WHAT SHOULD BE DONE TO ADDRESS CLIMATE CHANGE?

And what can be done?

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Section One: What *should* be done to address climate change?

The Science of Climate Change

Average global temperatures have increased by at least 0.8°C over the past century and continue to rise. Scientists have determined with 100% certainty that the greenhouse effect, created by anthropogenic emissions of CO_2 and other greenhouse gases (GHGs), is the primary cause of global warming and the main contributing factor towards climate change. [1] Simultaneously, changes in land use have caused the planet to be more reflective overall, thus contributing a significant cooling effect on the planet.[2] Aerosol emissions similarly contribute a significant global cooling effect.[3] However, since the ability for GHG emissions to warm the planet overwhelmingly dominates both the albedo and aerosol cooling affects, it is imperative to control GHG emissions if we are to effectively limit the rise in global temperatures and curtail its impact on ecological and social systems.

Setting a Goal: 1.5℃ or 2℃?

There is much debate as to whether the world can feasibly achieve the goal, set out in the Paris Climate agreement, to limit the rise in global temperatures under 2℃ while working towards a threshold of 1.5℃.[4] [5] Notably, the 0.5℃ difference between 1.5℃ and 2℃ is likely to lead to a sharp increase in the likelihood of catastrophic and dangerous events.[6] [7]

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[1] See Fact Sheet 1
[2] Andrews, Timothy, Richard A. Betts, Ben B. Booth, B, Chris D. Jones, and Gareth S. Jones. "Effective Radiative Forcing from Historical Land Use Change." *Climate Dynamics; Heidelberg* 48, no. 11–12 (June 2017): 3489–3505.
[3] Nazarenko, L., D. Rind, K. Tsigaridis, A. D. Del Genio, M. Kelley, and N. Tausnev. "Interactive Nature of Climate Change and Aerosol Forcing." *Journal of Geophysical Research: Atmospheres* 122, (March 27, 2017): 3457–80.
[4] *Adoption of the Paris Agreement* FCCC/CP/2015/L.9/Rev. 1 (UNFCCC, 2015)
[5] Millar, Richard J., et al. "Emission Budgets and Pathways Consistent with Limiting Warming to 1.5 °C." *Nature Geoscience*, vol. 10, (2017)
[6] IPCC, 2018: Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels.* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, Maycock, M. Tignor, and T. Waterfield (eds.)]. *World Meteorological Organization, Geneva, Switzerland, 32 pp.*
[7] See appendix, figure 1

The differences between 1.5℃ and 2℃ are potentially differences of scale, however, not differences of kind. Indeed, it is uncertain if there any significant tipping points between 1.5℃ and 2℃.[8] Furthermore, the expected marginal abatement costs for 1.5℃ emissions pathways "are roughly 3-4 times higher than in pathways limiting global warming to below 2°C".[9] Aiming at a global economic transformation with such severe economic costs could have a net negative impact on climate action, since countries that consider a 1.5℃ goal unreasonable may be less willing to take *any* action on climate, knowing that they could not possibly attain the goal.

Setting a Goal: 1.5℃ → *$GtCO_2$*

Still, the difference between 1.5℃ and 2℃ are substantial enough that the world should fully engage in an effort to avoid 1.5℃. While meeting a goal of 1.5℃ is ambitious, it is not a geophysical impossibility.[10] In order to achieve this goal, we should set a carbon emissions threshold goal based on CO_2 emissions in $GtCO_2$/yr (gigatons of carbon dioxide emitted per year), rather than on $GtCO_2e$ (carbon dioxide equivalent) terms. This is because CO_2 is by far the most significant greenhouse gas by volume and impact, and can last for centuries in the atmosphere. Short-lived greenhouse gases which would contribute to CO_2e calculations, such as methane and nitrous oxide, should have separate reduction goals since they dissipate relatively quickly (over about a decade). They should be regulated separately at an appropriate flow level. Furthermore, the question of how to calculate CO_2e contributes uncertainty to the threshold, which could further complicate international agreements. Conversely, the goal of limiting total atmospheric CO_2 is relatively easy to measure and universally understood. Another reason to set

[8] See appendix, figure 2
[9] IPCC, 2018: Summary for Policymakers. In: *Global Warming of 1.5°C.*
[10] Millar, Richard J., Jan S. Fuglestvedt, Pierre Friedlingstein, Joeri Rogelj, Michael J. Grubb, H. damon Matthews, Ragnhild B. Skeie, Piers M. Forster, David J. Frame, and Myles R. Allen. "Emission Budgets and Pathways Consistent with Limiting Warming to 1.5 °C." *Nature Geoscience; London* 10, no. 10 (October 2017): 741–47.

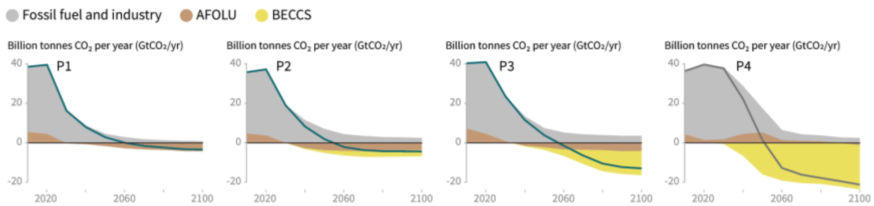
a goal on limiting total $GtCO_2$ is because countries can directly impact their carbon emissions, as opposed to limiting a rise in temperature which countries do not have direct control over.

The IPCC1.5 report illustrates mitigation pathways to limit total global warming to 1.5°C:

Characteristics of four illustrative model pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limits global warming to 1.5°C with no or limited overshoot. All pathways use Carbon Dioxide Removal (CDR), but the amount varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for emissions and several other pathway characteristics.

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Global indicators	P1	P2	P3	P4	**Interquartile range**
Pathway classification	No or limited overshoot	No or limited overshoot	No or limited overshoot	Higher overshoot	No or limited overshoot
CO_2 emission change in 2030 (% rel to 2010)	-58	-47	-41	4	(-58,-40)
↳ in 2050 (% rel to 2010)	-93	-95	-91	-97	(-107,-94)
Kyoto-GHG emissions in 2030 (% rel to 2010)*	-50	-49	-35	-2	(-51,-39)
↳ in 2050 (% rel to 2010)	-82	-89	-78	-80	(-93,-81)
*Final energy demand** in 2030 (% rel to 2010)*	-15	-5	17	39	(-12,7)
↳ in 2050 (% rel to 2010)	-32	2	21	44	(-11,22)
Renewable share in electricity in 2030 (%)	60	58	48	25	(47,65)
↳ in 2050 (%)	77	81	63	70	(69,86)
Primary energy from coal in 2030 (% rel to 2010)	-78	-61	-75	-59	(-78, -59)
↳ in 2050 (% rel to 2010)	-97	-77	-73	-97	(-95, -74)
from oil in 2030 (% rel to 2010)	-37	-13	-3	86	(-34,3)
↳ in 2050 (% rel to 2010)	-87	-50	-81	-32	(-78,-31)
from gas in 2030 (% rel to 2010)	-25	-20	33	37	(-26,21)
↳ in 2050 (% rel to 2010)	-74	-53	21	-48	(-56,6)
from nuclear in 2030 (% rel to 2010)	59	83	98	106	(44,102)
↳ in 2050 (% rel to 2010)	150	98	501	468	(91,190)
from biomass in 2030 (% rel to 2010)	-11	0	36	-1	(29,80)
↳ in 2050 (% rel to 2010)	-16	49	121	418	(123,261)
from non-biomass renewables in 2030 (% rel to 2010)	430	470	315	110	(245,436)
↳ in 2050 (% rel to 2010)	833	1327	878	1137	(576,1299)
Cumulative CCS until 2100 ($GtCO_2$)	0	348	687	1218	(550,1017)
↳ of which BECCS ($GtCO_2$)	0	151	414	1191	(364,662)
Land area of bioenergy crops in 2050 (million km^2)	0.2	0.9	2.8	7.2	(1.5,3.2)
Agricultural CH_4 emissions in 2030 (% rel to 2010)	-24	-48	1	14	(-30,-11)
in 2050 (% rel to 2010)	-33	-69	-23	2	(-47,-24)
Agricultural N_2O emissions in 2030 (% rel to 2010)	5	-26	15	3	(-21,3)
in 2050 (% rel to 2010)	6	-26	0	39	(-26,1)

NOTE: Indicators have been selected to show global trends identified by the Chapter 2 assessment. National and sectoral characteristics can differ substantially from the global trends shown above.

** Kyoto-gas emissions are based on IPCC Second Assessment Report GWP-100*
*** Changes in energy demand are associated with improvements in energy efficiency and behaviour change*

*Figure 1: Pathways to achieve 1.5C. Differences in models accrue to the potential for BECCS (bioenergy with carbon capture and storage) to remove carbon dioxide from the atmosphere. **The world should choose the P2 scenario**, since there are serious issues that complicate the widespread adoption of BECSS technology (as I will explain in a later section). However, it is also important to recognize the potential for carbon capture and storage with fossil fuels, which P1 neglects.*

Key Takeaways

According to the P2 model, we must meet the following mitigation and CDR goals:

1) Peak global CO_2 emissions by about 2025
2) Reduce global CO_2 emissions in 2030 to approximately 50% of 2010 levels
3) Achieve net zero emissions by 2050
4) Remove an average of roughly 4 $GtCO_2$/yr from 2050 to 2100
5) Reduce agricultural methane emissions to 50% of 2010 levels by 2030
6) Reduce agricultural nitrous oxide emissions to 75% of 2010 levels by 2030
7) Do not emit more than 420 $GtCO_2$ in total (gives a 67% chance of avoiding 1.5℃)[11]

The Remaining Carbon Budget: Uncertainties about Sources and Sinks

There is a large difference between gross carbon emissions and net carbon emissions, since roughly 60% of global emissions are taken up by the world's forests and oceans (carbon "sinks").[12] Indeed, there is significant uncertainty how the increasing temperatures will affect global carbon sink potential over time.[13] This is in part because the absorption of atmospheric carbon by oceans causes ocean acidification, a process that can undermine the oceanic ecosystem services that humans rely on and cause unknown feedback effects.[14] Furthermore, there is significant uncertainty regarding the amount of additional methane emissions that wetlands and thawed permafrost zones will contribute as temperatures rise.[15] The impossibility of predicting precise changes in climate resulting from carbon emissions suggests that we should take a relatively conservative approach that does not underestimate the threat.

[11] See appendix, figure 2
[12] Bellassen, Valentin, and Sebastiaan Luyssaert. "Carbon Sequestration: Managing Forests in Uncertain Times." *Nature News* 506, (2014)
[13] Fernández-Martínez, M., J. Sardans, F. Chevallier, P. Ciais, M. Obersteiner, S. Vicca, J. G. Canadell, et al. "Global Trends in Carbon Sinks and Their Relationships with CO 2 and Temperature." *Nature Climate Change* 9, no. 1 (January 2019): 73.
[14] Doney, Scott C., Victoria J. Fabry, Richard A. Feely, and Joan A. Kleypas. "Ocean Acidification: The Other CO_2 Problem." *Annual Review of Marine Science* 1, no. 1 (January 2009): 169–92.
[15] Comyn-Platt, Edward, Garry Hayman, Chris Huntingford, Sarah E. Chadburn, Eleanor J. Burke, Anna B. Harper, William J. Collins, et al. "Author Correction: Carbon Budgets for 1.5 and 2 °C Targets Lowered by Natural Wetland and Permafrost Feedbacks." *Nature Geoscience* 11, no. 11 (November 2018): 882.

Technological Options to Reduce Emissions

In order to bring net emissions to zero we must increase energy efficiency, decarbonize of electricity and fuels, and transforming energy end uses.[16] Improving energy efficiency and fuel economy can be done by setting technological standards such as a minimum mpg standards for vehicles, or requiring that all appliances become more efficient. However, it is important to account for the rebound effect, whereby increasing the efficiency of a technology lowers the cost of using it and therefore increases its use.

Governments should stimulate investment in renewable energy sectors and subsidize the growth of those markets. This could come through lowering consumer prices, mandating renewable energy purchases (as a percentage of consumption), investing in research and development, writing incentives into the tax code, or the implementing feed-in tariffs.[17] Governments should directly invest in building ultra-high-speed DC voltage transmission networks to address the issue of transporting renewable energy across the country. Governments should also invest in the scaling of battery technology that can overcome the storage issues that limit the penetration of renewable energy technology into domestic energy systems.

Simultaneously, any subsidies to fossil fuel companies should immediately cease, and coal production needs to be phased out as quickly as possible. We should also organize key stakeholders in major emitting industries (such as the construction industry) to evaluate and set reduction standards for CO_2 and methane emissions that stem from each step in their supply chain[18]. Remaining gaps between energy demand and renewable energy supply should be addressed with a combination of nuclear energy and biomass.

[16] DDPP. "Synthesis Reports by The DDPP." *DDPP*, http://deepdecarbonization.org/ddpp-reports/. Access 21 Apr. 2019
[17] Zhang, M. M., D. Q. Zhou, P. Zhou, and H. T. Chen. "Optimal Design of Subsidy to Stimulate Renewable Energy Investments: The Case of China." *Renewable and Sustainable Energy Reviews* 71 (May 1, 2017): 873–83.
[18] Simon, Frédéric. "Swiss Researchers Chart Path to Zero-Emission Cement." *Euractiv.Com* (blog), October 31, 2018. https://www.euractiv.com/section/energy/news/swiss-researchers-chart-path-to-zero-emission-cement/.

Economic Tools

As a tool to help catalyze the decarbonization of global energy systems, we should introduce a carbon fee (equal to the social cost of carbon) that would transform both the supply and demand of fossil fuel energy. This should be done in a fashion similar to the Swiss model, which differentiates fee prices by levying a lower tax on electricity and heating fuel as opposed to transportation fuel, thereby creating an equitable and progressive carbon tax.[19] [20] A base tax level of $50 per ton CO_2, (roughly equivalent to an increase in $0.50USD per gallon of gasoline) would be a reasonable starting point, given that majority of the current carbon taxes hover below $50/t$CO_2$ and are generally considered too low to be effective at reducing emissions across domestic emitting industries.[21] [22] Furthermore, in order to ensure both political feasibility and equitable outcomes, the revenue from the tax should be distributed as household rebates.

Carbon taxes should be favored over Emissions Trading Schemes (ETS) because setting a price on carbon is more effective at avoiding future damages than using a quantity-based instrument. [23] However, if currently existing ETS systems established a more effective price floor (higher than most current ETS systems, and with less exemptions) they could serve as a much more effective economic tool to limit emissions.[24]

Adaptation

All climate policy must consider adaptation as a means of reducing climate risk, in part because the planet can no longer avoid all of the effects of climate destabilization. Governments

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[19] Landis, Florian, Sebastian Rausch, and Mirjam Kosch. “Differentiated Carbon Prices and the Economic Cost of Decarbonization.” *Environmental and Resource Economics* 70, no. 2 (June 1, 2018): 483–516.
[20] Sonnenschein, Jonas, and Luis Mundaca. “Is One Carbon Price Enough? Assessing the Effects of Payment Vehicle Choice on Willingness to Pay in Sweden.” *Energy Research & Social Science* 52 (June 1, 2019): 30–40.
[21] Haites, Erik. “Carbon Taxes and Greenhouse Gas Emissions Trading Systems: What Have We Learned?” *Climate Policy* 18, (2018): 955–66.
[22] Plumer, Brad, and Nadja Popovich. “These Countries Have Prices on Carbon. Are They Working?” *The New York Times*, April 2, 2019, sec. Climate. https://www.nytimes.com/interactive/2019/04/02/climate/pricing-carbon-emissions.html
[23] Goulder, Lawrence H, and William A Pizer. “The Economics of Climate Change.” Working Paper. NBER, (2006)
[24] Abrell, Jan, Sebastian Rausch, and Hidemichi Yonezawa. “Higher Price, Lower Costs? Minimum Prices in the EU Emissions Trading Scheme.” *The Scandinavian Journal of Economics* 121, no. 2 (April 2019): 446–81.

should subsidize the adaptive choices of industrial actors affected by climate change, while tethering subsidies to products that are more advantageous for the public good. Governments should also conduct research and educate private firms on climate challenges in their sector, while guaranteeing a base level of adaptive potential for their citizens. For example, as the number of extreme hot weather days continues to rise, it is crucial to ensure that households across the socioeconomic spectrum are able to afford and access cooling systems–the lack of which will prove increasingly fatal.[25]

Land Use, Land Use Change, and Forestry (LULUCF)

Averted deforestation can have an immediate and significant impact on emissions, as deforestation is estimated to be the second largest source of GHG emissions globally.[26] Governments should seek to compensate land managers for avoiding deforestation and incentivizing afforestation on their properties, using an agreed upon measure of the economic value, such as the "Total Green Value".[27] In addition, they should promote savvy water management and sustainable agriculture practices. Climate-conscious land use management will have to compete with current agricultural practices, but could have a major impact on climate mitigation and is technology is instantly ready to deploy at scale.[28]

Carbon Dioxide Removal (CDR)

Point-source carbon capture and storage is the process of capturing and storing emissions from fossil fuel use in industrial contexts. This technology should be made mandatory for all industrial actors. [29] Non-point source CO_2 may still be removed from the atmosphere through air capture technologies, such as the uptake of CO_2 through air "scrubbing" facilities or with

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[25] See Fact Sheet 3
[26] Ibid.
[27] Loomis, John J., Michael Knaus, and Maurício Dziedzic. "Integrated Quantification of Forest Total Economic Value." *Land Use Policy* (2019)
[28] See Fact Sheet 3
[29] Ibid.

biomass growth. While little has been invested in air scrubbing technology, some economists estimate that costs could lower to $100/tC, which would make it cost effective by some measures of the social cost of carbon. On these grounds DAC ought to be explored further.[30]

The most promising avenue for biological capture is to ultimately use the biomass as a fuel, while capture its emissions with CCS (a process termed bioenergy with capture, or BECSS).[31] BECSS is, however, limited by scale—it would require the use of a significant proportion of total arable cropland—and cost, as it would require expensive investments in transportation and storage. The theoretical rate of sequestration is promising enough that it warrants further investments in research and development, however we should not count on BECSS to scale widely given that it will compete with amount of land needed to feed a growing population.[32] Other CDR instruments, such as ocean fertilization and chemical "weathering" are both environmentally and politically risky methods to capture carbon dioxide, with potential adverse impacts that may outweigh benefits.[33]

Solar Geoengineering

Solar geoengineering, or the deliberate modification of climate by solar deflection, is an economically and scientifically feasible route for keeping global temperatures in check. Yet, it poses irreversible planetary risks that are impossible to predict. For this reason, governments should focus current investments on promising CDR technologies and incentivizing savvy land use practices—both of which have better understood impacts—before even considering deploying geoengineering. That being said, it is worth continuing to develop this technology, because it may become necessary to deploy solar geoengineering a backstop solution, especially

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[30] Ibid.
[31] Ibid.
[32] Henry, R. C., K. Engström, S. Olin, P. Alexander, A. Arneth, and M. D. A. Rounsevell. "Food Supply and Bioenergy Production within the Global Cropland Planetary Boundary." *PLoS ONE* 13, no. 3 (2018)
[33] See fact sheet 3

if the rate of temperature rise due to carbon emissions is on the higher end of the confidence interval.[34] Policies to govern this technology must be studied immediately so that governments can be prepared for the political complications that may ensue if a country considers acting unilaterally to deploy this method.

Section Two: What *can* be done to address climate change?

Moving from Domestic to Global Policy

Individual countries may adopt some combination of the aforesaid policies in order to address climate change. Given that we live in an intertwined global economy, however, we must consider how changes in one country's domestic policy affects others. Moreover, since climate change is a global problem that necessitates international cooperation, we must approach international climate change policy through the lens of development equity and fair trade.

Trade Leakage

When a country adopts domestic climate policy that imposes a cost on its energy-intensive industries, it confers a comparative advantage to energy-intensive industries in other countries. This can increase the carbon emissions of responding countries—in addition to raising their employment levels—all at the expense of the country originating the policy. These phenomena are referred to as carbon and jobs leakages. If more countries are simultaneously imposing costs on domestic energy-intensive industries (i.e. cooperating on mitigation), leakage is reduced. Generally speaking, leakage rates are estimated to be between 0 and 100%, meaning that the net effect of the domestic policy change would indeed be an international reduction in emissions. However, in order to address the negative outcomes associated with trade leakage,

[34] Ibid.

countries must enter into an international agreement such that domestic policies to address climate change do not stimulate emissions elsewhere.[35]

Emissions Accounting

Furthermore, in a globalized economy we must not only set targets on domestic emissions but also on the carbon emissions embodied in the goods and services a country consumes. Based on this understanding, it is possible that leakage could exceed 100% in some cases, such as when industrial activity moves from a country with more carbon-efficient production to a country with less carbon-efficient production. Therefore, in order to control both the supply and demand side of country's emissions, international agreements should include thresholds on both production and consumption of fossil fuels. [36]

Technological Leakage

Conversely, technological leakage can amplify global emissions reductions. In this scenario, one country may invest in innovation in order to reduce abatement costs. The development of a new technology may ultimately lower the global prices for that technology, increasing its' economic viability and, ultimately, its adoption in other countries. In this way, reduction in one country's emissions can lead to further emissions reduction in another country.

International Energy Market Leakage

Reducing the demand for a fossil fuel energy source (such as coal) in a country would decrease the worldwide price of that good, therefore increasing consumption of the good outside the country. Furthermore, if firms in the fossil fuel industry anticipate increasing carbon prices in the future, they are incentivized to extract and process more fossil fuels in the current time period

[35] See Fact Sheet 4
[36] Ibid.

while taxes are low. Both of these economic reactions can create a considerable leakage effect, which further necessitates international agreement.[37]

Policy Implications considering the Leakage Effect

Due to concerns about leakage, countries acting individually should first seek to impose a higher carbon tax on households and commercial sectors rather than on industrial sectors. Furthermore, countries should introduce border tax adjustments, such as a carbon tax on imported goods, in an effort to minimize trade leakage and reduce their consumption of products with embodied carbon emissions. However, border tax adjustments do not affect leakages resulting from changes in energy markets, which are signaled by price. Lastly, the imposition of trade tariffs to countries that do not co-operate in domestic emissions reductions (i.e. "climate clubs") could be a way to reduce trade leakage, however WTO rules may complicate this possibility (more on this later).[38]

The Free-rider Problem

The "free rider" problem severely complicates the effort to reach international agreement on climate. Basically, emissions cuts are very expensive to the home country while also greatly benefiting the global community. This creates an incentive for countries to signal participation in emissions reductions agreements–so that other countries will reduce their emissions–without actually complying with the agreement themselves. Countries have every short-term incentive to delay the economic costs of cooperating while reaping the rewards of other country's actions.

Bargaining Problems

International agreements must also be sensitive to differential responsibilities for the task of addressing climate change. For example, historically rich countries have undoubtedly

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[37] Ibid.
[38] Ibid.

contributed more to atmospheric greenhouse gas concentrations than developing or newly rich countries, which suggests that they pay a comparatively steeper cost in international negotiations. Additionally, countries are likely to be affected differently by incremental climate change (i.e. Bangladesh vs. Canada), which incentivizes some countries to act more immediately than others.

Learning from History

Of the several significant international climate agreements, none of these treaties have had strong enough enforcement mechanisms to effectively coerce countries into sticking to their agreements. Despite the fact that some of the agreements are legally binding, they are only binding for countries who are party to the agreement. Therefore, countries who choose not to follow through on their commitments can simply opt out of the agreement to avoid legal consequences. Furthermore, "naming and shaming" through the expert review process (a la the Paris agreement) has turned out not to be an effective enforcement mechanism. International evaluation processes to determine if countries are meeting their climate goals need to be strengthened, as do enforcement mechanisms that coerce countries into meeting their targets. [39]

Treaty Design

To incentivize global action on climate change, we must change the nature of the negotiation from a prisoner's dilemma scenario to a coordination agreement.[40] Ultimately, gains from cooperation on trade must be extremely high compared to gains from free-riding, and each country's individual incentives need to be aligned with the global incentive that maximizes total welfare.[41] The success of the Montreal Protocol–which imposed trade restrictions on non-signatories and successfully coerced countries into participation–showed that the threat of trade

[39] See Fact Sheet 5
[40] See Fact Sheet 6
[41] Ibid.

restrictions is crucial. Furthermore, it showed that rules to limit production *and* consumption of emissions can help create a coordination game and lead towards a successful international treaty.

Climate Clubs, a WTO legal exception

Imposing trade restrictions on countries not party to an international agreement (by forming a "climate club") can indeed overcome the free-rider problem.[42] The legal code of the WTO should allow this sort of action on the issue of climate change, since the potential global consequences are so severe. It may seem like an unequitable approach to coerce other countries to comply, but if the agreement included a global climate fund for adaptation, as well as provisions for rich countries to finance sustainable development, it could ensure equity for developing countries in the process of addressing climate change.

Equitable Climate Action

Rich countries can pay the incremental costs of countries that forego elements of their economic transition that would otherwise rely on fossil fuel emissions. This will catalyze renewable energy-based development and/or advance grow carbon dioxide removal systems in developing countries (i.e. rich countries help fund carbon capture and storage systems for factories in developing countries). Developing a global ETS through coercive measures would incentivize rich countries to purchase carbon credits by paying developing countries to advance their domestic climate action (a la the Clean Development Mechanism in the Kyoto Protocol).[43] In the context of an international ETS, however, the emissions budgets for developing countries needs to be set appropriately so that rich countries cannot simply purchase "hot-air" (carbon credits that would not have been emitted by another country even in absence of a purchase).[44]

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[42] Nordhaus, William. "Climate Clubs: Overcoming Free-Riding in International Climate Policy." *The American Economic Review* 105, (2015)
[43] Cooper, Richard N. "Financing for Climate Change." *Energy Economics*, Green Perspectives, 34 (November 1, 2012): S29–33.
[44] Klepper, Gernot, and Sonja Peterson. "Trading Hot-Air. The Influence of Permit Allocation Rules, Market Power and the US Withdrawal from the Kyoto Protocol." *Environmental and Resource Economics* 32, no. 2 (October 1, 2005): 205–28.

Sectoral agreements in absence of overarching climate agreements

In the absence of substantial climate agreements between world governments, we can promote a series of international sectoral agreements on specific industries. Since many of the largest carbon-emitting industries are relatively concentrated, it is in some ways easier to negotiate sectoral agreements on climate change by facilitating negotiation between key stakeholders in the private sector. Creating ETS systems for different industries may be one approach that enables private firms to participate in the sustainable development of their industry by purchasing credits from firms in developing countries.[45]

Climate Change Education and Communication

Improving the nature of climate change communication is essential in order to shift demand for fossil fuels and motivate people's desires to adopt potentially costly mitigation measures. Modifying scientific reports to more effectively communicate climate change impacts, and embarking on national media campaigns that utilize effective communications strategies, could decrease the political consequences of enacting potentially expensive domestic climate change policy, making climate change legislation more likely to pass. [46] [47] [48]

Grassroots Divestment Campaigns

Campaigns that pressure institutional investors to divest their financial portfolios from equity in fossil fuel extraction companies have had considerable success, with divestment commitments topping $8trillion in funds.[49] Such campaigns are useful tools to catalyze the necessary shift in private and public investment from fossil fuel companies to renewable energy

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[45] Cook, Gregory, and Jean-Pierre Ponssard. "A Proposal for the Renewal of Sectoral Approaches Building on the Cement Sustainability Initiative." *Climate Policy; London* 11, no. 5 (2011): 1246–56.
[46] Ockwell, David, Lorraine Whitmarsh, and Saffron O'Neill. "Reorienting Climate Change Communication for Effective Mitigation: Forcing People to Be Green or Fostering Grass-Roots Engagement?" *Science Communication* 30, no. 3 (March 1, 2009): 305–27.
[47] Harris, Adam J. L., Han-Hui Por, and Stephen B. Broomell. "Anchoring Climate Change Communications." *Climatic Change* 140 (2017):
[48] Hu, Sifan, and Jin Chen. "Place-Based Inter-Generational Communication on Local Climate Improves Adolescents' Perceptions and Willingness to Mitigate Climate Change." *Climatic Change; Dordrecht* 138, no. 3–4 (October 2016): 425–38.
[49] Gunningham, Neil. "Building Norms from the Grassroots Up: Divestment, Expressive Politics, and Climate Change." *Law & Policy* 39 (2017):

companies, and also to change the public's perceptions by framing the issues in a symbolic and moral way.[50] Given that the prolonged existence of the fossil fuel industry is incompatible with the necessary transition to a zero-carbon economy, divestment campaigns should be supported as a means to expedite the necessary economic transition. At the same time, it is important to consider the impacts of divestments on firms whose entire existence relies on fossil fuels as there is no avenue for them to change their model in order to regain investment.[51] Ultimately, the impact of divestment on the fossil fuel industry has proven to be more effective at keeping the issue of climate change in the political discourse, rather than levying real economic harm on the fossil fuel industry, which is still a useful outcome. [52]

Conclusion

Given the enormity of the global economic transition that would need to occur in order to meet a 1.5℃ goal, it is imperative to adopt a suite of policies and agreements that tackles the problem in a multi-lateral fashion and with many policy instruments. Given that the likelihood of adverse impacts—including loss of life and global political instability—are substantially higher in a 2℃-world compared to 1.5℃, it is crucial to make every effort to reach the goal. While it is still a geophysical possibility, the window of opportunity gets narrower and narrower every year.

[50] "Divestment Commitments." Fossil Free: Divestment. Accessed April 28, 2019. https://gofossilfree.org/divestment/commitments/.
[51] Ockwell, David, Lorraine Whitmarsh, and Saffron O'Neill. "Reorienting Climate Change Communication for Effective Mitigation: Forcing People to Be Green or Fostering Grass-Roots Engagement?" *Science Communication* 30, no. 3 (March 1, 2009): 305–27.
[52] Bergman, Noam. "Impacts of the Fossil Fuel Divestment Movement: Effects on Finance, Policy and Public Discourse." *Sustainability* 10, no. 7 (July 1, 2018): 2529. https://doaj.org.

Appendix

Tipping Element	Global Warming Trigger	Transition Timescale	Impacts
Arctic summer ice	0.5-2 °C	10 yr	Amplified warming, ecosystem change
Greenland Ice Sheet	1-2 °C	> 300 yr	Sea level 2-7 m
West Antarctic Ice Sheet	3-5 °C	> 300 yr	Sea level 5 m
Atlantic Thermohaline Circulation	3-5 °C	100 yr	Regional cooling, sea level
El Nino-Southern Oscillation	3-6 °C	100 yr	Drought in SE Asia
Indian Summer Monsoon	N/A	1 yr	Drought, decreased carrying capacity
Sahara/Sahel and West African Monsoon	3-5 °C	10 yr	Increased carrying capacity
Amazon Rainforest	3-4 °C	50 yr	Biodiversity loss, decreased rainfall
Boreal Forest	3-5 °C	50 yr	Biome switch
Antarctic Bottom Water	Unclear	100 yr	Ocean circulation, carbon storage
Tundra	—	100 yr	Amplified warming, biome switch
Permafrost	—	< 100 yr	CH_4 and CO_2 release
Marine Methane Hydrates	Unclear	10^3-10^5 yr	Amplified global warming
Ocean Anoxia	Unclear	10^4 yr	Marine mass extinction
Arctic Ozone	Unclear	< 1 yr	Increased UV at surface

Lenton et al. (2007).

Figure 1: Lenton, Timothy M., Hermann Held, Elmar Kriegler, Jim W. Hall, Wolfgang Lucht, Stefan Rahmstorf, and Hans Joachim Schellnhuber. "Tipping Elements in the Earth's Climate System" PNAS, no. 6 (2008): 1786–93

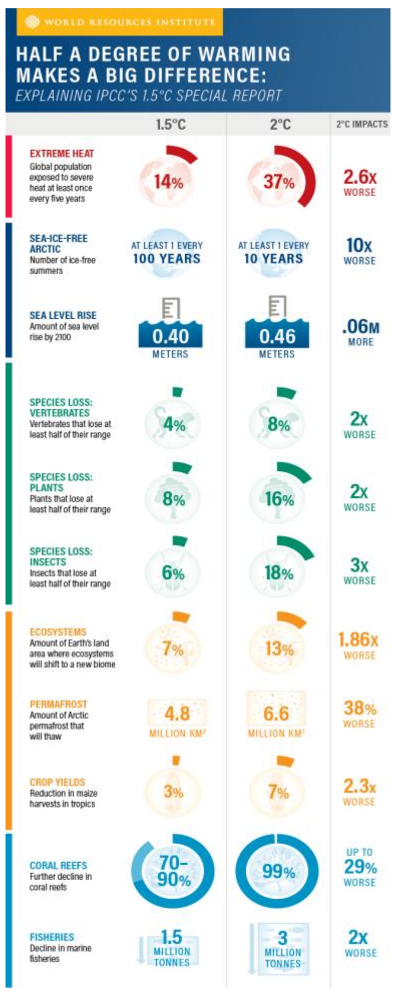

Figure 2: "Half a Degree and a World Apart: The Difference in Climate Impacts Between 1.5˚C and 2˚C of Warming, World Resources Institute." https://www.wri.org/blog/2018/10/half-degree-and-world-apart-difference-climate-impacts-between-15-c-and-2-c-warming (2018)

Fact Sheet 1: The Science of Climate Change
Kevin Karl

GLOBAL TEMPERATURE TRENDS

The scientific study of climate change can be segregated into four distinct yet interwoven lines of academic pursuit: 1) the study of the physical processes that determine our current climate system, 2) the study of how and why the climate has changed in the past, 3) the study of the contemporary impacts of climate change, and 4) modeling predictions about the future of the climate. [1]

One major advancement in the study of climate was the advent of the weather station. Since about 1850, there have been enough weather stations on the planet to reliably estimate surface temperatures for about 80% of the planet.[2]

These tools have enabled scientists to collect statistical data on the evolution of our climate nearly 170 years. Such records show that the average global temperature has increased by about 0.8°C (about 1.4°F) over the past century or so, with most of the change taking place since the 1970s.[3]

Another measure of the steady change in our climate is the study of ocean temperatures. Oceanographers have used millions of measurements taken by ships crisscrossing the globe to determine that the ocean's temperature has increased by roughly 0.1°C to 0.2°C over the past 50 years or so.[4] This is especially important, not only because the ocean covers roughly 70% of the Earth's surface, but also due to the ocean's large thermal inertia (the fact that it's temperature changes more slowly than surface or air temperatures).[5]

Other methods to detect changes in the Earth's temperature over time, such as boreholes that detect changes in temperature just below the Earth's surface, and satellites that monitor temperatures in the lower atmosphere, all corroborate the warming trend discovered through the aforementioned observational methods.[6]

CAUSES OF GLOBAL WARMING

Since the global warming trend is incontrovertible, the next important question is to determine the causes of the change, as measured by the annual average temperature relative to the base year of 1850. In 2012, NASA's Institute for Space Studies (GISS) led a team of dozens of international climate science groups to disentangle the various causes of global warming using advanced

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[1] deMenocal, P.B. (2009) "Taking the Temperature of the Planet," *Climate Change: Picturing the Science*. Edited by Gavin Schmidt and Joshua Wolfe. W.W. Norton Publishing, pp. 19-44
[2] deMenocal, P.B. (2009) "Studying Climate", *Climate Change: Picturing the Science*. Edited by Gavin Schmidt and Joshua Wolfe. W.W. Norton Publishing, pp. 19-44
[3] Ibid.
[4] Ibid.
[5] Ibid.
[6] Ibid.

computerized models.[7] Their findings show that changes in the earth's orbital patterns contributes very little explanatory power to climate change, and that changing patterns in solar intensity similarly accounts for a negligible portion of the trend. Volcanic activity actually has had a significant cooling effect after a few eruptions in the late 19th and 20th centuries, but that does little to explain the overall warming trend.

Indeed, the combination of natural factors (such as solar, orbital, and volcanic) does not come close to accounting for the warming scientists have observed since 1850. It is therefore necessary to examine anthropogenic causes that could explain the phenomenon of climate change.

One causal factor could be an increased in deforestation. However, scientists predict that due to the relative reflectivity of cleared patched (as opposed to dark forests), deforestation actually has a minor cooling effect on the planet.

Another factor could be the increase in the production of aerosols- like those created by the burning of coal- but that also leads to overall cooling of the atmosphere (in a surprisingly significant way).

Tropospheric ozone (O_3), which is created by pollution, is known trap heat and act as the second most important contributor to the human-induced greenhouse effect.[8] Still, ozone only accounts for a small percentage of the overall warming effect.

By disentangling all of the various possible natural and anthropogenic explanatory variables, the international effort led by GISS confirmed that there is no doubt that the vast majority of climate change is caused by greenhouse gas emissions.[9] Only models that included this variable- overwhelmingly attributed to the effects of CO_2 in the atmosphere- were able to match the warming trend observed since 1850.

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[7] Miller, R. L., et al. (2014), "CMIP5 historical simulations (1850–2012) with GISS ModelE2", *J. Adv. Model. Earth Syst*., 6, pp. 441–478

[8] Stocker, T.F., et al. (2013), "Climate Change 2013: The Physical Science Basis". Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press

[9] Miller, R. L., et al. (2014), "CMIP5 historical simulations (1850–2012) with GISS ModelE2", *J. Adv. Model. Earth Syst*., 6, pp. 441–478

Fact Sheet 2: Technological Options for Reducing Emissions
Kevin Karl

THE NEED FOR ZERO EMISSIONS

In preindustrial times, atmospheric CO_2 concentration was 280 ppm.[1] **Current estimates place CO_2 concentrations at roughly 410ppm**.[2] While the precise impact of CO_2 concentrations on global mean temperature is uncertain, scientists have predicted that a doubling in atmospheric concentrations from preindustrial levels will result in a rise of 1.5℃ to 4.5℃,[3] and observational data suggest that it may be around 2℃.[4] This range of temperatures reflects a level of uncertainty in "climate sensitivity" to CO_2 concentrations .[5] However, to avoid the catastrophic impacts of even a 1.5℃ rise in global mean temperature, **we must limit atmospheric CO_2 concentration to less than 500pm**, safely less than double the CO_2 concentration of preindustrial times. [6]

In order to guarantee that CO_2 concentrations do not exceed 500ppm, **we need to bring global CO_2 emissions down to zero over the next few decades**.[7] If we were able to halt emissions within 50 years we can still stabilize the climate and allow temperatures to gradually decrease.[8]

REDUCING EMISSIONS IN WEDGES

Davis et. al (2013) proposes an introduction of as many as 31 wedges in order to effectively reduce CO_2 emissions to zero in the next 50 years, based on a "business as usual" projection of emissions growth and assumption of technological stagnation.[9] Each wedge represents an emissions drawdown of 25 GtC/year.

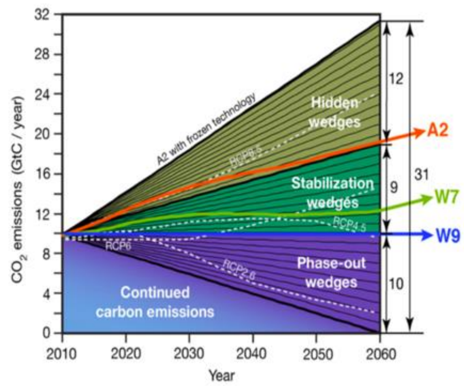

Figure 2. Idealization of future CO_2 emissions under the business-as-usual SRES A2 marker scenario. Future emissions are divided into *hidden* (sometimes called 'virtual') wedges (brown) of emissions avoided by expected decreases in the carbon intensity of GDP by ~1% per year, *stabilization* wedges (green) of emissions avoided through mitigation efforts that hold emissions constant at 9.8 GtC y^{-1} beginning in 2010, phase-out wedges (purple) of emissions avoided through complete transition of technologies and practices that emit CO_2 to the atmosphere to ones that do not, and allowed emissions (blue). Wedges expand linearly from 0 to 1 GtC y^{-1} from 2010 to 2060. The total avoided emissions per wedge is 25 GtC, such that altogether the hidden, stabilization and phase-out wedges represent 775 GtC of cumulative emissions.

The model brings emissions to zero by adding wedges in three groups: twelve "hidden" wedges that represent the status quo pace of global emissions reductions projected into the future, nine "stabilization" wedges that represent new efforts to mitigate emissions and ten "phase-out" wedges that represent the transition from net CO_2 emitting industry and infrastructure to net-neutral industry and infrastructure.

HIDDEN AND MITIGATION WEDGES

We should not assume that the current global intensity of carbon, defined as carbon emissions per unit of GDP, will decrease at the current pace. Since its decreasing trajectory can be attributed largely to increased energy efficiency in both industrial and residential consumption, it is imperative that we continue to promote the advancement of global real energy

[1] Pacala, S., and R. Socolow. (2004) "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies." *Science*, vol. 305, no. 5686, pp. 968–972.
[2] Smith, C. J. et al. (2018)." FAIR v1.3: A simple emissions-based impulse response and carbon cycle model." *Geosci. Model Dev*. 11\, 2273–2297
[3] J. T. Houghton *et al.*, (1996) *Climate Change 1995: The Science of Climate Change* (Cambridge Univ. Press, UK, 1996).
[4] Caldeira, K. *et al*. (2003). "Climate sensitivity uncertainty and the need for energy without CO2 emission". *Science, 299*(5615), 2052-4.
[5] Ibid.
[6] Ibid.
[7] Davis, S. *et al*., (2013) "Rethinking Wedges." *Environmental Research Letters*, Volume 8, Issue 1, p. 11001
[8] Ibid
[9] Ibid.

efficiency.[10] This can be done through incentivizing technological development that improves marginal **energy efficiency gains in industrial engineering**, while at the same time supporting **minimum energy performance standards** across the board.[11] Policies that promote **increased fuel economy, building efficiency, and dramatic declines in car travel** are all options for new mitigation wedges.[12]

"PHASE-OUT" WEDGES

Perhaps the most critical, and most difficult, element of a complete emissions drawdown is transitioning to a completely CO2-emission neutral economy. This will require breakthroughs in economics and technology that fundamentally transform the nature of the global economy.[13] Substituting fossil fuel energy sources for CO_2-free energy sources will be a key element to any such transition.

Wind energy is already economically feasible on a small scale, but is costly to scale up since it requires building a whole new energy transmission infrastructure based on high-voltage direct current. The current grid system is also not equipped to store excess power created by wind for use when energy generation is low. **Solar energy** similarly suffers from transmission and storage mismatches with current energy infrastructure, but is already economically competitive with fossil fuels in sun-rich locations, and grows more economically viable each year. **Nuclear energy** is proven to be cost-competitive with fossil fuels, but suffers from uncertainty about the safety of long-term storage, proliferation concerns and often intense negative public perception. **Carbon capture and storage** from fossil fuel plants, through biomass generation and industrial air capture, can contribute significantly to reductions emissions. **Adaptation** efforts such as geoengineering are risky, but may be valuable as last-ditch options in the future.[14]

Fortunately, there is enough emission-free power available to easily cover all global energy needs. **An internationally accepted carbon penalty, coupled with massive investments in R&D** is the least of what is required to advance the global transition. We must encourage, and invest in, rapid technological advancement in all forms of emission-free power since only a multi-faceted, technologically-driven approach can achieve climate stability while we still have the opportunity.

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[10] Rodríguez M, and Y. Pena-Boquete. (2017), "Carbon intensity changes in the Asian Dragons. Lessons for climate policy design". *Energy Economics*, vol. 66, pp.17-26

[11] Sonnenschein, J., Van Buskirk, R., Richter, J.L. et al. (2019), "Minimum energy performance standards for the 1.5 °C target: an effective complement to carbon pricing." *Energy Efficiency* 12: 387.

[12] Pacala, S., and R. Socolow. "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies." *Science*, vol. 305, no. 5686, 2004, pp. 968–972.

[13] Barret, S. (2009), "The Coming Global Climate–Technology Revolution" *Journal of Economic Perspectives*, Volume 23, Number 2, pp. 53–75

[14] Ibid.

Fact Sheet 3: Beyond Emissions, Alternative Options for Reducing Climate Risk
Kevin Karl

ADAPTATION

All climate policy must consider adaptation as a means of reducing climate risk, in part because the planet can no longer avoid all of the effects of climate destabilization. For example, farmers should plan to plant crops that thrive in marginally warmer climates than their current, while also planting a wider variety of crops that can together withstand significant interannual weather variations.[1] In this case, governments may choose to subsidize the adaptive choices of farmers—which would justly support them as victims of climate change—while tethering subsidies to crops that are more advantageous for the public good. Governments should also conduct research and educate private firms on climate challenges in their sector. Indeed, there are significant fiscal gains to be reaped from investments in adaptation:

Country	Sector	Net impact w/o adaptation	Net impact w adaptation
U.S.	Agriculture	-\$8 to -\$18 bn	+\$3 to -\$11bn
U.S.	Coasts	-\$6 to -\$12 bn	-\$0.1 to -\$0.6 bn
India	Agriculture	-\$3 to -\$4 bn	-\$1.4 to -\$2.4 bn

Source: R. Mendelsohn (2000), "Efficient Adaptation to Climate Change," *Climatic Change* 45: 583-600; citing various studies.

Figure 1: Fiscal Impact of investments in adaptation, compiled by Professor Scott Barrett

Beyond stabilizing private markets, governments should also guarantee a base level of adaptive potential for their citizens. As the number of extreme hot weather days continues to rise, it is crucial to ensure that households across the socioeconomic spectrum are able to afford and access cooling systems--the lack of which will prove increasingly fatal.[2] Yet, as governments undergo the complex calculus of climate policy, it is necessary to understand that *investments in adaptation are by no means substitutes for abatement initiatives*. Both strategies are crucial elements of any sound climate policy.

LAND USE

Averted deforestation can have an immediate and significant impact on emissions, as deforestation is estimated to be the second largest source of GHG emissions globally.[3]

Table 2. Average annual ha deforested and carbon emitted as a result between 2005 and 2030

Model	Central and South America	Africa	Southeast Asia	Global
	Million ha·yr⁻¹ (Gt CO_2·yr⁻¹)			
GTM	4.84 (1.86)	4.58 (1.72)	2.23 (1.07)	11.65 (4.69)
DIMA	3.62 (1.15)	4.98 (1.61)	1.14 (0.31)	10.60 (3.22)
GCOMAP	4.31 (1.57)	5.99 (1.37)	1.90 (0.38)	12.20 (3.31)

Figure 2: Annual emissions due to deforestation based on three land use models

Governments should seek to compensate land managers for avoiding deforestation on their properties. In addition, they should incentivize reforestation and afforestation, while promoting savvy water management and sustainable agriculture practices-- a combination of which could save up to 5 GtCO_2/year at potentially low costs (see Figure 4). Climate-conscious land management will have to compete with current agricultural practices, but is instantly ready to deploy at scale.

CARBON DIOXIDE REMOVAL (CDR)

Point-source carbon capture and storage (CCS) allows for the continued use of fossil fuels in industrial factories while capturing and storing emissions. This technology could have a significant impact on total CO_2 concentrations.[4]

Table SPM.1. Profile by process or industrial activity of worldwide large stationary CO_2 sources with emissions of more than 0.1 m tonnes of CO_2 ($MtCO_2$) per year.

Process	Number of sources	Emissions ($MtCO_2$ yr⁻¹)
Fossil fuels		
Power	4,942	10,539
Cement production	1,175	932
Refineries	638	798
Iron and steel industry	269	646
Petrochemical industry	470	379
Oil and gas processing	Not available	50
Other sources	90	33
Biomass		
Bioethanol and bioenergy	303	91
Total	7,887	13,466

Figure 3: Total emissions from stationary industrial sites, in ***$MtCO_2$/year***

There are, however, significant technical, economic, and political issues with CCS, including the cost and location of storage facilities and transportation of CO_2. Even if most factories are equipped with CCS capabilities, there are still vast amounts of non-point-source carbon emissions,

[1] Mendelsohn, R. (2000) "Efficient Adaptation to Climate Change." *Climatic Change*
[2] Kahn, Matthew E., (2016) "The Climate Change Adaptation Literature" *Review of Environmental Economics and Policy*
[3] Kinderman, G.et al, (2008) "Global cost estimates of reducing carbon emissions through avoided deforestation" *Proceedings of the National Academy of Sciences*
[4] IPCC Working Group III (2005) "Special Report: Carbon Dioxide Capture and Storage" *Summary for Policymakers*

such as from planes and cars, that would continue to escalate atmospheric CO_2 concentrations.[5]

AIR CAPTURE

Non-point source CO_2 may still be removed from the atmosphere through "air capture" technologies. This category includes the capture of CO_2 through biomass or with air "scrubbing" facilities.

The most promising avenue for biological capture is to ultimately use the biomass as a fuel, while capture its emissions with CCS (a process termed bioenergy with capture, or BECSS). [6]

TABLE 2.2 Summary of the Potential Impacts of Various CDR Strategies

	CDR Method	Rate of Capture or Sequestration [$GtCO_2$/yr]	Cumulative CDR to 2100 [$GtCO_2$]	Cost [$/$tCO_2$]	Limitations
	Land management Afforestation/ Reforestation	2-5[a]	100[b]	1-100[c]	• Irreversible land changes from deforestation or past land uses • Decreased biodiversity • Competition for land for agricultural production
Combined Capture and Sequestration	Accelerated weathering Land	2 (U.S. only)	~100 (U.S. only)	20-1,000[e]	• Land—available cheap alkalinity and aggregate markets for product • Ocean—available cheap alkalinity
	Ocean	1[d]	~ 100	50-100[f]	
	Ocean iron fertilization	1-4[g]	90-300	500[h]	• Environmental consequences and potential co-benefits • Uncertainty in net carbon sequestration
Capture	Bioenergy with capture	15-18[i] (Theoretical)	100-1,000[j]	~100[k]	• Sequestration of 18 $GtCO_2$/yr requires ~1,000 million acres of arable land (1,530 million acres available worldwide[l]; actual amount of arable land available for bioenergy production will likely be significantly less because much of arable land area is required for food production)
	Direct air capture	10[m] (U.S. only)	~1,000 (U.S. only)	400-1,000[n]	• Land available for solar ~100,000,000 acres of BLM land in southwestern United States

Figure 4: Potential Impacts of various CDR strategies

BECSS is limited by scale-- it would require the use of a significant proportion of total arable cropland-- and cost, as it would require expensive investments in transportation and storage. However, the theoretical rate of sequestration is promising enough that it warrants further investments in research and development.

Ocean fertilization and chemical "weathering" are both environmentally and politically risky methods, with potential adverse impacts that may outweigh benefits.

Direct air capture (DAC) facilities can be advantageously located at a storage site. While little has been invested in DAC technology, some economists estimate that costs could lower to $100/tC, which would make it cost effective by some measures of the social cost of carbon. On these grounds CCS ought to be explored further.[7]

Table 2b – Cost of air capture as a percentage of global GDP, assuming 2.5% global GDP growth to 2100 after Stern (2007).

	\$500/tC	\$360/tC	\$100/tC
450 ppm cost to 2050	3.0%	2.2%	0.6%
550 ppm cost to 2050	0.0%	0.0%	0.0%
450 ppm cost to 2100	2.7%	2.0%	0.5%
550 ppm cost to 2100	2.0%	1.4%	0.4%

Figure 5: Sourced from Pilke Jr., Roger A. (2009) "An idealized assessment of the economics of air capture of carbon dioxide in mitigation policy"

GEOENGINEERING

Solar eoengineering, or the deliberate modification of climate by solar deflection, is an economically and scientifically feasible route for keeping global temperatures in check.[8] Yet, it poses irreversible planetary risks that are impossible to predict. For this reason, governments should invest heavily in promising CDR technologies while incentivizing savvy land use practices—both of which have better understood impacts—before even considering geoengineering.

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[5] Lackner, Klaus S., et. al (2012) "The urgency of air capture" *Proceedings of the National Academy of Sciences*
[6] Ibid.
[7] Stern N. (2007) "The Economics of Climate Change: The Stern Review" *Cambridge University Press*
[8] Barret, S. (2007) "The Incredible Economics of Geoengineering". *Environmental Resource Economics*

Fact Sheet 4: Leakage, Trade, and "Competitiveness"
Kevin Karl

TRADE LEAKAGE

When a country adopts domestic climate policy that imposes a cost on its energy-intensive industries, it confers a comparative advantage to energy-intensive industries in other countries. This can result in an increase in the responding countries' carbon emissions, as well as an increase in their employment levels associated with the rise in production. The consequence is a decrease in the net global emissions reductions that can be accrued to the initial policy change, on top of a potential decrease in domestic employment in the originating country. These phenomena are referred to as carbon and jobs leakages, and are oft used in arguments against cap-and-trade bills. [1,2]

The leakage rate will vary depending on international circumstances at the time of policy adoption. If more countries are simultaneously imposing costs on domestic energy-intensive industries (i.e. cooperating), leakage will be reduced. It also varies depending on the magnitude of the cost imposed. Generally, leakage rates are estimated to be between 0 and 100%, meaning that the net effect of the domestic policy change would indeed be an international reduction in emissions.[3]

Some sectors are more vulnerable to leakage than others; such as chemicals, cement, iron and steel.[4] Leakage in forestry is also remarkably high, as evidenced by the following figure:

Country	Leakage for 1% increase in conservation
US	0.767
Canada	0.423
EU	0.861
Australia/New Zealand	0.890
East Asia	0.698
Southeast Asia	0.762
Latin America	0.742
Sub Saharan Africa	0.872
Russia	0.954
ROW	0.650
Cooperation by regions	
US, Canada, EU, Australia, New Zealand	0.639
SEA, LAM, SSA	0.779

Jianbang Gan and Bruce A. McCarl (2007). "Measuring Transnational Leakage of Forest Conservation, *Ecological Economics*, 64(2): 42 432.

Figure 1: Leakage in Forestry

EMISSIONS ACCOUNTING

When aggregated, the leakage associated with the Kyoto Protocol was initially estimated to be somewhere between 5% and 20%.[5] Thus far, however, we have been referring to a country's emissions as those that originate from domestic production. In a globalized economy, however, we must consider emissions from the perspective of a country's consumption to incorporate the nuances of global trade.

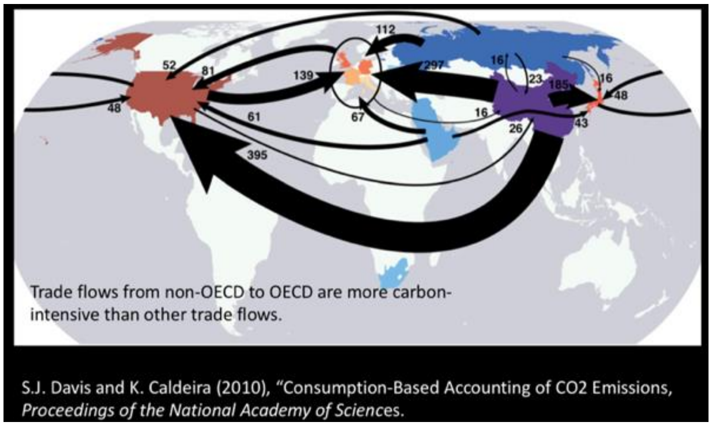

Figure 2: The Importation of Emissions

Based on this understanding, it is possible that leakage could exceed 100% in

[1] Eckersley, Robyn. "The Politics of Carbon Leakage and the Fairness of Border Measures | Ethics & International Affairs." *Cambridge Core*, Cambridge Press, 14 Apr. 2011
[2] "Competitiveness and climate policy: Avoiding leakage of jobs and emissions: Committee on Energy and Commerce." *Internet Archive*, Government Publishing Office, 18 Mar. 2009
[3] Barrett, Scott. "Rethinking Climate Change Governance and Its Relationship to the World Trading System." *The World Economy*, 18 Dec. 2011,
[4] IPCC AR4 (2007)
[5] Ibid.

some cases, such as when industrial activity moves from a country with more carbon-efficient production to a country with less carbon-efficient production.[6] In fact, one study indicates that a country's decision to lower emissions will cause that country to increase imports from other countries by about 8% on average. Moreover, the imported goods are produced in a way that is, on average, 3% more carbon intensive. This accounting framework makes a case that leakage from Kyoto Protocol countries could be as high as 40%.[7]

TECHNOLOGY LEAKAGE

Technological leakage can produce an effect that amplifies international emissions reductions. In this scenario, one country may invest in innovation in order to reduce abatement costs. The concomitant development in mitigation technology ultimately lowers the global prices for that technology, increasing its' economic viability and, ultimately, its adoption in other countries. In this way, a reduction in one country's emissions can lead to further emissions reduction in another country.[8]

INT'L ENERGY MARKET LEAKAGE

The principles of supply and demand indicate that reducing the demand for a fossil fuel energy source (such as coal) in a country (i.e. through domestic policy change) would decrease the worldwide price of that good, therefore increasing consumption of the good outside the country. This is a geospatial leakage effect.

On the supply side, if firms in the fossil fuel industry anticipate increasing carbon prices in the future, they are incentivized to extract and process more fossil fuels in the current time period, while the taxes are low. Both of these economic reactions can create a considerable leakage effect related to the production and consumption of fossil fuels.

POLICY PATHWAYS

Due to concerns about leakage, many climate policies, such as those of Sweden or California, seek to impose a higher carbon **tax on households and commercial sectors** than on industrial sectors. **Border tax adjustments**, such as a carbon tax on imported goods, can minimize trade leakage but does not affect leakages resulting from changes in energy markets. Lastly, the imposition of trade tariffs to countries that do not co-operate in domestic emissions reductions (i.e. **"climate clubs"**) could be a way to reduce trade leakage, however WTO rules may complicate this possibility.[9]

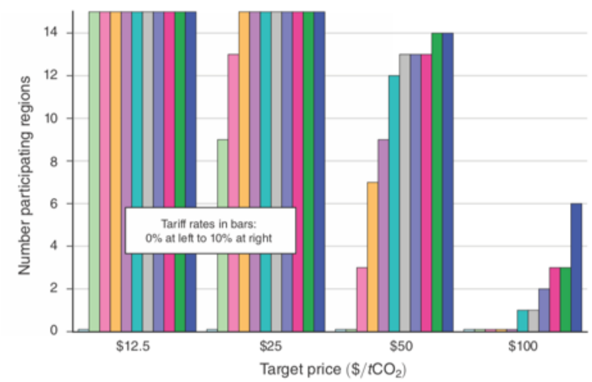

FIGURE 3. NUMBER OF PARTICIPATING REGIONS BY INTERNATIONAL TARGET CARBON PRICE AND TARIFF RATE

Notes: This and the following figures have the following structure. The four sets of bars are the model results for four different global SCCs, running from left to right as shown on the bottom. The 11 bars within each set are the penalty tariff rates, running from 0 percent to 10 percent. Note that each set has zero participants for a 0 percent tariff. The vertical scale here is the number of participants, while the following graphs show other important results.

Figure 3: Tradeoff between Carbon Price and Number of Cooperating Countries

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[6] Barrett, Scott. "Rethinking Climate Change Governance and Its Relationship to the World Trading System." *The World Economy*, 18 Dec. 2011,
[7] Aichele, Rachel and Gabriel Felbermayr (2012), "Kyoto and Carbon Leakage: An Empirical Analysis of the Carbon Content of Bilateral Trade," *Review of Economics and Statistics 97(1)*: 104-115.
[8] Gerlagh, Reyer and Kuik, Onno, Carbon Leakage with International Technology Spillovers (Mach 2007). FEEM Working Paper No. 33.2007.
[9] Nordhaus, William. "Climate Clubs: Overcoming Free-Riding in International Climate Policy," *American Economic Review 105*(4): 1339-1370.

Fact Sheet 5: The History of Climate Negotiations
Kevin Karl

THE FREE-RIDER PROBLEM

Before delving into the history of climate negotiations, it is worth mentioning some of the issues that complicate the process of reaching international climate agreements. The "free rider" problem is especially salient in this context, since emissions cuts are very expensive to the home country while also greatly benefiting the global community. This creates an incentive for countries to signal participation in emissions reductions agreements- so that other countries will reduce their emissions- without actually complying with the agreement themselves. Indeed, countries have every short-term incentive to delay the economic costs of cooperating while reaping the rewards of other country's actions.

BARGAINING PROBLEMS

All countries have a role to play in addressing climate change. However, it is not clear how countries should divvy up the responsibility for the task. For example, historically rich countries have undoubtedly contributed more to atmospheric greenhouse gas concentrations than developing or newly rich countries, which suggests they ought to pay a comparatively steeper cost in international negotiations.

Furthermore, different countries are likely to be affected differently by gradual forms of climate change (i.e. Bangladesh vs. Canada). The precise extent to which different countries must contribute more or less to the overall solution, however, remains to be debated.

HISTORY OF NEGOTIATIONS

Figure 1 presents a summary of the main international climate agreements. The agreements differ in their approach to goal setting, enforcement, and types of contribution they seek to extract from each country.

	Collective goal	Targets and timetables
Toronto 1988	Reduce global emissions of CO_2 20% from the 1988 level by 2005	None, though many countries announced **unilateral** targets and timetables.
Rio 1992	Limit concentrations to avoid "dangerous" climate change	"aim of returning individually or jointly to … 1990 [emission] levels" by 2000.
Kyoto 1997	"In pursuit of the ultimate objective of the" UNFCCC…	Annex I parties "shall… ensure that their….emissions…do not exceed their assigned amounts…" for 2008-2012.
Copenhagen 2009	Limit "global emissions so as to hold the increase in global temperature below 2 degrees Celsius…."	"Annex I Parties commit to implement individually or jointly the quantified economy wide emissions targets for 2020, **to be submitted**…by Annex I parties….
Paris 2015	"Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C…."	Nationally determined contributions.

Figure 1: History of Major Climate Agreements

EARLY EFFORTS

Parties to the Toronto Conference agreed on a global goal of CO_2 emissions reductions, and countries made unilateral declarations of how they would advance the goal. However, countries' unilateral pledges were not ultimately met.

The '92 Framework Convention in Rio de Janeiro aimed to limit individual countries' emissions, however no specific targets were successfully negotiated. Parties did however agree to prevent dangerous anthropogenic damage in the abstract, signaling a common understanding of the potential consequences of climate change.

KYOTO PROTOCOL

The Kyoto Protocol successfully set emissions limits between 2008-2012 for Annex I (developed) countries, while creating a trading program between countries. It also creating the "Clean Development Mechanism", which allows industrialized countries to pay developing countries to reduce their emissions–a creative method for promoting sustainable, climate-conscious economic development.

Despite its' successes, Kyoto was largely ineffective due to the non-participation of the U.S. and the non-compliance of Canada, as well as its approach to enforcement, which will be discussed later.

THE COPENHAGEN ACCORD

The Conference of Parties suffered from a lack of negotiating cohesion. Five unique negotiating texts were prepared by different blocks of countries, underscoring the large discrepancy between the negotiating platforms of rich countries and developing countries.

A last-minute accord was ultimately reached between the majority of member countries, but it lacked the unanimity required for U.N. ratification. The Green Climate Fund was created to apportion funds for international efforts in adaptation and mitigation, with the intention of it reaching $100 billion a year in funds by 2020. Total pledges to the fund are roughly $10 billion.

THE PARIS AGREEMENT

Countries agreed on a collective temperature goal of limiting global temperature to well below 2°C. Countries were asked to submit Intended Nationally Determined Contributions (INDCs), within a framework that emphasizes "transparency". It established an expert review process, whereby countries would be monitored as to their progress at meeting their INDCs.

However, even if countries were to meet their INDCs, the effects would likely not he commensurate with the goals of keeping global temperature change under 2°C, since emissions would continue to rise.

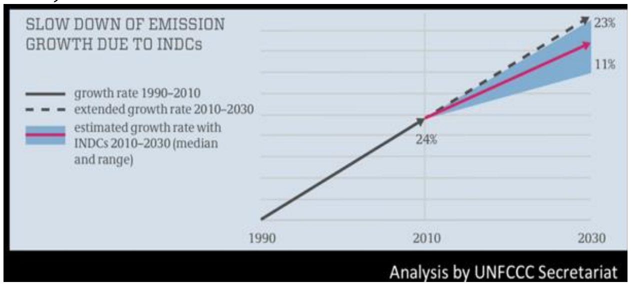

Figure 2: Projected effect of INDCs on Emissions

LEGALITY AND ENFORCEMENT

The legal responsibilities for countries party to the main international agreements are as follows:

	Legal nature	Obligations
Toronto 1988	Unofficial	None; unilateral declarations voluntary.
UNFCCC	Legally binding for all parties	Vague and aspirational.
Kyoto Protocol	Legally binding for all parties	Negotiated, but only for Annex I parties.
Doha Amendment	Legally binding (when it enters into force) for all parties	Declared rather than negotiated.
Copenhagen Accord	"Noted," not adopted; would not have been binding even if it had been adopted.	Voluntary
Paris Agreement	Legally binding treaty but one that can be approved or adopted by the US President by Executive Order.	Voluntary

None of these treaties have had significant enough enforcement mechanisms to effectively coerce countries into sticking to their agreements. Despite the fact that many of the agreements are legally binding, they are only binding for countries who are party to the agreement. Therefore, countries who choose not to follow through on their commitments can simply opt out of the agreement to avoid legal consequences.

"Naming and shaming" through the expert review process has turned out not to be an effective enforcement mechanism. Attempts to pioneer new means of enforcement–such as through climate clubs and economic sanctions against non-compliers–are promising, but face obstacles navigating the World Trade Organization's court system.

Fact Sheet 6: Treaty Design
Kevin Karl

COLLECTIVE ACTION PROBLEMS

International treaties must overcome the free-rider problem, whereby countries have an incentive to delay the economic costs of cooperating while reaping the positive externalities of other countries' climate actions. This makes it difficult for countries to adopt climate policies, since there is no way to guarantee that others will simultaneously take on the additional costs. The pitfalls of collective action problems can thwart efforts to reach climate treaties.

THE PRISONERS' DILEMMA

The prisoners' dilemma clarifies the tension between collective and individual interests. For example, assume every G20 country is given one red card and one black, and they must turn in one card to the UN. Each country receives $5billion if they keep the red card, plus $1billion for every red card handed back. The countries do not know which cards have been handed in. Turning in a red card in this game is a metaphor for acting on climate change

If all countries hand in a red card then each would gain $20b. However, if 19 hand in their red card while one keeps theirs, the "altruistic" countries receive $19b and the withholder gains $24b. If only one hands in a red card, and all others withhold, that one country receives $1b, while all others receive $6b. The outcome in which all countries contribute a red card is, in aggregate, the best collective outcome that maximizes global income. However, each country has a complete incentive to play black, since it makes them better off in every situation (see figure 1). This will result in each country playing black–the Nash equilibrium of the game.

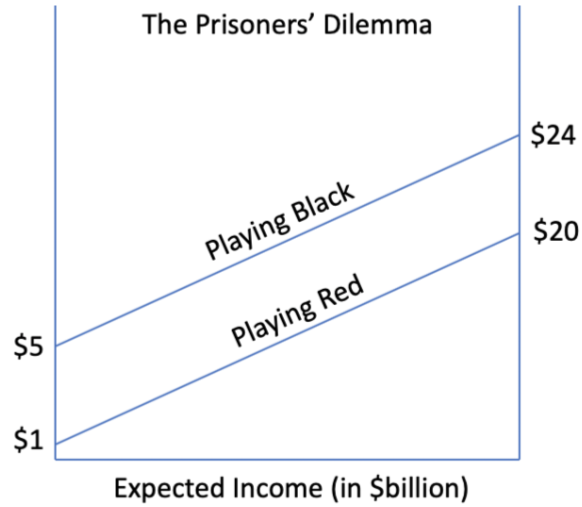

Figure 1: A Collective Action Problem Illustrated

THREE PILLARS OF A TREATY

An effective climate treaty must change status quo incentives and motivate parties to 1) participate in the treaty 2) comply with the treaty and 3) drastically reduce emissions (contribute greatly). To get countries to act on climate change, we must avoid entering a prisoners' dilemma.

COORDINATION

Imagine a situation, similar to the previous, where every G20 country is given one red and one black card, and every country must hand in one card without the others knowing which one. This time, if a country turns in a black card they will receive $10b minus $1b for every red card handed in. If they hand in the red card, they get $1b for every red card handed in. In this game, every country would get $10b if they all keep their red cards or $20b if every red card is returned. Essentially this creates two Nash equilibria, one where the payout is $20b/country (if cooperating) or $10bn/country (if not). Unlike the prisoners' dilemma, each country's expected payoff is dependent upon what other countries are playing. Therefore, in a coordination game, there is much greater potential for countries to play their red cards (act on climate).

Fact Sheet 6: Treaty Design
Kevin Karl

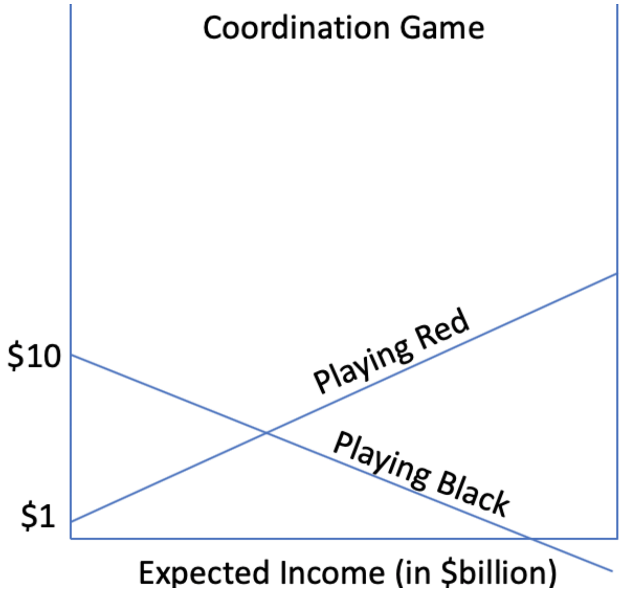

Figure 2: Coordination Game Equilibria

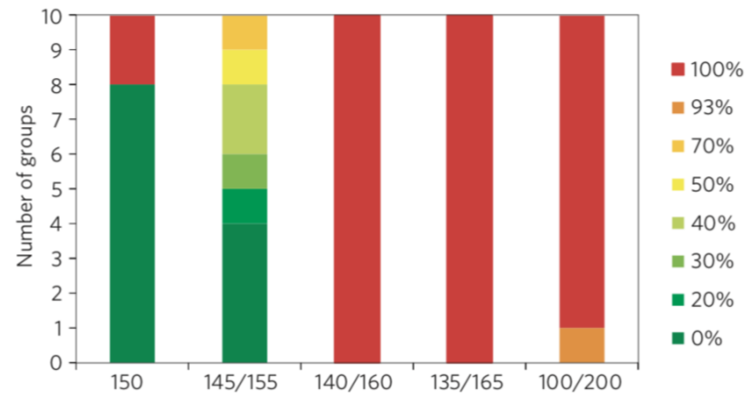

Figure 3: Barrett and Dannenberg (2014) Here, different groups were given a range of threshold estimates in order to see under what circumstances people coordinate their resources to avoid the catastrophic threshold. When the threshold was set clearly at 150, the vast majority of groups avoided catastrophe. As the threshold became less certain, robust cooperation dwindled, and fewer groups were able to avoid the threshold.

UNCERTAINTY

There are two types of obstacles that hinder a coordination game–uncertainty about the impact of climate change and uncertainty about where there is a threshold to a tipping point.[1] [2] Impact uncertainty is a lack of full confidence in the exact magnitude of the consequences of climate change, and threshold uncertainty is the lack of knowledge about when, exactly, a "dangerous" tipping point may be crossed.

Both theory and experimental evidence suggest that impact uncertainty is not significant in climate change negotiations, whereas the issue of threshold uncertainty is essential. Evidence suggests that when threshold uncertainty is small, groups overwhelmingly tend to coordinate to avoid the collective loss.[3]

TREATY DESIGN IMPLICATIONS

Limiting reductions by country creates a prisoners' dilemma. Yet, it is also true that the imposition of a minimum contribution limit can lead to larger contribution rates–*but only when participation is forced* in some way.[4]

Ultimately, the success of the Montreal Protocol–which limited signatories to only trade with other signatories and coerced countries into participation–showed the threat of trade restrictions can be successful. Furthermore, it showed that rules to limit production and consumption, instead of rules to limit emissions, can create a coordination game and ultimately a successful international treaty.[5]

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[1] Barrett, Scott, and Astrid Dannenberg. "Sensitivity of Collective Action to Uncertainty about Climate Tipping Points." *Nature Climate Change*, vol. 4, no. 1, 2014, pp. 36-39
[2] Barrett, Scott, and Astrid Dannenberg. "Climate Negotiations under Scientific Uncertainty." *Proceedings of the National Academy of Sciences of the United States of America*, vol. 109, no. 43, 2012, pp. 17372–17376.
[3] Ibid.
[4] Dannenberg, Astrid, et al. "Participation and Commitment in Voluntary Coalitions to Provide Public Goods." *Economica*, vol. 81, no. 322, Apr. 2014, pp. 257–275.
[5] Scott Barrett, Astrid Dannenberg, Tipping Versus Cooperating to Supply a Public Good, *Journal of the European Economic Association*, Volume 15, Issue 4, August 2017, Pages 910–94