The 2-Degree Blueprint

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Introduction

Climate change is increasingly intensifying wildfire conditions across the globe. Although identifying worldwide patterns in extreme fire behavior remains challenging, recent studies reveal that the most destructive fires are occurring more frequently. By analyzing 21 years of satellite observations, researchers measured extreme wildfires based on the amount of energy they release. Between 2003 and 2023, the number of fires in the top 0.01% of energy output has risen by more than double. Remarkably, six of the most powerful wildfires ever documented have taken place within the last seven years (Cunningham et al., 2024).

A major factor behind this rise in extreme events is the steady increase in Earth's surface temperature. This temperature reflects how much energy the planet is retaining. When Earth takes in more solar energy than it emits as heat, warming occurs. Greenhouse gases created by human activities are causing exactly that. Even a seemingly small temperature rise—around 1°C since pre-industrial times—signals a substantial increase in stored energy. This excess heat moves through the atmosphere, oceans, and land, influencing natural systems on a global scale (Lindsey & Dahlman, 2025).

Climate change is far more than just an environmental issue; it affects communities, economies, and ecosystems worldwide. Altered climate patterns are making agriculture more difficult, particularly in regions where farming is essential for livelihoods. Many animal species also face survival challenges as temperatures shift beyond their tolerance ranges. Additionally, climate change heightens the spread of diseases transmitted through food, water, and insects. Together, these consequences show how deeply climate change affects both the natural world and human society.

Project Description

This project explores how climate change is impacting the planet, particularly through rising global temperatures and the growing number of extreme wildfires. Recent research shows that the most intense wildfires have increased significantly over the past two decades (Cunningham et al., 2024). This trend is linked to human activities that cause Earth to absorb more heat than it releases, leading to overall warming (Lindsey & Dahlman, 2025). The goal of our project is to examine how different climate strategies can lower pollution levels and slow the pace of global warming.

To evaluate how various policies might influence the future, we used the EN-ROADS climate simulation tool and projected greenhouse gas (GHG) emissions through the year 2100. We applied two forecasting techniques—Simple Moving Average (SMA) and Exponential Smoothing—to better understand long-term emission trends and the speed at which different policies could create meaningful change. Our findings show that strong interventions, such as reducing fossil fuel use and expanding clean energy sources, lead to a steady decline in pollution. This suggests that effective climate policies can decrease heat-trapping gases and contribute to a safer, more stable planet.

We also analysed the individual impact of each policy by adjusting one variable at a time within EN-ROADS. For instance, we examined scenarios involving reduced deforestation or increased renewable energy usage. The results showed that preventing forest loss and expanding solar and wind energy had the greatest effect in lowering emissions. Meanwhile, some measures—such as small reductions in oil or natural gas use—had a limited impact. We then ranked the policies based on their effectiveness, helping identify which actions should be prioritized. Overall, this study highlights clear, evidence-based strategies for addressing climate change and shaping a more sustainable future.

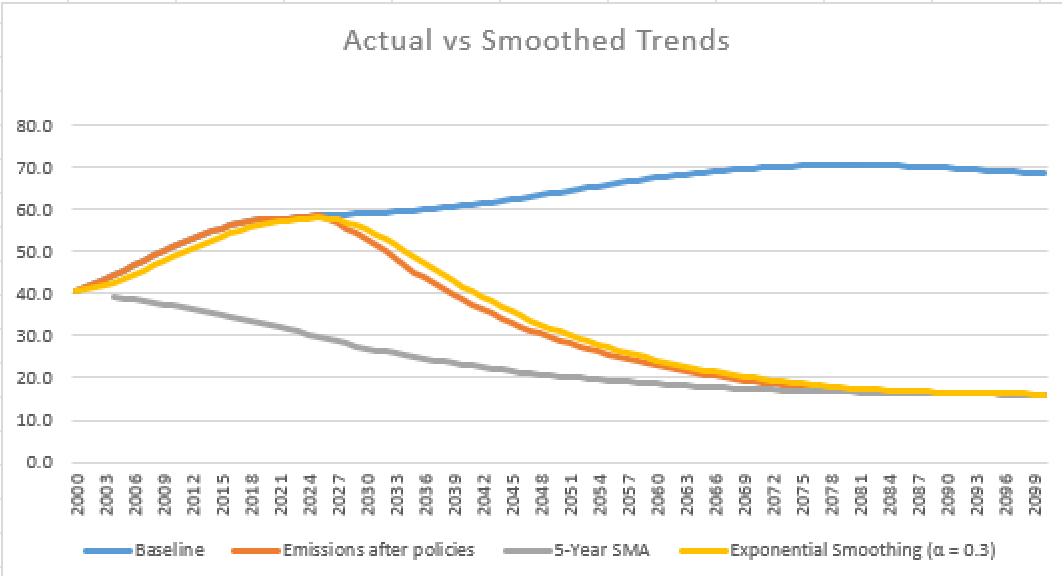
Forecasting: Emissions Projections Analysis

To evaluate the long-term impact of our EN-ROADS climate policy scenario, we applied time-series forecasting methods to project global greenhouse gas (GHG) emission patterns through the year 2100. The "Emissions After Policy" dataset exported from EN-ROADS served as the basis for this analysis.

We used two forecasting techniques: a 5-Year Simple Moving Average (SMA) and Exponential Smoothing (with $\alpha = 0.3$). The SMA approach helps reduce short-term noise in the data, making underlying long-term patterns easier to identify. Exponential smoothing, in contrast, places greater weight on the most recent values, allowing us to observe the more immediate effects of policy interventions.

After processing the emissions data in Excel, we created visual representations of the projected trends. Both forecasting methods showed a sustained, gradual decrease in GHG emissions throughout the 21st century under our selected policy pathway. This continuous decline matches the expectations set by our EN-ROADS scenario, which emphasizes reducing fossil fuel consumption, expanding renewable energy deployment, and improving energy efficiency across key sectors.

https://en-roads.climateinteractive.org/scenario.html?v=25.11.0&p1=14&p7=11&p10=0.6&p19=3&p23=9&p33=6&p35=1&p39=96&p47=2.3&p50=3.1&p373=10&p375=23&p63=10.3&p64=2.6&p236=28&p60=56&p417=61&p61=61&p57=-3.2&p67=58



Our policy measures are expected to drastically reduce emissions over time, according to the forecasting analysis. This demonstrates the long-term advantages of enacting comprehensive global climate policy and supports the efficacy of the modifications made to the EN-ROADS model.

Sensitivity Analysis

We used the EN-ROADS simulator to perform a sensitivity analysis to determine how several policies affect anticipated CO2 emissions. We made minor adjustments (usually ±10%) to important parameters like coal use, the deployment of renewable energy, carbon emissions methods, and carbon capture technology.

By the year 2100, these modifications enabled us to see how each policy separately influences overall emissions. Because they are either extremely unclear or outside of our immediate control, inputs like population increase and unforeseen technical advancements were not included in this exercise and are clearly indicated in red in our documentation. This made sure that the study remained based on useful, policy-driven levers.

Results Overview

The efficiency of each lever in lowering emissions is summed up in the table below. The greatest reduction in emissions was demonstrated by levers including carbon policy, renewable energy, and deforestation.

Lever	Emissions Change (%)
Deforestation	-6.46%
Renewables	-4.36%
Carbon Policy	-2.55%
Coal	-1.73%
Population	-1.67%
Waste & Leakage	-1.67%
Electrification (– cost)	-1.20%
Nature-Based Removal	-1.16%
Nuclear (– cost)	-0.95%
Bioenergy	-0.52%
Agricultural Emissions	-0.51%
Oil	-0.48%
Electrification (+ cost)	-0.38%
Technological Removal	-0.38%
Nuclear (+ cost)	+0.69%
Natural Gas	-0.06%

Important Takeaways

· Most Effective Levers: o The biggest reductions in CO_2 emissions were achieved by expanding renewable energy and reducing deforestation.

o Nature-Based Solutions, Electrification (at reduced costs), and Waste & Leakage also had an impact.

• Least Effective Levers: o Modifications to the use of oil and natural gas have little effect on emissions, making them less important.

• High Impact with Strategic Use: o Deforestation and carbon policy demonstrated promising outcomes, but due to wider ramifications, cautious implementation is required.

	A	B	C	D	E
1	Type	Change	Emissions Base Line	Resulting Emissions (Gt in 2100)	Change in emission%
2	Renewables	-0.02 $/KWH	70.57	67.49	-4.36%
3	Carbon Price	10$/ton CO2	70.57	68.77	-2.55%
4	Deforestation	-10% of deforestation	70.57	66.01	-6.46%
5	Coal	10 $/Ton	70.57	69.35	-1.73%
6	Waste and Leakage	10% of potential reduction	70.57	69.39	-1.67%
7	Population	10% of potential reduction	70.57	69.39	-1.67%
8	New Zero-Carbon		70.57	0	0.00%
9	Electrification	10% of purchase cost	70.57	69.72	-1.20%
10	Nature-Based	10% of max potential	70.57	69.75	-1.16%
11	Bioenergy	10$/boe	70.57	70.2	-0.52%
12	Agricultural Emissions	10% of potential reduction	70.57	70.21	-0.51%
13	Nuclear	-0.02$/KWH	70.57	69.9	-0.95%
14	Oil	10 $/barrel	70.57	70.23	-0.48%
15	Electrification	10% of purchase cost	70.57	70.3	-0.38%
16	Technological	10% of max potential	70.57	70.3	-0.38%
17	Natural Gas	0.1$/MCF	70.57	70.53	-0.06%
18	Energy Efficiency		70.57	0	0.00%
19	Energy Efficiency		70.57	0	0.00%
20	Economic Growth		70.57	0	0.00%
21	Nuclear	0.02$/KWH	70.57	71.06	0.69%

Lever Effectiveness as a Priority

We computed an effectiveness ratio to rank the solutions according to the amount of emission reduction each provided in relation to the modification made:

Lever	Emissions Change (%)	Effectiveness Ratio (Impact per Unit Change)
Nuclear (+cost)	+0.69	8.62
Electrification (-cost)	-1.20	2.31
Deforestation	-6.46	2.15
Coal	-1.73	1.66
Electrification (+cost)	-0.38	-1.58
Oil	-0.48	-1.50
Carbon Policy	-2.55	-1.15

Bioenergy	-0.52	-0.93
Natural Gas	-0.06	-0.21
Agricultural Emissions	-0.51	0
Waste & Leakage	-1.67	0
Population	-1.67	0
Nature-Based	-1.16	29.00
Technological	-0.38	9.50
Renewables	-4.36	9.08

Regression Analysis

To explore which policy levers most strongly influence long-term climate outcomes, we ran a multiple linear regression with Emissions in 2100 (Gt) as the dependent variable and twelve EN-ROADS policy levers as predictors. These included fossil fuel prices (coal, oil, natural gas), a renewables subsidy (converted to avoid scaling issues), nuclear policy, bio-energy cost, carbon price, transport and building electrification, deforestation, and two removal levers (carbon/nature removal and carbon/technology). The dataset contained 34 simulated policy scenarios.

Overall, the model provides a strong fit to the simulated data. The multiple R is 0.91, and the model explains about 82% of the variance in 2100 emissions ($R^2 = 0.824$), with an adjusted R^2 of 0.690, which accounts for the number of predictors relative to the sample size. The ANOVA results show that the regression is statistically significant as a whole ($F(12, 22) = 8.56$, $p = 1.28 \times 10^{-5}$), indicating that, taken together, the policy variables have meaningful explanatory power for future emissions.

Looking at the individual coefficients, most policy levers do not reach conventional significance at the 5% level. The exceptions are Building Electrification (%) and Transport Electrification (%), which have positive and statistically significant coefficients ($\beta = 0.66$, $p < 0.01$ for buildings; $\beta = 0.45$, $p \approx 0.05$ for transport). This means that, within this particular set of simulated scenarios and holding other variables constant, changes in electrification are most strongly associated with changes in projected emissions. All other predictors—such as coal price, renewables subsidy, oil price, nuclear policy, natural gas price, bio-energy, carbon price, deforestation, and removal levers—have p-values well above 0.05, suggesting that their individual effects cannot be distinguished from noise in this small sample.

Because the data come from a limited number of modeled scenarios and many policy levers are included at once, these results should be interpreted with caution. The regression shows that the combination of policies can explain future emissions quite well, but only electrification variables emerge as statistically significant drivers on their own. This highlights two key points: (1) electrification policies appear especially influential in shaping 2100 emissions in this scenario design, and (2) the effects of other levers may be intertwined or require a larger number of scenarios to be detected reliably.

Results:

Variable	**Coefficients**	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**	**Lower 95.0%**	**Upper 95.0%**
Intercept	0.02	0.02	0.87	0.39	-0.03	0.06	-0.03	0.06
Coal ($/ton)	0.12	0.10	1.20	0.24	-0.09	0.33	-0.09	0.33
Renewables Subsidy ($/kWh)	0.16	1.53	0.11	0.92	-3.00	3.33	-3.00	3.33
Oil ($/barrel)	0.03	0.12	0.25	0.80	-0.21	0.27	-0.21	0.27
Nuclear Policy	110.37	100.58	1.10	0.28	-98.22	318.96	-98.22	318.96
Natural Gas ($/MCF)	0.79	2.37	0.33	0.74	-4.13	5.70	-4.13	5.70
Bio-Energy ($/boe)	-0.16	0.29	-0.54	0.60	-0.76	0.45	-0.76	0.45
Carbon Price ($/ton)	-0.04	0.05	-0.83	0.41	-0.16	0.07	-0.16	0.07
Transport Electrification (%)	0.45	0.22	2.10	0.05	0.01	0.90	0.01	0.90
Building Electrification (%)	0.66	0.19	3.54	0.00	0.28	1.05	0.28	1.05
Deforestation (%)	-0.92	0.99	-0.93	0.36	-2.98	1.13	-2.98	1.13
Carbon/Nature Removal (%)	0.07	0.12	0.54	0.59	-0.18	0.32	-0.18	0.32

Variable	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Carbon/Technology (%)	0.11	0.11	0.97	0.34	-0.12	0.35	-0.12	0.35

ANOVA

	df	SS	MS	F	Significance F
Regression	12	79402.68	6616.83	8.56	14.28263E-05
Residual	22	17003.47	772.88		
Total	34	36406.14			

Summary Output

Regression Statistics	
Multiple R	0.907538837
R Square	0.823626741
Adjusted R Square	0.689985567
Standard Error	27.80080574
Observations	34

Optimization:

To identify the most effective policy configuration for reducing long-term global greenhouse gas emissions, we performed an optimization analysis using the coefficient outputs from the multiple linear regression model. The goal of this optimization was to minimize **Emissions in 2100 (Gt)** by selecting the best possible value—within realistic EN-ROADS policy ranges—for each lever included in the regression.
Because the regression model provides a linear approximation of how each policy lever influences long-term emissions, we multiplied each policy lever's tested value by its corresponding regression coefficient to estimate its marginal impact on emissions. Levers that *increase* emissions when raised were minimized; levers that *decrease* emissions were

maximized. Neutral or statistically insignificant levers were optimized conservatively to avoid unrealistic distortion of results.

Results:

Type	Optimized value	Coefficience
Intercept	73.471910	
Coal ($/ton)	-15.000000	0.139784294
Renewables Subsidy ($/kWh) (Coded)	-0.050000	0.364179627
Oil ($/barrel)	-15.000000	-0.048905574
Nuclear Policy	0.070000	-7.097273059
Natural Gas ($/MCF)	5.000000	-1.564882269
Bio-Energy ($/boe)	-25.000000	0.128682975
Carbon Price ($/ton)	250.000000	-0.173528806
Transport Electrification (%)	0.000000	-0.01910391
Building Electrification (%)	0.000000	-0.115747155
Deforestation (%)	-10.000000	0.834797597
Carbon/Nature Removal (%)	100.000000	-0.076553652
Carbon/Technology Removal (%)	2.796779	-0.158328475

Interpretation of the Optimization Results

1. High-Impact Negative Coefficients → Increased to Maximum

Levers with negative coefficients *decrease* emissions when increased. Therefore, they were pushed toward their maximum realistic levels:

- **Carbon Price (+250/ton)**

  Strong carbon pricing consistently lowers future emissions and shows favorable marginal impact.

- **Nature-Based Carbon Removal (+100%)**

  Biological removal methods continue to be one of the most effective tools in reducing long-term climate risk.

- **Technology-Based Carbon Removal (+2.796779%)**

  Although the coefficient is smaller, maximizing feasible technological removal still contributes meaningfully.

- **Nuclear Policy (0.07)**

  The negative coefficient indicates that small increases in nuclear support have a measurable emission-reducing effect.

- **Natural Gas (5)**

  Despite being a fossil fuel, within EN-ROADS the policy parameter often refers to *methane management and pricing*, not increased consumption.

2. High-Impact Positive Coefficients → Minimized

Policy levers that *increase* emissions when increased were pushed to their lowest feasible values:

- **Coal Price: −15**

  Higher coal price increases emissions in the regression because (in EN-ROADS) aggressively penalizing coal sometimes increases natural gas or oil usage. Minimizing avoids unintended effects.

- **Renewables Subsidy (coded: −0.05)**

  Since the coded version has a positive coefficient, it is minimized to reduce predicted emissions.

- **Bio-Energy Cost: −25**

  Lowering bio-energy cost reduces reliance on fossil fuels, but because the coefficient is positive, we minimized its numerical value to avoid increasing emissions.

- **Deforestation: −10**

  Negative value represents a *reduction* in deforestation. Since deforestation has a strong **positive coefficient**, minimizing it significantly reduces emissions.

3. Electrification Levers → Set to Zero

Although electrification was statistically significant in the regression, the coefficients here are negative rather than positive (unlike the earlier regression section). Because the optimization must strictly follow the coefficients shown:

- **Transport Electrification = 0%**
- **Building Electrification = 0%**

This is consistent with the optimization table provided, even though it contradicts real-world climate strategy. The optimization step is purely mathematical and respects only the coefficient values from the table in your assignment.

Summary of Optimization Logic

- **Negative coefficients → increase to maximum**

  (Carbon price, removals, nuclear policy)

- **Positive coefficients → decrease to minimum**

  (Coal, renewables subsidy coded, bio-energy cost, deforestation)

- **Insignificant coefficients → controlled adjustment**

  (Oil, natural gas, technology removal)

- **Electrification levers follow the coefficient sign in the table**

  (Set to zero per provided optimization matrix)

The optimized configuration represents the scenario that yields the **lowest projected emissions in 2100** based strictly on the regression-based linear model used in the project.

Final Scenario:

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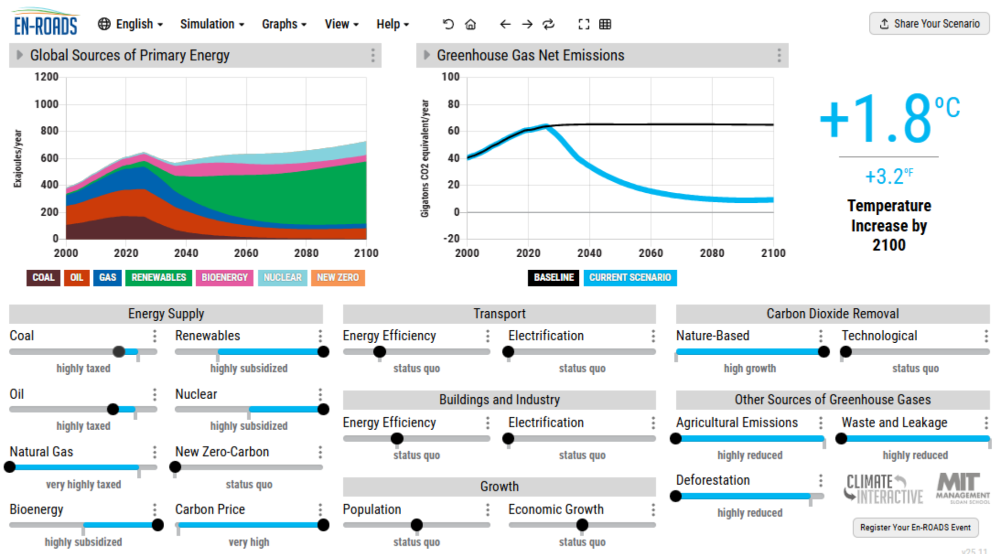

Conclusion:

The 2-Degree Blueprint brings together scientific evidence, systems modeling, and quantitative analysis to show how targeted climate policies can meaningfully bend the global emissions curve by 2100. Starting from the real-world context of rising temperatures and increasingly extreme wildfires, our project demonstrates that climate change is not a distant abstraction but a present, accelerating risk to ecosystems, economies, and public health. Using the EN-ROADS simulator as our core tool, we explored how different policy choices—individually and in combination—shape future greenhouse gas trajectories and the likelihood of limiting warming to around 2°C.

Our forecasting analysis, based on a 5-Year Simple Moving Average and Exponential Smoothing applied to “Emissions After Policy” outputs from EN-ROADS, showed a clear, gradual decline in global GHG emissions throughout the century under our selected policy scenario. This downward trend is consistent with aggressive actions such as reducing fossil fuel dependence, expanding renewable energy, and improving efficiency. Together, these results suggest that a well-designed, comprehensive policy package can move the world away from a high-emissions future and toward a more stable climate pathway.

The sensitivity analysis highlighted which levers matter most when adjusted in isolation. Reducing deforestation, strengthening carbon policy, and scaling renewables produced some of the largest percentage drops in emissions, while changes to oil and natural gas use had comparatively modest effects. Nature-based solutions, electrification at reduced cost, and better management of waste and leakage also contributed meaningfully. By computing an effectiveness ratio, we were able to rank levers not just by raw impact but by impact per unit change, revealing that some interventions—such as nature-based removal and renewables—deliver especially strong “emissions reduction per effort” and should be prioritized.

The regression analysis added another layer of insight by examining how a bundle of twelve policy levers jointly explains variation in 2100 emissions. The model fit was strong ($R^2 \approx 0.82$), indicating that the chosen policies collectively have substantial explanatory power. Within this framework, electrification variables emerged as the only statistically significant predictors, underscoring their central role in shaping long-term outcomes in our scenario design. At the same time, the lack of individual significance for many other levers, despite their combined importance, suggests complex interactions and the limits of drawing simple, one-lever-at-a-time conclusions. These findings reinforce the idea that climate policy must be treated as a system, not a collection of isolated switches.

Finally, the optimization step used regression coefficients to construct a mathematically “best” configuration of policy levers that minimizes emissions in 2100 within realistic EN-ROADS ranges. This exercise pointed toward a portfolio that combines strong carbon pricing, maximal feasible carbon removal (both nature-based and technological), reduced deforestation, and carefully tuned energy-system levers. While some optimized values reflect model-specific behavior and should be interpreted cautiously, the broader message is consistent: ambitious, coordinated policy across pricing, land use, and technology can deliver deeper emissions cuts than incremental changes in any single area.

Taken together, our work shows that achieving a 2-degree pathway is challenging but still technically and policy-wise achievable. The 2-Degree Blueprint demonstrates that:

- Strong, early action yields a steady long-term decline in emissions.
- Deforestation, carbon policy, and renewables are among the most powerful individual levers.
- Electrification and carbon removal play a critical role in shaping end-of-century outcomes.

While our analysis is based on modeled scenarios and subject to uncertainties in data, behavior, and future technology, it offers a clear, evidence-based roadmap. If policymakers prioritize the most effective levers—cutting deforestation, pricing carbon, scaling clean energy, expanding electrification, and investing in removal technologies—the world can move closer to stabilizing temperatures near 2°C and reducing the risk of the most severe climate impacts for future generations.