POSITIVE DISRUPTION 2021
ROADMAP WITH NATURE TO 1.5°C
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ABOUT

Epic Institute
Epic Institute (Epic) – an independent nonprofit founded in 2018 – maintains a mission to monitor and communicate the role of market forces in accelerating the most promising climate solutions globally. Epic engages a two-pronged approach: Data Analytics and Targeted Acceleration. With Data Analytics, Epic is developing tools and datasets to explore decarbonization pathways based on market forces, with focus on the minimum necessary set of technologies and practices currently scaling in global markets. Epic works with partners to utilize this data to create high-impact and targeted acceleration events in critical markets around the world.

The Nature Conservancy
The Nature Conservancy (TNC) is a global environmental nonprofit working to create a world where people and nature can thrive. Founded at its grassroots in the United States in 1951, TNC has grown to become one of the most effective and wide-reaching environmental organizations in the world. Thanks to more than a million members and the dedicated efforts of its diverse staff and more than 400 scientists, TNC impacts conservation in 79 countries and territories across six continents.

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Finally, the authors wish to acknowledge the generous support of the Shugar Magic Foundation, which partially funded the work of PD21.

COVER PHOTOGRAPH: Christian_Dupraz@INRAE
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Key Findings

Code Red for humanity. That is where we are in 2021, according to the UN Secretary General, expressing the consensus of the world’s top climate scientists. This comes amid a spate of extreme weather events around the globe which are confirming the dire predictions of climate scientists. But these same scientists also emphasize that it’s not too late to avoid the most dire impacts of climate change, if we choose to rapidly deploy proven climate solutions now.

In this report, we demonstrate how climate solutions are advancing across seven vertical sectors of the economy, the ‘V7’. By projecting historical rates of technological adoption, we show the potential for rapid transformation across these sectors. Yet despite the tremendous promise of emissions reduction at the projected speed of market transformation, there is still a gap to bridge to the SR1.5 pathway. That gap can largely be filled by accelerating natural climate solutions (NCS): protection, restoration, and improved land management activities that avoid greenhouse gas emissions and/or increase carbon storage across forests, wetlands, grasslands, and agricultural lands. We estimate these NCS will cost society approximately $14 trillion to implement between now and 2060, including $3 trillion ($300B/yr) by 2030, but some of this cost can be offset by the myriad co-benefits NCS provide, including healthier food, soil, air, and water; increased climate resilience; restored habitat, and sustained biodiversity. By comparison, engineered carbon dioxide removal (eCDR) is over five times higher cost ($72 trillion by 2060 and $14 trillion by 2030) and lacks the co-benefits for people and nature provided by NCS. In other words, spending $300B/year today globally on NCS now could save the world’s next generation $60 trillion in future eCDR costs.

Given what’s at stake and the size of our challenge, we need to backstop our path forward by researching and improving eCDR technology as we begin deploying NCS. Combined, the forces of market disruption, policy changes and acceleration of NCS present an elegant, proven, and least-cost path towards climate stability. But there is no time to waste. Near-term, the world must invest in market disruption through policy changes, and NCS if we plan to pass a livable planet on to our grandchildren.

Nature isn’t a ‘nice to have.’ It’s a solution provider to addressing some of the biggest challenges we face. Natural climate solutions offer some of our best options in responding to climate change. They can simultaneously boost jobs and protect communities around the world. They’re also powerful, cost effective, and can be implemented right now.
The V7 framing provides a simple guiding framework for decarbonization of the economy. We categorize climate solutions into seven disruptive solution sets which provide a roadmap and dashboard for tracking the progress of climate solutions. The V7 comprises solutions within the following industry verticals: 1) electricity, 2) buildings, 3) transportation, 4) industry, 5) agricultural NCS, 6) forest & wetland NCS, and 7) CDR, both engineered and natural.

The V7 lead to DAU21, an emissions curve defined by rapid adoption of climate solution technologies and practices. Each of the V7 contributes to reductions from the baseline emissions curve (Figure A). V1 to V6 deliver 74% of the needed mitigation in the DAU21 emissions curve, but fall short of SR1.5, the mitigation needed to avoid 1.5 degrees of warming. CDR (V7) fills this 26% gap with approximately 2/5 of this coming from natural climate solutions like reforestation that pull carbon from the atmosphere.

Each emissions curve results in a distinct climate outcome (Figure B). The DAU21 trajectory leads to 1.1°C in 2100, with a peak around 1.4°C near mid-century.

1Historical temperatures, reference periods, smoothing, and uncertainty ranges for SR1.5 are adapted from SPM.1 in IPCC (2018). To reflect increased uncertainty in market projections, the uncertainty range from SR1.5 is applied to the DAU21 curve and expanded linearly through 2100, where it reaches roughly double the 2100 SR1.5 uncertainty range.
NCSmax scenarios could inspire deeper NCS adoption for certain nations in the design and revision of their Nationally Determined Contributions (NDCs). As shown in Figure D for the year 2050. Nations looking to bolster their NDCs under the Paris Agreement are urged to take stock of their NCS opportunities, while empowering their energy markets to find competitive solutions. NCS can be a source of income to landholders through the emerging ecosystem services markets when supported by carbon pricing.

The climate solutions we need already exist. They are ready and scaling in many parts of the world, relying on market forces, often supported by policy initiatives. Yet, we show the expected transition speeds of the market supported by existing policy levels would risk breaching the 1.5C threshold.

Promoting the rapid adoption of all climate solutions is an urgent need. While government policies should be set to accelerate emissions reduction from electricity, transportation, buildings, and industry, the world must also prepare to invest $3 trillion by 2030 ($300 billion per year) to expand natural climate solutions (Figure E). By 2060, the NCS pathway would save the world and future generations an estimated $60 trillion in reaching the IPCC’s targeted SR1.5 pathway.

Nature can be a powerful remedy to climate change, or she can turn on us. We are at a stage of the climate crisis where we need swift and data-driven decisions. A rise exceeding 1.5C should not be an option. For the negative emissions needed for the 2030 goal, we must seek a full and immediate embrace of natural climate solutions.
“Nature can be a powerful remedy to climate change, or she can turn on us.”
Glossary of Terms

1.5°C  1.5 degrees Celsius, agreed by the Paris Accords as the goal for ‘well below 2 degrees’
Agroforestry  A land-use management system in which trees or shrubs are intentionally grown around or among crops or pastureland
Baseline  An emissions trajectory widely perceived as business-as-usual, typically consisting of a linear projection of recent trends in market transitions across the V7
Carbon tech  Sequestering CO₂ into products, e.g. concrete, transport fuels, running shoes, etc.
CDR  Carbon dioxide removal
COP  Conference of Parties
CH₄  Methane
CO₂  Carbon dioxide
CO₂e  Carbon dioxide equivalents, including but not limited to methane (CH₄), N₂O, and F-gases
DAC  Direct air capture, as a method of carbon dioxide removal (CDR)
DAU  Disruption-as-usual
eCDR  Engineered carbon dioxide removal, e.g. direct air capture (DAC), carbontech, and other means
Epic  Epic Institute, lead author of this study
F&W  Forests & Wetlands
F-gases  Fluorinated gases, a category of greenhouse gases (GHGs)
Global Targets  50% emissions reduction by 2030 and net zero emissions by 2050, as suggested by the IPCC
GHGs  Greenhouse gases (CO₂, CH₄, N₂O, F-gases)
GtCO₂  Gigatons of CO₂
GtCO₂e  Gigatons of CO₂-equivalent, includes the CO₂ equivalent of methane, N₂O, and F-gases
IEA  International Energy Agency
IPCC  Intergovernmental Panel on Climate Change
NO₂  Nitrogen dioxide
nCDR  Nature-based carbon dioxide removal (see NCS)
NCS  Natural climate solutions, also referred to as nature-based solutions, here categorized as regenerative agriculture and forests & wetlands restoration and avoided losses
NDCs  Nationally Determined Contributions
NZE  Net zero emissions
PD21  Positive Disruption 2021, this report
PD17  Positive Disruption 2017, earlier version of this report
PD20  Positive Disruption 2020, previous of this report
PDP  Positive Disruption Paradigm
RA  Regenerative agriculture
SSP2-RCP1.9  Emissions trajectory on a CO₂e basis is adapted from Rogelj, J. et al. Scenarios towards limiting global mean temperature increase below 1.5 °C. Nature Climate Change, 8(4), 325-332.
RMI  Rocky Mountain Institute, a founding author of the Positive Disruption Paradigm
Subvertical  A technology or practice that contributes to a vertical, e.g. solar and wind are each subverticals to electricity; silvopasture and cropland soil health are subverticals to regenerative agriculture
TNC  The Nature Conservancy, one of the authors of this study
V7  The seven vertical sectors of the economy labeled and modeled by Epic
Vertical  Refers to a vertically-integrated sector of the economy, e.g. electricity, transportation, buildings
UNFAO  United Nations Food and Agriculture Organization
The Positive Disruption Paradigm (PDP) posits that there are disruptive market forces at play today driving a rapid transition to renewable energy and regenerative practices across seven vertical sectors of the economy, which together will contribute to stabilizing the Earth’s climate by 2100. In this report, we quantify the speed and scale of market disruption by climate solutions in the 21st century, determine their combined impact on climate, and assess how to bridge the gap to a target emissions trajectory that avoids the worst of climate change.

For the energy sector, our Disruption-as-Usual (DAU21) scenario assumes that adoption of new technologies follows an S-curve trajectory under current market conditions with existing levels of policy by the nations of the world, while the speed of these results could be ensured with enhanced and targeted policy. The projected S-curve adoption will be achieved as a result of market forces in market economies, and rational, least-cost planning with competitive industrial policy by planned economies. For the land-use sector, our results are better described as the adoption at global scale of well-documented agriculture and forestry practices that have already demonstrated localized and measurable success using replicable models. Global adoption of these land-use practices could be expanded by national policy and/or ecosystem services markets supported by carbon pricing.

The PDP recognizes that there continues to be a vibrant entrepreneurial explosion of mission-driven climate-tech startups emerging as dominant players in the energy and land-use sectors, and that the market is a powerful force in driving adoption at disruptive speeds. Because government actions in response to climate change have been inadequate to date, this assessment relies on competitive market forces in market economies and rational actions in planned economies to seek least-cost energy infrastructure and competitiveness within the global economy, as China is demonstrating today.

While it is the market that will bring about these transitions, governments play a key role. They have played a vital role in places such as Germany in the early 2000s, with a feed-in-tariff policy that drove steady declines in the cost of solar and wind energy, setting the stage for solar and wind to proliferate globally as least-cost options today. Solutions continue to be supported regionally through tax incentives, renewable portfolio standards, and other preferential treatment, as a means to overcome the systemic impediments to a level playing field with entrenched industries. These existing levels of support give rise to our S-curves of market disruption. As we will show, some sectoral transitions are in greater need of government support in implementing solutions at the speed and scale required to reduce the risk of breaching the 1.5°C threshold.

We present this report in 21 charts, displaying how market forces and NCS can reverse the trajectory of climate change by 2100, with a detailed methodology as an Appendix. Specifically, we present modeling that details adoption of the V7 across 16 global regions, on its way to 165-region granularity with next year’s publication.

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1 This report does not evaluate the relative efficiency of alternative policy mechanisms, rather we assume that, where policy is called for, best practice programs are employed to their maximum effectiveness.
1 The Positive Disruption Paradigm
DAU is the Real BAU

The Positive Disruption Paradigm (PDP) holds that there are disruptive market forces at play today that will drive a rapid transition to renewable energy and regenerative practices across seven vertical sectors of the economy, all necessary to stabilize Earth’s climate by 2100. The PDP maintains that disruption-as-usual (DAU) is the real business-as-usual (BAU).

Market disruption is a standard feature of well-functioning economies and is responsible for the emergence of most of the ubiquitous modern technologies we take for granted today. Electricity, automobiles, air conditioning, and cell phones have all emerged at disruptive speeds within the past century, as shown in Figure 1.

iii As demonstrated by Germany, Italy, Portugal, Spain, China, India, UK, US, Mexico, Vietnam, and others.

vi The energy output of a power plant reflects the hours in a time period in which it can be expected to operate at full capacity. Typical capacity factors for a nuclear plant are 92%, as compared with 18-30% for a solar plant, depending upon geographical location and module orientation.

v The last nuclear plant completed in the US, Watts Bar One in Tennessee, took 22 years and 7 months to complete.

vi For example in 2020, Vietnam installed 13 gigawatts of distributed solar, despite the global Coronavirus pandemic. This is the capacity equivalent to 13 nuclear power plants built in a single year and the energy equivalent of 3-4 such plants; for comparison, it can take years to decades to install just one gigawatt of nuclear power.

An electric motorbike-taxi in Rwanda. © Ampersand Rwanda
1. The Positive Disruption Paradigm

The V7 Framing

In this 2021 annual update to our Positive Disruption reporting (PD21), we present how market disruptions are tracking across seven vertical sectors of the economy, which we label the V7. Shown in Figure 3, these represent critical market transitions underway to reduce nearly all greenhouse gas (GHG) emissions from the global economy. This figure shows adoption which scales to saturation during this century for each of the V7 across all nations of the world. The V7 consists of decarbonization of the following industry verticals: 1) electricity, 2) buildings, 3) transportation, 4) industry, 5) agriculture, and 6) forests and wetlands, to which we add calculation of the needs from an emerging industry of 7) carbon dioxide removal (CDR) to meet the IPCC Goals.

CDR is a vertical that is calculated to achieve the emissions reduction needed to bridge the gap to global targets of the SR1.5 trajectory. The CDR vertical can be served by either expansion of the NCS verticals regenerative agriculture (V5) and restoring forests & wetlands (V6), which together are labeled nCDR, or by engineered means (eCDR), such as direct air capture (DAC), enhanced weathering, carbontech, or other means. A list of the contributing technologies and practices to all of the V7 is given in the Methodology and Appendix A.

Observed growth of the V7 through 2020 supports our contention that world markets are on a disruptive trajectory, as projected by our prior work in 2017 and 2020.

The energy technologies that make up the V7 were selected because they are proven, scalable, and/or scaling in global markets today, making them just-in-time solutions to address the urgency of the climate crisis. The V7’s land-use practices are proven and already scaling in many regions of the world, and could be assured of achieving the indicated global reach with broader government support and/or ecosystem services markets supported by carbon pricing.

This bears repeating, as both US Climate Envoy John Kerry and Bill Gates recently claimed that 50% (Kerry) to 90% (Gates) of climate solution technologies have “yet to be invented.” Technologies and practices of the V7 have not only been invented, but many have been undergoing continuous improvement for decades.

The historical observations of markets to 2020 are depicted by the solid lines of Figure 3. By tracking actual against projected adoption of the V7, Epic performs continuous checks on its market estimates. The speed of market transformation across the V7 is a subject treated at length in the Methodology and within our prior reports in 2017 and 2020.

We find that other recent work in the field supports and extends the Positive Disruption Paradigm. This offers further support for our projected speed of adoption across the V7, and contributes to increasing our confidence in the PDP.

This leads to a calculated adoption curve for CDR in Figure 3, rather than a market-based curve.

Often challenged, nuclear did not make the list of climate solutions, precisely because it is not scaling in global markets today.
Comparing Emissions Pathways

As new technologies and practices are adopted (Figure 3) net global emissions are reduced through increased avoided emissions and carbon removal (Figure 4a). We focus on two scenarios:

1. **Disruption-as-Usual 2021 (DAU21):** tracks the cumulative results of V1-V6, while excluding V7 (CDR), according to our 2021 assessment of market projections.

2. **SR1.5:** a trajectory that connects the global targets in 2030 (50% emissions reduction) and 2050 (net zero emissions) as set forth by the IPCC, shown accomplished by bridging the gap to DAU21 with the CDR vertical (V7).

We find the DAU21 emissions trajectory is comparable to the SSP2-RCP1.9 scenario examined in IPCC analysis, and has similar climate outcomes, as shown below. We model CDR as filling the gap needed to accomplish removal of CO$_2$ from the atmosphere sufficient to meet the global targets of the SR1.5 trajectory. The cumulative levels of CDR from 2020-2030 and 2030-2050 depicted in Figure 4a are 96 and 251 GtCO$_2$e respectively, with a total to 2050 of 347 GtCO$_2$e.

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*In a speech before UK Parliament, April 23, 2019.*

*Using the FAIR v1.3 model, see Methodology Section 7 for details.*
1. The Positive Disruption Paradigm

Global Climate Outcomes

The DAU21 emissions pathway, which is led by markets and excludes carbon dioxide removal (CDR), leads to 1.1°C in 2100, albeit with a peak of 1.4°C mid-century. This compares favorably with SSP2-RCP1.9 (Figure 5D). Stated otherwise, RCP1.9 approximates disruption-as-usual, i.e. the real business-as-usual.

The Paris Agreement target is to keep warming well below 2°C and to pursue efforts to limit warming to 1.5°C. This target is based upon a modeled increase of temperatures through 2100, which, given model uncertainty, provides a 66% chance of keeping warming below 1.5°C[2]. Adding CDR to achieve the SR1.5 trajectory would further reduce the risk of overshooting the 1.5°C threshold (SR1.5 curve, Figure 5d).

Both SSP2-RCP1.9 and DAU21 approach 1.5°C around mid-century before temperatures decline, with an uncertainty range well in excess of 1.5°C. These scenarios run a greater risk of irreversible damage, such as nonlinearities in methane release from permafrost, and collapse of polar ice shelves accelerating sea-level rise, in addition to a longer period of extreme heatwaves, flooding, and other events leading to displacement, death and destruction[15].

The SR1.5 emissions pathway peaks at 1.3°C (uncertainty to 1.6°C), and then trends downward beginning in 2040, yielding temperatures in 2100 of 1°C (uncertainty to 1.2°C) above pre-industrial levels, which is roughly where we are today. This represents a pathway which quickly steers the planet from elevated temperatures.

Figures 5a-5c respectively estimate CO₂ and CO₂e concentrations and radiative forcing levels to 2100, with similar relative results across the indicated emissions trajectories.

The global targets achieved by the SR1.5 pathway offer an important mitigation strategy by reducing CO₂ and CO₂e concentrations in 2100 to 315 and 361 ppm respectively, and further reducing atmospheric forcing throughout the remainder of the 21st century. SR1.5 arrives at 1.7 W/m² radiative forcing in 2100, a level not seen since 1996. DAU21 is comparable to the SSP2-RCP1.9 pathway, achieving roughly the same level of radiative forcing at 1.9 W/m² in 2100 (Figure 5c).

Thus, the adoption of climate solutions at non-linear rates is redefining business-as-usual, and sustained market disruption will serve as a powerful driver in the effort to avoid climate catastrophe. Yet we must do better to avoid irreversible tipping points along the way, hence the goal of achieving the IPCC's SR1.5 trajectory. We now turn our attention to examining the levers that could accelerate climate solutions in an effort to achieve the SR1.5 trajectory.

Figure 5: Global climate projections: (a) Atmospheric CO₂ Concentration, (b) Atmospheric GHG Concentration, (c) Radiative Forcing, (d) Global Mean Temperature
2 | Scenarios for Achieving Global Targets
The DAU21 base scenario estimates that emissions will be ~21 GtCO\(_2\)e/yr short of 2030 goals, and ~8 GtCO\(_2\)e/yr short of 2050 NZE goals (Figure 6). Note that the 2030 emissions target is 50% of the 2010 historical emissions value of 42 GtCO\(_2\)e/yr, and that to offset the remaining 2050 emissions from electricity, buildings, transportation and industry would require either accelerating their emissions reduction, or achieving net negative emissions by accelerating the two NCS verticals (Agriculture and F&W), which are shown to contribute up to 10 GtCO\(_2\)e/yr in negative emissions during the latter quartile of this century under this DAU scenario. We may also need to embrace eCDR for the additional negative emissions.

Here we examine a theoretical set of actions or conditions that could address these shortfalls, with a focus on which of the 7 verticals (V7) could be accelerated towards multi-gigaton mitigation in time to meet 2030 and 2050 global targets and the SR1.5 emissions trajectory. Five scenarios are investigated for their ability to bridge to SR1.5:

1. **Accelerating V4: Industry Decarbonization**
2. **Accelerating V5: Regenerative Agriculture** to its maximum extent by 2030
3. **Accelerating V6: Forests & Wetlands** to its maximum extent by 2030
4. **Accelerating all of the V7** by 15 years (earlier saturation point) using targeted and impactful policy
5. **Accelerating all of NCS (V5 and V6)** to their maximum extent by 2030

We present these scenarios on the following pages. For each of the scenarios, we then calculate the level of eCDR needed to address the remaining CO\(_2\) concentrations in the gap to SR1.5, if any, by using marginal abatement curves to estimate the cumulative cost of CDR at the scales needed in each scenario. All scenarios would need policy focus on the scenario driver, in addition to properly-functioning energy markets to maintain the base DAU trajectory.

An important caveat: there is an emerging understanding of asymmetric response to emissions versus removals, such that removals do not have as large an effect as emissions\[16\]. This phenomenon is an emerging science and is not accounted for here, which would increase the amount of removals necessary. Future PD modeling will strive to account for the latest science around such asymmetry.
2. Scenarios for Achieving Global Targets

1. The V4 Scenario: Industry - Accelerating industry decarbonization with focus on displacing fossil fuel use for industry heating needs

First, we examine the contributors to emissions from industry (Figure 7) and find that the primary contributor is the use of fossil fuel for industrial process heat, at ~8 GtCO$_2$e/yr at its peak. In Figure 8, we see that accelerating this vertical offers a meaningful – if insufficient – bridge toward achieving the SR1.5 trajectory, leaving 87 GtCO$_2$e to be addressed by CDR by 2030 alone. In addition, the V4 Scenario only offers emissions reduction, in a world where negative emissions are critically needed to offset the buildup of historical emissions. For that we turn to the opportunities with natural climate solutions.
2. The V5 Scenario: Regenerative Agriculture – Accelerating Regenerative Agriculture to its global maximum extent by 2030

Next, in Figure 9a, we display the subvertical contributions to the Regenerative Agriculture vertical, revealing the extraordinary contribution of agroforestry (trees in croplands and pasturelands), as well as getting carbon back into soils by practices leading to cropland soil health.

Figure 9a: Subverticals within regenerative agriculture, DAU21

Figure 9b displays these contributions under the scenario of accelerating the V5 vertical to its maximum extent by 2030, as reported by Griscom et al. (2017) [17]. We find that together, these contributions offer more than 8 GtCO$_2$e/yr in emissions mitigation at saturation, including a full 4 GtCO$_2$e of negative emissions which take several decades to achieve, largely due to the time it takes for the trees in croplands and silvopasture subverticals to reach maximum sequestration.

Figure 9b: Subverticals within Regenerative Agriculture (V5) under the scenario of achieving max extent by 2030.

In Figure 10, we see that accelerating this vertical to its maximum extent by 2030 offers a meaningful yet insufficient bridge to the SR1.5 trajectory, leaving the need for further CDR at 24 GtCO$_2$e by 2030 and 154 GtCO$_2$e by 2050.

Figure 10: Emissions mitigation pathway under a scenario of Regenerative Agriculture (V5) at max extent in 2030
2. Scenarios for Achieving Global Targets

3. The V6 Scenario - Forests & Wetlands: Restoring and protecting F&W to its global maximum extent by 2030

In Figure 11a, we display the subvertical contributions for the Forest & Wetlands vertical. Figure 11b estimates the same subvertical contributions when accelerated to their maximum extent by 2030. We find that together, they offer more than 8 GtCO₂e/yr in emissions mitigation at saturation, including up to 5 GtCO₂e negative emissions. At the accelerated adoption rates of NCSmax (Figure 11b), this result would take several decades to achieve due to ecological processes involved with natural systems restoration. In Figure 12, we see that accelerating this vertical to its maximum extent by 2030 offers a meaningful yet insufficient bridge toward achieving the SR1.5 trajectory, leaving the need for further CDR at 55 GtCO₂e by 2030 and 200 GtCO₂e by 2050.

Figure 11a: Subverticals in Forests & Wetlands (DAU21)

Figure 11b: Subverticals in Forests & Wetlands (V6) at maximum extent by 2030

Emissions Mitigated, V6, World

Figure 12: Emissions mitigation pathway under a scenario of Forests & Wetlands (V6) at max extent in 2030

Green mangrove trees in Gambia.
4. The Policy-Led Scenario - Accelerating all of the V7 with high-impact policy

Figure 13 portrays what could be the speed of adoption in a Policy-Led world; defined by high-impact policies sufficient to steepen the V7 logistic curves to reach 100% saturation 15 years ahead of the more organic, no-new-policy (DAU21) baseline (Figure 3).

Figure 13: V7 policy-led adoption curves depicted as 15-year acceleration over the base scenario of Figure 3

Figure 14 reveals that the resulting emissions trajectory would achieve the 2050 global target, while leaving the need for further CDR at 52 GtCO₂e by 2030 and 143 GtCO₂e by 2050.

Figure 14: Policy-led emissions mitigation chart revealing a DAU-PL emissions trajectory

5. The NCSmax Scenario - Accelerating all Natural Climate Solutions (V5 + V6) to their maximum extent by 2030

We represent an accelerated NCS case, NCSmax, by assuming both NCS verticals (V5 and V6) reach their maximum extent by 2030, which is in line with the analysis in Griscom et al. (2017), which assesses the maximum theoretical extent to which NCS could contribute to meeting global net emissions goals (Figure 15)[171]. Here we see both the Regenerative Agriculture and F&W verticals expand and accelerate to fully serve the CDR need, bridging to the SR1.5 trajectory. Accelerating proven nature-based solutions in this fashion would provide time for engineered CDR, if needed, to become demonstrated and scalable at cost-effectiveness, and to be deployed on a mass scale if and when real-time data shows that markets plus NCS are not sufficient to meet SR1.5.

In summary, in addition to market-led DAU21, if NCS can be caused to expand to its maximum extent by 2030, climate targets can be met and the worst of climate outcomes potentially avoided.
3 | Scenario Climate Outcomes
The prior scenarios were selected as they represent multi-gigaton emissions reduction opportunities by 2030 and 2050, when accelerated. The accelerated emissions trajectories without added CDR lead to climate outcomes as depicted in Figures 16a-d, where CO₂ and CO₂e concentrations, radiative forcing, and global mean temperature outcomes are shown.

While the gap between SR1.5 and any of the scenario trajectories above may appear small in Figure 16, each of the scenario temperature curves in Figure 16d is an improvement upon the DAU21 curve with a sharper downturn in global temperatures in most cases by 2040. While the scenarios without CDR may appear acceptable, they risk nearly unfathomable costs of life, property, and biodiversity, which, given a rational cost-benefit analysis, would warrant immediate shifts in policy and investment.

Finally, in Figure 16d, note the uptick in the NCSmax curve in the latter two decades of this century. This corresponds with declining negative emissions from some of the NCS subverticals as seen in Figure 13, explained as follows: carbon mitigation benefits from NCS are only counted if they provide carbon sequestration beyond what would have occurred without protection, restoration, or improved management. This additional sequestration is termed ‘additionality’. Eventually, newly planted vegetation matures and reaches a point where additional carbon is no longer sequestered. While the vegetation still does sequester carbon (and likely provides myriad co-benefits), the carbon sequestered is no longer considered ‘additional’, and thus the carbon mitigation declines, or saturates. How this becomes addressed is the subject of one final ‘endgame’ scenario played out in the summary to this report.

Figure 16: Global climate projections: (a) Atmospheric CO₂ Concentration, (b) Atmospheric GHG Concentration, (c) Radiative Forcing, (d) Global Mean Temperature. Historical temperatures, reference period, and smoothing are adapted from SPM.1 in [2].
4 | Cost of the CDR Bridge
Most of the prior scenarios leave a shortfall to the SR1.5 emissions trajectory, which establishes a requirement for negative emissions that can be fulfilled by means of both natural (NCS, or nCDR), and engineered carbon removal (eCDR). eCDR is more expensive than NCS, and providing negative emissions via NCS rather than CDR would save about $60 trillion between now and 2100. Costs for each option are approximated as follows:

- For NCS: 2030 average marginal abatement cost estimates from Griscom et al. (2017) for each subvertical are applied\(^{17}\).
- For CDR: Capital costs were modeled using a one-factor learning approach, where cumulative deployment determines the capital cost of the next unit. In the absence of specific operating cost values from industry, operating costs for low-temperature solid sorbent direct air capture (DAC) projects were assumed to be 3.7% of the annual capital cost, after adjusting for the utilization ratio, as observed in engineering cost estimates for other types of DAC projects, which are described in\(^{18,19}\). High-temperature liquid sorbent DAC was modeled to experience a one-factor learning rate of 10%, from\(^{20}\). See section 6 in the Methodology for more detail.

Whereas the DAU21 trajectory has a gap to meet the SR1.5 trajectory of 384 GtCO\(_2\)e, policies that increase NCS reduce the need for eCDR, thus reducing costs to society. The costs of NCS are offset by certain co-benefits, which are listed in qualitative terms in Table 1, while reported widely.

### Table 1: Level and cost of CDR needed to bridge the gap to the SR1.5 curve

<table>
<thead>
<tr>
<th>Bridge scenario to the SR1.5 curve</th>
<th>Negative emissions (\text{GtCO}_2)e</th>
<th>Cost [T]</th>
<th>Co-benefits (qualitative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCS (nCDR) eCDR</td>
<td>NCS</td>
<td>eCDR</td>
<td>Total</td>
</tr>
<tr>
<td>DAU21</td>
<td>0</td>
<td>384</td>
<td>0</td>
</tr>
<tr>
<td>V5: RA max by 2030</td>
<td>214</td>
<td>170</td>
<td>9</td>
</tr>
<tr>
<td>V6: F&amp;W max by 2030</td>
<td>160</td>
<td>222</td>
<td>5</td>
</tr>
<tr>
<td>Policy Led: V1-V6</td>
<td>87</td>
<td>143</td>
<td>4</td>
</tr>
<tr>
<td>NCSmax: V5 + V6</td>
<td>374</td>
<td>0</td>
<td>14</td>
</tr>
</tbody>
</table>

1. Soil health, food nutrient value, water retention in soils, climate-resilient agriculture, biodiversity, lower
2. species extinction rates, etc.
3. Same as (1), expanded rapidly and globally
4. Forest expansion, recreational habitat, expanded species habitat, biodiversity, shade for grazing livestock
5. (2,3) (2) and (3) combined

The timewise cumulative cost to 2060 of CDR to achieve the SR1.5 trajectory under each of the above scenarios is shown in Figure 17, resulting in $14 trillion by 2060 when the negative emissions bridge is provided by the NCSmax scenario and $72 trillion by 2060 when relying on eCDR to provide the bridge from the DAU21 curve.

![Figure 17: Cumulative CDR costs to bridge DAU21 to SR1.5 under the listed scenarios](image-url)

The NCSmax scenario, while meeting the SR1.5 emissions trajectory, is also the lowest cost pathway, and mitigates the need for engineered carbon dioxide removal (eCDR). Yet while giving priority to the NCS option, we caution that successful development of eCDR technology is an important backstop in the event the effectiveness of nature-based solutions is thwarted by feasibility constraints, including a changing earth climate system along the SR1.5 pathway.
Regional Contributions Toward Global Targets
Here we examine how ensuring properly-functioning energy markets and embracing NCS to their maximum extent by 2030 would enable the 16 global regions to align their NDCs with the global targets. Figures 18 and 19 present the contributions estimated at the regional level by each of the V7 in relation to that region’s respective contributions toward the 2030 and 2050 emissions targets. Such contribution levels serve as aspirational targets for the NDCs.

We find that the world on average, and OECD nations in particular, could meet or exceed the global target values in 2030 (Figure 18) and 2050 (Figure 19), assuming NCS are embraced to their maximum extent by 2030.

High speed electric train in South Korea, made by Hyundai.
6 Summary and Conclusions
A Climate Endgame Scenario

Examining Figure 16, we see that while the NCSmax scenario enables a quick downturn in temperatures alongside SR1.5, it deviates with an upturn in the latter part of the century as natural climate solutions reach a saturation point for carbon sequestration, and there remains a need for continuing negative emissions to offset historical emissions.*

As a final scenario, we add engineered CDR (eCDR) to the preferred NCSmax scenario in the latter part of this century to ensure a favorable emissions trajectory, and to give time for cost-effective eCDR technologies to be demonstrated at scale. Many NCS subverticals reach saturation near the end of this century and the addition of eCDR after NCS saturation allows the continued scaling of net negative emissions to target CO₂ concentrations below 350ppm in 2100. Additional benefits of this scenario include comparable favorable outcomes for temperatures and radiative forcing. This scenario thus sets the stage for an era in which humans have the tools to take control of net emissions.

We present in Figure 20 the emissions mitigated in the NCSmax case showing 109 GtCO₂e of CDR added from 2060-2100, followed by the climate outcomes for this scenario in Figure 21.

*For example, planting new trees in croplands results in additional carbon storage that was not there before. In each year of tree growth, trees capture more carbon, leading to additional carbon storage each year. As a tree matures and growth slows, the amount of additional carbon captured year-to-year decreases and eventually plateaus and saturates.
Summary and Conclusions

Roadmap and Dashboard for Climate

Finally, in Figure 22, we summarize the adoption curves for the V7 in this endgame scenario in the form of a roadmap and dashboard for monitoring progress of the V7. Here, the V7 logistic functions are displayed as projections offering a roadmap alongside historic data serving as a dashboard for stabilizing Earth’s climate by 2100.

Figure 22
The V7 adoption curves as a roadmap and dashboard for the Climate Endgame Scenario

Where We Go from Here
Summary Perspective

In this report we examined the result of a core set of technologies and practices setting the world on a course to reverse climate change by the end of this century. The majority of these are at scale and scaling in multiple regions under existing policy and other market drivers, such as cost, convenience, health, lifestyle, stigma, and others. With focused intervention, and when coupled to acceleration of the opportunity offered by natural climate solutions (NCS), the core set of solutions can be underway in time to achieve globally-defined emissions goals to minimize the scourge of climate change.

We have found that reliance on market forces alone is not sufficient to achieve the IPCC’s SR1.5 emissions trajectory, which traces through 50% emissions reduction by 2030 and net zero emissions by 2050. However, in addition to ensuring current levels of policy and properly-functioning markets to achieve the DAU21 results, adding policy targeted to accelerate the two NCS verticals - 1) Regenerative Agriculture, and 2) Forests & Wetlands - would achieve the required SR1.5 trajectory while meeting the need for negative emissions at minimum cost.

There is a large role that governments can play in promoting NCS, such as through policies promoting soil conservation and proper forest management practices. In addition, the NCS verticals have two emerging market based pathways: 1) investment to capture the market value of additional harvests, e.g. fruit, nut and timber production from agroforestry, and 2) the ecosystem services market, which is emerging to reward environmental co-benefits to society of specific NCS practices, including carbon
These results point to a clear call for the following actions on the part of nations:

1. Remove obstacles to, and provide incentives for properly-functioning energy markets, to enable a meaningful and natural disruption of energy use in electricity, transportation, buildings and industry.

2. Support reduced carbon intensity of industry, by ensuring that government procurement has progressive requirements for low-carbon steel, concrete, and other products of industry, sending a strong signal to suppliers, thus ensuring their competitiveness as carbon-content tariffs become established across global markets.

3. Time is clearly of the essence in choosing to embrace natural climate solutions. Embrace natural climate solutions to their maximum extent as the first priority for the CDR needed to achieve the IPCC’s SR1.5 trajectory, both through regenerative agriculture and preservation and restoration of forests & wetlands.

4. Fully account for the NCS opportunity with updated nationally determined contributions (NDCs).

5. Given the risk of feasibility constraints to natural climate solutions, advance engineered carbon dioxide removal (eCDR) as a backstop, to be deployed on a mass scale if and when real-time data shows that markets plus NCS are not sufficient to meet SR1.5.

A Call to NCS Stakeholders

1. There is an urgent need for the development of fast, science-based verification of the carbon offset value of the various NCS, to keep pace with the rapid growth of the ecosystem services markets.

2. There is need for consensus around the science for soil organic carbon (SOC) values attributable to various NCS practices of regenerative agriculture, including distinction by geography, soil type, depth of soil, SOC longevity, etc.

3. There is a need to demonstrate scalable models for private investment in restorative practices in Forests & Wetlands, such that they not reliant strictly on policy initiatives, which can fluctuate with administrations.

4. Climate impact investors may wish to broaden their focus to market opportunities in both the agriculture and F&W sectors. Existing opportunities include establishing venture funds for assisting farmers and ranchers invest in higher and more diversified yields, and in practices that lead to fewer costly inputs.

A Call to Individual Action

Purchasing choices matter. Individual and corporate choices driven by cost, lifestyle, health and/or other preferences are the very reasons why the V7 are accelerating along their growth curves today.

Markets have the ability to drive investments, spur innovation, and rapidly change society. Market disruption is the product of individual decisions, meaning that your personal decisions have global impact. Thus, driving the solutions set forth within this report is within our individual and collective control.

We provide in Appendix C a set of individual actions in support of climate solutions.

Future Modeling

Epic is committed to continuing its Positive Disruption modeling with annual updates that enhance both model versatility and data sources. For Positive Disruption 2022, future updates will include:

1. Increasing granularity from 16-region to 165-nation modeling.

2. Quantitative evaluation of projected co-benefits and externalities to each of the V7. Co-benefits include air, water and soil quality, human health impacts, impacts on food resilience, quality and nutritional features, biodiversity, and nutrient cycling to reduce chemicals in the environment. Emerging externalities include mining hazards related to lithium, cobalt, and other necessary constituents, self-driving cars reliant upon AI, use of forced labor practices, CO$_2$ leaks from pipelines, etc.

3. Deep dive into individual national opportunities, while categorizing nation-types based on region, culture, and political economy, to refine our market projections on a nation-scale.

4. Model updates to account for the latest understanding of asymmetry in the climate-carbon cycle response to positive and negative CO$_2$ emissions.
References


3. Rogelj, J. et al. Scenarios towards limiting global mean temperature increase below 1.5 °C. Nature Climate Change, 8(4), 325-332. https://doi.org/10.1038/s41558-018-0091-3


11. The Drawdown Review. https://www.drawdown.org/drawdown-review


Companion Publications

1. PD21 Extensions
   a. PD21 Methodology, including
      • Treatment of Other GHG Gases
      • Reconciling Model Results with the Physical World

2. V7 Compilation - An Epic New World - forthcoming
   a. V1: Electricity
   b. V2: Transportation
   c. V3: Buildings
   d. V4: Industry
   e. V5: Regenerative Agriculture
   f. V6: Forests & Wetlands
   g. V7: Carbon Dioxide Removal

3. Natural Climate Solutions (NCS): Pathways to acceleration
   • Disrupting Climate Disruption: A Roadmap to 1.5°C
   • Grid Decarbonization: UK vs. US
   • Regenerative Agriculture is all the Rage: A Silver Bullet for Climate?

4. Prior PD and Epic Publications
   • Positive Disruption 2017 (PD17)
   • Positive Disruption 2020 (PD20)
Appendix A: V7 Subvertical Contributors

V1: Electricity Decarbonization

V2: Transportation Decarbonization

Energy Demand, DAU21, World

Electricity Supply, DAU21, World
Appendix A: V7 Subvertical Contributors

V3: Building Decarbonization

Percent of Total PD Adoption, DAU21, Buildings, World

Energy Demand, DAU21, World
Appendix A: V7 Subvertical Contributors

V4: Industry Decarbonization

Percent of Total PD Adoption, DAU21, Industry, World

Emissions in Industry, DAU21, World

V5: Regenerative Agriculture

Percent of Total PD Adoption, DAU21, Regenerative Agriculture, World

Emissions in Regenerative Agriculture, DAU21, World
Appendix A: V7 Subvertical Contributors

V6: Forests & Wetlands

![Graph showing percent of total PD adoption for Forests & Wetlands, including Peat Restoration, Natural Regeneration, Improved Forest Management, Coastal Restoration, and Avoided Peat Impacts.]

Emissions in Forests & Wetlands, DAU21, World

![Graph showing emissions in Forests & Wetlands, DAU21, World, including Peat Restoration, Natural Regeneration, Improved Forest Management, Coastal Restoration, Avoided Peat Impacts, Avoided Forest Conversion, Avoided Coastal Impacts, and Deforestation.]  

V7: Carbon Dioxide Removal

<table>
<thead>
<tr>
<th>Technology/Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Temperature Solid Sorbent Direct Air Capture</td>
</tr>
<tr>
<td>High Temperature Liquid Solvent Direct Air Capture</td>
</tr>
<tr>
<td>Enhanced Weathering</td>
</tr>
</tbody>
</table>

TABLE A1: CDR TECHNOLOGIES AND PRACTICES INCLUDED IN THIS ANALYSIS
We define the Epic Index (EI) to provide a measure of how the V7 market verticals are tracking to global targets as well as to each region/nation’s alignment with those targets. We define the Epic Index as follows:

\[
EI_t = \frac{\left( \sum V7_t \right)}{Goal_t}
\]

\( V7_t \) = sum of the emissions reductions cumulative across the V7 in year \( t \)

\( Goal_t \) = Emissions Reduction Goals, expressed as

1. SR1.5 targets:
   a. t30: 50% emissions reduction in 2030
   b. t50: Net Zero Emissions (NZE) in 2050

The EI offers a quick reference toward climate solutions progress as follows:

- EI > 1 indicates that properly-functioning energy markets (the V7) plus NCS exceed mitigation contributions aligned with the Global Targets, while
- EI < 1 indicates there is a shortfall to Global Targets. We see that for the world, EI = 0.35 in 2030 and EI = 0.83 in 2050, without CDR, as shown in Figures B1-B2, but
- EI = 1 in all scenarios where CDR is added to meet the emissions targets and the SR1.5 trajectory (Figure B2), and in the NCSmax case when NCS serves all of CDR, Figure B3.

While 2030 is clearly a difficult target to achieve without CDR, the 2050 NZE goal is within striking distance. As shown, 2050 NZE could be achieved with global acceleration of NCS to max extent in order to fulfill the need for CDR.

Figure B1: V7 climate contributions globally relative to 2030 target. The blue dotted line represents an emissions mitigation goal of 50% reduction by 2030.

Figure B2: V7 climate contributions globally relative to 2050 target. The blue dotted line represents an emissions mitigation goal of net-zero by 2050.

Figure B3: V7 climate contributions globally relative to 2050 target with NCS at maximum extent in 2050 (NCSmax scenario). The blue dotted line represents an emissions mitigation goal of net-zero by 2050.
Appendix C: A Call to Individual Action

Markets have the ability to drive investments, spur innovation, and rapidly change society. Market disruption is the product of individual decisions, meaning that your decisions have global impact. Thus, the solutions set forth within this report are in our individual and collective control. Those fortunate and privileged enough to have access to options in the marketplace can help drive the necessary changes to fight climate change. People will need to choose what works for them, and these choices can be as simple as incremental lifestyle adjustments or making improvements to household infrastructure, such as:

- Walking or biking, if and where you can, or taking zero-carbon mass transit. If you must drive, choose to drive electric, if possible. Doing so can clean our air and reduce asthma and cancer rates.
- Eliminating the use of natural gas in your home by electrifying your home with heat pumps for hot water and space heating/cooling, and an electric or induction range for cooking. Following this, you could go all the way and turn off your connection to natural gas, ending any possibility of further indoor air pollution leading to asthma and other health issues.
- Investing in electric home appliances that normally are gas-powered, e.g. battery power lawn-mowers, battery-powered snow-blowers, etc.
- Installing solar on your rooftop, or joining a community solar grid, or electing for the renewable energy option from your local electric utility, if available.
- Increasing the fraction of fruits and vegetables in your diet. Dropping just one meat and dairy dish per week has an outsized impact.
- Supporting community initiatives to provide carbon-friendly public transportation such as electric buses. When compared to diesel options, which contribute to asthma and community health problems, electric buses today offer real carbon savings.
- Advocating for infrastructure projects that use low-carbon building materials, such as green steel, green concrete, or sustainably-sourced mass timber in their construction.
- Questioning whether your community is doing its part in supporting renewable energy – do you see wind turbines on the horizon and solar panels on your street?
- Choosing to fly less – or if you must fly, search for airlines with an aggressive timetable for carbon-neutral flights, and which, in the meantime, offer certified carbon offsets for your flights.
- If you are a farmer or grow your own food, using practices that reduce chemical inputs and increase carbon storage in soils. As a farmer, you could increase your income by using ecosystem services markets that pay you for regenerative methods.
- Where available, buying foods grown by farmers practicing regenerative methods.
- Composting your organic waste, preferably amended with biochar.
- Supporting a local organization engaged in ecosystem restoration activities, such as planting native trees and restoring wetlands.
- Consider the land-use footprint of your foods, especially products that are driving deforestation of carbon-rich ecosystems, such as palm oil, used in everything from candy and cookies to shampoos. Read the label!
- Buying certified, science-based carbon offsets wherever industry does not yet provide you with zero-carbon options.
- Add your congressional representatives to your contact list on your phone. If you don’t know who they are and you are a US citizen, find out quickly and easily here.
- Call your representatives every day. Call them when you’re driving. Call them when you’re walking your dog. Call them right when you wake up in the morning. Call them all the time. If it’s after hours, you can leave a message. Don’t be intimidated – they’re working for you. You don’t have to sound like a professional lobbyist. Just say who you are and why you care about this issue in your own words.
- And finally,
  - engaging with your local political process and planning commissions
  - supporting climate-smart politicians, by voting!
  - Visit a construction site and ask whether they are using green steel and green concrete, and if not, why not?