, cooling, and lighting. More effective windows lower emissions.

High-Performance Glass*

High-performance glass improves window insulation and makes building heating and cooling more efficient. By minimizing unnecessary energy use, it curtails emissions.

Green & Cool Roofs*

Green roofs use soil and vegetation as living insulation. Cool roofs reflect solar energy. Both reduce building energy use for heating and/or cooling.

District Heating*

District systems heat space and water more efficiently. A central plant and pipe network channel hot water to many buildings, with lower emissions than on-site systems.

High-Efficiency Heat Pumps*

Heat pumps extract heat from the air and transfer it—from indoors out for cooling, or from outdoors in for heating. With high efficiency, they can dramatically lower building energy use.

Solar Hot Water*

Solar hot water taps the sun's radiation, rather than fuel or electricity. By replacing conventional energy sources with a clean alternative, it reduces emissions.

Low-Flow Fixtures*

Cleaning, transporting, and heating water requires energy. More efficient fixtures and appliances can reduce home water use significantly, thereby reducing emissions.

Water Distribution Efficiency

Pumping water requires enormous amounts of electricity. Addressing leaks in water-distribution networks, especially in cities, can curb water loss, energy use, and emissions.

Building Retrofitting*

Retrofits address electricity and fuel waste with better insulation and windows, efficient lighting, and advanced heating and cooling systems. Improved efficiency lowers existing buildings' emissions.

NOTE: This solution represents an integration or system of other solutions. Emissions reductions associated with building retrofitting are accounted for in those individual solutions.

Enhance Efficiency + Shift Production

**also in Buildings*

Net-Zero Buildings*

Buildings with zero net energy consumption combine maximum efficiency and onsite renewables. They produce as much energy as they use annually, with low or no emissions.

NOTE: This solution represents an integration or system of other solutions. Emissions reductions associated with net-zero buildings are accounted for in those individual solutions.

Shift Production

**also in Industry*

Concentrated Solar Power

Concentrated solar power uses sunlight as a heat source. Arrays of mirrors concentrate incoming rays onto a receiver to heat fluid, produce steam, and turn turbines.

Distributed Solar Photovoltaics

Rooftop solar panels are one example of distributed solar photovoltaic systems. Whether grid-connected or part of stand-alone systems, they offer hyper-local, clean electricity generation.

Utility-Scale Solar Photovoltaics

Solar photovoltaics can be used at utility-scale—with hundreds or thousands of panels—to tap the sun's clean, free fuel and replace fossil fuel electricity generation.

SOLUTIONS

Shift Production (cont.)

**also in Industry*

Micro Wind Turbines	Micro wind turbines can generate clean electricity in diverse locations, from urban centers to rural areas without access to centralized grids.
Onshore Wind Turbines	Onshore wind turbines generate electricity at a utility scale, comparable to power plants. They replace fossil fuels with emissions-free electricity.
Offshore Wind Turbines	Winds over sea are more consistent than those over land. Offshore wind turbines tap into that power to generate utility-scale electricity without emissions.
Geothermal Power	Underground reservoirs of steamy hot water are the fuel for geothermal power. It can be piped to the surface to drive turbines that produce electricity without pollution.
Small Hydropower	Small hydropower systems capture the energy of free-flowing water, without using a dam. They can replace dirty diesel generators with clean electricity generation.
Ocean Power	Wave- and tidal-power systems harness natural oceanic flows—among the most powerful and constant dynamics on earth—to generate electricity without pollution.
Biomass Power	Biomass feedstock can replace fossil fuels for generating heat and electricity. Only perennial biomass is advisable, offering a "bridge" solution to clean, renewable production.
Nuclear Power	Nuclear power is slow, expensive, risky, and creates radioactive waste, but it has the potential to avoid emissions from fossil fuel electricity.

Waste-to-Energy*

Waste-to-energy processes (incineration, gasification, pyrolysis) combust waste and convert it to heat and/or electricity. Emissions reductions come with health and environmental risks, however.

Landfill Methane Capture*

Landfills generate methane as organic waste decomposes. Rather than getting released as emissions, that methane can be captured and used to produce electricity.

Methane Digesters*

Industrial-scale anaerobic digesters control decomposition of organic waste and convert methane emissions into biogas, an alternative fuel, and digestate, a nutrient-rich fertilizer.

Improve the System

The emissions reductions enabled by these solutions are allocated to electricity generation solutions.

Grid Flexibility

Smarter, more flexible electric grids can cut energy losses during distribution. They are critical to enable renewables, which are more variable than conventional electricity generation.

Microgrids

A microgrid is a localized grouping of distributed electricity generation technologies, paired with energy storage or backup generation and tools to manage demand or "load."

Distributed Energy Storage

Standalone batteries and electric vehicles store energy. They can enable 24/7 electricity supply even when the sun isn't shining or the wind isn't blowing.

Utility-Scale Energy Storage

Large-scale energy storage ensures electricity supply can match demand. It enables the shift to variable renewables and curbs emissions from polluting "peaker" plants.

1.2

Food, Agriculture & Land Use

Human activity has transformed a significant fraction of the planet's land, especially for growing food and harvesting forests. Land is the common ground of shelter, sustenance, feed for animals, fiber, timber, and some sources of energy, as well as the direct source of livelihood for billions of people.

Our pursuit of those ends often disrupts or displaces ecosystems, and the twin forces of a growing population and rising consumption mean the challenge of stewarding land in sustainable ways will only intensify. Today, agriculture and forestry activities generate 24% of greenhouse gas emissions worldwide.[2]

How can we reduce the pressures on ecosystems and land, while meeting the growing demands for food and fiber worldwide? How can we do what we do on land better, tending it in ways that decrease emissions from agriculture and forestry?

The answers to these questions are critical for stemming greenhouse gases, sustaining the planet's living systems, addressing food security, and protecting human health, all inextricably linked. Solutions in this sector are focused on waste and diets, ecosystem protection, and better agriculture practices.

Address Waste & Diets

By shifting diets and addressing food waste, the global demand for food can significantly drop. Eating lower on the food chain and ensuring what's grown gets eaten is a powerful combination that lowers farming inputs, land-clearing, and all associated emissions.

Protect Ecosystems

When land and ecosystems are deliberately protected, activities that release carbon from vegetation and soil are stopped before they start. In addition, improving food production on existing farmland may reduce the pressure on other, nearby landscapes, thereby sparing them from clearing.

Shift Agriculture Practices

Better agriculture practices can lower emissions from cropland and pastures, including methane generated by growing rice and raising ruminants, nitrous oxide emitted from manure and overusing fertilizers, and carbon dioxide released by disturbing soils.

Farming and forestry practices can also support the role of land in removing greenhouse gases from the atmosphere. Many solutions that stop land-based emissions also enhance carbon sinks (explored below). Solutions in this sector are significant for improving food security and agricultural resilience as well, because many of them contribute to a more robust food system, better able to withstand climate impacts.

Left: Central Kalimantan, Indonesia, is home to carbon-rich peatland forests, which face the pressures of drainage, illegal logging, and fire.

Top Right: At the 2019 Marcha das Mulheres Indígenas in Brasília, women lifted up the importance of indigenous peoples' land rights.

Bottom Right: A plant-rich dish of roasted eggplant with turmeric, yogurt sauce, roasted almonds, and smoked paprika.

Here, you see the potential emissions impact of each subgroup for this sector, as well as the individual solutions therein. Solutions are scaled relative to one another within this sector. Each sector is individually scaled for legibility.

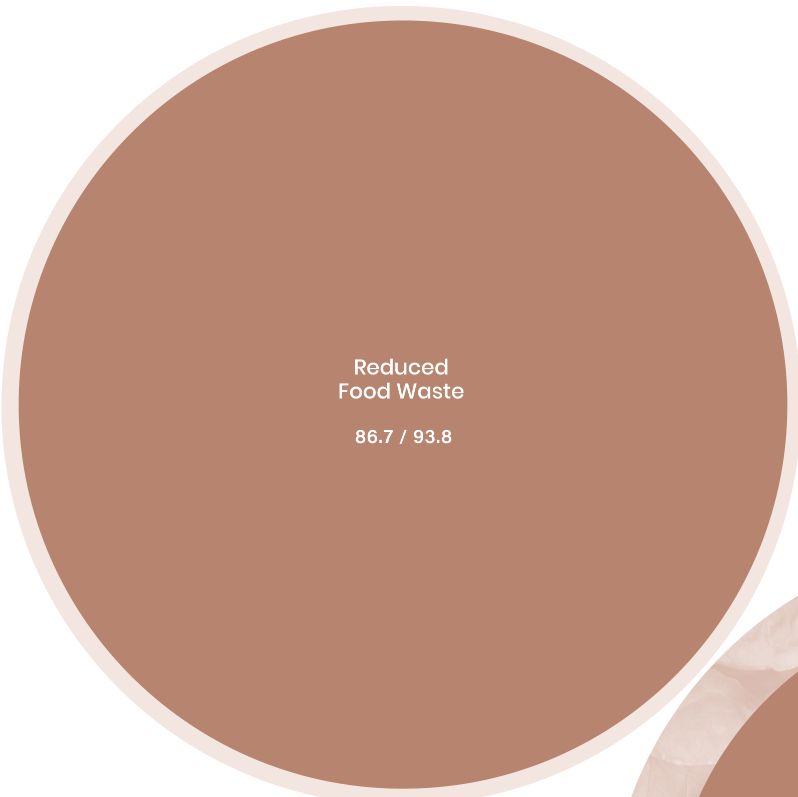
Minimum CO_2-eq (Gt) reduced/sequestered (2020-2050)

Maximum CO_2-eq (Gt) reduced/sequestered (2020-2050)

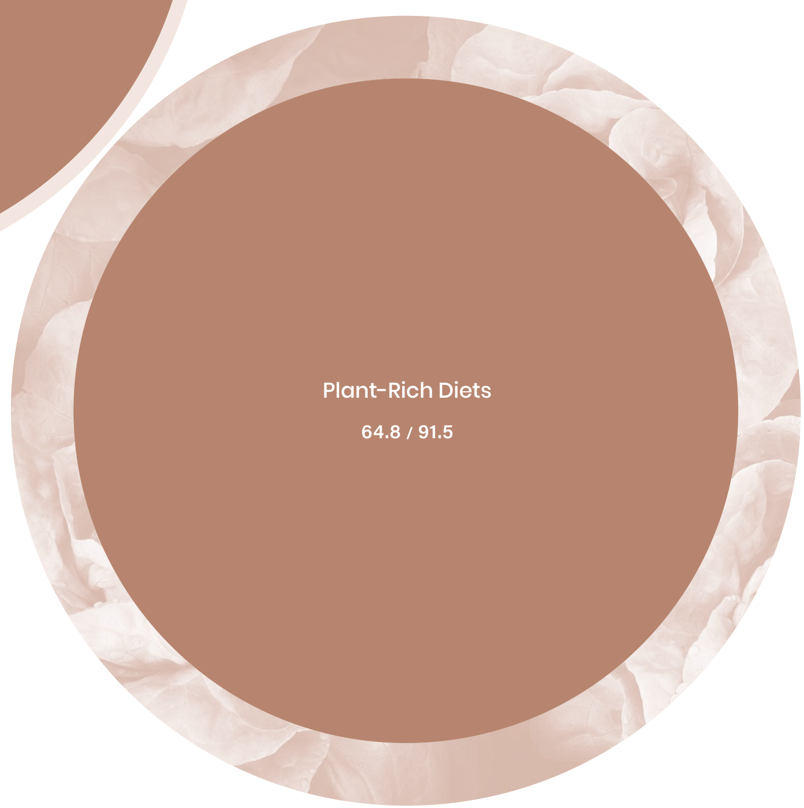
X / Y = Min / Max CO_2-eq (Gt) reduced/sequestered (2020-2050)

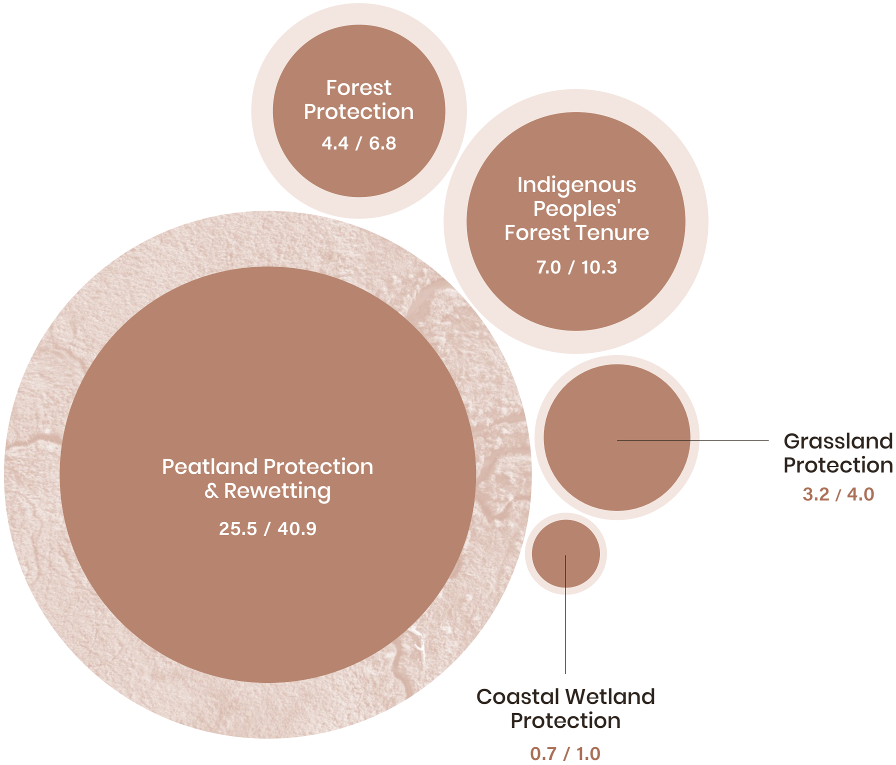
Overall Impact

Address Waste & Diets	MIN **151.4** | MAX **185.3**
Protect Ecosystems	MIN **40.8** | MAX **63.1**
Shift Agriculture Practices	MIN **11.5** | MAX **26.0**



1
Address Waste & Diets



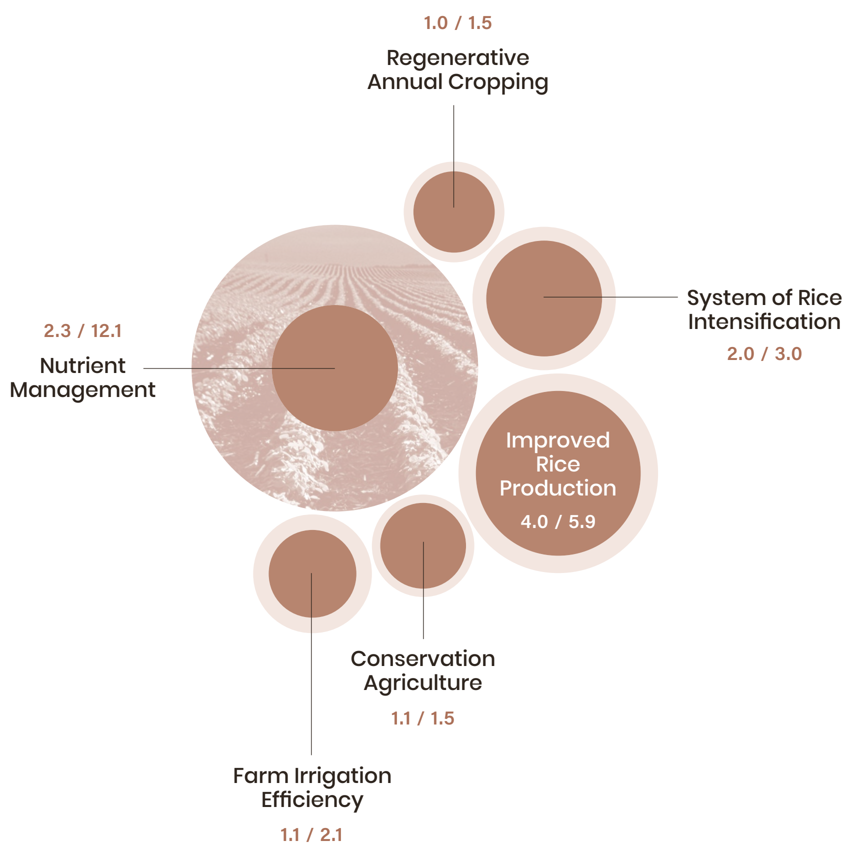


2

Protect Ecosystems

3

Shift Agriculture Practices



4

Protect Ecosystems + Shift Agriculture Practices

Sustainable Intensification for Smallholders 0.1 / 0.1

SOLUTIONS

Address Waste & Diets

**also in Land Sinks*

Plant-Rich Diets*

Consumption of meat and dairy, as well as overall calories, often exceeds nutritional recommendations. Paring down and favoring plant-based foods reduces demand, thereby reducing land clearing, fertilizer use, burping cattle, and greenhouse gas emissions.

Reduced Food Waste*

Roughly a third of the world's food is never eaten, which means land and resources used and greenhouse gases emitted in producing it were unnecessary. Interventions can reduce loss and waste, as food moves from farm to fork, thereby reducing overall demand.

Protect Ecosystems

**also in Land Sinks **also in Coastal & Ocean Sinks*

Forest Protection*

In their biomass and soil, forests are powerful carbon storehouses. Protection prevents emissions from deforestation, shields that carbon, and enables ongoing carbon sequestration.

Indigenous Peoples' Forest Tenure*

Secure land tenure protects indigenous peoples' rights. With sovereignty, traditional practices can continue—in turn protecting ecosystems and carbon sinks and preventing emissions from deforestation.

Grassland Protection*

Grasslands hold large stocks of carbon, largely underground. Protecting them shields their carbon stores and avoids emissions from conversion to agricultural land or development.

Peatland Protection & Rewetting*

Forestry, farming, and fuel-extraction are among the threats to carbon-rich peatlands. Protection and rewetting can reduce emissions from degradation, while supporting peatlands' role as carbon sinks.

Coastal Wetland Protection**

Mangroves, salt marshes, and seagrasses sequester huge amounts of carbon in plants and soil. Protecting them inhibits degradation and safeguards their carbon sinks.

Protect Ecosystems + Shift Agriculture Practices

also in Land Sinks

Sustainable Intensification for Smallholders*

Sustainable intensification practices can increase smallholder yields, which, in theory, reduce demand to clear additional land. Practices include intercropping, ecosystem-based pest management, and equal resources for women.

Shift Agriculture Practices

also in Land Sinks

Conservation Agriculture*

Conservation agriculture uses cover crops, crop rotation, and minimal tilling in the production of annual crops. It protects soil, avoids emissions, and sequesters carbon.

Regenerative Annual Cropping*

Building on conservation agriculture with additional practices, regenerative annual cropping can include compost application, green manure, and organic production. It reduces emissions, increases soil organic matter, and sequesters carbon.

Nutrient Management

Overuse of nitrogen fertilizers—a frequent phenomenon in agriculture—creates nitrous oxide. More efficient use can curb these emissions and reduce energy-intensive fertilizer production.

Farm Irrigation Efficiency

Pumping and distributing water is energy intensive. Drip and sprinkler irrigation, among other practices and technologies, make farm-water use more precise and efficient.

Improved Rice Production*

Flooded rice paddies produce large quantities of methane. Improved production techniques, including alternate wetting and drying, can reduce methane emissions and sequester carbon.

System of Rice Intensification*

SRI is a holistic approach to sustainable rice cultivation. By minimizing water use and alternating wet and dry conditions, it minimizes methane production and emissions.

1.3
Industry

From concrete to computers, cars to clothing, industry is the sector of production that makes them all. It includes strings of connected activities: extracting raw materials, manufacturing component parts and completed goods, provisioning them for use, dealing with disposal, and (possibly) putting waste back to work. The dominant mode of operation is take-make-use-trash—a linear flow of materials that is inefficient and untenable.

This sector derives its name from the Latin for "diligence." Industry's hard work certainly propels economic activity but it also creates substantial emissions—and some of the hardest to halt. Industry requires the use of energy-hungry machines, furnaces, and boilers, and often employs polluting processes. Many of its emissions happen on-site—at a plant or factory, for example—making industry directly responsible for 21% of all heat-trapping emissions.[2] Given its appetite for electricity, industry also drives almost half of off-site electricity generation emissions (as explored above). Within this sector, production of cement, iron, and steel top the emissions charts. Aluminum, fertilizers, paper, plastics, processed foods, textiles, and waste pile up the problem.

How can we improve industrial processes and materials produced? How can industry make use of waste and move toward flows of substances that are efficient and circular?

These questions have implications that reach well beyond this sector, as it's fundamentally linked with mobility, infrastructure, buildings, food, and technologies of all sorts. Industry solutions cluster around materials, waste, refrigerants, and energy efficiency.

Top Left: CopenHill is a waste-to-energy plant that doubles as an artificial ski slope in Copenhagen, Denmark.

Bottom Left: A dairy farm in Lancaster County, Pennsylvania, composts food waste and cow manure.

Right: Refrigerators and air conditioners rely on chemical refrigerants that require careful management and disposal.

Improve Materials

Plastic, metals, and cement are some of the most ubiquitous materials. They're also prime candidates for improvement and replacement with better alternatives that can meet the same needs, but with lower emissions.

Use Waste

Waste can be reclaimed as a resource—something of value, rather than something to discard—to reduce the use of raw materials and energy, thereby reducing emissions. The most advanced approaches move us toward a circular economy.

Address Refrigerants

The chemicals used in refrigeration are potent greenhouse gases, which often leak during use or disposal. We can better manage and dispose of the fluorinated gases currently used as refrigerants, and, ultimately, replace them with benign alternatives.

Enhance Efficiency

Industrial processes can also reduce emissions through energy-efficiency and using low- and no-carbon energy sources.

Industry—especially heavy industry—presents some of the biggest challenges for reducing emissions to zero. For example, the manufacturing of concrete, a staple of modern construction, releases a great deal of carbon dioxide. A number of industrial processes, such as fabricating steel, require very high temperatures that, for now, rely on burning fossil fuels. This sector is likely to see critical new solutions in the years ahead.

NOTE: To date, Project Drawdown has assessed a limited selection of industry solutions. This solution set will expand in the future (e.g., solutions for production of chemicals, steel, and textiles).

Here, you see the potential emissions impact of each subgroup for this sector, as well as the individual solutions therein. Solutions are scaled relative to one another within this sector. Each sector is individually scaled for legibility.

Minimum CO_2-eq (Gt) reduced/sequestered (2020-2050)

Maximum CO_2-eq (Gt) reduced/sequestered (2020-2050)

X / Y = Min / Max CO_2-eq (Gt) reduced/sequestered (2020-2050)

Overall Impact

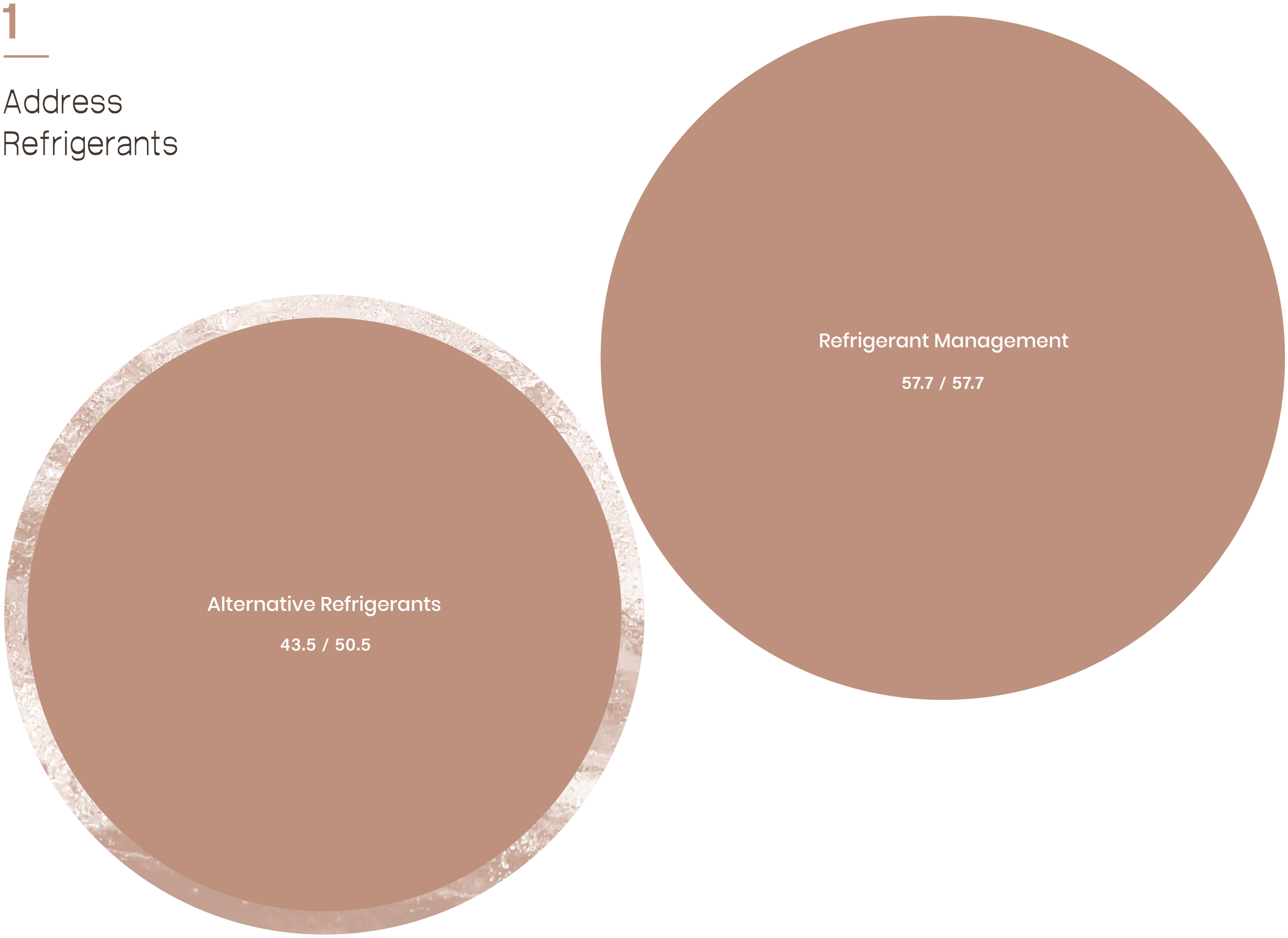
Address Refrigerants — MIN **101.3** | MAX **108.3**

Use Waste — MIN **12.7** | MAX **21.4**

Improve Materials — MIN **8.9** | MAX **19.9**

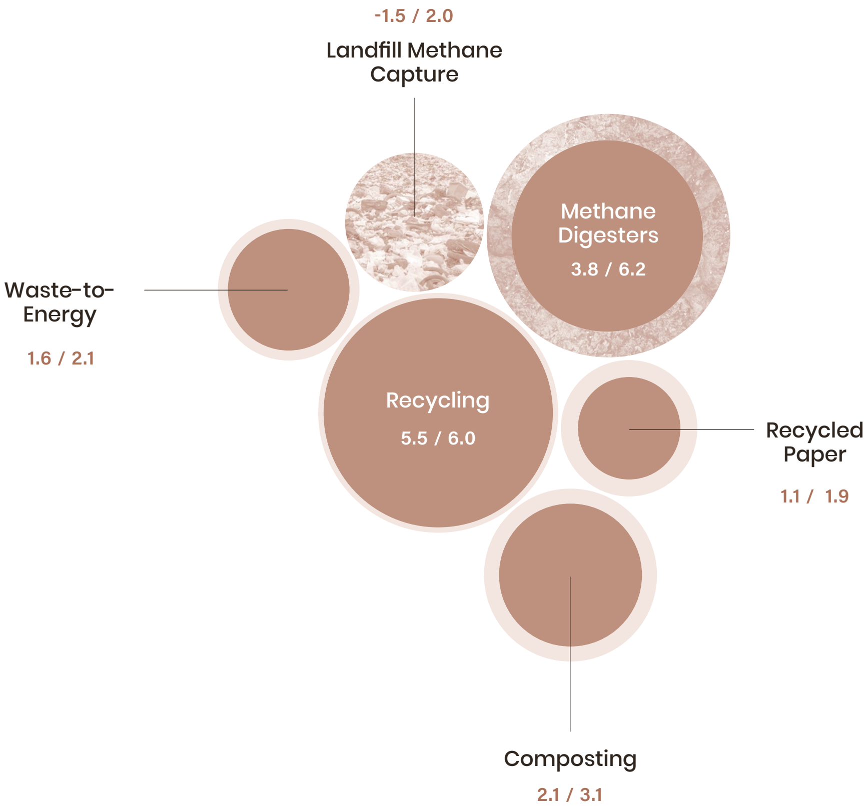
1

Address Refrigerants



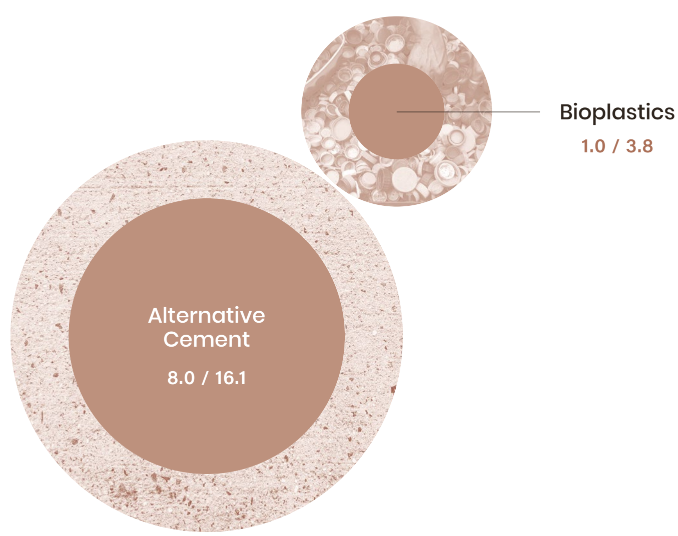
2

Use Waste



3

Improve Materials



SOLUTIONS

Improve Materials

Alternative Cement

Cement production requires significant energy and decarbonization of limestone. Fly ash, a waste product from burning coal, can replace some of that material and cut emissions.

Bioplastics

Most plastics are made from fossil fuels, but bioplastics utilize plants as an alternative source of carbon. They often have lower emissions and sometimes biodegrade.

A technician dismantles e-waste for recycling in Rwanda's Bugesera District.

Use Waste

**also in Electricity*

Composting

Composting can range from backyard bins to industrial-scale operations. Regardless, it converts organic waste into soil carbon, averting landfill methane emissions in the process.

Recycling

To produce new products from recovered materials requires fewer raw resources and less energy. That's how recycling household, commercial, and industrial waste can cut emissions.

Recycled Paper

Recycled paper takes a circular journey, rather than a linear flow from logging to landfill. Reprocessing used paper curtails extraction of virgin feedstock and lowers emissions.

Waste-to-Energy*

Waste-to-energy processes (incineration, gasification, pyrolysis) combust waste and convert it to heat and/or electricity. Emissions reductions come with health and environmental risks, however.

Landfill Methane Capture*

Landfills generate methane as organic waste decomposes. Rather than getting released as emissions, that methane can be captured and used to produce electricity.

Methane Digesters*

Industrial-scale anaerobic digesters control decomposition of organic waste and convert methane emissions into biogas, an alternative fuel, and digestate, a nutrient-rich fertilizer.

Address Refrigerants

**also in Buildings*

Refrigerant Management*

Fluorinated gases have a potent greenhouse effect and are widely used as refrigerants. Managing leaks and disposal of these chemicals can avoid emissions in buildings and landfills.

Alternative Refrigerants*

Fluorinated gases are not the only refrigerants available. Alternatives, such as ammonia or captured carbon dioxide, can replace these powerful greenhouse gases over time.

1.4

Transportation

Getting people or things from point A to point B, and perhaps back again: in some ways, transportation is incredibly simple. Human beings would be stuck at the speed of walk, run, swim, or horse if it weren't for planes, trains, automobiles, buses, bicycles, and boats. Mobility has played a critical and complex role in shaping society, and the demand for it is only growing.

Most of the energy driving mobility has, to date, been generated by burning liquid hydrocarbons, namely gasoline, diesel, and jet fuel. Why? Because of a formidable combination of energy density (the energy contained within a liter or gallon), abundance, and low cost. But account for what isn't included in that price, and petroleum-powered mobility is expensive indeed. Particulate matter harms human health. Oil spills ruin land and water. And then there's the cost to the climate system: transportation is responsible for 14% of global greenhouse gas emissions.[2]

How can we support the social good of mobility, but end its dependence on petroleum? In what ways do vehicles, infrastructure, and operations need to change to eliminate transportation emissions?

These are the questions society must answer if we want to keep moving—ourselves or other items—for reasons of necessity, pleasure, or commerce. Transportation solutions address alternatives, fuel efficiency, and electrification.

Shift to Alternatives

Alternative modes of mobility reduce demand for fossil-fueled transportation or replace it altogether. With public and "pooled" transit, we can make the most of available seats. Compact cities, intentional infrastructure, and advanced communication technologies make it possible to walk, cycle, or simply stay put.

Enhance Efficiency

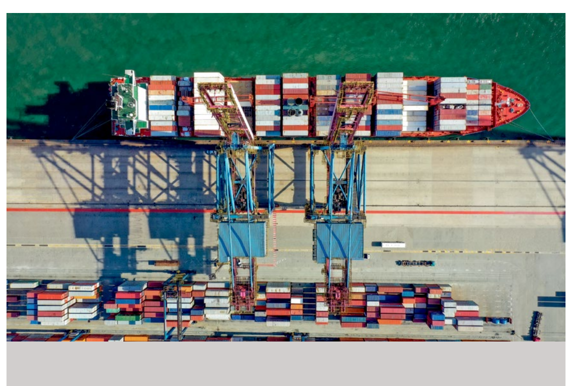
Where combustion engines remain in use, vehicles can be made far more fuel-efficient through mechanical improvements, lightweighting, better design, and more artful operation.

Electrify Vehicles

Electrification of vehicles completely replaces petroleum—and has even greater benefits when paired with renewable electricity generation.

These transportation solutions have the potential to save money and preempt pollution, but the transformations required are substantial and the sector can be slow to move. Vehicles remain in use for many years. New transportation infrastructure is expensive and takes time to build. Clean fuels for airplanes remain distant. But many of the solutions can, if done intelligently, create more equitable mobility and livability in our cities and communities, without forfeiting the stability of our climate.

The "L" in Chicago is one of the largest and busiest public transit systems in the United States.



A cargo ship docks in Guarujá, a coastal town near São Paulo, Brazil.

Here, you see the potential emissions impact of each subgroup for this sector, as well as the individual solutions therein. Solutions are scaled relative to one another within this sector. Each sector is individually scaled for legibility.

Minimum CO_2-eq (Gt) reduced/sequestered (2020-2050)

Maximum CO_2-eq (Gt) reduced/sequestered (2020-2050)

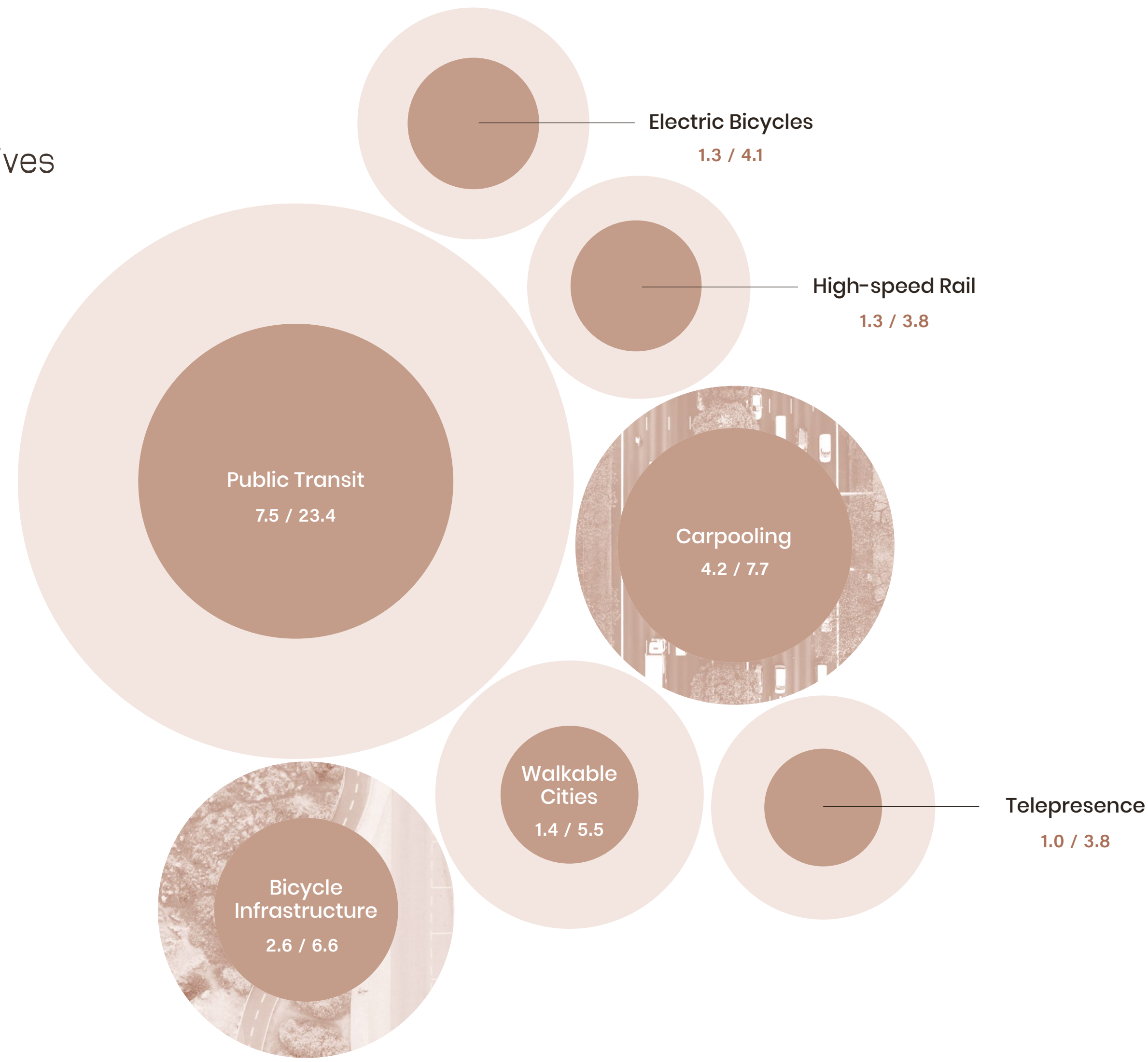
X / Y = Min / Max CO_2-eq (Gt) reduced/sequestered (2020-2050)

Overall Impact

Shift to Alternatives	MIN 19.3 | MAX 54.8
Enhance Efficiency	MIN 19.9 | MAX 33.1
Electrify Vehicles	MIN 12.0 | MAX 16.3

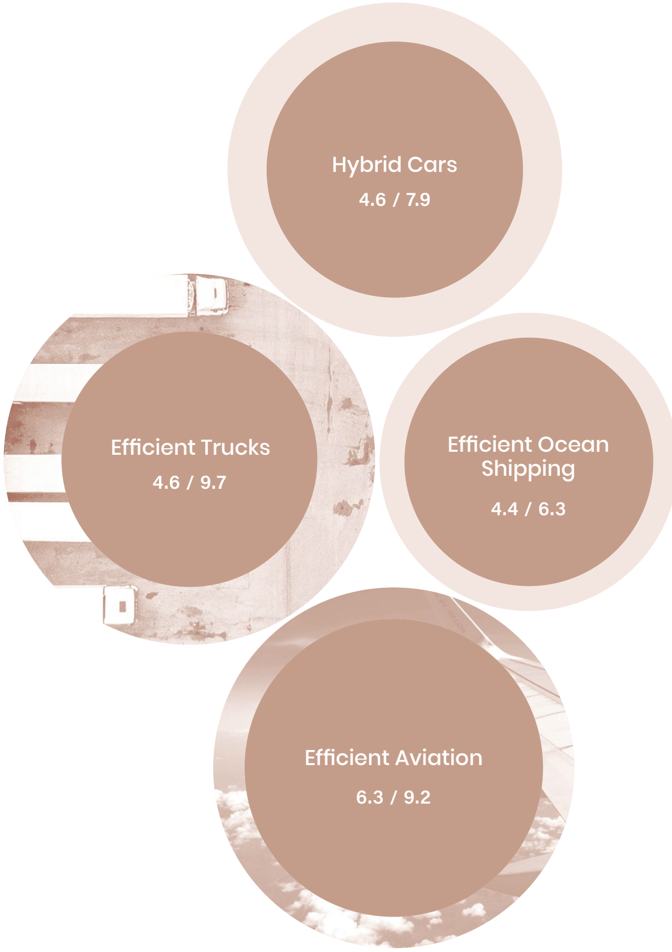
1

Shift to Alternatives



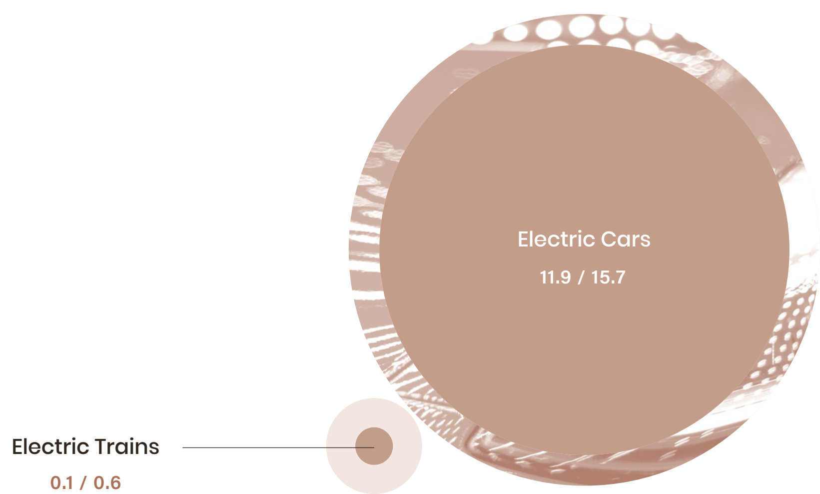
2

Enhance Efficiency



3

Electrify Vehicles



SOLUTIONS

Shift to Alternatives

Walkable Cities	Walkable cities use planning, design, and density to maximize walking and minimize driving, especially for commuting. Emissions decrease as pedestrians take the place of cars.
Bicycle Infrastructure	Bicycles offer an alternative to cars and fossil fuel transport, especially in cities. Infrastructure is essential for supporting safe and abundant bicycle use, thereby curbing emissions.
Electric Bicycles	Small battery-powered motors give electric bicycles a boost. It makes them a more compelling alternative to more polluting forms of motorized transport, namely cars.
Carpooling	When people share common origins, destinations, or stops en route, they can ride together. Carpooling uses seats and fuel more efficiently, cutting emissions.
Public Transit	Streetcars, buses, and subways offer alternative, efficient modes of transport. Public transit can keep car use to a minimum and avert greenhouse gases.
High-Speed Rail	High-speed rail offers an alternative to trips otherwise made by car or airplane. It requires special, designated tracks, but can dramatically curtail emissions.
Telepresence	Telepresence integrates high-performance visual, audio, and network technologies, so people can interact across geographies. It cuts down on travel—especially flying—and its emissions.

Enhance Efficiency

Hybrid Cars	A transitional technology, hybrid cars pair an electric motor and battery with an internal combustion engine. The combination improves fuel economy—more miles on a gallon—and lowers emissions.
Efficient Trucks	Fuel-efficiency is critical to reduce road-freight emissions. Existing fleets can be retrofitted, while new trucks can be built to be more efficient or fully electric.
Efficient Aviation	Various technologies and operational practices can lower airplane emissions to some degree. They include better engines, wingtips, and light weighting to improve fuel efficiency.
Efficient Ocean Shipping	Huge volumes of goods are shipped across oceans. Fuel-saving ship design, onboard technologies, and operational practices can improve efficiency and trim emissions.

Electrify Vehicles

Electric Cars	Electric motors supplant gasoline or diesel engines, which are polluting and less efficient. EVs always reduce car emissions—dramatically so when powered by renewable electricity.
Electric Trains	Rail electrification enables trains to move beyond dirty diesel-burning engines. When powered by renewables, electric trains can provide nearly emissions-free transport.

1.5 Buildings

Inside is where most people are most of the time. As central features of human life, buildings furnish space in which to dwell, gather, labor, trade, make, learn, heal, and revel. Of all the things we create, buildings are the largest, and they generally persist for decades, if not centuries. Already the world has more than 230 billion square meters of building space. Another 65 billion square meters could be added this decade.[6]

It's no surprise that buildings are major drivers of emissions. Some stem from the materials that comprise buildings and the process of construction, renovation, or demolition—what's known as "embodied carbon." Many more emissions are the result of ongoing use. Fuels are burned on site, primarily to heat space or water or for cooking. The chemicals used for cooling and refrigeration can escape as emissions. Through these direct, on-site sources buildings produce 6% of heat-trapping emissions worldwide.[2] Buildings also use more than half of all electricity, creating an off-site, upstream impact on electricity-generation emissions (as explored above).

How can we retrofit existing buildings and create new buildings to minimize energy use? How can we stop other, on-site sources of emissions?

These questions are at the heart of making buildings not only better for the planet, but also more affordable to operate and healthier, better places for the people inside and around them. Building solutions orient around energy efficiency, energy sources, and refrigerants.

A green roof in Leuven, Belgium, a city that has invested heavily in sustainability and liveability.

Enhance Efficiency

Whether for building retrofits or brand new construction, energy-efficiency solutions are largely the same. Many address the building "envelope" and insulation—means of keeping conditioned air in and unconditioned air out—while others use technology to optimize energy use.

Shift Energy Sources

Clean alternatives can replace more polluting fossil energy sources typically used to heat space, warm water, or prepare meals.

Address Refrigerants

The gases used as refrigerants today are potent greenhouse gases. We can reduce emissions by managing leaks that often happen within buildings, as well as properly disposing of refrigerants (a waste process that falls under industry, above). Ultimately, these fluorinated gases can be replaced with alternatives that are not greenhouse gases.

Many building solutions reduce on-site emissions and enhance electricity efficiency, reducing emissions at the power plant. Taken together, these solutions can transition buildings from being a major problem to potentially net-positive, as the "greenest" buildings can produce more energy than they consume. These solutions can also help ease the "energy burden" many low-income households face, as energy bills often eat up a significant and disproportionate percentage of income.

Biogas cookstoves can improve indoor air quality, protect forests, and prevent emissions.

Here, you see the potential emissions impact of each subgroup for this sector, as well as the individual solutions therein. Solutions are scaled relative to one another within this sector. Each sector is individually scaled for legibility.

Minimum CO_2-eq (Gt) reduced/sequestered (2020–2050)

Maximum CO_2-eq (Gt) reduced/sequestered (2020–2050)

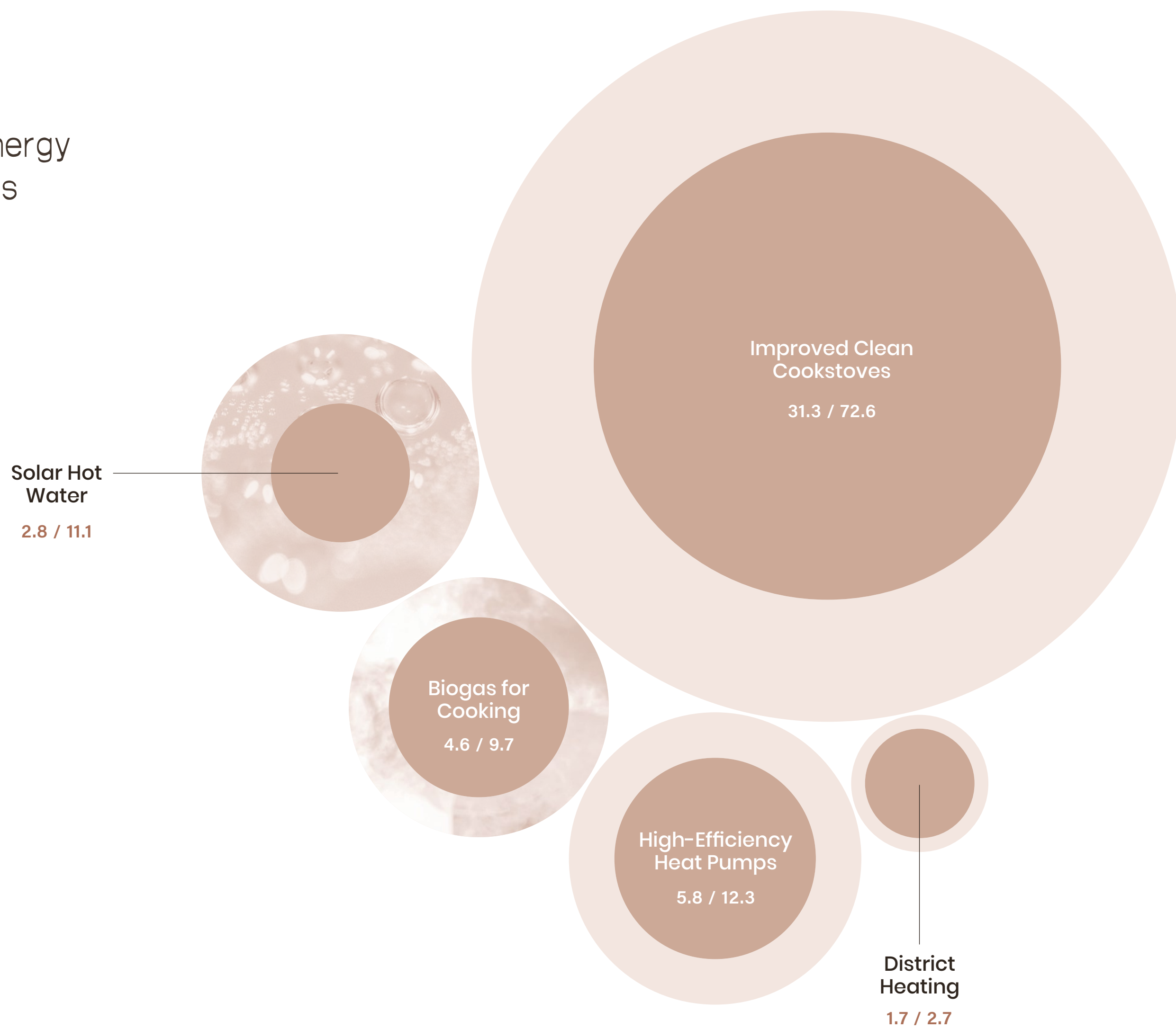
X / Y = Min / Max CO_2-eq (Gt) reduced/sequestered (2020–2050)

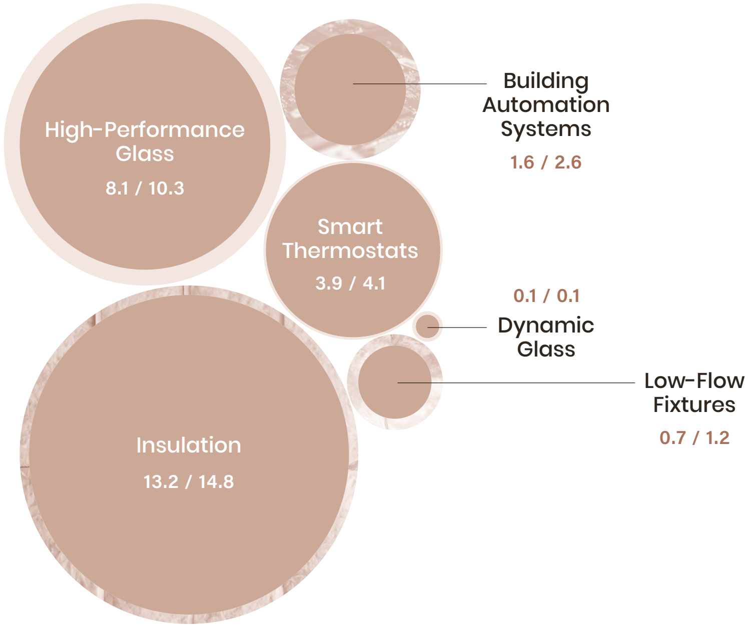
Overall Impact

Shift Energy Sources	MIN **46.3** | MAX **108.4**
Enhance Efficiency	MIN **27.4** | MAX **32.9**
Address Refrigerants	N/A

1

Shift Energy Sources





2

Enhance Efficiency

Building Retrofitting N/A

Net-Zero Buildings N/A

Green & Cool Roofs -0.2 / -0.1

Insulation, a key energy-efficiency measure, gets installed in Montreal, Canada.

3

Address Refrigerants

Refrigerant Management N/A

Alternative Refrigerants N/A

NOTE: Where a solution's impact is N/A, emissions reductions are allocated to other solutions. (See more below.)

NOTE: All refrigerant-related emissions reductions are allocated within Industry.

SOLUTIONS

Enhance Efficiency

also in Electricity

Smart Thermostats*

Thermostats are mission control for space heating and cooling. Smart thermostats use algorithms and sensors to become more energy efficient over time, lowering emissions.

Building Automation Systems*

These systems can control heating, cooling, lighting, and appliances in commercial buildings. They cut emissions by maximizing energy efficiency and minimizing waste.

Insulation*

Insulation impedes unwanted airflow in or out of buildings. In new construction or retrofits, it makes heating and cooling more energy efficient, with lower emissions.

Dynamic Glass*

By responding to sunlight and weather, dynamic glass can reduce a building's energy load for heating, cooling, and lighting. More effective windows lower emissions.

High-Performance Glass*

High-performance glass improves window insulation and makes building heating and cooling more efficient. By minimizing unnecessary energy use, it curtails emissions.

Green & Cool Roofs*

Green roofs use soil and vegetation as living insulation. Cool roofs reflect solar energy. Both reduce building energy use for heating and/or cooling.

Low-Flow Fixtures*

Cleaning, transporting, and heating water requires energy. More efficient fixtures and appliances can reduce home water use significantly, thereby reducing emissions.

Enhance Efficiency + Shift Energy Sources

also in Electricity

NOTE: These solutions represent an integration or system of other solutions. Emissions reductions associated with building retrofitting and net-zero buildings are accounted for in those individual solutions.

Building Retrofitting*

Retrofits address electricity and fuel waste with better insulation and windows, efficient lighting, and advanced heating and cooling systems. Improved efficiency lowers existing buildings' emissions.

Enhance Efficiency + Shift Energy Sources (cont.)

Net-Zero Buildings*

Buildings with zero net energy consumption combine maximum efficiency and onsite renewables. They produce as much energy as they use annually, with low or no emissions.

Shift Energy Sources

**also in Electricity*

District Heating*

District systems heat space and water more efficiently. A central plant and pipe network channel hot water to many buildings, with lower emissions than on-site systems.

High-Efficiency Heat Pumps*

Heat pumps extract heat from the air and transfer it—from indoors out for cooling, or from outdoors in for heating. With high efficiency, they can dramatically lower building energy use.

Solar Hot Water*

Solar hot water taps the sun's radiation, rather than fuel or electricity. By replacing conventional energy sources with a clean alternative, they reduce emissions.

Biogas for Cooking

Anaerobic digesters process backyard or farmyard organic waste into biogas and digestate fertilizer. Biogas stoves can reduce emissions when replacing biomass or kerosene for cooking.

Improved Clean Cookstoves

Improved clean cookstoves can address the pollution from burning wood or biomass in traditional stoves. Using various technologies, they reduce emissions and protect human health.

Address Refrigerants

**also in Industry*

NOTE: All refrigerant-related emissions reductions are allocated within Industry.

Refrigerant Management*

Fluorinated gases have a potent greenhouse effect and are widely used as refrigerants. Managing leaks and disposal of these chemicals can avoid emissions in buildings and landfills.

Alternative Refrigerants*

Fluorinated gases are not the only refrigerants available. Alternatives, such as ammonia or captured carbon dioxide, can replace these powerful greenhouse gases over time.

1.6 Other

10% of global greenhouse gas emissions fall under the category of "other"—additional emissions mainly related to the production and use of fossil fuels.[2]

Before coal, oil, or natural gas is burned, there is mining, extraction, refining, processing, storage, and transport. All of these processes within the energy system also generate heat-trapping emissions. Methane, for example, escapes from natural gas wells and pipelines as "fugitive emissions." As we work toward a clean energy future, this sector of emissions also requires solutions in the years of transition, to minimize damage while fossil fuels remain in the mix. Ending their use, quickly and comprehensively, is the true solution.

NOTE: Project Drawdown has not assessed solutions in this sector to date.

Gas flaring—burning off methane—is a common practice in fossil fuel drilling, fracking, refining, and processing, which generates significant carbon dioxide emissions, along with other toxic pollutants. Leaks and venting—intentionally releasing gas directly into the air—are less visible and even more damaging to the atmosphere, as pure methane is a far more potent greenhouse gas.

2

Support Sinks

uplifting nature's carbon cycle

2.1

Land Sinks

Land is a critical component of the climate system, actively engaged in the flows of carbon, nitrogen, water, and oxygen—essential building blocks for life. Carbon is the core of trees and grasses, mammals and birds, lichens and microbes. Linking one atom to the next, and to other elements, it's the fundamental material of all living organisms. Plants and healthy ecosystems have an unparalleled capacity to absorb carbon through photosynthesis and store it in living biomass.

In addition, soils are, in large part, organic matter—once-living organisms, now decomposing—making them an enormous storehouse of carbon. Land can therefore be a powerful carbon sink, returning atmospheric carbon to living vegetation and soils. While the majority of heat-trapping emissions remain in the atmosphere, land sinks currently return 26% of human-caused emissions to earth—literally.[4]

How can we help sequester more carbon in biomass and soil? What can we do to support and enhance natural processes, including the capacity of land to renew?

These questions matter not only for emissions but for a diversity of human needs—and for maintaining a healthy diversity of flora and fauna. Because soil with more carbon content can also be more productive and resilient, these questions are critical for building a thriving food system, too.

Climate solutions that enhance land-based sinks cluster around waste and diets, ecosystem protection and restoration, improved agriculture practices, and prudent use of degraded land.

NOTE: Land sinks absorb roughly 29% of the carbon dioxide emissions pumped into the atmosphere each year. When we consider other greenhouse gases, including methane, nitrous oxide, and fluorinated gases, land absorbs approximately 26% of the total emissions. (Global Carbon Project analysis adjusted to include all greenhouse gases at 100-year global warming potential.)

A model farm in Yangambi, DRC, aims to improve yields, food security, and prevent deforestation of the country's vast tropical forest.

Address Waste & Diets

Reducing food waste and shifting to plant-rich diets are two critical interventions to prevent deforestation. Lower demand for food and farmland spares nature from additional clearing, indirectly protecting carbon sinks.

Protect & Restore Ecosystems

"Let nature be nature" is a powerful principle—let peatlands, grasslands, and forests continue to do what they do best by protecting them from human disturbance. Where ecosystems have been degraded, restoration can help them recuperate form and function, including absorbing and storing more carbon over time.

Shift Agriculture Practices

What and how we grow, graze, or harvest can be a means to cultivate biomass and regenerate soil carbon. An array of "regenerative agriculture" methods are being rediscovered and developed worldwide, and show promising results. The integration of trees into farming through agroforestry practices is particularly powerful. All solutions that sustainably raise yields on existing farmland can also reduce the pressure to clear other areas.

Use Degraded Land

Lastly, degraded lands can be put to use in ways that revive productivity, increase biomass, and promote soil carbon sequestration—all while producing wood, fiber, or food.

There is significant overlap in the solutions that stop land-based sources of greenhouse emissions and those that support land-based carbon sinks. Their unique power is doing both at the same time. All of them are critical to coming back into balance with the planet's living systems.

Bamboo can thrive—and sequester carbon—on inhospitable degraded lands.

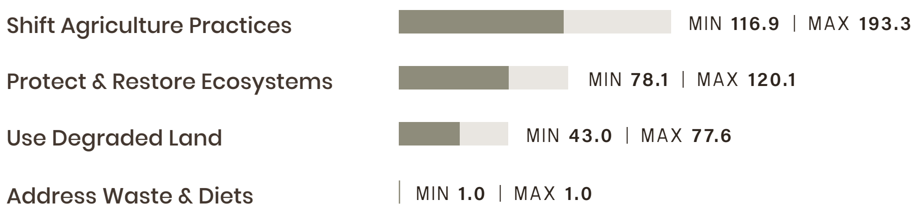
Here, you see the potential emissions impact of each subgroup for this sector, as well as the individual solutions therein. Solutions are scaled relative to one another within this sector. Each sector is individually scaled for legibility.

Minimum CO_2-eq (Gt) reduced/sequestered (2020-2050)

Maximum CO_2-eq (Gt) reduced/sequestered (2020-2050)

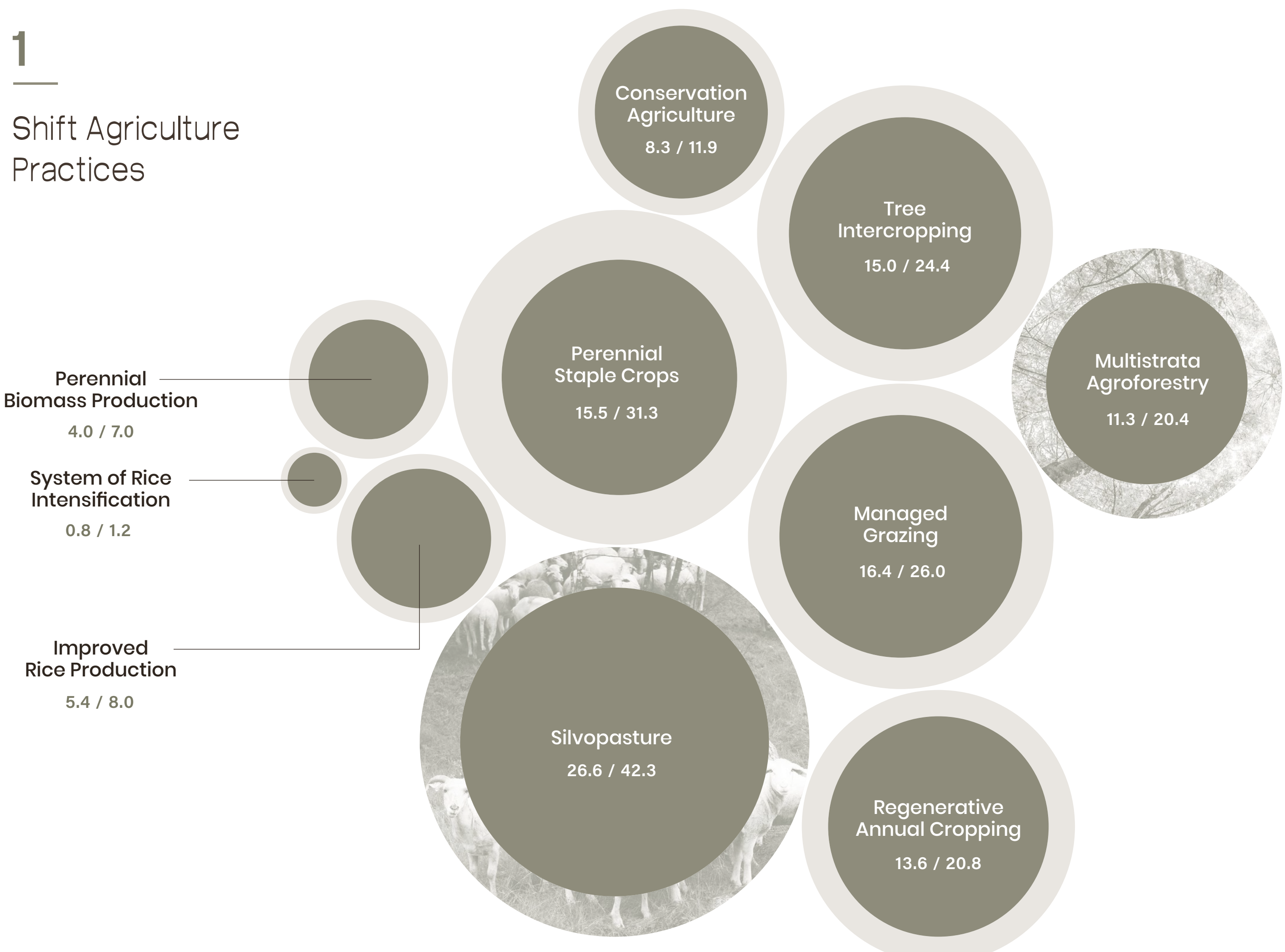
X / Y = Min / Max CO_2-eq (Gt) reduced/sequestered (2020-2050)

Overall Impact



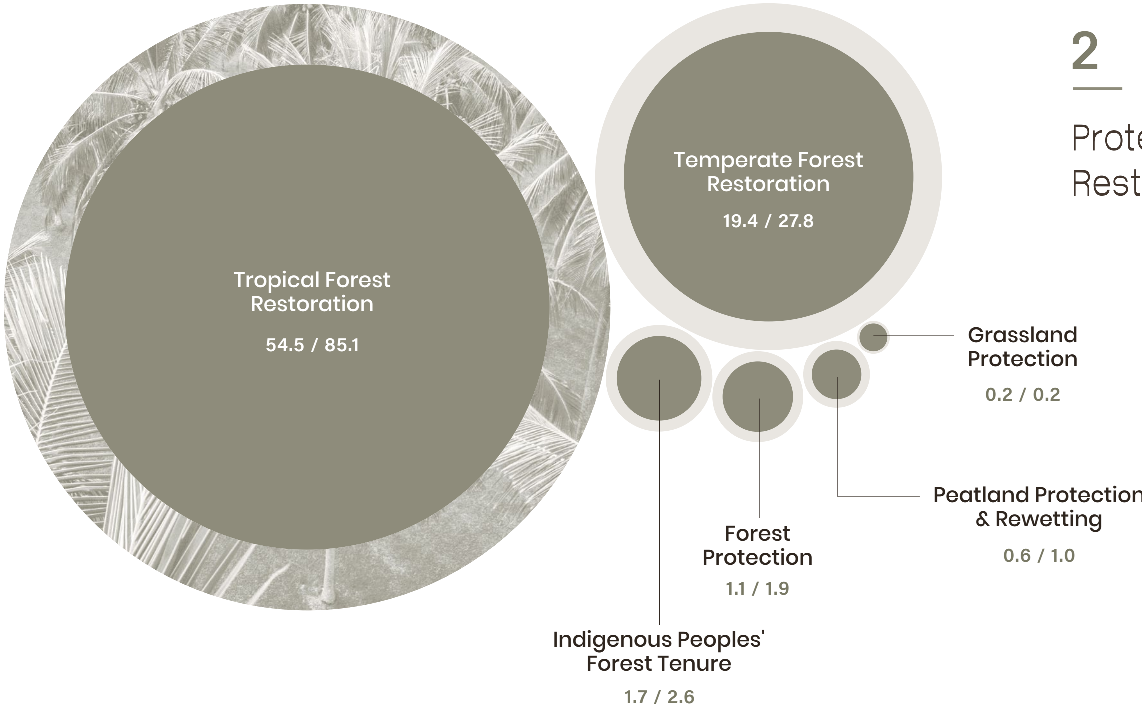
1

Shift Agriculture Practices



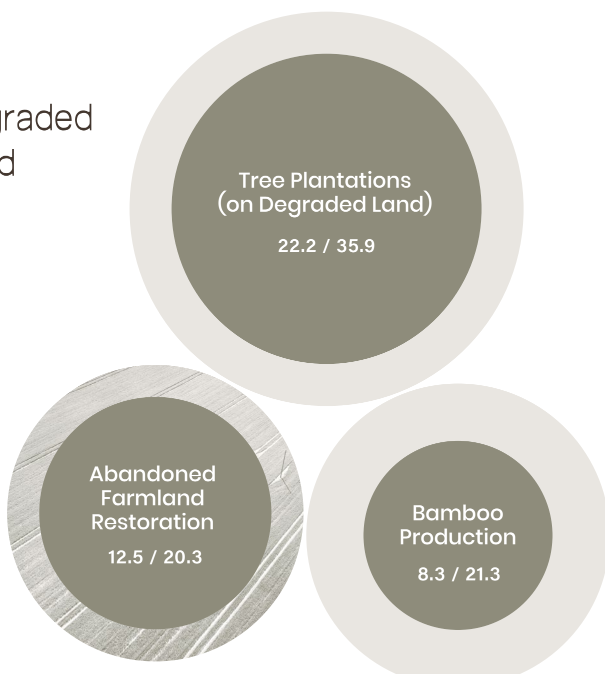
2

Protect & Restore Ecosystems



3

Use Degraded Land

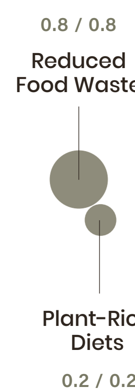


4

Protect & Restore Ecosystems + Shift Agriculture Practices

5

Address Waste & Diets



SOLUTIONS

Address Waste & Diets

**also in Food, Agriculture & Land Use*

Plant-Rich Diets*

Consumption of meat and dairy, as well as overall calories, often exceeds nutritional recommendations. Paring down and favoring plant-based foods reduces demand, thereby reducing land clearing, fertilizer use, burping cattle, and greenhouse gas emissions.

Reduced Food Waste*

Roughly a third of the world's food is never eaten, which means land and resources used and greenhouse gases emitted in producing it were unnecessary. Interventions can reduce loss and waste, as food moves from farm to fork, thereby reducing overall demand.

Protect & Restore Ecosystems

**also in Food, Agriculture & Land Use*

Forest Protection*

In their biomass and soil, forests are powerful carbon storehouses. Protection prevents emissions from deforestation, shields that carbon, and enables ongoing carbon sequestration.

Indigenous Peoples' Forest Tenure*

Secure land tenure protects indigenous peoples' rights. With sovereignty, traditional practices can continue—in turn protecting ecosystems and carbon sinks and preventing emissions from deforestation.

Temperate Forest Restoration

Almost all temperate forests have been altered in some way—timbered, converted to agriculture, disrupted by development. Restoring them sequesters carbon in biomass and soil.

Tropical Forest Restoration

Tropical forests have suffered extensive clearing, fragmentation, degradation, and depletion of biodiversity. Restoring these forests also restores their function as carbon sinks.

Grassland Protection*

Grasslands hold large stocks of carbon, largely underground. Protecting them shields their carbon stores and avoids emissions from conversion to agricultural land or development.

Peatland Protection & Rewetting*

Forestry, farming, and fuel-extraction are among the threats to carbon-rich peatlands. Protection and rewetting can reduce emissions from degradation, while supporting peatlands' role as carbon sinks.

Protect Ecosystems + Shift Agriculture Practices

**also in Food, Agriculture & Land Use*

Sustainable Intensification for Smallholders*

Sustainable intensification practices can increase smallholder yields, which, in theory, reduce demand to clear additional land. Practices include intercropping, ecosystem-based pest management, and equal resources for women.

Shift Agriculture Practices

**also in Food, Agriculture & Land Use*

Conservation Agriculture*

Conservation agriculture uses cover crops, crop rotation, and minimal tilling in the production of annual crops. It protects soil, avoids emissions, and sequesters carbon.

Regenerative Annual Cropping*

Building on conservation agriculture with additional practices, regenerative annual cropping can include compost application, green manure, and organic production. It reduces emissions, increases soil organic matter, and sequesters carbon.

Managed Grazing

Managed grazing involves carefully controlling livestock density, and timing and intensity of grazing. Compared with conventional pasture practices, it can improve the health of grassland soils, sequestering carbon.

Silvopasture

An agroforestry practice, silvopasture integrates trees, pasture, and forage into a single system. Incorporating trees improves land health and significantly increases carbon sequestration.

Multistrata Agroforestry

Multistrata agroforestry systems mimic natural forests in structure. Multiple layers of trees and crops achieve high rates of both carbon sequestration and food production.

Tree Intercropping

Growing trees and annual crops together is a form of agroforestry. Tree intercropping practices vary, but all increase biomass, soil organic matter, and carbon sequestration.

Perennial Staple Crops

Perennial staple crops provide important foods, such as bananas, avocado, and breadfruit. Compared to annual crops, they have similar yields but higher rates of carbon sequestration.

A researcher tests soils in western Kenya, to assess the impact of minimum tillage, integrated soil fertility management, and other farming practices.

SOLUTIONS

Shift Agriculture Practices (cont.)

**also in Food, Agriculture & Land Use*

Perennial Biomass Production	Bioenergy relies on biomass—often annual crops such as corn. Perennial plants (e.g., switchgrass, silvergrass, willow, eucalyptus) are a more sustainable source and sequester modest amounts of soil carbon.
Improved Rice Production*	Flooded rice paddies produce large quantities of methane. Improved production techniques, including alternate wetting and drying, can reduce methane emissions and sequester carbon.
System of Rice Intensification*	SRI is a holistic approach to sustainable rice cultivation. By minimizing water use and alternating wet and dry conditions, it minimizes methane production and emissions.

Use Degraded Land

Abandoned Farmland Restoration	Degraded farmland is often abandoned, but need not be. Restoration can bring these lands back into productivity and sequester carbon in the process.
Tree Plantations (on Degraded Land)	Degraded lands present potential locations for tree plantations. Managed well, they can restore soil, sequester carbon, and produce wood resources in a more sustainable way.
Bamboo Production	Bamboo rapidly sequesters carbon in biomass and soil and can thrive on degraded lands. Long-lived bamboo products can also store carbon over time.

2.2

Coastal & Ocean Sinks

Ours is a water world. Though Earth has a land-centric name, oceans cover 71% of its surface and make land livable.[7] Some of the planet's most critical processes happen where sea and air meet, as oceans absorb and redistribute heat and carbon—both rising due to the glut of emissions in the atmosphere.

Oceans have absorbed at least 90% of the excess heat generated by recent climate changes, and, since the 1980s, have taken up 20-30% of human-created carbon dioxide.[7] The latter happens through the biological processes of photosynthesis and building calcium carbonate shells, and through simple chemistry, as carbon dioxide dissolves in seawater. Coastal and ocean sinks bring 17% of all heat-trapping emissions back to Earth.[4]

While this uptake of heat and carbon has buffered the planet from more severe climate change, oceans are paying a steep price. How so? Water temperatures, marine heat waves, and sea levels are rising. More carbon dioxide in seawater makes the ocean more acidic and less hospitable for shellfish to build shells or coral to build their skeletons. Oxygen levels in ocean water have already declined somewhat. In the future, biomass production through photosynthesis may also drop, destabilizing the base of the food chain. What's more, with fewer organisms alive, fewer would die and sink into the deep ocean, carrying their carbon with them.

What practices can be used to sequester carbon in coastal, marine, and open ocean environments? How can human activity support and enhance natural processes?

These questions are vital for addressing emissions but also for shoring up oceans' life-sustaining role. Even as oceans suffer, they also are home to significant solutions. Solutions for coastal and ocean sinks center on ecosystem protection and restoration and improved agriculture practices.

Protect & Restore Ecosystems

Protecting ecosystems—including mangroves, salt marshes, and seagrass meadows—supports ongoing photosynthesis and carbon storage. Because these "blue carbon" ecosystems have been lost or degraded in many places, restoration also has a vital role to play.

Shift Agriculture Practices

Along coasts and in the open ocean, select regenerative practices may augment natural carbon sequestration from seaweed and kelp, while growing fiber and food from the sea.

Oceans will continue to be on the frontlines of climate change, as will people who live near them. Solutions focused on coastal and marine sinks can provide additional benefits from storm protection to healthy fisheries. It's impossible to separate blue and green, land and sea. They, and we, are fundamentally intertwined.

NOTE: Project Drawdown has assessed a very limited selection of coastal and ocean solutions to date. This solution set will expand in the future (e.g., solutions for regenerative ocean farming and marine ecosystem restoration).

Above: Planting mangroves as part of a blue carbon project on the Persian Gulf.

Left: Kelp forests along the Southern California coast have benefitted from restoration efforts but continue to struggle amidst warming waters.

Here, you see the potential emissions impact of each subgroup for this sector, as well as the individual solutions therein. Solutions are scaled relative to one another within this sector. Each sector is individually scaled for legibility.

Minimum CO_2-eq (Gt) reduced/sequestered (2020-2050)

Maximum CO_2-eq (Gt) reduced/sequestered (2020-2050)

X / Y = Min / Max CO_2-eq (Gt) reduced/sequestered (2020-2050)

Overall Impact

Protect & Restore Ecosystems | MIN **1.1** | MAX **1.5**

1

Protect & Restore Ecosystems

NOTE: This sector is significantly magnified for legibility.

SOLUTIONS

Protect & Restore Ecosystems

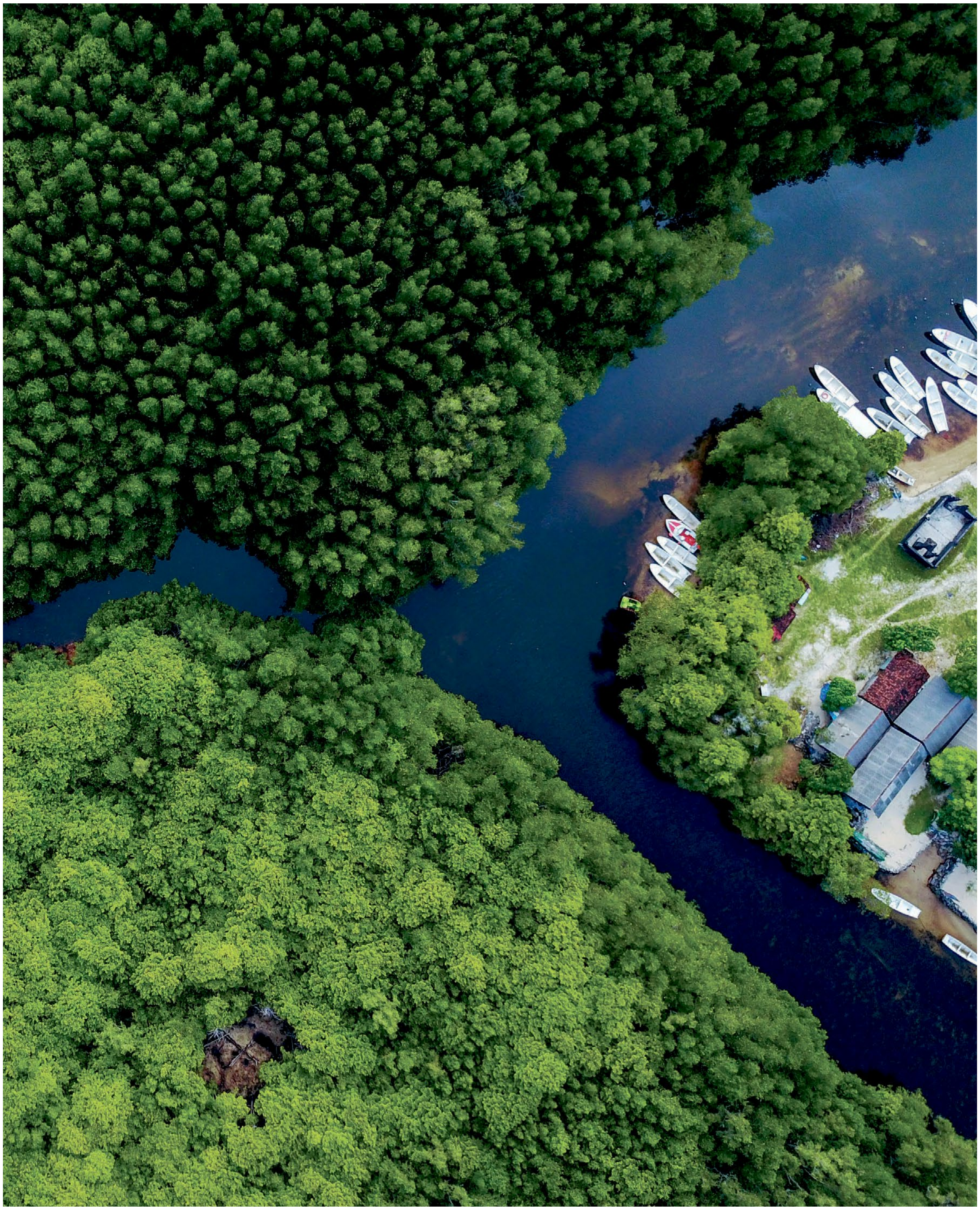
**also in Food, Agriculture & Land Use*

Coastal Wetland Protection*

Mangroves, salt marshes, and seagrasses sequester huge amounts of carbon in plants and soil. Protecting them inhibits degradation and safeguards their carbon sinks.

Coastal Wetland Restoration

Agriculture, development, and natural disasters have degraded many coastal wetlands. Restoring mangrove forests, salt marshes, and seagrass beds to health revives carbon sequestration.



Mangrove forest on the island of Nusa Lembongan, off the coast of Bali.

2.3 Engineered Sinks

Can human engineering play a supporting role to nature? That's a question that grows in relevance and urgency, given the gap between where global emissions stand and where they need to be, posthaste. The sheer quantity of excess greenhouse gases means natural processes can't do it all when it comes to carbon sequestration. Select nascent technologies show some promise to supplement terrestrial, coastal, and ocean sinks.

Remove carbon. Do something with it. Those are the central premises of engineered sinks. Remove can mean pulling carbon from the concentrated exhaust of a power plant or industrial process, which falls under the umbrella of "carbon capture." Remove can also mean pulling carbon out of the air, where it's much less concentrated.

Where carbon goes next is the other critical piece of the equation. It can be stored or buried—pairing "capture" and "storage." Carbon can also be used—cycled quickly, perhaps for adding bubbles to a beverage or to make more sustainable jet fuels. Or it can be locked up for a long while, perhaps in concrete or through the ancient practice of baking biomass into biochar, then buried. This so-called "semi-permanent sequestration" is most powerful.

Could recaptured carbon become a commodity? Something of value? Perhaps. For now, solutions in this sector are "coming attractions," and issues of cost, scale, and the energy required all remain in the balance.

NOTE: Project Drawdown has assessed a very limited set of solutions for engineered sinks to date. This solution set will expand in the future (e.g., direct air capture).

Here, you see the potential emissions impact of each subgroup for this sector, as well as the individual solutions therein. Solutions are scaled relative to one another within this sector. Each sector is individually scaled for legibility.

Minimum CO_2-eq (Gt) reduced/sequestered (2020-2050)

Maximum CO_2-eq (Gt) reduced/sequestered (2020-2050)

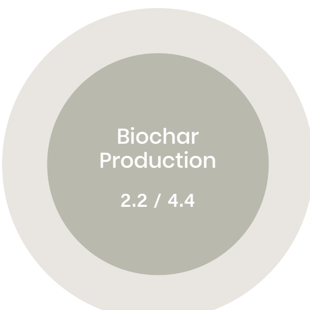
X / Y = Min / Max CO_2-eq (Gt) reduced/sequestered (2020-2050)

Overall Impact

Remove & Store Carbon MIN **2.2** | MAX **4.4**

1

Remove & Store Carbon



NOTE: This sector is significantly magnified for legibility.

Biochar produced from forest waste in Dillard, Oregon, with the aim of sequestering carbon and enhancing soil.

SOLUTIONS

Remove & Store Carbon

**also in Food, Agriculture & Land Use*

Biochar Production

Biomass slowly baked in the absence of oxygen becomes biochar, retaining most of the feedstock's carbon. It can be buried for sequestration and potentially enrich soil.

3 Improve Society

fostering equality for all

Health & Education

Climate solutions are never just climate solutions. Those that move the world beyond fossil fuels toward clean energy also bring down air pollution, perhaps the world's worst health crisis.

Many of the agricultural practices that regenerate soil can be a boon for farmers and ranchers and foster a more resilient food system. The benefits of protecting and restoring ecosystems go well beyond carbon sequestration and storage. Many solutions can be wisely designed and employed to meet near-term needs—affordable energy, nutritious food, good jobs, storm protection, clean water, community, or beauty, for example—while advancing the long-term aim of reaching Drawdown. That's *multi-solving.*

Other initiatives, designed primarily to ensure rights and foster equality, can also have cascading benefits to climate change. For example, where indigenous peoples' land rights are protected, so too are culture, traditional practices, and forest ecosystems. The ripple effects of indigenous peoples' forest tenure are vital to all life on Earth. Similarly, access to high-quality, voluntary reproductive healthcare and to high-quality, inclusive education are fundamental human rights and cornerstones of gender equality. In more indirect ways, making strides in health and education can also benefit the climate—discussed in more detail below. **Climate and social systems are profoundly connected, and those connections open up solutions that are often overlooked.**

3.1
Health & Education

How many people might call this planet home in 2050 or 2100? That will depend, in large part, on fertility rates and the headway we make on securing gender equality and advancing human well-being. When levels of education rise (in particular for girls and young women), access to reproductive health-care improves, and women's political, social, and economic empowerment expand, fertility typically falls.[8] Across the world and over time, this impacts population.

Currently, we humans number 7.7 billion, and the United Nations estimates the human family will grow to between 9.4 billion and 10.1 billion in 2050.[8] As we consider the future of climate solutions, it matters how many people will be eating, moving, plugging in, building, buying, using, wasting, and all the rest. Population interacts with the primary drivers of emissions: production and consumption, largely fossil-fueled.

It's critical to note the vast disparities in emissions from high-income countries compared to low, and between the wealthiest individuals and those of lesser financial means. For example, almost half of consumption-related emissions are generated by just 10% of people globally.[9] The topic of population also raises the troubling, often racist, classist, and coercive history of population control. People's choices about how many children to have should be theirs and theirs alone. And those children should inherit a livable planet. It is critical that human rights are always centered, that gender equality is the aim, and that benefits to the planet are understood as positive ripple effects of access and agency.

In its most recent report on "world population prospects," the United Nations notes that the international community has committed to ensuring that all people have access to family planning, should they wish to use it, and the ability to decide how many children to have and when.[10] That can mean changes in everything from contraception to culture. Living up to those commitments will be a major determinant for which possible trajectory becomes our path forward.

Here, you see the potential emissions impact of each subgroup for this sector, as well as the individual solutions therein. Solutions are scaled relative to one another within this sector. Each sector is individually scaled for legibility.

Minimum CO_2-eq (Gt) reduced/sequestered (2020-2050)

Maximum CO_2-eq (Gt) reduced/sequestered (2020-2050)

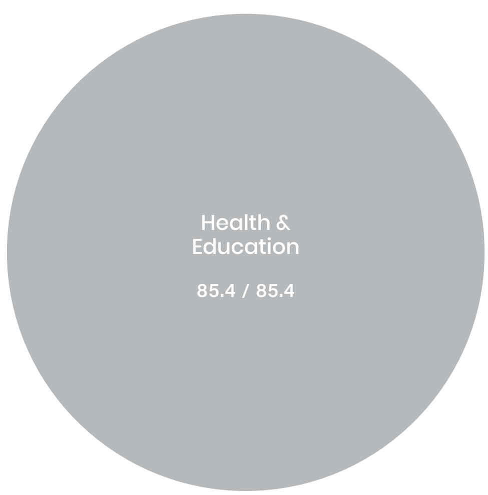
X / Y = Min / Max CO_2-eq (Gt) reduced/sequestered (2020-2050)

Overall Impact

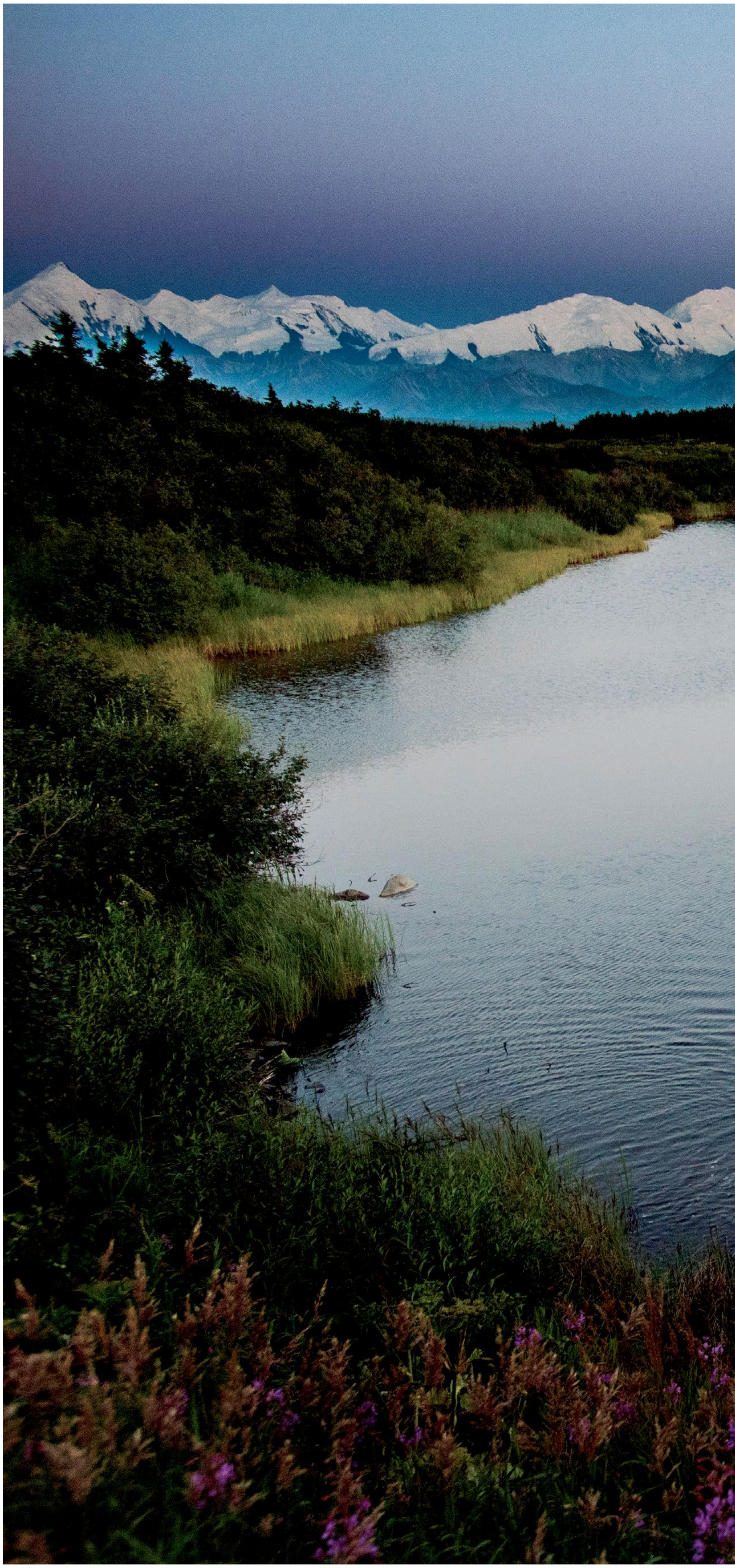
Remove & Store Carbon — MIN 85.4 | MAX 85.4

1

Health & Education



Above: A student attends secondary school in the Absheron District of Azerbaijan.



Solutions *Beyond* the Drawdown List

Project Drawdown has assessed an extensive but not exhaustive set of global climate solutions, as presented here. We continue to add to it as we review and quantify the potential of solutions to stop emissions and/or support sinks, as well as broader societal transformations that also have climate benefits. Among them are what we dubbed "coming attractions" in *Drawdown*—practices and technologies that are nascent but look to have promise, pending further development and investigation. Project Drawdown's assessment of solutions will continue to be a living project.

Our analysis depends on the availability of critical inputs—namely robust data and peer-reviewed research. Some solutions get outsized attention from the research community, while others may be undervalued or passed over. Synthesis is only as inclusive and robust as the information being synthesized. We acknowledge those limitations and encourage research on an increasingly broad solution set, especially solutions emerging from impacted and frontline communities.

Other climate solutions are clearly powerful but more systemic in nature and challenging to quantify, such as resisting the development of new fossil fuel infrastructure, increasing overall urban density, or reducing consumption through sharing, repair, and re-use. Project Drawdown recognizes the limitations of the scope of our analysis here, too. A broad aperture for solutions is vital, and we continue to evolve approaches that support it.

A moose wades in waters at Denali National Park and Preserve, Alaska.

Assessing Solutions

Project Drawdown's analysis seeks to determine whether reaching Drawdown—*the future point in time when levels of greenhouse gases in the atmosphere stop climbing and start to steadily decline*—is possible using existing, well-proven climate solutions. To uncover that answer, we review and evaluate the potential performance of diverse technologies and practices that reduce greenhouse gas emissions and/or increase carbon sequestration from the atmosphere. All of these climate solutions are financially viable and already scaling, at least in some places.*

Drawdown fellows analyze solutions, drawing upon years of advanced study, experience, and a wide range of backgrounds. For each technology or practice, we review extensive literature and data describing its potential scale, impact, and cost. We then build analytical models to estimate how many gigatons of carbon dioxide (or equivalent amounts of other greenhouse gases)** a given solution could avoid and/or remove over time, as well as the cost of implementing and operating it. We use conservative estimates of the financial cost and emissions impact for each solution. In other words, assumptions about costs fall on the high end, while assumptions about emissions reductions or sequestration rates fall on the low end.

Throughout our analysis, the total CO_2-eq reduced/sequestered is based on the number of "solution units" (e.g., number of new wind turbines installed, number of new hectares of forests protected) active between 2020–2050. "First cost" refers to the cumulative cost to purchase and install those solution units—in other words, the implementation cost. "Lifetime cost" is the cost to operate those units throughout a lifetime of use. (For some solutions, financial data is insufficient or unavailable.)‡

Each solution's impacts and costs are then compared to the current practices or technologies it replaces. We call this a baseline scenario—a world where few or no new climate solutions are adopted. For example, the potential emissions reductions from onshore wind turbines are based on comparison to using fossil fuel power plants for electricity generation. Costs for installing and operating those turbines are also compared to fossil fuel plants. The "net" difference results from comparison to the emissions or costs of the baseline scenario.

To establish a baseline scenario, we use the work of the AMPERE Project. Their baseline scenario of future energy use, land use, and greenhouse gas emissions illustrates a possible future where no new climate action is taken—a future with rising emissions, elevated greenhouse gas levels in the atmosphere, and continued strong warming for decades. (See more at www.ampere-h2020.eu.)

The individual "bottom-up" solution models can be run in isolation, but we also integrate the models within and across multiple sectors. This allows us to consider how the ensemble of solutions might work together, reducing emissions, sequestering carbon, and moving the world toward Drawdown. Model integration ensures that resource constraints are accounted for (e.g., available land for forests or crops), avoids any double-counting of impacts from overlapping solutions (e.g., different modes of transportation), and addresses interaction between solutions where possible (e.g., increasing demand for electricity from electric vehicles or electric heat pumps).

After integration, the results are totaled to determine if and when we reach Drawdown and at what cost (or savings) for implementation and operation.

** It is important to note that while we evaluate a wide range of solutions, across many sectors, we do not consider all possible climate solutions. Given the methods used, we cannot evaluate promising new technologies or emerging solutions where sufficient data is not yet available.*

*** Carbon dioxide (CO_2) is not the only greenhouse gas. Other heat-trapping gases include methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (e.g., HFCs). Each has long-term impacts on climate, depending on how much of it is in the atmosphere, how long it remains there, and how much heat it traps during its lifetime. Based on these factors, we can calculate the global warming potential of each greenhouse gas, which makes it possible to have a "common currency," translating any given gas into its equivalent in carbon dioxide over a 100-year period.*

‡ It is important to note that we do not evaluate additional savings from the climate-driven damages we might avoid by reaching Drawdown. This could represent extremely large savings and avoid incalculable non-monetary impacts.

An inspector rappels down the blades of a 3 megawatt wind turbine in Boulder, Colorado.

Reaching Drawdown

Project Drawdown uses different scenarios to assess what determined, global efforts to address climate change might look like. These scenarios represent various levels of ambition in bringing the set of climate solutions to scale. All are plausible and economically realistic, but they can vary significantly in terms of when we might reach Drawdown, how high atmospheric concentrations of greenhouse gases might rise before then, and what the implications for Earth's climate might be. Two scenarios are presented in this Review.

Drawdown **Scenario 1** is ambitious, at least compared to today's political commitments to climate action, but it does not reach Drawdown within the period of study (2020–2050). **Scenario 1** would be on track to reach Drawdown in the mid-2060s. Drawdown **Scenario 2** is bolder, with faster and more pervasive adoption of climate solutions, reaching the point of Drawdown in the mid-2040s.

We translate these emissions scenarios into illustrations of future greenhouse gas concentrations and global temperatures using the FAIR model—a simple model of Earth's carbon cycle and climate. (See more at tiny.cc/FAIRmodel.) The baseline scenario (based on AMPERE) and the two Drawdown Scenarios are fed into the FAIR model, which then estimates the resulting CO_2-eq concentration in Earth's atmosphere (measured in parts per million) and global mean temperature (measured in degrees Celsius).

As of early 2020, atmospheric carbon dioxide alone is over 410ppm; with other greenhouse gases, we approach 460ppm CO_2-eq. Under Drawdown **Scenario 1**, CO_2-eq concentrations would rise to ~540ppm in 2050. The resulting global mean temperature would be 1.74˚C above pre-industrial levels in 2050 and rise to 1.85˚C in 2060—on a path to warm by 2˚C by century's end.

Under the more ambitious Drawdown **Scenario 2**, CO_2-eq concentrations would peak at ~490 ppm in the mid-2040s and fall slightly by 2050 to ~485 ppm. Because there is a time lag between emissions and planetary warming, global mean temperature would continue to rise after the point of Drawdown, with peak warming around 1.52˚C through the 2050s.

The Paris Agreement, drafted in late 2015 and adopted in 2016, set a global aspiration to keep warming well below 2°C and to pursue efforts to limit it to 1.5°C. As the IPCC 2018 special report, *Global Warming of 1.5°C*, lays out, a 1.5°C world and a 2°C world are dramatically different in terms of extreme heat, sea-level rise, species loss, ecosystem damage, and more. (See more at ipcc.ch/sr15/.)

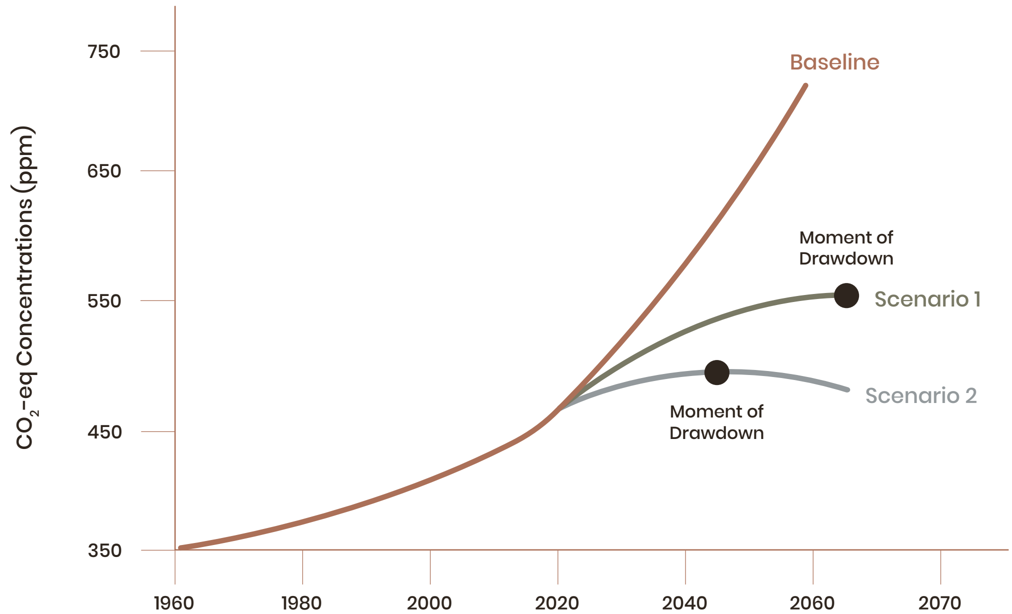
Interestingly, the Drawdown Scenarios align, respectively, with meeting a minimum goal of 2°C and a more ambitious goal of 1.5°C. Drawdown **Scenario 1** is roughly in-line with 2˚C temperature rise by 2100, while Drawdown **Scenario 2** is roughly in-line with 1.5˚C temperature rise at century's end. In other words, *we can avoid catastrophic warming with climate solutions in hand today*. What's more, our analysis does not include all possible climate solutions already available. With other potential solutions, such as those focused on reducing industrial emissions or capping fugitive methane, the world might reach Drawdown even more quickly.

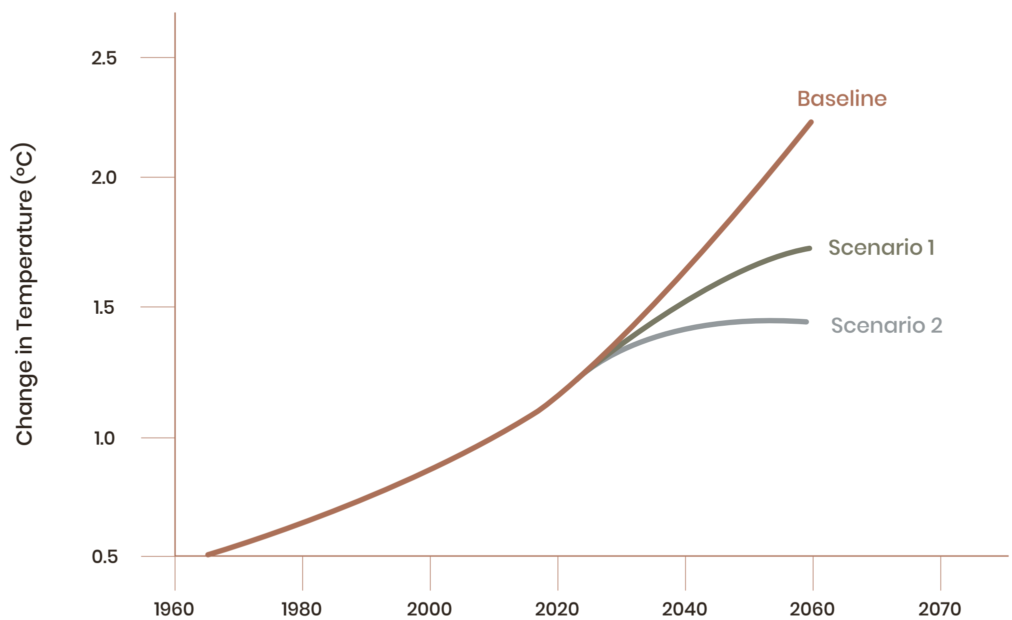
> We can avoid *catastrophic* warming with climate solutions in hand today.

The Drawdown Scenarios also show that meeting climate targets can be achieved while ensuring global food security, protecting and restoring ecosystems, and producing biomass for essential uses—all without clearing any additional land. That requires bold adoption of solutions to reduce global food, feed, and fiber demands (mostly by addressing food waste and shifting diets), alongside multifaceted land-use solutions that produce food and biomass as well as sequester carbon (including agroforestry, perennial crops, and restoring degraded forests). In short, this analysis shows we can meet ambitious climate targets, nourish the world, and restore healthy ecosystems, without consuming the planet—if we pursue all possible solutions.

Of course, scenarios are stories of what could be, not what will be. What will be? That will be decided by our collective ambition and determined action this decade and beyond.

For more information on the solutions, scenarios, and research methodology, visit Drawdown.org.





NOTE: Total greenhouse gas levels include carbon dioxide, methane, nitrous oxide, and fluorinated gases, expressed in carbon dioxide equivalents (CO_2-eq).

Forward

Project Drawdown's work points to two fundamental realities: We can reach Drawdown by mid-century if we pursue climate solutions already in hand; and, doing so will require immense ambition and bold action.

It's an emotional paradox in some ways, perhaps prompting a simultaneous sense of hope for what's possible and overwhelm about just how much needs to be done. This is especially true given that, globally, current commitments and plans for climate action fall far short of what's required.

The two Drawdown Scenarios may seem unrealistic today—especially the more ambitious one. (See above.) But it's important to note that what may be *politically unrealistic* at present is *physically* and *economically realistic*, according to our analysis. There is a path forward for the world. The question is how to bring physical, economic, and political possibility into alignment.

An aerial view of Drakes Bay in the Point Reyes Peninsula, California.

Accelerating Solutions

Project Drawdown defines "solutions" as practices and technologies that materially affect the concentration of greenhouse gases in the atmosphere. Their impact is specific and measurable. But solutions do not scale themselves. We need means of removing barriers and accelerating implementation and expansion.

"Accelerators" create the conditions for solutions to move forward. Some are closer-in and have more direct impacts; others are further out and more indirect in their effect. They intersect and interact and, like solutions, are dependent on social and political context. What might work well in a given time or place might not work in another. Accelerators also work at different scales, from individual to larger groups to entire nations. As with solutions, none are singularly effective, and we need them all.

1 **Shape Culture** Culture is critical context for climate solutions and action, telling us what's right or wrong, what's possible or impossible. Stories, the arts, dialogue, and visioning are some of the means of (re)shaping culture and collective beliefs about how the world works, or could. Cultural change can feel diffuse, but it sets the context for what we do as a society and can foster a sense of collective courage.

2 **Build Power** Power is a precondition for creating change. In the past, too much power has been deployed against climate action; too little has been assembled to advance solutions. We build power by building community, movements, and diverse leadership. When the concentrated power and entrenched interests of industry or government work against transformation, people power offers a corrective.

3 **Set Goals** Goals govern direction. What are we reaching for, and why? On climate but also more broadly, goals can be specific and numeric (e.g., "carbon neutral by 2030"), or they can be higher-order, more systemic ambitions (e.g., "a climate-just future"). Sometimes a new goal can dramatically shift where we're headed—and the solutions and approaches we bring to bear.

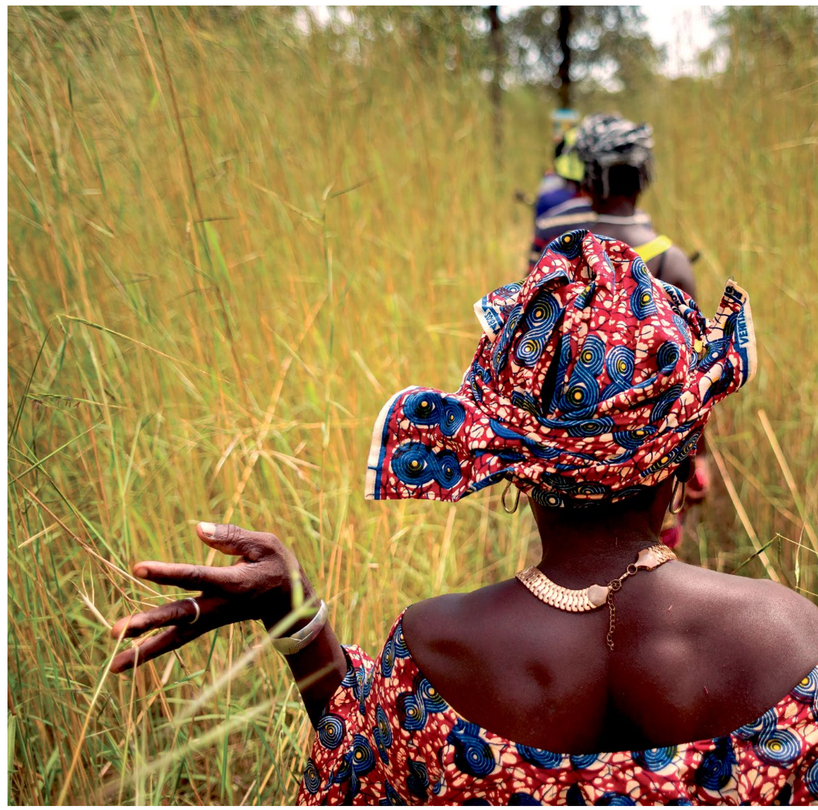
4 **Alter Rules and Policy** Rules create boundaries. They tell us what is desirable and perhaps encouraged, or what is unwanted and perhaps punished. Laws, regulations, taxes, tax breaks, subsidies, and incentives are means of changing the state of play on climate, but hinge on who writes the rules. Policy shifts can advance solutions, while stopping sources of the problem.

5 Shift Capital Given our economic system, money is necessary fuel for making change. Public and private investment and philanthropic giving can stimulate and sustain climate solutions and efforts to move them forward. Divestment is also powerful, shifting capital away from sources of the problem, essentially restricting their blood flow.

6 Change Behavior From individuals to corporations and beyond, behavior is what's done and how. All climate solutions have behavioral dimensions, and some hinge almost entirely on human habit. Knowledge, norms, standards, and motivations can shift behavior and create new ways of operating. Where changes in behavior aggregate, outcomes can shift significantly.

Utility-scale solar photovoltaics in Chile's Atacama Desert.

Members of a rural women's cooperative on Îles Tristao, Guinea.



7 Improve Technology To stop the sources of emissions, technology must evolve. "*Now* is better than *new*" when it comes to climate solutions, but through innovation, research, and development, technology may continue to improve and add to the solutions at hand. This is especially critical for the most intractable sectors, such as heavy industry and aviation.

On both accelerators and solutions, efforts will be aided by connecting them through communication and collaboration; supporting continual learning through education, knowledge-building, and prototyping; and centering the experiences, wisdom, and solutions of impacted communities. We need all of the above—a wide variety of solutions and accelerators to move the world toward Drawdown, quickly, safely, and equitably.

We are living in a time of dramatic transformation. The basic physics, chemistry, and biology of this planet make that non-negotiable; stasis is not an option. Society has a choice to make about what shape that transformation will take. Will we employ collective courage and determination and the legion of existing solutions to move the world away from widespread climate catastrophe? Will we pursue climate action in ways that heal systemic injustices and foster resilience, wellbeing, and equality? Who will we choose to be in this pivotal moment of human history?

A transformation that moves us toward Drawdown is possible, as demonstrated here, but it will require much more than the right technologies and practices being available. Genuine evolution is in order—evolution in what we value, how we treat one another, who holds the reins of power, the ways institutions operate, and the very contours of our economies. This time of transformation also asks that we learn from cultures and communities that have sustained human-nature symbiosis for centuries, even millennia.

At times, this can all feel like a draconian assignment. But it's also an invitation into deeply meaningful work. Our purpose as human beings in this moment is to create a livable future, together—to build a bridge from where we are today to the world we want for ourselves, for all of life, and for generations yet to come. With commitment, collaboration, and ingenuity, we can depart the perilous path we are on and come back into balance with the planet's living systems. A better path is still possible. May we turn that possibility into reality.

SUMMARY OF SOLUTIONS

Solutions by Sector

Some of the results shown here may surprise you; in particular, the solutions that have a beneficial emissions impact overall but some detrimental impact in a given sector (shown as negative CO_2-eq). We invite a deeper dive into the many particularities and nuances of all of these solutions, laid out in technical materials on Drawdown.org.

NOTE:

** Indicates that a solution falls under two sectors; results are apportioned and allocated to each sector.*
*** Indicates that a solution enables or integrates others; emissions reductions are allocated elsewhere.*

The total CO_2-eq reduced/sequestered is based on the number of solution units active between 2020–2050, compared to the emissions of a baseline scenario.

"First cost" refers to the cumulative cost to install those solution units. "Lifetime cost" is the cost to operate those units throughout a lifetime of use. The "net" difference results from comparison to the costs of a baseline scenario. Where a cost is a negative number, it indicates savings.

Reduce Sources bringing emissions to zero

Sector	Subgroup	Solution	SCENARIO 1 Total CO_2-eq (Gt) Reduced / Sequestered (2020–2050)	SCENARIO 2 Total CO_2-eq (Gt) Reduced / Sequestered (2020–2050)
Electricity	Enhance Efficiency	Smart Thermostats *	3.1	3.3
		Building Automation Systems *	4.9	7.9
		LED Lighting	16.1	17.5
		Insulation *	3.8	4.3
		Dynamic Glass *	0.2	0.3
		High-Performance Glass *	2.0	2.4
		Green & Cool Roofs *	0.7	1.3
		District Heating *	4.6	7.2
		High-Efficiency Heat Pumps *	-1.7	-3.0
		Solar Hot Water *	0.8	3.2
		Low-Flow Fixtures *	0.2	0.4
		Water Distribution Efficiency	0.7	0.9
		Building Retrofitting * **	N/A	N/A
	Enhance Efficiency + Shift Production	Net-Zero Buildings * **	N/A	N/A
	Shift Production	Concentrated Solar Power	18.6	24.0
		Distributed Solar Photovoltaics	28.0	68.6
		Utility-Scale Solar Photovoltaics	42.3	119.1
		Micro WInd Turbines	0.1	0.1
		Onshore Wind Turbines	47.2	147.7
		Offshore WInd Turbines	10.4	11.4
		Geothermal Power	6.2	9.8
		Small Hydropower	1.7	3.3
		Ocean Power	1.4	1.4
		Biomass Power	2.5	3.6
		Nuclear Power	2.7	3.2
		Waste-to-Energy *	0.5	0.9
		Landfill Methane Capture *	0.2	-0.1
		Methane Digesters *	3.6	2.3
	Improve the System	Grid Flexibility **	N/A	N/A
		Microgrids **	N/A	N/A
		Distributed Energy Storage **	N/A	N/A
		Utility-Scale Energy Storage **	N/A	N/A
	ELECTRICITY TOTAL		**200.6**	**441.1**

Reduce Sources bringing emissions to zero

Sector	Subgroup	Solution	SCENARIO 1 Total CO_2-eq (Gt) Reduced / Sequestered (2020–2050)	SCENARIO 2 Total CO_2-eq (Gt) Reduced / Sequestered (2020–2050)
Food, Agriculture & Land Use	Address Waste & Diets	Plant-Rich Diets *	64.8	91.5
		Reduced Food Waste *	86.7	93.8
	Protect Ecosystems	Forest Protection *	4.4	6.8
		Indigenous Peoples' Forest Tenure *	7.0	10.3
		Grassland Protection *	3.2	4.0
		Peatland Protection & Rewetting *	25.5	40.9
		Coastal Wetland Protection *	0.7	1.0
	Protect Ecosystems + Shift Agriculture Practices	Sustainable Intensification for Smallholders *	0.1	0.1
	Shift Agriculture Practices	Conservation Agriculture *	1.5	1.1
		Regenerative Annual Cropping *	1.0	1.5
		Nutrient Management	2.3	12.1
		Farm Irrigation Efficiency	1.1	2.1
		Improved Rice Production *	4.0	5.9
		System of Rice Intensification *	2.0	3.0
	FOOD, AGRICULTURE & LAND USE TOTAL		**204.2**	**273.9**
Industry	Improve Materials	Alternative Cement	8.0	16.1
		Bioplastics	1.0	3.8
	Use Waste	Composting	2.1	3.1
		Recycling	5.5	6.0
		Recycled Paper	1.1	1.9
		Waste-to-Energy *	1.6	2.1
		Landfill Methane Capture *	2.0	-1.5
		Methane Digesters *	6.2	3.8
	Address Refrigerants	Refrigerant Management *	57.7	57.7
		Alternative Refrigerants *	43.5	50.5
	INDUSTRY TOTAL		**128.7**	**143.7**

Reduce Sources bringing emissions to zero

Sector	Subgroup	Solution	SCENARIO 1 Total CO_2-eq (Gt) Reduced / Sequestered (2020–2050)	SCENARIO 2 Total CO_2-eq (Gt) Reduced / Sequestered (2020–2050)
Transportation	Shift to Alternatives	Walkable Cities	1.4	5.5
		Bicycle Infrastructure	2.6	6.6
		Electric Bicycles	1.3	4.1
		Carpooling	7.7	4.2
		Public Transit	7.5	23.4
		High-Speed Rail	1.3	3.8
		Telepresence	1.0	3.8
	Enhance Efficiency	Hybrid Cars	7.9	4.6
		Efficient Trucks	4.6	9.7
		Efficient Aviation	6.3	9.2
		Efficient Ocean Shipping	4.4	6.3
	Electrify Vehicles	Electric Cars	11.9	15.7
		Electric Trains	0.1	0.6
	TRANSPORTATION TOTAL		**58.0**	**97.4**
Buildings	Enhance Efficiency	Smart Thermostats *	3.9	4.1
		Building Automation Systems *	1.6	2.6
		Insulation *	13.2	14.8
		Dynamic Glass *	0.1	0.1
		High-Performance Glass *	8.1	10.3
		Green & Cool Roofs *	-0.1	-0.2
		Low-Flow Fixtures *	0.7	1.2
	Enhance Efficiency + Shift Energy Sources	Building Retrofitting * **	N/A	N/A
		Net-Zero Buildings * **	N/A	N/A
	Shift Energy Sources	District Heating *	1.7	2.7
		High-Efficiency Heat Pumps *	5.8	12.3
		Solar Hot Water *	2.8	11.1
		Biogas for Cooking	4.6	9.7
		Improved Clean Cookstoves	31.3	72.6
	Address Refrigerants	Refrigerant Management *	N/A	N/A
		Alternative Refrigerants *	N/A	N/A
	BUILDINGS TOTAL		**73.7**	**141.2**
	REDUCE SOURCES TOTAL		**665.3**	**1,097.4**

Support Sinks uplifting nature's carbon cycle

Sector	Subgroup	Solution	SCENARIO 1 Total CO_2-eq (Gt) Reduced / Sequestered (2020–2050)	SCENARIO 2 Total CO_2-eq (Gt) Reduced / Sequestered (2020–2050)
Land Sinks	Address Waste & Diets	Plant-Rich Diets *	0.2	0.2
		Reduced Food Waste *	0.8	0.8
	Protect & Restore Ecosystems	Forest Protection *	1.1	1.9
		Indigenous Peoples' Forest Tenure *	1.7	2.6
		Temperate Forest Restoration	19.4	27.8
		Tropical Forest Restoration	54.5	85.1
		Grassland Protection *	0.2	0.2
		Peatland Protection & Rewetting *	0.6	1.0
	Protect & Restore Ecosystems + Shift Agriculture Practices	Sustainable Intensification for Smallholders *	1.2	0.6
	Shift Agriculture Practices	Conservation Agriculture *	11.9	8.3
		Regenerative Annual Cropping *	13.6	20.8
		Managed Grazing	16.4	26.0
		Silvopasture	26.6	42.3
		Multistrata Agroforestry	11.3	20.4
		Tree Intercropping	15.0	24.4
		Perennial Staple Crops	15.5	31.3
		Perennial Biomass Production	4.0	7.0
		Improved Rice Production *	5.4	8.0
		System of Rice Intensification *	0.8	1.2
	Use Degraded Land	Abandoned Farmland Restoration	12.5	20.3
		Tree Plantations (on Degraded Land)	22.2	35.9
		Bamboo Production	8.3	21.3
	LAND SINKS TOTAL		**243.1**	**387.8**
Coastal & Ocean Sinks	Protect & Restore Ecosystems	Coastal Wetland Protection *	0.3	0.5
		Coastal Wetland Restoration	0.8	1.0
	COASTAL & OCEAN SINKS TOTAL		**1.1**	**1.5**
Engineered Sinks	Remove & Store Carbon	Biochar Production	2.2	4.4
	ENGINEERED SINKS TOTAL		**2.2**	**4.4**
	SUPPORT SINKS TOTAL		**246.4**	**393.7**

Improve Society fostering equality for all

Sector	Subgroup	Solution	SCENARIO 1 Total CO_2-eq (Gt) Reduced / Sequestered (2020–2050)	SCENARIO 2 Total CO_2-eq (Gt) Reduced / Sequestered (2020–2050)
Health & Education	N/A	Health & Education	85.4	85.4
	HEALTH & EDUCATION TOTAL		**85.4**	**85.4**
	IMPROVE SOCIETY TOTAL		**85.4**	**85.4**

Two shamans who live in the forest community of Cashiboya, Loreto, Perú.

SUMMARY OF SOLUTIONS

Individual Solutions

The rankings shown here are based on projected emissions impact globally. The relative importance of a given solution can differ significantly depending on context and particular ecological, economic, political, or social conditions.

Scenario 1

Overall Ranking	Solution	Total CO_2-eq (Gt) Reduced/Sequestered (2020–2050)	Net First Cost to implement solution (Billions $US)	Net Lifetime Cost to operate solution (Billions $US)	Net Lifetime Profit after implementation and operation (Billions $US)
1	Reduced Food Waste	87.4	-	-	-
2	Health & Education	85.4	-	-	-
3	Plant-Rich Diets	65.0	-	-	-
4	Refrigerant Management	57.7	-	600	-
5	Tropical Forest Restoration	54.4	-	-	-
6	Onshore Wind Turbines	47.2	800	-3,800	-
7	Alternative Refrigerants	43.5	-	-	-
8	Utility-Scale Solar Photovoltaics	42.3	-200	-12,900	-
9	Improved Clean Cookstoves	31.3	100	1,900	-
10	Distributed Solar Photovoltaics	27.9	400	-7,800	-
11	Silvopasture	26.5	200	2,300	1,700
12	Peatland Protection & Rewetting	26.0	-	-	-
13	Tree Plantations (on Degraded Land)	22.2	16	100	2,100
14	Temperate Forest Restoration	19.4	-	-	-
15	Concentrated Solar Power	18.6	400	800	-
16	Insulation	16.9	700	-21,700	-
17	Managed Grazing	16.4	33	-600	2,100
18	LED Lighting	16.0	-1,700	-4,500	-
19	Perennial Staple Crops	15.4	83	800	1,400
20	Tree Intercropping	15.0	100	600	200
21	Regenerative Annual Cropping	14.5	77	-2,300	100
22	Conservation Agriculture	13.4	91	-2,800	100
23	Abandoned Farmland Restoration	12.4	98	3,200	2,600
24	Electric Cars	11.8	4,400	-15,200	-

NOTE: Where a cost is a negative number, it indicates savings. Where a dash is shown, results are not available.

Overall Ranking	Solution	**Total CO_2-eq (Gt)** Reduced/Sequestered (2020–2050)	**Net First Cost** to implement solution (Billions $US)	**Net Lifetime Cost** to operate solution (Billions $US)	**Net Lifetime Profit** after implementation and operation (Billions $US)
25	Multistrata Agroforestry	11.2	54	100	1,700
26	Offshore Wind Turbines	10.4	600	-600	-
27	High-Performance Glass	10.0	9,000	-3,300	-
28	Methane Digesters	9.8	200	2	-
29	Improved Rice Production	9.4	-	-400	200
30	Indigenous Peoples' Forest Tenure	8.6	-	-	-
31	Bamboo Production	8.2	52	500	1,700
32	Alternative Cement	7.9	-63	-	-
33	Hybrid Cars	7.8	3,400	-6,100	-
34	Carpooling	7.7	-	-5,300	-
35	Public Transit	7.5	-	-2,100	-
36	Smart Thermostats	6.9	100	-1,800	-
37	Building Automation Systems	6.4	200	-1,700	-
38	District Heating	6.2	200	-1,500	-
39	Efficient Aviation	6.2	800	-2,400	-
40	Geothermal Power	6.1	80	-800	-
41	Forest Protection	5.5	-	-	-
42	Recycling	5.5	10	-200	-
43	Biogas for Cooking	4.6	23	100	-
44	Efficient Trucks	4.6	400	-3,400	-
45	Efficient Ocean Shipping	4.3	500	-600	-
46	High-Efficiency Heat Pumps	4.1	76	-1,000	-
47	Perennial Biomass Production	3.9	200	1,500	900
48	Solar Hot Water	3.5	700	-200	-
49	Grassland Protection	3.3	-	-	-
50	System of Rice Intensification	2.7	-	-14	500
51	Nuclear Power	2.6	100	-300	-
52	Bicycle Infrastructure	2.5	-2,600	-800	-
53	Biomass Power	2.5	51	-200	-
54	Nutrient Management	2.3	-	-23	-
55	Biochar Production	2.2	100	700	-
56	Landfill Methane Capture	2.1	-4	6	-
57	Composting	2.1	-60	100	-
58	Waste-to-Energy	2.0	100	96	-
59	Small Hydropower	1.6	49	-300	-
60	Walkable Cities	1.4	-	-1,600	-
61	Ocean Power	1.3	200	1,000	-
62	Sustainable Intensification for Smallholders	1.3	-	-100	300

Overall Ranking	Solution	Total CO_2-eq (Gt) Reduced/Sequestered (2020–2050)	Net First Cost to implement solution (Billions $US)	Net Lifetime Cost to operate solution (Billions $US)	Net Lifetime Profit after implementation and operation (Billions $US)
63	Electric Bicycles	1.3	-300	-600	-
64	High-Speed Rail	1.3	600	800	-
65	Farm Irrigation Efficiency	1.1	200	-500	-
66	Recycled Paper	1.0	400	-	-
67	Telepresence	1.0	86	-1,200	-
68	Coastal Wetland Protection	1.0	-	-	-
69	Bioplastics	1.0	88	-	-
70	Low-Flow Fixtures	0.9	1	-400	-
71	Coastal Wetland Restoration	0.8	-	-	-
72	Water Distribution Efficiency	0.7	17	-200	-
73	Green & Cool Roofs	0.6	600	-300	-
74	Dynamic Glass	0.3	69	-98	-
75	Electric Trains	0.1	600	-700	-
76	Micro Wind Turbines	0.1	52	19	-
Not Ranked*	Building Retrofitting	N/A	-	-	-
	Distributed Energy Storage	N/A	-	-	-
	Grid Flexibility	N/A	-	-	-
	Microgrids	N/A	-	-	-
	Net-Zero Buildings	N/A	-	-	-
	Utility-Scale Energy Storage	N/A	-	-	-
SCENARIO 1 TOTAL		**993.8**	**22,479**	**-95,112**	**15,600**

** The emissions impacts included in or enabled by these solutions are allocated elsewhere.*

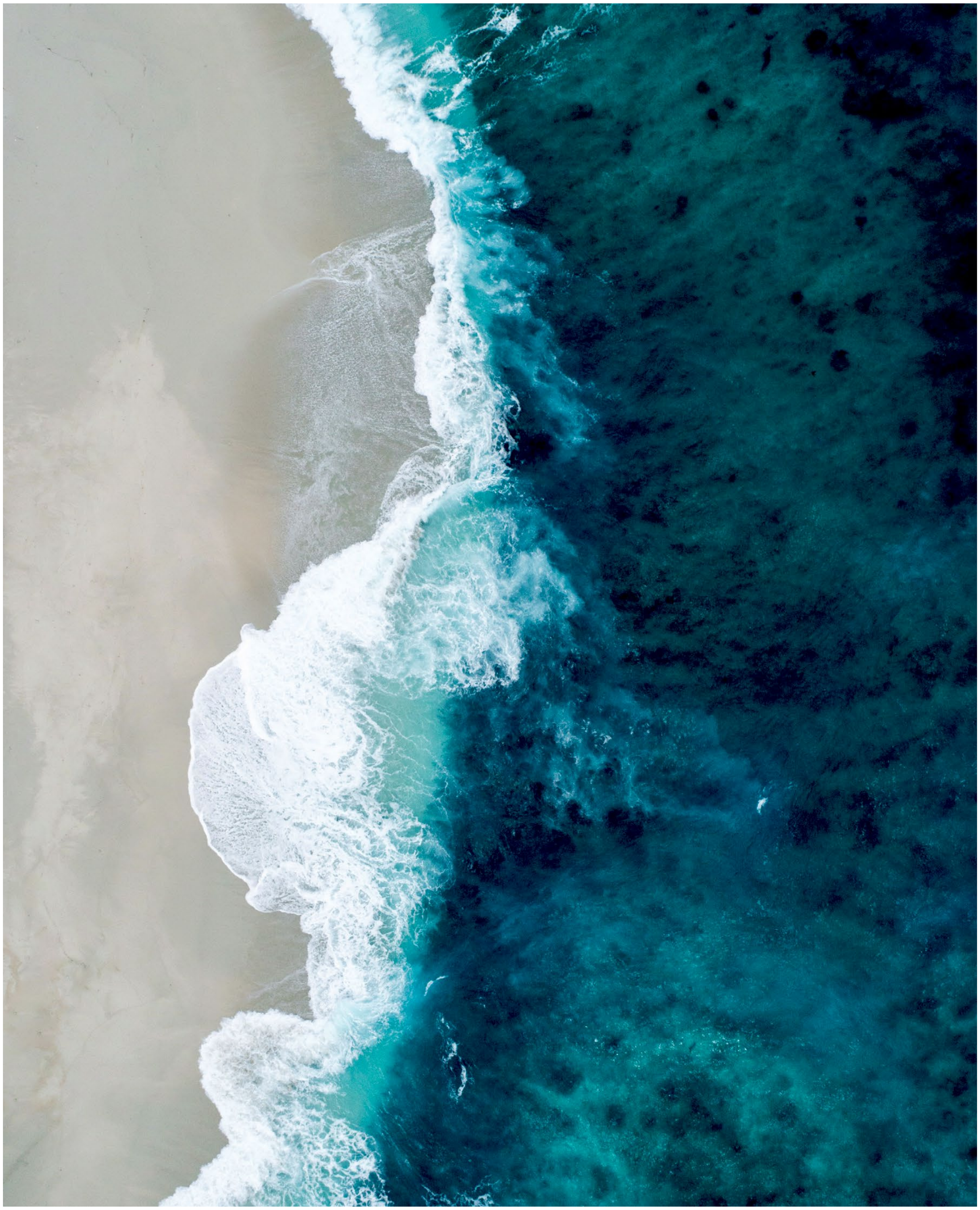
Scenario 2

Overall Ranking	Solution	Total CO_2-eq (Gt) Reduced/Sequestered (2020–2050)	Net First Cost to implement solution (Billions $US)	Net Lifetime Cost to operate solution (Billions $US)	Net Lifetime Profit after implementation and operation (Billions $US)
1	Onshore Wind Turbines	147.8	1,700	-10,200	-
2	Utility-Scale Solar Photovoltaics	119.2	-1,528	-26,500	-
3	Reduced Food Waste	94.6	-	-	-
4	Plant-Rich Diets	91.8	-	-	-
5	Health & Education	85.4	-	-	-
6	Tropical Forest Restoration	85.2	-	-	-
7	Improved Clean Cookstoves	72.7	300	4,191	-
8	Distributed Solar Photovoltaics	68.7	300	-13,600	-
9	Refrigerant Management	57.8	-	630	-
10	Alternative Refrigerants	50.6	-	-	-

Overall Ranking	Solution	Total CO_2-eq (Gt) Reduced/Sequestered (2020–2050)	Net First Cost to implement solution (Billions $US)	Net Lifetime Cost to operate solution (Billions $US)	Net Lifetime Profit after implementation and operation (Billions $US)
11	Silvopasture	42.4	300	3,120	2,400
12	Peatland Protection & Rewetting	42.0	-	-	-
13	Tree Plantations (on Degraded Land)	36.0	100	260	3,400
14	Perennial Staple Crops	31.3	200	1,922	3,400
15	Temperate Forest Restoration	27.9	-	-	-
16	Managed Grazing	26.1	100	-1,100	3,500
17	Tree Intercropping	24.5	300	1,080	500
18	Concentrated Solar Power	24.0	600	1,116	-
19	Public Transit	23.4	-	-6,600	-
20	Regenerative Annual Cropping	22.3	200	-3,600	300
21	Bamboo Production	21.4	200	1,444	4,400
22	Multistrata Agroforestry	20.5	100	246	3,100
23	Abandoned Farmland Restoration	20.4	200	5,272	4,400
24	Insulation	19.1	900	-24,200	-
25	LED Lighting	17.6	-2,036	-5,000	-
26	Alternative Cement	16.2	-64	-	-
27	Electric Cars	15.7	5,800	-21,900	-
28	Solar Hot Water	14.3	2,700	-1,200	-
29	Improved Rice Production	13.9	-	-700	400
30	Indigenous Peoples' Forest Tenure	13.0	-	-	-
31	High-Performance Glass	12.7	10,800	-4,000	-
32	Nutrient Management	12.1	-	-100	-
33	Offshore Wind Turbines	11.5	800	-800	-
34	Building Automation Systems	10.5	300	-3,100	-
35	District Heating	9.9	400	-2,500	-
36	Geothermal Power	9.9	100	-1,300	-
37	Efficient Trucks	9.8	800	-6,100	-
38	Biogas for Cooking	9.7	100	210	-
39	Conservation Agriculture	9.5	100	-2,000	100
40	High-Efficiency Heat Pumps	9.3	200	-2,600	-
41	Efficient Aviation	9.2	900	-3,700	-
42	Forest Protection	8.8	-	-	-
43	Smart Thermostats	7.5	200	-2,100	-
44	Perennial Biomass Production	7.1	400	2,751	1,700
45	Bicycle Infrastructure	6.7	-7,539	-2,400	-
46	Efficient Ocean Shipping	6.3	800	-900	-
47	Methane Digesters	6.2	200	2	-
48	Recycling	6.1	100	-300	-

Overall Ranking	Solution	Total CO_2-eq (Gt) Reduced/Sequestered (2020–2050)	Net First Cost to implement solution (Billions $US)	Net Lifetime Cost to operate solution (Billions $US)	Net Lifetime Profit after implementation and operation (Billions $US)
49	Walkable Cities	5.5	-	-6,500	-
50	Hybrid Cars	4.7	1,700	-3,000	-
51	Biochar Production	4.4	400	1,437	-
52	System of Rice Intensification	4.3	-	-100	900
53	Grassland Protection	4.3	-	-	-
54	Carpooling	4.2	-	-2,800	-
55	Electric Bicycles	4.1	-1,155	-1,900	-
56	Telepresence	3.9	400	-4,400	-
57	Bioplastics	3.8	100	-	-
58	High-Speed Rail	3.8	1,300	2,164	-
59	Biomass Power	3.6	100	-300	-
60	Small Hydropower	3.3	100	-600	-
61	Nuclear Power	3.3	200	-400	-
62	Composting	3.2	-84	174	-
63	Waste-to-Energy	3.1	200	-1	-
64	Farm Irrigation Efficiency	2.1	400	-1,000	-
65	Recycled Paper	2.0	1,000	-	-
66	Low-Flow Fixtures	1.6	100	-800	-
67	Coastal Wetland Protection	1.5	-	-	-
68	Ocean Power	1.4	300	1,440	-
69	Green & Cool Roofs	1.2	1,000	-600	-
70	Coastal Wetland Restoration	1.1	-	-	-
71	Water Distribution Efficiency	0.9	100	-400	-
72	Sustainable Intensification for Smallholders	0.7	-	-100	200
73	Electric Trains	0.7	2,900	-3,400	-
74	Dynamic Glass	0.5	200	-200	-
75	Micro Wind Turbines	0.1	100	28	-
76	Landfill Methane Capture	-1.6	-	22	-
Not Ranked*	Building Retrofitting	N/A	-	-	-
	Distributed Energy Storage	N/A	-	-	-
	Grid Flexibility	N/A	-	-	-
	Microgrids	N/A	-	-	-
	Net-Zero Buildings	N/A	-	-	-
	Utility-Scale Energy Storage	N/A	-	-	-
SCENARIO 2 TOTAL		**1,580.4**	**28,394**	**-145,492**	**28,700**

** The emissions impacts included in or enabled by these solutions are allocated elsewhere.*



The Indian Ocean meets shore in the Maldives, an archipelago of low-lying islands and atolls. It is among the small island nations whose very existence is threatened by climate change.

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