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2018
MCM/ICM
Summary Sheet

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Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

It has long been debated if the benefits of renewable energy outweigh the costs. We focus on one particular problem in balancing the switch to renewable energy in a way that is financially feasible but also produces enough to compensate for the loss in production of fossil fuels. We have developed two models to inform politicians on how to move forward on energy production.

In the predictive model, we fitted a polynomial or logarithmic function with the data set for each combination of state and resource. We then used these models to project where each state would trend toward in production for each resource. For some models, a polynomial model fit the data better but would project illogical values in the future, so we decided to use logarithmic models in their place.

In the ideal model, we choose a given percentage to reduce total fossil fuel production by per year and it calculates how much it will cost taxpayers to make up for the lost production from transferring to a more expensive energy source. Our model simplifies the transition from nonrenewable to renewable production, but it is effective in helping to determine how aggressive to make energy policies based on what politicians believe is a reasonable amount to tax.

Our models disregard carrying capacities of production plants. We attempt to mitigate this by using predominately logarithmic models that fit the data. Since the logarithmic models do not have the steep increases or decreases of the polynomial models, we believe they provide realistic values when paired with the energy production data.

Given previous data, our models can work with any state and help determine a policy that lines up with their intentions for the energy industry. Our models do not address overlying costs such as infrastructure of renewable energy production, nor do they model job loss.

Joining the ThinkTANCc
Using Energy Models to Inform Interstate Policies

MCM Team #88462

February 13, 2018

Contents

1 Analysis

1.1 Intro

As fossil fuels have become more scarce and fluctuated in price and increased awareness of environmental impact of non renewable energy sources, industries have sought cheaper, cleaner, and more efficient sources of energy. The impact of using fossil fuels on the environment has also proven to be a dividing topic across the nation. With these motivating factors, several different options of renewable energy have been developed over the past sixty years. Renewable energy is better for the environment and has the potential to provide cheap, reliable alternative sources of energy.

We will take a look at how Arizona, California, New Mexico, and Texas have produced energy over the past 50 years. Using this data, we will project where each state will be in the future and compare this with how they could move toward renewable energy over the course of the next few decades. These models are at the heart of the Think TANCc = (T)exas (A)rizona (N)ew Mexico (C)alifornia (c)ompact, an initiative to move toward producing more renewable energy instead of fossil fuels. We use these models to show realistic goals for each state to strive for in the coming decades.

1.2 Energy Profiles

A snapshot of how each state is currently balancing their energy production is displayed in the Energy Profiles table below. Arizona has focused its efforts on nuclear as the core of its renewable energy production. California is strong across the board; they generate all renewable energies on some level but they stand out in solar, as they are the only state out of the four to produce significant amounts of solar energy. New Mexico is very dependent on fossil fuels, producing more than California. Relative to their size, their strength in renewable energy lies in ethanol production. Texas also produces large amounts of fossil fuels. However, they have their hand in many renewable energy sources like California. They are notably the leader in wind energy production by a large margin. The allocation of each states' energy production depends on various factors ranging from geography to politics. We list some of those factors below the Energy Profiles table.

Energy Profiles - 2009				
	Arizona	California	New Mexico	Texas
Coal	160705.9	0.0	466100.4	455507.1
Gas	727	309834.9	1557687	8074816
Ethanol	1308.4	1177.5	654.2	3984.5
Crude Oil	266.8	1328165	354646.8	2646911
Nuclear	320723	332249.4	0	434065.1
Hydro	62730.9	272187.2	2644.6	10039.7
Solar	138.1	125443.2	0	0
Wind	288.4	56996.6	15096	195454.8
Renewable	88571.4	635062.4	33785.2	303697.1
Total	570994	2605312	2412219	11914997

All values given in Billions of BTUs, except for Ethanol, given in thousands of barrels.

Influential factors of similarities and differences between states:

Texas and California have significantly larger amounts of land so they will have higher potentials for producing solar and wind energy by virtue of having more land available for solar plants and wind turbines. Arizona and New Mexico are ranked top 3 in average hours of direct sunlight per year so in that sense they may be the best options for solar energy. California and then Texas follow closely behind and with the amount of uninhabited land they have to offer, they are both great options for solar energy as well. [5]

All four states have extremely high potential for producing wind energy, but Texas and California currently produce the largest amounts. [15]
Hydro energy is a clean and naturally occurring source of power - but it's strength comes and goes with the amount rainfall in the area. All four states fall in the bottom third of rainfall per year[2], so their capabilities in hydro energy will be limited. [7]

Arizona, California, and Texas are all already invested in producing nuclear energy with Arizona leading the charge - over 50% of their energy produced comes from nuclear plants. [6]

1.3 Modeling Energy

1.3.1 Predictive Model

After looking at the energy profile for 2009 let us look at how these profiles have changed from 1960 to 2009. We have written a model to fit polynomials or logarithmic functions to the change in resource production over time. The following paragraphs will discuss the increase or decrease of renewable resources within these four states: these resources being wind, hydroelectric, nuclear, ethanol and geothermal energy production.

The state of Arizona is currently on a trend that shows a decrease in coal and natural gas production, and has not produced crude oil in years. Based on the data that we have, we have found that with Arizona's current policy, their nuclear power production has been increasing while the price has been remaining relatively constant. Just like their nuclear energy production, Arizona has been increasing their hydroelectric energy production and wind energy production, but not quite at the same rate. Furthermore it can be said that their total renewable energy production is increasing. They recently began producing ethanol gas, though with the data we have on their ethanol production, we cannot say much about its production over time.

California is currently a rather green state, as they do not produce any energy from coal, but are on an upward trend of production for natural gas. As for their renewable resources, California has been increasing production of nuclear, hydroelectric, and solar energies. They are also the only state that produces a substantial amount of geothermal energy. This makes sense as geothermal energy is produced mostly around volcanically active areas, and California lies close to the "ring of fire". Their solar production is also logical, as California has around 280 days of sun each year. [5]

New Mexico has been on a slightly decreasing trend for their coal production, and have had an increasing trend for all other resource productions. The only renewable energy sources that New Mexico produce are ethanol fuel and wind. Of these two, the production in wind energy is growing much faster than that of ethanol. For both energy sources, New Mexico is new to production, so these trend lines and equations are difficult to fit well as there is not enough data regarding New Mexico's production.

Texas is one of the largest producers of natural gas in the country, which leads to their focus on nonrenewable energies. Looking at their trends since 1960, it is noticeable that their wind energy is increasing recently, as is their production of hydroelectric energy as well as total renewable energy production. As of 2009, Texas produced three times as much wind energy than any other state in the TANCc, due to how much open land they have as well as how flat Texas is. In recent years Texas has begun producing ethanol; however, we cannot fit a model to the ethanol production as it is quite uncommon and inconsistent for the state. Texas has also been producing plenty of nuclear energy, though has not seen a large increase since 1995, which is only seven years after they began production.

After looking at each of the states' energy profiles and their changes since 1960, it seems that Arizona is the state in the TANCc with the best profile for cleaner renewable energy. This is due to Arizona's high proportion of renewable energy production to total energy production, at around 65% of their energy. Arizona does not define nuclear energy as a renewable resource, which causes some discrepancies between our renewable energy percentages and the percentages that Arizona reports. If we do not define nuclear energy as a renewable resource then Arizona only produces 15% of their energy renewably, meaning that California is also doing quite well in regards to percentage of renewable energy at just around 25%.

1.3.2 Ideal Model

While the predictive model predicts what will happen following current policies and energy trends, the ideal model predicts what will happen if we follow the policies that we feel best fits the current trends for each state in order to decrease non-renewable energy production. The ideal model works by decreasing the total non-renewable energy production by a fixed percentage of the total nonrenewable production every year and transferring the production to a specified renewable source. The proportion of total non-renewable energy can then be found with $(1 - \textbf{percentage})^{\textbf{years}}$. Since we need to model out to 2050, this formula finds what percentage we need to use to get a certain percent reduction. For example, if we want to reduce our total non-renewable energy production by 80% by the year 2050, we simply need to take the 40^{th} root of 0.2; in this case, we would need to decrease by 3.95% each year.

We compute the difference in the energy production of the non-renewable sources and the renewable source when using the same funding. With this measured difference in energy we can calculate the financial difference between the two types of energy production when producing the same amount of energy. By doing this, we can plan for energy goals in the future and show a real example of how we might make it work. Not only can we show the shift in power production from non-renewable sources to a renewable source, but we can also see the cost to each taxpayer by dividing this extra cost of production by the number of eligible citizens in each state that can pay taxes. We estimate the number of tax paying citizens by using the most recent population data point for each state provided in the data, and multiplying by the proportion of citizens over 18, according to the US census data collected in 2010.

As far as transitioning from the non-renewables, we chose to reduce coal first, since coal is currently the maximum source of carbon emissions from fossil fuels, followed by oil, and lastly natural gas [1]. This maximizes the environmental impact of our policy, since we start by removing the most polluting source first, until we completely replace it. If we have a year where transitioning the production of non-renewable energy to renewables would move more than production than the non-renewable is producing, we take the difference in current production and the amount we are transitioning into renewables and take this amount away from the next non-renewable source. This guarantees that we will hit whichever goal we set for our model, since the model takes away the same percentage from the total at every single year.

1.4 Projecting Forward

With our predictive model, we can look at what we believe the production of renewable resources will be in the distant future ignoring any possible policy or goal changes. These predictions will allow us to create realistic renewable energy goals for 2025 and 2050.

For the state of Arizona, we see trends of decreasing coal production, significant increases in nuclear production, and small increases in hydroelectric production and total renewable energy (in the absence of policy changes). Below, a chart can be found that shows the predicted energy usage in 2009, 2025, and 2050 for each form of production. This makes sense as a model, as currently Arizona produces around 60% of its energy through nuclear means, leading to a logical assumption that their nuclear energy is a priority with current policy.

Looking at the energy profile of California over time, we notice a very similar trend to Arizona, but to less of an extreme. Their overall renewable

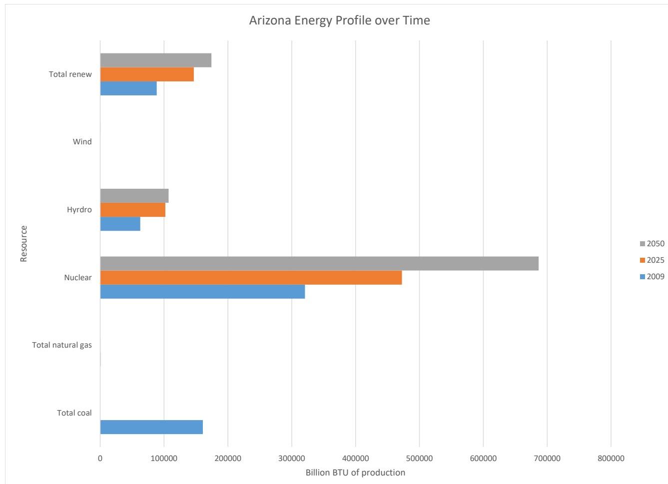

Figure 1: Arizona Energy Profile over Time

energy production is increasing, as well as the production of each of the individual renewable energy resources increases with each year. As of 2009, California was not producing any coal, so our projection of their future energy profile does not have coal present. They are also slowly decreasing their production of natural gas over time. All of this data is represented in the California Energy Profile over Time chart below, giving predictions for the years 2025 and 2050.

As of 2009, New Mexico had what seemed to be the worst green energy profile of the four states in the TANCc, and if we do not have any policy change this observation does not change. Over time it seems that natural gas production in New Mexico is increasing, and coal production is decreasing. Of renewable energy sources, New Mexico produces mostly wind energy, and we do see a slight increase in wind production with this predictive model over 40 years. Again, below is a chart that shows the predicted production change for resources in New Mexico in the years 2009, 2025, and 2050.

Now to look at the predictions of our model for the state of Texas. Texas is a very large producer of natural gas, and our model shows a sharply increasing trend towards 2009. This trend predicted very large increases in the natural gas production in Texas, as well as increases in wind production and overall

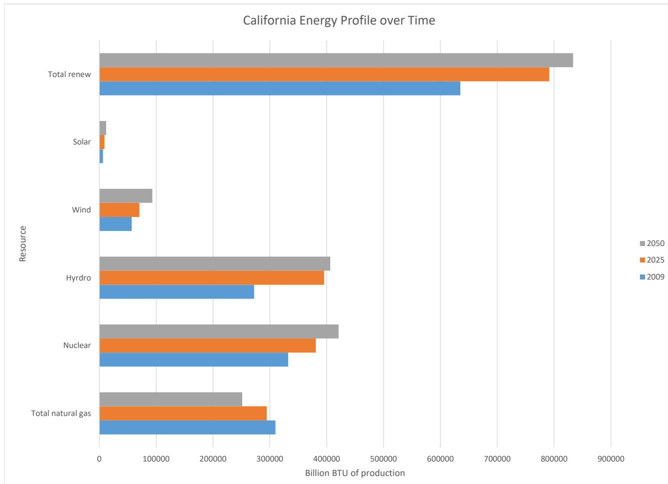

Figure 2: California Energy Profile over Time

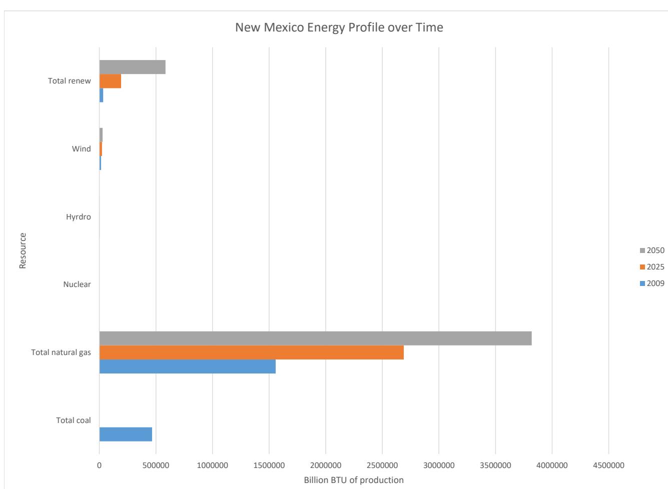

Figure 3: New Mexico Energy Profile over Time

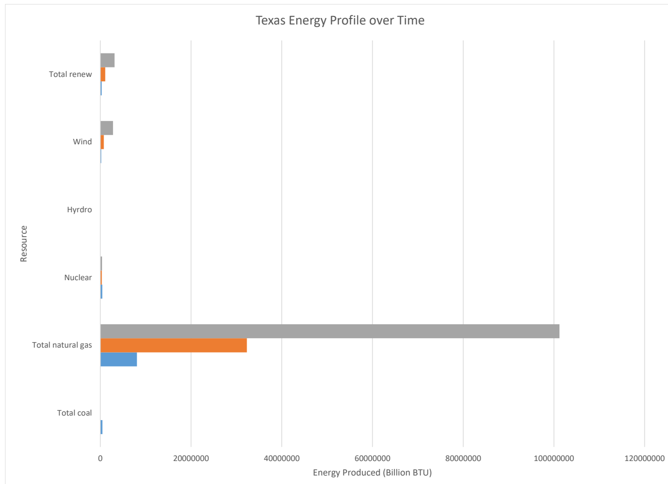

Figure 4: Texas Energy Profile over Time

renewable energy production. Our model also predicts a downward trend in the production of coal energy. Above, we have the predicted energy profile for Texas for the years 2009, 2025, and 2050. This profile seems to over predict natural gas production, a fact that will be discussed in the strengths and weaknesses section.

2 Policy Decisions

2.1 Goals for the TANCc

Given that our criterion for best energy profile for each state is defined to be the state with the highest proportion of renewable energy produced relative to total energy produced, is Arizona by our assumptions that nuclear counts as a renewable energy source, whereas it falls on California if it is not.

- Arizona as the most lax renewable target of the states in the TANCc, with a goal of 15% renewable sources, not including nuclear, by 2025 as specified by their Renewable Energy Standard [4]. Since Arizona themselves do not count nuclear energy production as a renewable energy source, they do not currently meet this target. However, by our definitions, they are well above this target.

- California has shown interest that they wish to shift to 50% renewable energy sources by 2025, and 100% by 2045. California currently has the goals of 33% by 2020 and 50% by 2040, which are certainly attainable with our model ([3], [9]).
- New Mexico currently has the goal of 20% renewable by 2020, and have proposed bills with renewables as high as 80% by 2040 ([10],[12]).
- TX recently voted to discontinue their RPS program as they had already surpassed their 2025 goal in 2009. Since they have shown a commitment to renewable (as evident by also voting to close the CREZ program that added 18,500 megawatts of wind power to the state as it had been completed early), we propose Texas continue their aggresive renewable pursuit by setting goals inline with those by California and New Mexico ([14],[8]).

While well above some states' existing policies, we propose setting a long term goal of a 70% reduction of non-renewable energy production by 2050. This gives us a 37% reduction by 2025, which is enough to ensure that the states are progressing well towards the 2050 goal. The 2050 target is currently less than the goal for New Mexico and less than a proposed goal for California, so we hope these targets will be acceptable to the two states. As for Texas and Arizona, by following our model, we hope that they can begin to follow the example set by California and New Mexico.

To ensure the reader can understand the scope of the policy changes our model implements, we feel it is necessary to state that 1000 trillion is equal to one quadrillion.

2.2 Actions for meeting goals

For each state, we recommend specializing in one type of renewable energy by transferring funding away from non-renewable sources. Each state's specialization was chosen by which renewable had the strongest presence or trend in the state.

2.2.1 Arizona

For Arizona, we propose increasing nuclear production in order to replace coal usage, as Arizona already has a strong nuclear presence, with 56% of their current total energy production coming from nuclear. Since our model reduces the amount of total non-renewable production by a fixed percentage, Arizona only reduces their coal consumption by just over 73%. While this may seem insignificant, because coal is the most polluting source of non-renewable energy, this transition drastically reduces the carbon output from energy production in the state. The cost of this transfer to each tax paying Arizonan is only 1.5 cents per year, meaning a citizen could pay 75 cents and have contributed the entirety of their part to their states transition to renewables.

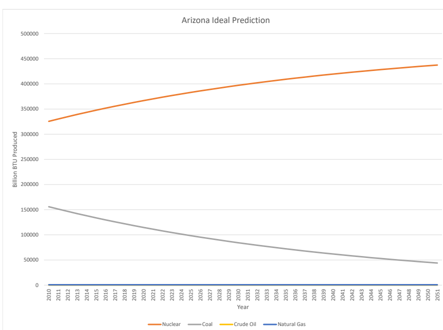

Figure 5: Arizona Ideal energy policy

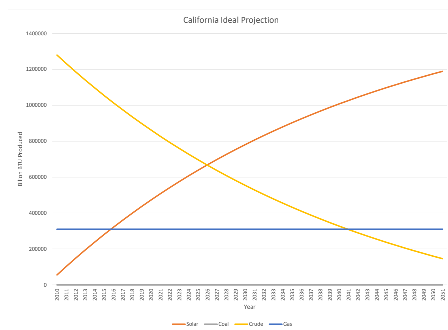

Figure 6: California Ideal energy policy

2.2.2 California

For California, we propose switching to solar, as California already produces a disproportionate share of the total solar within the TANCc. Since California is coal-free in 2009, we propose phasing out California's crude oil usage, reducing it by just under 90%, from 1.32 quadrillion btu down to 145.9 trillion btu by 2050. Since California was producing so much energy from crude, the amount of energy California produces from natural gas is unchanged. In order to pay for the 188 times increase in solar output, each tax paying Californian only needs to pay an extra 4 cents each year.

2.2.3 New Mexico

For New Mexico, we propose increasing wind power production while phasing out first coal before switching to decreasing the natural gas consumption. This is in line with a report conducted by the Union of Concerned Scientists, who modeled New Mexico's energy production and suggested a switch to wind and solar [11]. With a 3 percent decrease in total non-renewable energy production each year, New Mexico can completely eliminate production dependent on both coal and crude oil, and reduce energy production from natural gas by 46% from approximately 1560 trillion btus to approximately 705 trillion btus. To make up the difference in energy production from shifting funding from the cheap but dirty non-renewables to wind, wind production has increased by more than two orders of magnitude, from 15.1 trillion btu to just over 1.73 quadrillion btu. This shift from non-renewable to wind power comes at a cost of 28.38 dollars per year to the individual taxpayer.

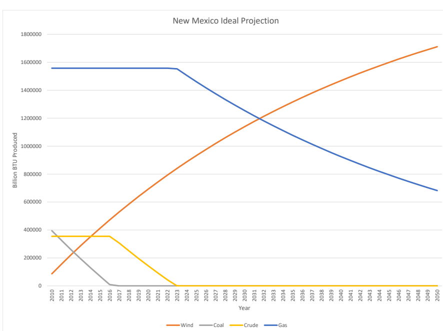

Figure 7: New Mexico Ideal energy policy

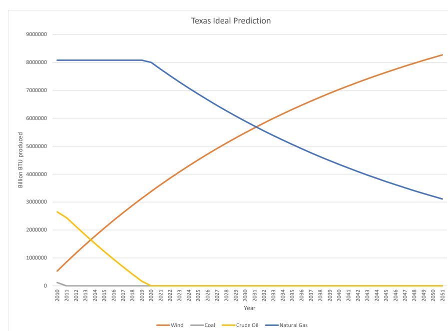

Figure 8: Texas Ideal energy policy

2.2.4 Texas

We propose Texas also increase their wind power to replace their coal production, oil based production, and more than halve their reliance on natural gas for energy. Following the model, Texas would be coal free by the end of the first year, and crude oil free by the tenth year. By shifting these funds from non-renewables to wind, Texas increases their wind production by more than 40 times what they previously produced, from over 195 trillion btu to more than 8.25 quadrillion btu. To make up for the increased costs, each tax paying Texan only needs to pay $1.60 extra each year in taxes.

3 Strengths and Weaknesses

3.1 Predictive Model

3.1.1 Strengths

The predictive model we used is quite simple to use, as it takes in one variable, time, and outputs predictions for 32 production variables, 8 for each of the 4 states. This gives the user an easily understandable interface to use if they are looking to find predicted production values with time without policy change. The design is quite simple, each variable being predicted with a basic polynomial or logarithmic growth function. Each equation has an R-squared value of at least 0.6, and most have an R-squared value of above 0.85. This means that each of our equations explains at a minimum 60% of the variability about the predicted values. All of this indicates that the predictive model traces the data we have quite well, but does not tell us much about how accurate the model is when expanded out to the future.

3.1.2 Weaknesses

A downside to our model is that it does not account for carrying capacity or the fact that a state cannot produce negative amounts of energy. For our models' future prediction of coal production, it had Arizona, California, and Texas all producing negative coal sourced energy, but for our charts, the outputs of these predictions we clipped to 0 so as to report possible numbers. After looking into the data it seems that this negative trend came from all three of these states having fast downturns in coal production close to the year 2009. The models that we built were very sensitive to drastic changes close to 2009, so these quick changes in a decreasing direction skewed the future predictive values very far in the negative direction.

3.2 Ideal Model

3.2.1 Strengths

There are multiple benefits to the ideal model we used. First, it is a straightforward model, requiring little outside knowledge of the problem. Since it mostly works off human intuition of transferring percentages of non-renewables to renewables every year, many people can understand why the model works, if not follow the process. Since it is accessible to a wide range of people, it can be discussed in terms of social impact, both positive and negative, by a much more diverse social makeup than otherwise. While this may not immediately seem important, public engagement and agreement on governmental policy leads to a more transparent government and public satisfaction with energy policies.

Second, since the model is designed to be easily changeable and straightforward, we can run the model many times without needing to decipher what the output means. This gives us a way to visualize and experiment with how different percentages of transitioning each year impact both the total production of non-renewables over time, as well as the costs to the taxpayers. Furthermore, since we can work backwards as discussed previously, we can use it to set explicit goals by certain years. This allows the model to work towards any goals that we set that we believe the TANCc should be working towards.

We can also model the costs to the taxpayers of the respective states. This is useful since it allows us to discuss the feasibility of implementing these changes, as well as giving us a figure we can explain to each of the governors to inform them on the economic impacts of implementing our policy changes - something most governors would argue is one of the most important factors in terms of feasibility.

3.2.2 Weaknesses

Since the ideal model works both with production and cost, the model suffers from many inaccuracies. First off, there is no pricing data for each of the individual renewable sources. In order to solve this problem, we took the sum of the output of our renewables, and divided by the total cost of all renewables. While this gave us a value for each renewable, they all share the same price, meaning we could use any renewable energy to replace our non-renewables without any price difference. There is also no data on creating the infrastructure for each of the renewable energy sources, meaning we cannot accurately model the total cost to each citizen. Furthermore, the upkeep is not specifically mentioned anywhere for any source, meaning we cannot factor in the cost associated with maintaining the energy production facility, in whatever form it may be, after we have built it. Lastly, there is no data on the jobs within each sector, so we cannot predict the impact of our policy on the workers within each of the production sources. This is a significant metric to not be included, since the people whose jobs are either lost or created from the transition are going to be impacted most directly in the short term.

A large part of shifting to renewables besides the obvious environmental savings is the social cost of carbon. This is a metric that attempts to model the cost to social health, productivity, agricultural impacts, and many other negative impacts that increased atmospheric carbon has on our society [13]. While our original ideal model attempted to factor this in, it became difficult to quantify the tons of carbon each type of non-renewable source produced per billion btus, especially since each non-renewable source can have minute differences in the exact chemical makeup that lead to differing carbon output. Furthermore, there are several methods of producing energy from the same source that result in different amounts of carbon released to the atmosphere. While it would aid in modeling the social benefits of our models and policies, we decided to avoid including the social cost of carbon in our model due to time and complexity constraints.

The model also assumes that the population of each state stays the same, meaning that the taxes can be modeled with a constant, as we have. However, without this assumption being true, like in the real world, populations can be very dynamic, meaning the taxes could change for each of the states over time. Another large issue is that we have no numbers for jobs in each energy source. Without knowing the number of jobs that would be created or lost from our policy changes, we cannot satisfactorily describe the impact of our policies to the governors of each state (by our standards).

Lastly, since we separated our predictive and ideal models, we assume production stays the same for each energy source over time. We know this not to be the case, since we created models predicting how the energy production would change over time, and our models do not predict a constant production value for the non-renewable energy sources. While this is something we feel would've strengthened our ideal model's accuracy, due to the polynomial fits in our predictive models, there are instances where our predictive model increases at unrealistic rates where applying our ideal model would not be able to accurately predict impacts of policy changes on energy production moving forward.

4 Gubernatorial Memorandum

Dear Governors of the TANCc,

We have organized an energy profile for each of your states to give you a sense of where your state currently stands. In addition, we have created several models to compare the possible trajectories your respective states could take in the future with energy production. We hope to show that switching to renewable energy is quite affordable and will reap huge dividends in the long run.

Currently, all four states in the TANCc show great efforts in producing renewable energy. With the advances made in the past 50 years, we believe that each of your states have the potential to produce significantly more. To show the magnitude of this potential, we first look at where your state will be if you continue your energy production trends.

Based on data from 1960 to 2009 we created a predictive model based on current trends and policy. With this model, we found that within the TANCc, coal production is on a downward trend, and most renewable resources are on an upward trend. Though this is the predictive state of resources, it is not an ideal situation. In multiple states, we also see an increase in natural gas production, a non renewable resource. The predicted future of renewable energy within TANCc states is not quite where we believe it should be in the coming years, so we have also outlined an ideal model to switch over to renewable resources, and have looked at the financial implications of switching resource production over to this model.

Based on the most recent data available to us, the ideal model estimates the increase in renewable production, the decrease in each of the non-renewable sources being used, and the cost to the individual taxpayer of each of your states. We prioritized reducing the non-renewable sources that have the highest carbon output, since this gives the most impactful policy both environmentally and socially. For each of your states, we suggest specializing in a renewable energy source that you already have shown a strong commitment to or presence in. Using our model, we propose setting a goal of reducing non-renewable production by 37% by 2025, and by 70% by 2050.

This is in line with some of your states current policies, and strengthens the other states' commitments to renewables.

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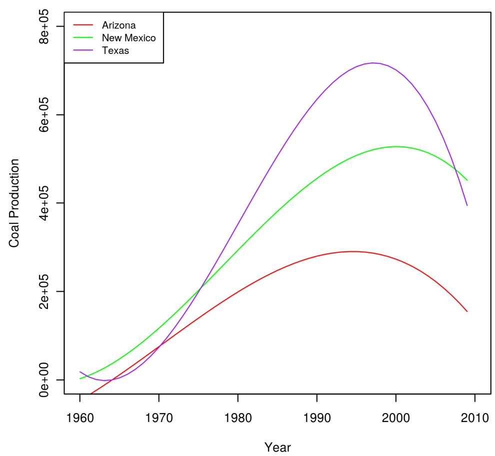
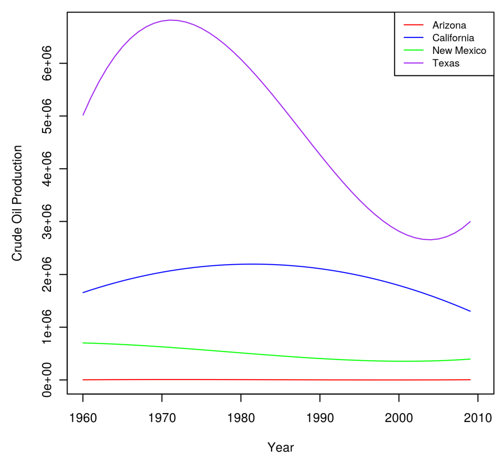
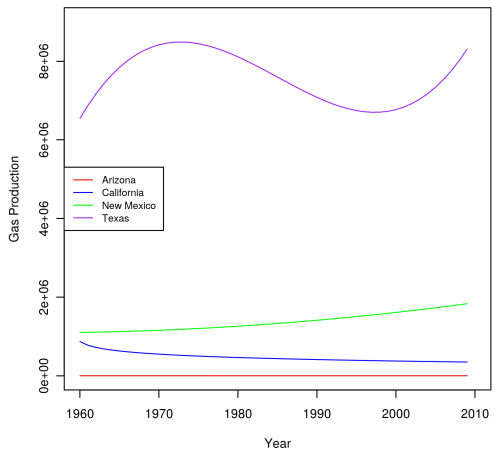
6 Appendix



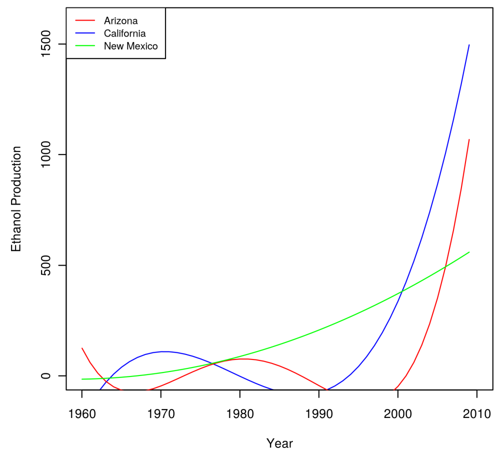
Coal Production



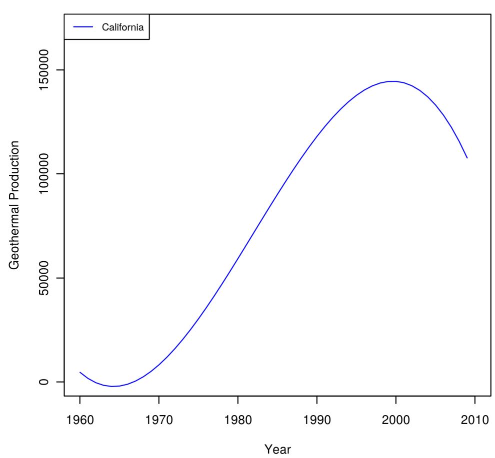
Crude Oil Production



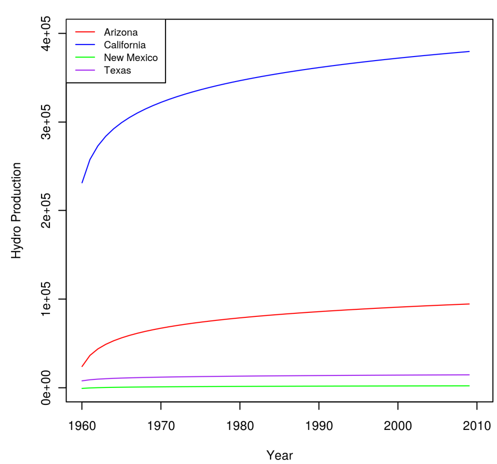
Natural Gas Production



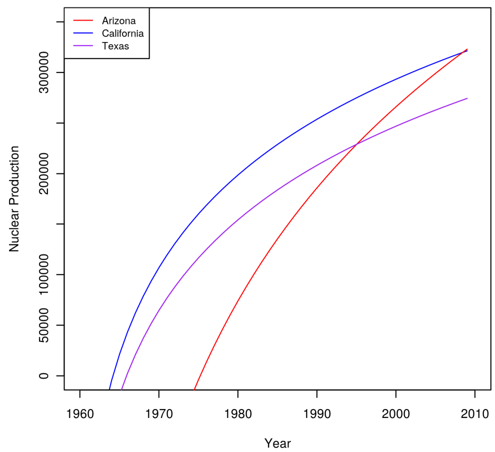
Ethanol Production



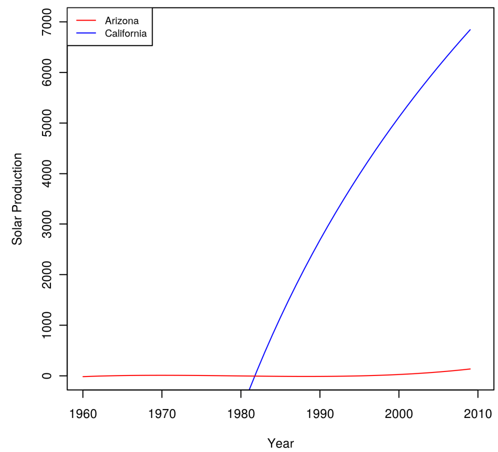
Geothermal Production



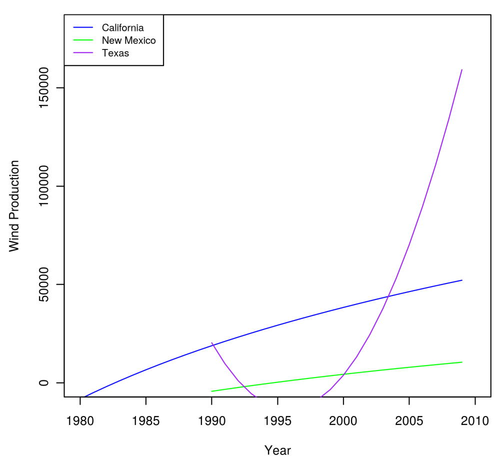
Hydroelectric Production



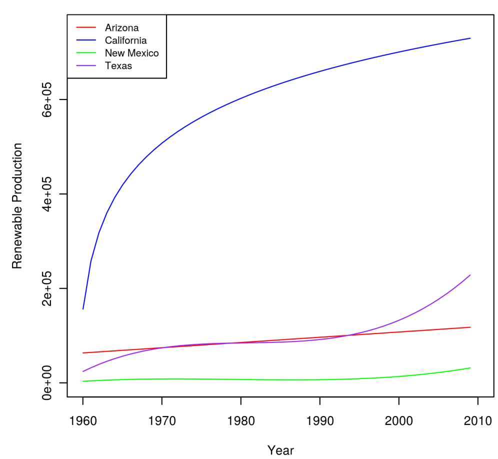
Nuclear Production



Solar Production



Wind Production



Total Renewable Production