Policy Suggestions for a Southwestern Energy Compact

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Abstract

A coalition of southwestern states wishes to coordinate their clean energy goals. We researched each state and constructed simple energy profiles to breakdown their energy consumption. To compare energy profiles, we created a metric called **Green Score** which measures a state's commitment to clean energy by assuming all generated clean power replaces potential emissions. Using game theory, we model the negotiation of optimal contracts between states with no preference for cooperation. We crafted a model from historical and environmental data that recommends to each state a cardinally ordered list of energy sources. This model includes an estimate of nuclear catastrophe risk calculated through earthquake data and the Gutenberg-Richter law. Our final model sets strong limits on carbon emissions and gives each state an individualized plan to meet those limits on a realistic budget.

Contents

1 Introduction

1.1 Problem Background

Energy policy poses a herculean challenge for lawmakers pursuing a balance between financial and environmental well-being. The existential threat and tangible future cost of climate change necessitate action, but nuances within policy, geography, and economics preclude an easy solution. Increasing CO_2 levels have caused worldwide temperatures to increase and in response, governments have attempted to transition towards cleaner energy sources. The 2015 Paris Agreement aimed to keep worldwide temperatures from increasing by 2° C. This report aims to follow the lead of the UN by providing mathematical models that measure the actual and prospective environmental impact of energy consumption in Arizona, California, New Mexico, and Texas. Apart from measurement and speculation, our models also provide policy suggestions for these states as they consider entering a clean energy compact [23, 25].

To do this, we created energy profiles for each state, whose overall performance with respect to averting emissions is encapsulated in its "Green Score." As shall be seen, this metric provides a simple yet comprehensive portrayal of the current and prospective energy consumption behavior of each state. Informed by each state's energy profile, our models aim to increase each state's Green Score in the most cost effective manner by selecting clean energy sources suitable to each state.

1.2 Problem Restatement

Four governors wish to negotiate a clean energy compact that is mutually beneficial to their states. In accord with the most prominent contracts in climate change, we assume that the environmental impact of energy is measured by carbon emissions. Our goal is to provide the governors with individual state insights, a suggested compact structure, realistic emission goals, and recommendations for energy investments.

1.3 Constants and Variables

- Carbonizing factor = $\frac{\text{total carbonized energy in 2009}}{\text{total dirty MBTU in 2009}} = 151.3 \frac{\text{lbs. CO}_2}{\text{MBTU}}$
- Actual = emissions in a given year
- Averted = (clean BTUs in a given year) × (carbonizing factor)
- Total Carbonized Energy (TCE) = (Actual) + (Averted)
- Green Score = $\frac{\text{Averted}}{\text{Total Carbonized Energy}}$

1.4 Definitions and Assumptions

- **Clean energy** is characterized by negligible emissions during consumption. Clean energy consists precisely of hydroelectric, solar, nuclear, wind, and geothermal energy.
- **Dirty energy** is characterized by substantial emissions during consumption. It consists precisely of petroleum, coal, natural gas, wood and waste, and ethanol.

- Clean energy is assumed to produce no emissions.
- All solar energy is assumed to be solar-thermal.
- An energy compact is a contract: a binding agreement between the four states, consisting of some set of duties for each state. This may include some punishment (e.g., fines) for noncompliance.

2 Energy Profiles

Motivated by the effects of using different energy sources on the environment, our model's energy profiles includes information about each state's "actual emissions" and "averted emissions" of CO_2, the primary greenhouse gas [38]. Actual emissions correspond to the amount of CO_2 emitted into the atmosphere by "dirty" sources (coal, petroleum, etc.), while the averted emissions correspond to the amount of CO_2 that would have been emitted had all energy produced from "clean" generated the average amount of CO_2 as the average "dirty" MBTU in 2009. Using these two values, our model uses a "Green Score" that determines the percentage averted emissions compose of Total Carbonized Energy (the sum of "actual" and "averted emissions")

$$\text{Green Score} = \frac{\text{Averted Emissions}}{\text{Total Carbonized Energy}}.$$

The Green Score is intended to serve as a general metric of how well each state is using clean sources. Alongside these Green Scores, our energy profiles break down the actual and averted emissions created by "dirty" and "clean" production methods respectively. Thus, our energy profiles account for nearly all energy sources in the EIA dataset [33].

Arizona Energy Profile

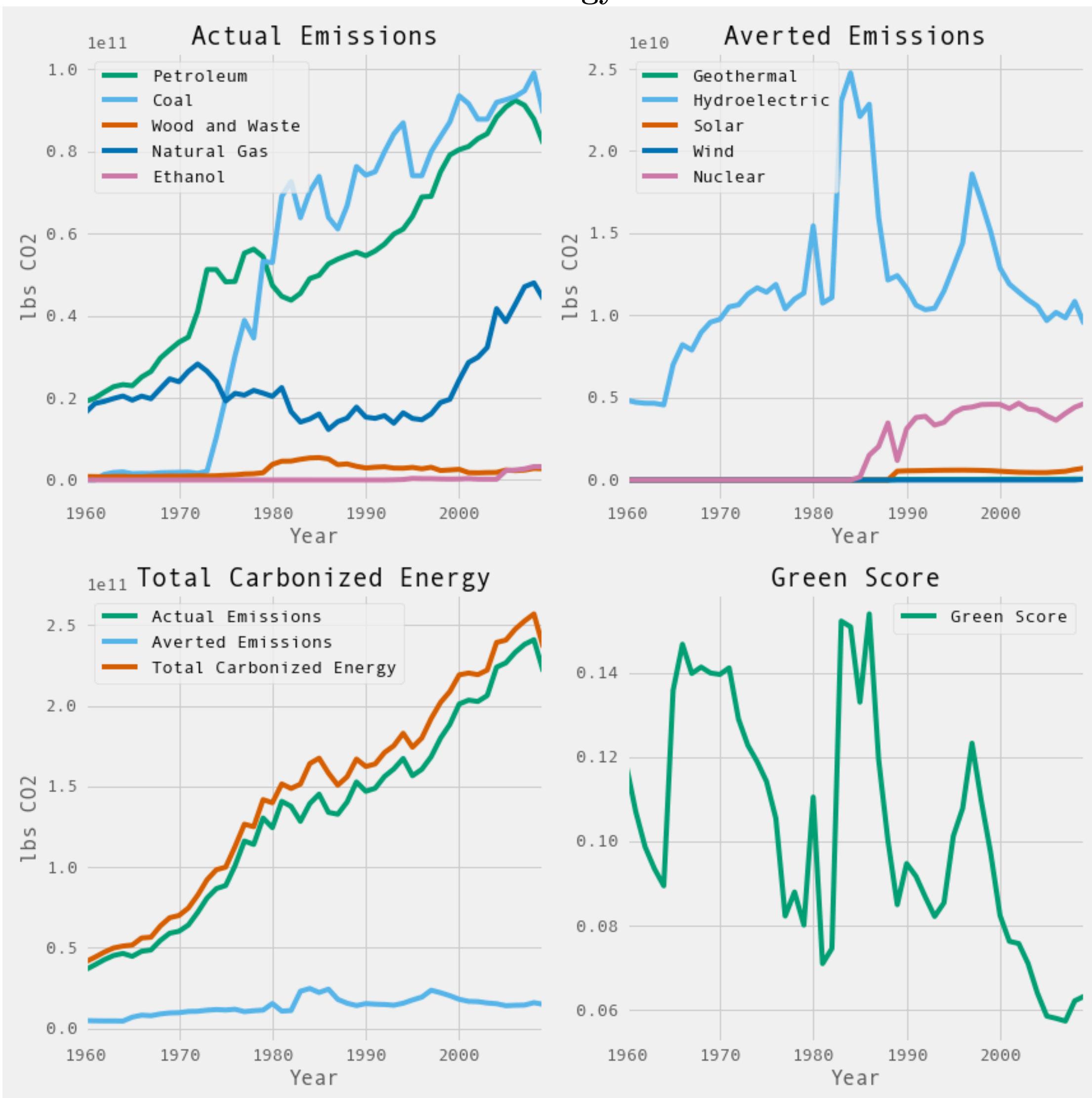

Figure 1: Arizona's 2009 Green Score is 0.0633.

The state of Arizona possesses few fossil fuel resources, but has abundant access to sunlight and wind [34]. Historically, much of Arizona's clean energy has been hydroelectric; it is home to the iconic Hoover Dam and several other hydroelectric facilities. In the clean energy graph (upper-right), a sharp drop occurs in 1987– the year after the Electric Consumers Protection Act imposed strict regulations on hydropower [39]. Our allocation model suggests that Arizona should invest in geothermal and wind technologies. These natural resources are largely untapped, and may be superior alternatives for future energy production.

California Energy Profile

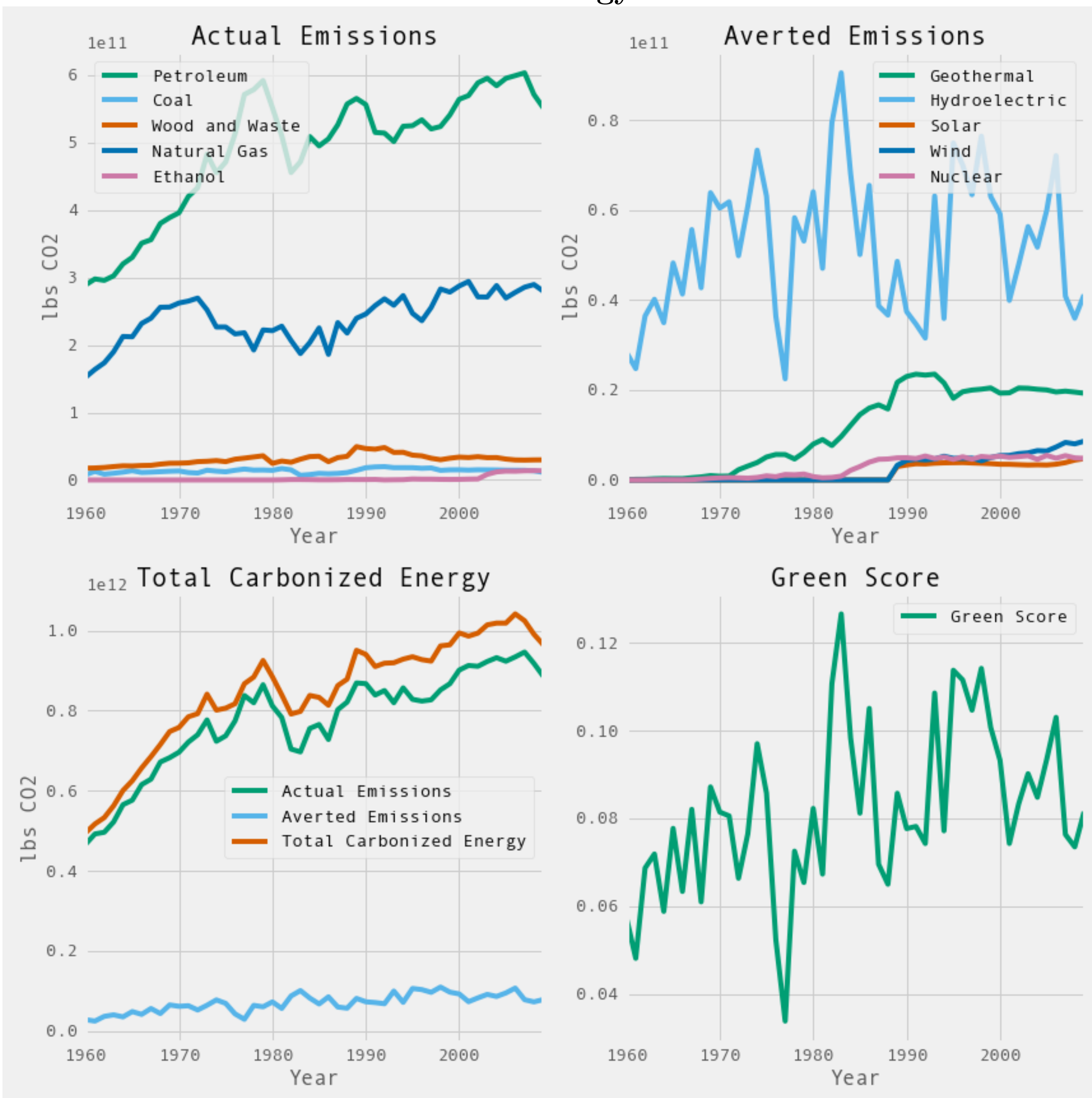

Figure 2: California's 2009 Green Score is 0.0815.

Of the four states, California currently holds the highest Green Score. As the right-side graphs indicate, this is largely due to California's substantial hydroelectric and geothermal infrastructure [35]. Like Arizona, California was strongly affected by the 1986 Electric Consumer Protection Act. However, California's heavy reliance on hydropower subjects its Green Score to season fluctuations in rainfall [40]. Despite this, the state has excellent resources for hydropower, and it should continue investing in this sector, but it could stabilize its green score through a continued investment in geothermal.

New Mexico Energy Profile

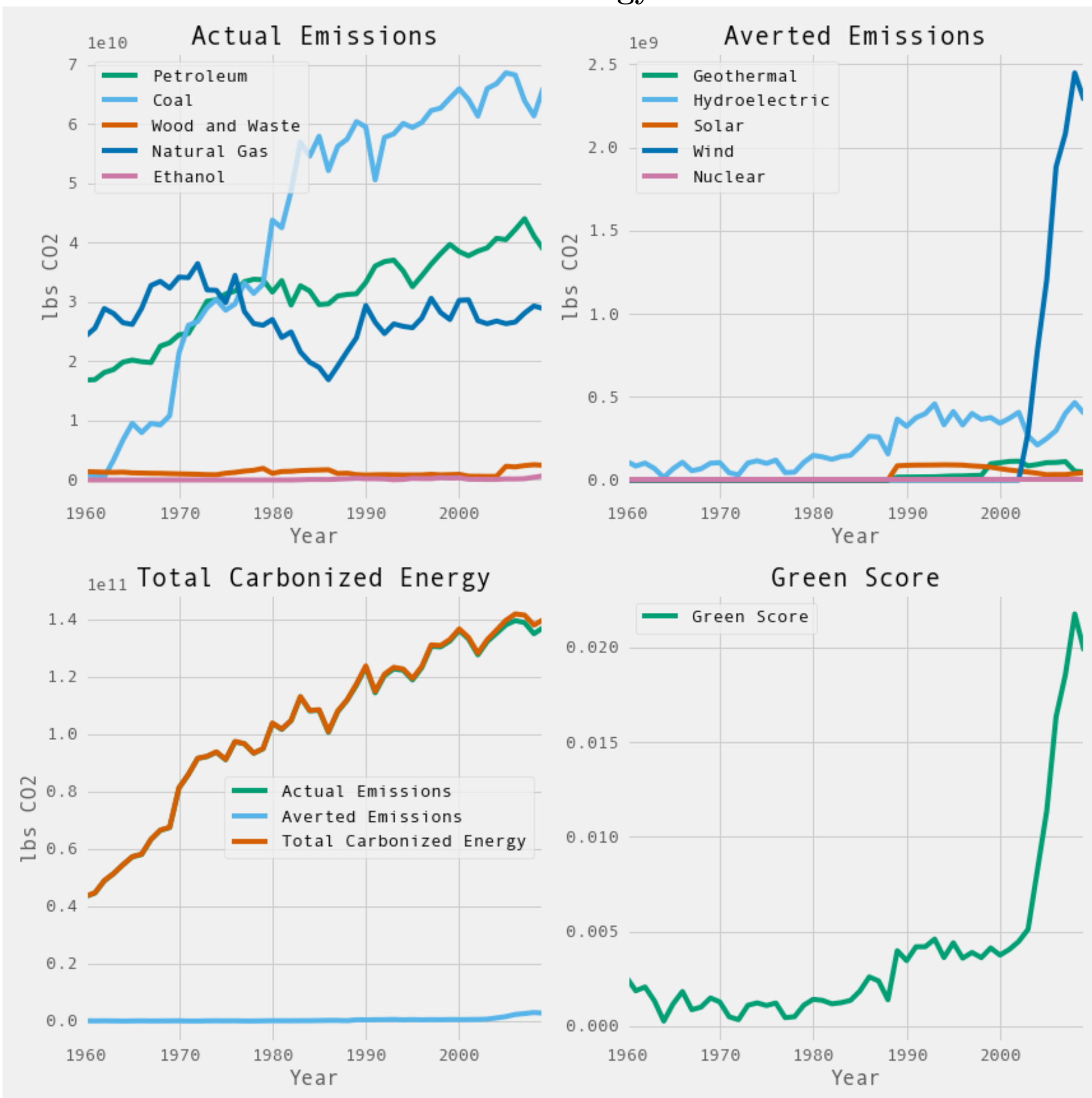

Figure 3: New Mexico's 2009 Green Score is 0.0198.

New Mexico's low population allows the state to export large quantities of generated energy to neighboring states [36]. The state has no nuclear plants, which is curious granted that it possesses the second largest uranium reserves in the US [36]. As seen in the graph of averted emissions (upper-right), New Mexico is increasingly harnessing its wind and solar resources, resulting in a dramatic increase in the state's Green Score. We found that due to its low seismic activity and abundant uranium resources, New Mexico is in the best position of the four states to bolster clean energy production with nuclear power. Even if New Mexico determines it is unwilling to incur the costs and risks of nuclear plants, we recommend it invests resources in nuclear research. Such a policy will work to make nuclear power safer while also increasing the value of the state's uranium reserves.

Texas Energy Profile

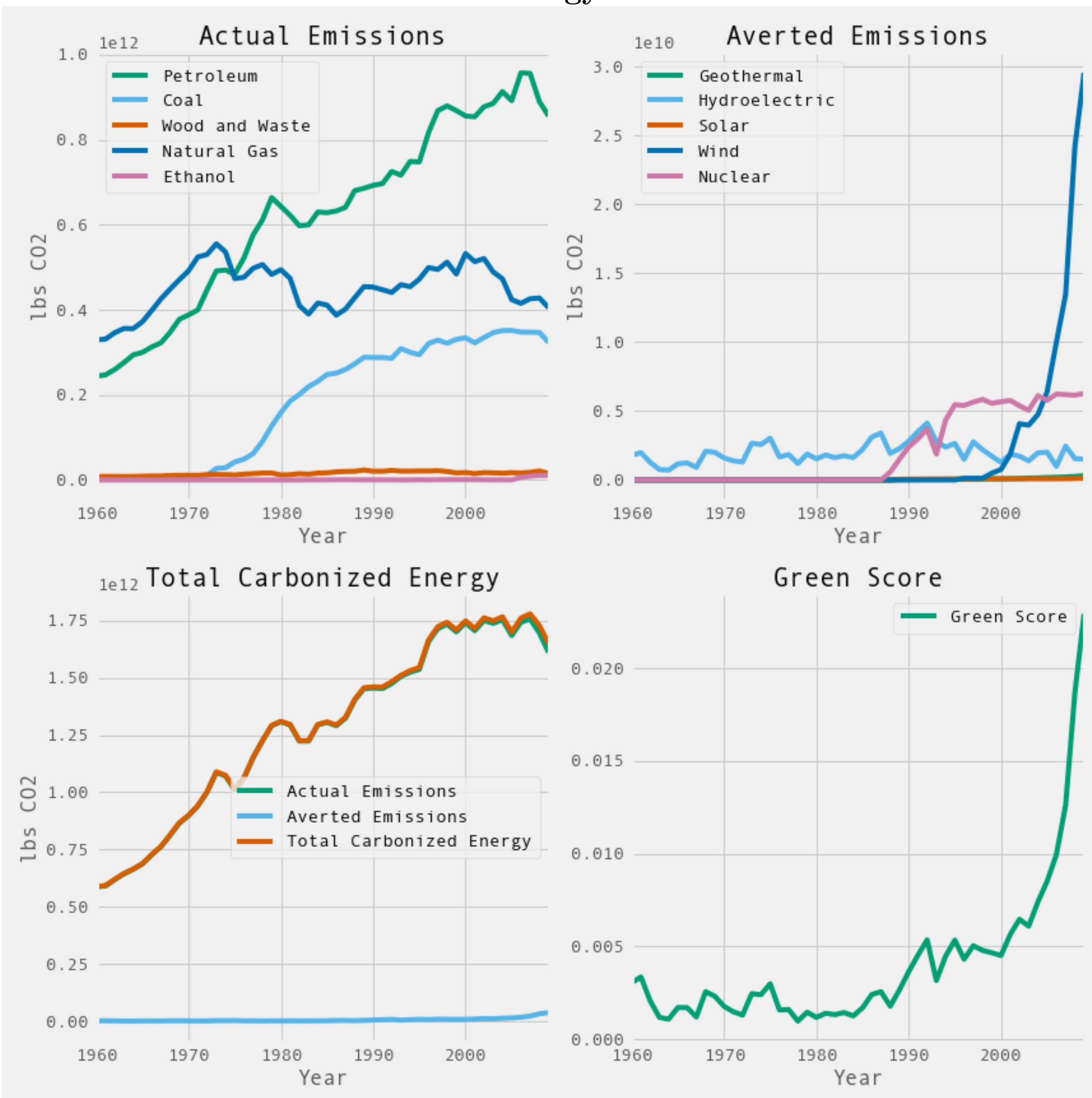

Figure 4: Texas's 2009 Green Score is 0.0229.

Texas currently leads the nation in total energy and is the largest consumer of coal. Like New Mexico, the state has recently increased its usage of wind energy [37]. This has increased its Green Score by a proportional amount. In addition to wind energy, they have started to increase their usage of nuclear and geothermal energy. Precipitation history indicates that the region would most benefit from an investment into hydropower. Like Arizona and New Mexico, we recommend Texas supplement its investments in hydropower by utilizing its wind resources.

2.1 Extrapolation of Energy Profiles

The governors asked us to provide them with energy profile forecasts for 2025 and 2050. We felt uncomfortable extrapolating so far outside our data, and we were concerned that trying too many models would lead to overfitting.

We considered predicting the historical average value, but our knowledge of the data indicates that this is a bad model: historically, energy usage and GDP have increased at a steady pace. We chose to be very cautious with these forecasts: although we considered several complex methods, we ultimately decided on simple **least-squares regression. The numeric predictions of this model for each state's energy profile in 2025 and 2050 are available in the appendix.**

3 Models of Contract Bargaining

What makes a contract good, and how can we assess a particular contract? In our first model, we frame this as an optimization question in game theory. Our second model builds on those ideas with historical evidence.

3.1 Assumptions

- Assume that there is no cost associated with negotiating.
- Assume each state assigns equal value to $USD.
- Assume that states may transfer money between themselves, with no transaction fees.[1]

3.2 Game theory & selfish states

It is **unacceptable** and unnecessary to assume that states will optimize environmental well-being. It is unlikely that if the optimal strategy for reducing emissions pushed heavy costs onto Arizona, the governor of Arizona would accept the compact. Thus, we assume by default that each state is a rational agent, totally indifferent to the status of other states.

We view a contract is primarily valuable because it allows a self-interested agent to **restrict** his action set in a beneficial way. For example, the prisoner's dilemma becomes trivial if the prisoners are allowed to negotiate a binding contract: they can agree to remove the action of defection, which improves the payoff for both players.

Ideally, we would like to propose a contract that all states find desirable. To do this, we convert the problem into a mathematical game and analyze its optimal strategy.

Definition 3.1. *A **policy** is a proposal of certain payoffs for each of the players in the game. If all players mutually agree to a policy, it takes effect and they each receive the payoffs.*

Definition 3.2. *A **contract** is composed of some linear combination of policies: i.e., all players must agree to all policies within the contract for it to take effect.*

[1]Assumptions 2 and 3 are unnecessary but convenient. Assumption 1 is necessary: it allows the game to continue for arbitrary time.

Player	AZ	CA	NM	TX
Payoff	E_P	E_P	E_P-C_P	E_P

Figure 5: Table of payoffs when New Mexico implements some policy P.

Definition 3.3. *The **contract game** is a game with four players, corresponding to the four states. Any player may propose an environmental policy P. To each P we associate some positive global payoff E_P (an environmental benefit) for all states, and a negative payoff C_P (cost of implementation) for the state proposing the policy. A player may also create a policy T, which directly transfers some amount of wealth to another player.*

With these assumptions and definitions, we can measure the quality of a policy or contract.

Definition 3.4. *Assuming each state plays an optimal strategy, a policy or contract is **ideal** if all four states approve it.*

Not every game has an optimal strategy, so we construct one explicitly. Without loss of generality, we may ignore contracts and consider a single arbitrary policy P. (We accept a contract if and only if we would accept all of its component policies.)

The total value created by P is the sum of all payoffs: $4E_P$-C_P. If this value is negative, we reject the policy. Otherwise, the problem is now reduced to the following game:

Suppose n rational players must split a dollar. In round i of this game, player (i mod n) proposes a distribution of the dollar. If all players accept the distribution, the players receive their payoffs and the game ends. Otherwise, the game continues: there is no round limit. The value of the dollar remains constant, i.e., the players have infinite time and patience.

Lemma 3.5 (Optimality of the fair split)**.** *The optimal strategy for any player in this game is the "fair split" strategy: the player should accept a distribution if and only if they are allocated an amount $c \geq 1/n$. The player should propose the fair distribution (1/n to all players) with some positive frequency.*

Proof 3.6. *Note that ordering of players does not matter in this game: for example, suppose player 1 has the best strategy. Then player 2 can deny the first offer, and it is now player 2's turn. This game is indistinguishable from the original, so player 2 can steal player 1's strategy. Hence, the optimal strategy is identical for all players.*

This implies that the players receive identical payoffs. If all players adopt the fair split strategy, they will each receive a payoff of $\frac{1}{n}$, so the optimal strategy must give a payoff $\geq \frac{1}{n}$. The optimal strategy cannot give a reward greater than $\frac{1}{n}$: this would contradict the constant-sum property of the game. Hence the expected value of the game is $\frac{1}{n}$, and our strategy is optimal. □

In short, the optimal decision criterion is the obvious one: accept a contract if and only if you are offered more than 1/4 of its value. Among rational agents, this means that a contract is ideal if and only if it offers uniform positive payoffs to all players.

Given a policy P with value > 0, we may easily convert it to an ideal contract. All states must receive a payoff of $E_P - \frac{C_P}{4}$. So, for any policy of positive value, three states should transfer $\frac{C_P}{4}$ to the policy-making state. By bundling the three transaction policies with the environmental policy, we create an ideal contract.

This model indicates that we should offer a contract that imposes symmetric costs across all states. For example, we might pick some number greater than a target, and contract each state to spend that amount on clean energy.

3.3 A less-idealized adaptation

Our last model is not very practical. Assuming total independence of state priorities is a heavy assumption, and imposing a cost on negotiations allows a much wider range of acceptable contracts.

Definition 3.7. *We say a contract is **acceptable** if it is not ideal and all four players accept it. Such an acceptance might occur due to negotiation fees or dependent state priorities.*

Acceptable contracts span a much larger space. In particular, most real contracts are merely acceptable, so we found an example to use as a guide.

Our contract suggestion is modeled after the Regional Greenhouse Gas Initiative, that began development in 2005, and became active in 2009 [32]. Several states in the New England region participate in this program to regulate their emissions. Each state is given a "carbon budget" or emissions cap: the average of its 2000-2002 emissions. They may purchase additional emissions from state auctions of carbon rights.

Since this model actually worked, we will emulate it. We set a limit cap on actual emissions for each state: the average of its 2000-2002 emissions. A similar carbon market can either be established or joined, but for simplicity we assume that each state will not intentionally exceed their carbon budget. In a real market, this could be achieved by setting sufficiently high penalties for exceeding limits.

Assuming state energy demand is linear, enacting a hard cap on actual emissions forces a state to invest in its clean energy sectors. Once we establish comparative price estimates, we can test this model.

4 Comparison of Energy Sectors by State

The table above provides a useful starting point for determining the efficiency of each clean energy source, but we decided that we should create a model that accounts for state-by-state differences in energy-type effectiveness [22, 26, 41].

To do this, we associate some data to each energy source: e.g., rainfall and hydroelectric power. For each type of clean energy, we use the data to construct a set of price weights. These weights adjust the energy prices for each state: for instance, a particularly rainy state will be given a lower price for hydroelectric power.

Energy Source	Average Price per MBTU
Hydroelectric	$15
Solar	$25.64
Nuclear	$27.99
Wind	$45.87
Geothermal	$15

Figure 6: Average Cost per MBTU in United States

4.1 Effectiveness of Hydroelectric Power

Our model takes the baseline price of hydroelectric per MBTU and determines its relative effectiveness in a given state by considering the ratio of said state's average yearly rainfall with the average rainfall across all four states.[2]

The average yearly rainfall across these four states is 22.04 in/yr [27]. We used this to create the table of price-scaling factors for each state.

State	Avg Yearly Rainfall (in)	% Greater Than Avg
AZ	13.6	61.71%
CA	22.2	100.73%
NM	14.6	66.24%
TX	28.9	131.13%

4.2 Effectiveness of Nuclear Power

We decided that nuclear power requires some unique and specialized criteria for determining its relative effectiveness in a given state. Nuclear plants do not require specific geographic conditions to function, but do bear the risk of catastrophic failure during earthquake events [31]. We performed a comparative risk analysis on each state's seismic activity to its aptitude for nuclear power with the idea being to discourage states with high seismic activity from pursuing nuclear.

We began with data of earthquakes from 2010-2015 greater than 3.0 [7].

State	Avg # of Earthquakes Mag 3.0+ (Yrs)
AZ	61
CA	1545
NM	39
TX	82

From this data we extrapolated the average frequency of earthquakes of magnitude greater than 8.0 using the Gutenberg-Richter Law [2]:

$$log_{10}N = a - bM \approx a - M$$

[2]Due to difficulty finding earlier data, we approximated the price of hydropower using a source from 2012 [26]

Taking the approximation that $b \leq 1$, we calculate a lower bound for the frequency of earthquakes of magnitude 8.0 or greater.

State	Avg Freq of Earthquakes Mag 8.0+ (Yrs)	% of Largest
AZ	1,600	61.53%
CA	64	2.50%
NM	2600	100.00%
TX	1,300	50.00%

4.3 Effectiveness of Geothermal Power

Due to the relative obscurity of geothermal energy, we could only obtain price data for California. Since geothermal efficiency requires tectonic activity, we estimate prices for other regions by comparing their seismic activity to California.[3]

Seismic activity is approximated by taking the natural logarithm of earthquake counts from the table in the last section. This is a rough model, but should be reasonable since earthquakes follow a power law distribution.

State	Seismic Coefficient (Natural Log Earthquakes)	% of Largest
AZ	4.11	0.56
CA	7.34	1
NM	3.66	0.5
TX	4.40	0.59

4.4 Effectiveness of Solar Power

Our model adjusts the national average price of solar per MBTU according to the weighted average percentage of sunny days by land area in each of the four states. We computed the average percentage of sunny days across these four states to be 69.9% [29]. Our model uses this to determine the relative effectiveness of solar power generation in each state.

State	Avg % Sunniness	% Greater Than Avg
AZ	85	121.60%
CA	68	97.28%
NM	76	108.73%
TX	61	87.27%

4.5 Effectiveness of Wind Power

Our model takes the average price of wind and adjusts it according to the weighted average wind speed by land area in each of the four states. We computed the average wind speed across these four states to be 15.534 mph [28]. Our model uses this to determine the relative effectiveness of wind power generation in each state .

[3]Due to difficulty finding earlier data, we approximated the price of geothermal energy using a source from 2014 [41].

State	Avg Wind Speed (mph)	% Faster Than Avg
AZ	15.92	102.48%
CA	13.54	87.16%
NM	17.82	114.72%
TX	15.55	100.10%

4.6 Our Recommendations for Each State

We divided the average price by the effectiveness factors given in the above sections to generate the table below. The two most effective types of energy for each state according to our model are represented by bolded entries.

State	Hydroelectric	Nuclear	Geothermal	Solar	Wind
AZ	**30**	45.5	**30**	37.7	**25.0**
CA	**20**	1120	**20**	47.1	29.42
NM	30	**27.9**	30	42.2	**22.4**
TX	**20**	60	30	52.6	**25.6**

Figure 7: Comparative Price Estimates for Clean Energy ($/MBTU)

5 Modeling Averted Emissions Targets and Percent GDP Expenditure

We have defined this model more generally than we could utilize with our data. By finding an analytic solution, this model can account for changing energy prices and consider arbitrary investment strategies.

Our model assumes that all states agree to a certain cap on their allowable yearly carbon emissions: a **"carbon budget"**. We denote this constant by **Cap(state)**, which we define to be the average actual emissions from 2000 to 2002 inclusive. Our cap is a less stringent version of the carbon cap established in the by-laws of the RGGI (see Section 3.3) [32].

State	Maximum permitted CO_2 emissions (lbs.)
AZ	2.005683×10^{11}
CA	9.036874×10^{11}
NM	1.341063×10^{11}
TX	1.693489×10^{12}

Figure 8: Carbon Caps by State

Let $\hat{\boldsymbol{\beta}}$**(year, state)** denote the **simple regression** model described in Section 2.1. $\hat{\beta}$ is the linear model which assumes no policy changes. We denote, for instance, the 2020 prediction for Arizona's total carbonized energy by $\hat{\beta}_{\text{TCE}}(2020, AZ)$.

Let **E(state, year)** be the cost of the **cheapest, clean energy** for a given state and year. For this model, each state has a **constant value of E** as determined by Section 4.

Finally, let the **investment plan** V**(year, state, x)** be a function which estimates the CO_2 in a given state and year, if the quantity $x is invested. For this model, we have the following, where 151.3 is the carbonization constant:

$$V(\text{year, state}, x) = \frac{151.3x \cdot GDP(\text{year, state})}{E(\text{year, state})} + \hat{\beta}_{\text{Averted}}(\text{year, state})$$

In this naive approach V, we **assume that the state is directly paying the cost of energy**, and **energy prices remain constant**. We also assume that GDP and Total Carbonization Energy are **well predicted** by $\hat{\beta}$.

$$\text{TCE} = \text{Actual Emissions} + \text{Averted Emissions}$$

Since TCE increases linearly and actual emissions are fixed at the constant cap, our averted emissions must increase linearly. To continue the linear growth of energy, a state must meet a target for averted emissions.

State	Averted Target 2025	Averted Target 2050
AZ	1.242589×10^{11}	2.349531×10^{11}
CA	3.047290×10^{11}	5.286176×10^{11}
NM	4.744790×10^{10}	9.575592×10^{10}
TX	6.305009×10^{11}	1.274152×10^{12}

Figure 9: Averted Emissions Targets for 2025 and 2050 (lbs. CO_2)

$$\text{Clean Target(year, state)} = \hat{\beta}_{\text{TCE}}(\text{year, state}) - \text{Cap(state)}.$$

We would like to find the cost a state incurs when meeting its projected energy needs under its carbon cap. To do this, we set V equal to the Clean Target.

$$\frac{151.3x \cdot GDP(\text{year, state})}{E(\text{year, state})} = \hat{\beta}_{\text{TCE}}(\text{year, state}) - \text{Cap(state)}.$$

We solve for x, the proportion of GDP the state must spend to meet its energy needs.

$$x = \frac{E(\text{year, state})}{151.3 \cdot GDP(\text{year, state})} \cdot \left(\hat{\beta}_{\text{Actual}}(\text{year, state}) - \text{Cap(state)}\right)$$

5.1 Numerical Results

Completing the above computation, we find the following values:

State	% GDP 2025	% GDP 2050
AZ	5.744%	3.955%
CA	1.089%	0.756%
NM	7.367%	5.125%
TX	6.159%	4.278%

Figure 10: Recommended Percentage of GDP to be spent in 2025 and 2050

Although it is not desirable for a state to increase energy spending by 7% of its GDP, it is within the feasible set. Our model of investment was the simplest possible model: it assumes a situation where the governor simply pays the power bills for his state without any compounding returns. Hence 7% is an upper bound and we are confident that deeper analysis of investment plans would reveal a less costly solution.

State	Green Score 2025	Green Score 2050
AZ	0.383	0.539
CA	0.252	0.369
NM	0.261	0.417
TX	0.271	0.429

Figure 11: Projected Green Scores by State (Policy)

State	Green Score 2025	Green Score 2050
AZ	0.0547	0.0252
CA	0.1059	0.1207
NM	0.0136	0.0195
TX	0.0122	0.0172

Figure 12: Projected Green Scores by State (No Action)

6 Future Work

6.1 Energy Profiles

Continuing our model, we would have liked to include an analysis of environmental factors aside from carbon dioxide emissions. Consideration of other greenhouse gases would contribute to a richer model.

In our energy profiles, we choose our model to primarily consider Green Score. Green Score strictly considers carbon dioxide emissions. As carbon dioxide is the primary contributor to adverse environmental effects, this was the best choice. However, our model could have benefited from considering the renewable nature of different energy sources. For example, a fuel such as ethanol is a renewable source even though it contributes enough carbon emissions to be classified as "dirty." Our model could add a consideration of renewability that would act as a factor in the relative cost of different energy sources in different states.

In addition to considerations about carbon dioxide through the production of energy, our model could also consider the production of carbon dioxide and other greenhouse gases during other stages in the energy production progress. While building reservoirs for example, a large quantity of methane, a gas that is "at least 34 more potent than another greenhouse gas," is released [24]. Because of this, the one-time environmental costs of different energy sources would be well worth considering. Additionally, modelling the one-time building costs of plants, turbines, etc instead of relying on just a simple country average for the price of energy would have allowed for more accurate predictions.

6.2 Energy sectors by state

We attempted to create a collection of functions that consider individual differences among the states and suggest worthwhile investments for maximizing each state's Green Score. In some respects, this model was successful; it suggested the superiority of hydro and geothermal in California, which we then found to be confirmed in the EIA data. It also seems to provide good suggestions for New Mexico and Texas. The coarseness of our model, however, is revealed in its suggestion that Arizona pursue geothermal when we have no reason to believe geothermal a superior choice to wind or hydroelectric. An improvement of this model would consider initial costs of plants of a given energy type, prevalence of energy type infrastructure, differences between regions within each state, and possess tighter normalization among resulting comparative prices such that price data will be a more meaningful indication of a given state's best, clean energy options. Considering the chance of nuclear meltdown by state helped our model to start to explore negative effects apart from CO_2, modeling other factors such as the feasibility and cost of discarding nuclear waste would more accurately account for each state's nuclear aptitude.

7 Memo to the Governors

Governors of Arizona, California, New Mexico, and Texas,

We studied each of your state's energy habits, and developed a Green Score as a simple metric of your environmental progress. You can increase your Green Score by increasing clean energy generation or reducing dirty energy. We list each state's scores:

- Arizona: 6.3%
- California: 8.2%
- New Mexico: 2.0%
- Texas: 2.3%

The goal of an energy compact among your states is to collectively reduce carbon emissions and increase each state's Green Score. To meet this goal, we suggest the adoption of carbon caps for each state, set at each state's average 2000-2002 emissions. To meet rising energy needs, each state in the compact will use a percentage of its gross domestic product to make up the difference between yearly energy needs and the carbon cap. It is worth noting that the percentage of GDP necessary to meet projected energy needs will decrease significantly as time passes. How these costs will be met may be subject to discussion, but what is indisputable is that your adoption of this policy will drastically improve your state's Green Score from what it would be without our policy suggestion. Projected Green scores for 2025 are as below:

- Arizona : 5.47%
- California : 10.59%
- New Mexico : 1.36%
- Texas : 1.22%

We predict that if no policies are passed, Green Scores will stagnate. If adopted, by 2025 our policy will raise Arizona's 2009 Green Score by 607%, California's by 307%, New Mexico's by 1,134%, and Texas' by 1,355%. In 2025 alone, the compact will collectively avert upwards of one hundred sixty-six billion pounds of carbon dioxide emissions.

We strongly encourage that you consider adopting our policy proposals for the sake of your states and for the sake of our planet.

Signed,
Team #93883

8 References

[1] State Energy Data System (SEDS) Complete Dataset through 2009. *Data.gov*, Publisher National Renewable Energy Laboratory, 29 Aug. 2017, catalog.data.gov/dataset/state-energy-data-system-seds-complete-dataset-through-2009#sec-dates.

[2] Gutenberg–Richter Law. *Wikipedia*, Wikimedia Foundation, 23 Jan. 2018, https://en.wikipedia.org/wiki/Gutenberg-Richter_law.

[3] *State Energy Data 2015: Consumption, Section 2. Coal.* U.S. Energy Information Administration, 2015, https://www.eia.gov/state/seds/sep_use/notes/use_coal.pdf.

[4] How Much Carbon Dioxide Is Produced When Different Fuels Are Burned? *U.S. Energy Information Administration*, U.S. Energy Information Administration, www.eia.gov/tools/faqs/faq.php?id=73&t=11.

[5] How Much Carbon Dioxide Is Produced from Burning Gasoline and Diesel Fuel? *U.S. Energy Information Administration*, U.S. Energy Information Administration, 19 May 2017, www.eia.gov/tools/faqs/faq.php?id=307&t=11.

[6] Almost All U.S. Gasoline Is Blended with 10% Ethanol. *U.S. Energy Information Administration*, U.S. Energy Information Administration, 4 May 2016, www.eia.gov/todayinenergy/detail.php?id=26092.

[7] Earthquake Statistics. *U.S. Geological Survey*, USGS Earthquake Hazards Program, earthquake.usgs.gov/earthquakes/browse/stats.php.

[8] Felzer, Karen. *Universality of the Gutenberg-Richter Relationship (with b=1).* Pasadena, United States Geological Survey, 2018, https://pasadena.wr.usgs.gov/office/kfelzer/SCEHAP_GR_Felzer.pdf.

[9] Sustainable Energy. *Wikipedia*, Wikimedia Foundation, 9 Feb. 2018, en.wikipedia.org/wiki/Sustainable_energy.

[10] Jacobson, Mark Z. Review of Solutions to Global Warming, Air Pollution, and Energy Security. *Energy Environmental Science*, vol. 2, ser. 2009, 1 Dec. 2008, pp. 148173. 2009, doi:10.1039/b809990c.

[11] Energy Transition. *Wikipedia*, Wikimedia Foundation, 11 Feb. 2018, en.wikipedia.org/wiki/Energy_transition.

[12] United States Emission Standards. *Wikipedia*, Wikimedia Foundation, 6 Feb. 2018, en.wikipedia.org/wiki/United_States_emission_standards.

[13] Rascoe, Additional Ayesha, et al. UPDATE 2-US EPA Approves California Auto Emissions Standard. *Reuters*, Thomson Reuters, 30 June 2009, www.reuters.com/article/autos-epa-california/update-2-us-epa-approves-california-auto-emissions-standard-idUSN3044688920090630.

[14] Kyoto Protocol. *Wikipedia*, Wikimedia Foundation, 10 Feb. 2018, en.wikipedia.org/wiki/Kyoto_Protocol.

[15] Montreal Protocol. *Wikipedia*, Wikimedia Foundation, 8 Feb. 2018, en.wikipedia.org/wiki/Montreal_Protocol.

[16] Western Interstate Energy Compact. *Ballotpedia*, Lucy Burns Institute, ballotpedia.org/Western_Interstate_Energy_Compact.

[17] Western Interstate Energy Compact. *National Center for Interstate Compacts*, apps.csg.org/ncic/Compact.aspx?id=210.

[18] Jenden, James, and Jason Donev. End Use Energy. *Energy Education*, University of Calgary, energyeducation.ca/encyclopedia/End_use_energy.

[19] Donev, Jason. Primary vs End Use Accounting. *Energy Education*, University of Calgary, energyeducation.ca/encyclopedia/Primary_vs_end_use_accounting.

[20] *Carbon Emissions From Burning Biomass For Energy.* Partnership For Policy Integrity, http://www.pfpi.net/wp-content/uploads/2011/04/PFPI-biomass-carbon-accounting-overview_April.pdf.

[21] State Energy Data 2015: Consumption, Section 5. Renewable Energy Sources. U.S. Energy Information Administration, 2015, https://www.eia.gov/state/seds/sep_prices/notes/pr_renew.pdf.

[22] *Lazard's Levelized Cost Of Energy Analysis.* 4th ed., Lazard, 2010, http://www.puc.pa.gov/pcdocs/1173215.pdf.

[23] Matthew, Mason. Renewable Energy: All You Need to Know. *EnvironmentalScience.org*, www.environmentalscience.org/renewable-energy.

[24] Weiser, Matt. The Hydropower Paradox: Is This Energy as Clean as It Seems? *The Guardian*, Guardian News and Media, 6 Nov. 2016, www.theguardian.com/sustainable-business/2016/nov/06/hydropower-hydroelectricity-methane-clean-climate-change-study.

[25] United Nations Framework Convention on Climate Change. The Paris Agreement. *United Nations Climate Change*, United Nations, unfccc.int/paris_agreement/items/9485.php.

[26] Facts About Hydropower. *Wisconsin Valley Improvement Company*, Wisconsin Valley Improvement Company , www.wvic.com/Content/Facts_About_Hydropower.cfm.

[27] Average Annual Precipitation by State. *Current Results*, Current Results Publishing Ltd., www.currentresults.com/Weather/US/average-annual-state-precipitation.php.

[28] U.S. Average Wind Speed State Rank. *USA.com*, World Media Group, LLC., www.usa.com/rank/us–average-wind-speed–state-rank.htm.

[29] Average Annual Sunshine by State. *Current Results*, Current Results Publishing Ltd., www.currentresults.com/Weather/US/average-annual-state-sunshine.php.

[30] *Technical Support Document: Social Cost Of Carbon For Regulatory Impact Analysis.* United States Government, 2017, https://19january2017snapshot.epa.gov/sites/production/files/2016-12/documents/scc_tsd_2010.pdf.

[31] Earthquakes and Nuclear Power Plants. *Science on a Sphere*, National Oceanic and Atmospheric Administration, sos.noaa.gov/datasets/earthquakes-and-nuclear-power-plants/.

[32] "Linking to Obtain the Potential Benefits of Broader Carbon Markets: Requirements of the Regional Greenhouse Gas Initiative (RGGI)" *Western Interstate Energy Board*, westernenergyboard.org/wieb-board/documents/.

[33] U.S. Energy Facts. *Energy Information Administration*, U.S. Department of Energy, 19 May 2017, www.eia.gov/energyexplained/?page=us_energy_home.

[34] Arizona - Profile Analysis. *U.S. Energy Information Administration*, 27 Dec. 2017, www.eia.gov/state/analysis.php?sid=AZ.

[35] California - Profile Analysis. *U.S. Energy Information Administration*, 19 Oct. 2017, www.eia.gov/state/analysis.php?sid=CA.

[36] New Mexico - Profile Analysis. *U.S. Energy Information Administration*, 18 Jan. 2018, www.eia.gov/state/analysis.php?sid=NM.

[37] Texas - Profile Analysis. *U.S. Energy Information Administration*, 18 Jan. 2018, www.eia.gov/state/analysis.php?sid=TX.

[38] Overview of Greenhouse Gases. *EPA*, Environmental Protection Agency, 14 Apr. 2017, www.epa.gov/ghgemissions/overview-greenhouse-gases.

[39] https://energylaw.uslegal.com/government-regulation-and-programs/ecpa/

[40] Use and Capacity of Global Hydropower Increases. *Use and Capacity of Global Hydropower Increases*, Worldwatch Institute, www.worldwatch.org/node/9527.

[41] "Geothermal FAQs." *Department of Energy*, Office of Energy Efficiency & Renewable Energy, energy.gov/eere/geothermal/geothermal-faqs.

9 Appendix

Linear Regression Predictions for Energy Profiles

State	Year	Petroleum	Coal	Wood and Waste	Natural Gas
AZ	2025	1.118865e+11	1.487142e+11	4.069057e+09	3.434220e+10
AZ	2050	1.473921e+11	2.084263e+11	5.143659e+09	4.152938e+10
CA	2025	7.102312e+11	1.756089e+10	4.332063e+10	3.090941e+11
CA	2050	8.468541e+11	1.998338e+10	5.114599e+10	3.516528e+11
NM	2025	5.046758e+10	1.022354e+11	1.446305e+09	2.506404e+10
NM	2050	6.221815e+10	1.390613e+11	1.566363e+09	2.359954e+10
TX	2025	1.215154e+12	5.588917e+11	2.514903e+10	4.980405e+11
TX	2050	1.581041e+12	7.891450e+11	3.117688e+10	5.273733e+11

Nuclear	Ethanol	Geothermal	Hydroelectric	Solar
6.831046e+09	1.714590e+09	6.658982e+07	1.631731e+10	8.806452e+08
9.925578e+09	2.566790e+09	9.728174e+07	1.915144e+10	1.281296e+09
8.447948e+09	1.007421e+10	3.412525e+10	5.991907e+10	5.955784e+09
1.199542e+10	1.501303e+10	4.797731e+10	6.479663e+10	8.681728e+09
0.000000e+00	4.167224e+08	1.088783e+08	5.423099e+08	9.708272e+07
0.000000e+00	6.053083e+08	1.607510e+08	7.447379e+08	1.396395e+08
8.527564e+09	4.731526e+09	2.147345e+08	2.454146e+09	1.374208e+08
7.060700e+09	3.182987e+08	2.762820e+09	2.011838e+08	1.605455e+10

Wind	Green Score	Averted Emissions	Actual Emissions	TCE
5.028922e+06	0.054735	2.410062e+10	3.007266e+11	3.248272e+11
7.594698e+06	0.025178	3.046319e+10	4.050582e+11	4.355213e+11
9.687312e+09	0.105868	1.181354e+11	1.090281e+12	1.208416e+12
1.420451e+10	0.120662	1.476557e+11	1.284649e+12	1.432305e+12
1.175715e+09	0.013571	1.923986e+09	1.796302e+11	1.815542e+11
1.766131e+09	0.019533	2.811259e+09	2.270509e+11	2.298622e+11
1.068979e+10	0.012184	2.202366e+10	2.301966e+12	2.323990e+12
1.640850e+10	0.017187	3.184410e+10	2.935797e+12	2.967641e+12