Mamba Worldwide Consulting

Actuarial Valuation of Carbon Credits

Society of Actuaries 2020 Student Research Case Study Challenge

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Executive Summary

Greenhouse gas emissions have been a rising concern throughout the world, particularly for the country of Pullanta. In order to address this concern and keep the nearly 20 million Pullantian people safe and healthy, implementing a regulatory carbon emission reduction plan is vital. Mamba Worldwide Consulting (MWC) will reduce carbon emissions to a level of 675,314,112 tonnes, with 90% certainty, by 2030 through the use of a carbon credit program. This program will individually address the data from each sector provided by Pullanta's government. Each sector is required to decrease a certain percentage of emissions from the 2018 amount by 2030, ranging from a 10% decrease all the way to a 35% decrease. This percentage is broken down evenly per year until 2030.

MWC will implement a cap and trade program in which companies purchase carbon credits in exchange for releasing carbon emissions. Our plan will gradually integrate carbon credits into the economy by increasing the portion of carbon credits companies must purchase each year; from 4% of their previous year's emissions in 2020, up to 40% of their 2029 emissions in 2030.

Carbon credits are purchased through a quarterly auction or through a limited number of financial instruments. An annually increasing floor and ceiling have been placed on carbon credits to stabilize the market, starting at Ᵽ27.25 and Ᵽ58.33, respectively. Companies are able to trade carbon credits amongst themselves in a secondary market, with strict rules and regulations to best account for potential risk. All profits from the carbon credit program, after expenses, will be used in various consumer benefit programs.

Introduction

With the alarming concern of climate change and rising carbon emissions, Pullanta's Department of Environmental Concerns approached our company, MWC, to create and implement a plan to not only reduce carbon emissions but also to generate revenue for additional climate change mitigation efforts. Specifically, our goal is to reduce Pullanta's total carbon emissions to 25% below the 2018 level by 2030.

A carbon credit program is essentially a way to give a monetary value to the emission of carbon, therefore assisting in the government's ability to control emissions through the financial market. We will specifically be using what is known as a cap and trade program. There will be a cap on the amount of greenhouse gas emissions allowed to be emitted, gradually getting stricter over time. The trading aspect of the plan involves a market for companies to buy and sell carbon credits as needed, giving an incentive to decrease emissions (How Cap and Trade Works, 2020).

Within the last decade, many developed countries have created various types of carbon credit programs with the shared goal of reducing greenhouse gas emissions. One of the most established is the California Cap and Trade Program, the fourth largest program worldwide. Due to their program, California is expecting greenhouse gas emissions to drop an impressive 16% from their levels in 2013 by the end of 2020 (California Cap and Trade, 2018). Since increasing greenhouse gas emissions is a global problem, many nations have joined in an effort to combat this issue. The Paris Agreement, formed to improve and replace the Kyoto Protocol, contains 187 parties that have agreed to create and implement their own nationally determined plans to reduce emissions (What is the Paris Agreement?, 2019). MWC will follow in their footsteps to create a plan with similar successful results for Pullanta.

Preliminary Investigation

Preliminary Charts

Before creating a carbon credit program it was vital to understand the data we were given. Based on the graph below it is clear that the Energy, Manufacturing, and Construction sector has consistently been the largest contributor to emissions, meaning this would have to be a focal point of our program.

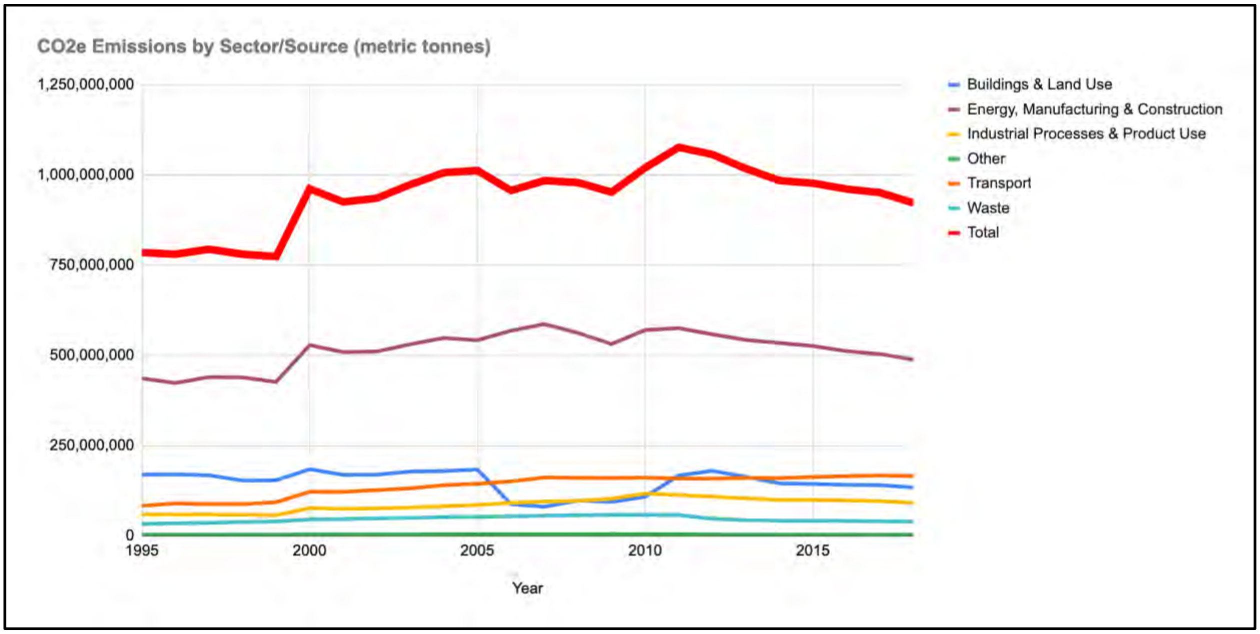


Figure 1 shows the annual aggregate emissions separated by their sector/source from 1995 to 2018

The graph below shows the breakdown of each sector's percent of total emissions from 2018. Since 2019 was predicted at mid-year, we did not think that data was reliable enough to use in our calculations.

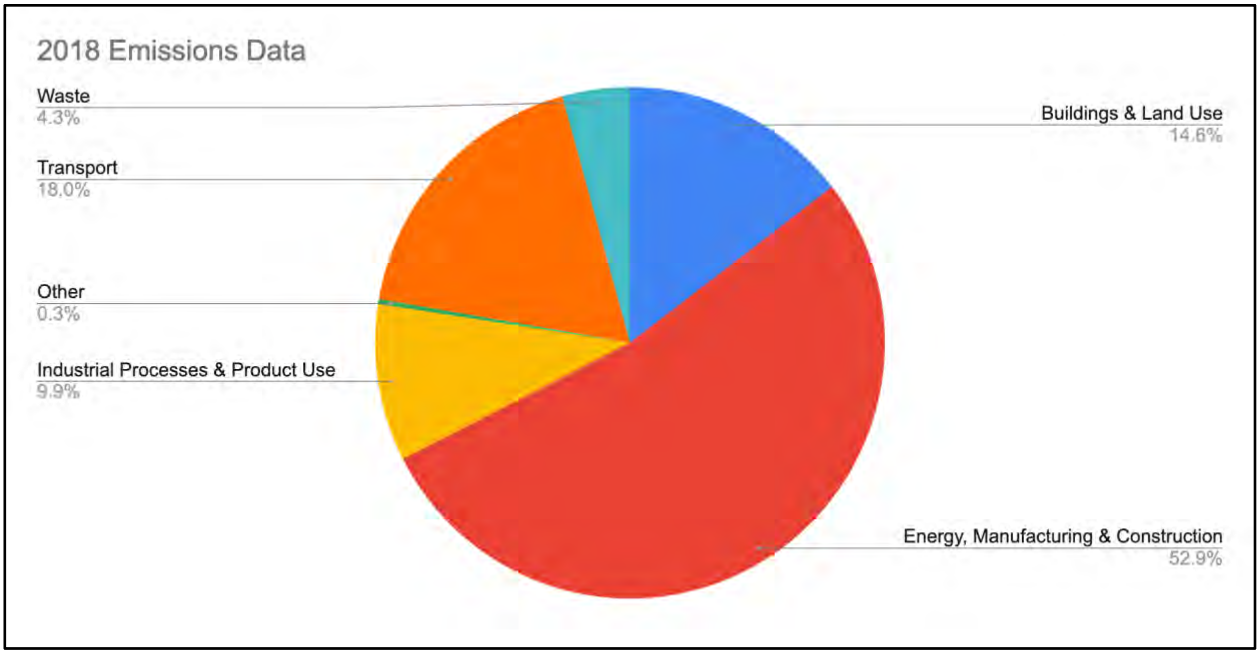


Figure 2 shows the proportion of total emissions from each sector in 2018

The table below shows the correlation between potential independent variables for the model we will create to predict carbon emissions. The numbers in bold represent a high correlation.

	Population	GDP	Land Area	Forested Land	Percent of Population in Urban Areas	Energy Use	Renewable Energy Consumption
Population	1.0000	**0.9382**	**0.8698**	-0.0693	0.1255	-0.3514	**0.8549**
GDP	**0.9382**	1.0000	**0.9202**	0.0523	0.2029	-0.1699	0.8079
Land Area	**0.8698**	**0.9202**	1.0000	0.1754	0.4004	-0.0220	0.7395
Forested Land	-0.0693	0.0523	0.1754	1.0000	0.1985	0.5797	-0.2339
Percent of Population in Urban Areas	0.1255	0.2029	0.4004	0.1985	1.0000	0.1269	0.1297
Energy Use	-0.3514	-0.1699	-0.0220	0.5797	0.1269	1.0000	-0.5532
Renewable Energy Consumption	**0.8549**	0.8079	0.7395	-0.2339	0.1297	-0.5532	1.0000

Figure 3 shows the correlation of several variables tested to come up with a fitting model

Company Data

In order to get a sense of the significance and validity of the given company data, we first wanted to investigate how much of the total emission data was reflected in the company data. Below shows each sector's reported data for 2018 in comparison to the government's aggregate reports.

Based on 2018 data	Energy, Manufacturing, & Construction	Buildings & Land Use	Industrial Processes & Product Use	Other	Transport	Waste	Total
Reported Emissions	467,506,863	0	84,671,229	3,074,147	158,938,923	35,277,016	749,468,178
Unreported Emissions	20,795,618	134,355,788	6,800,040	-29,847	6,750,643	4,300,646	172,972,888
Total Emissions	488,302,481	134,355,788	91,471,269	3,044,300	165,689,566	39,577,662	922,441,066
Percent of Emissions Reported	95.74%	0.00%	92.57%	100.98%	95.93%	89.13%	81.25%

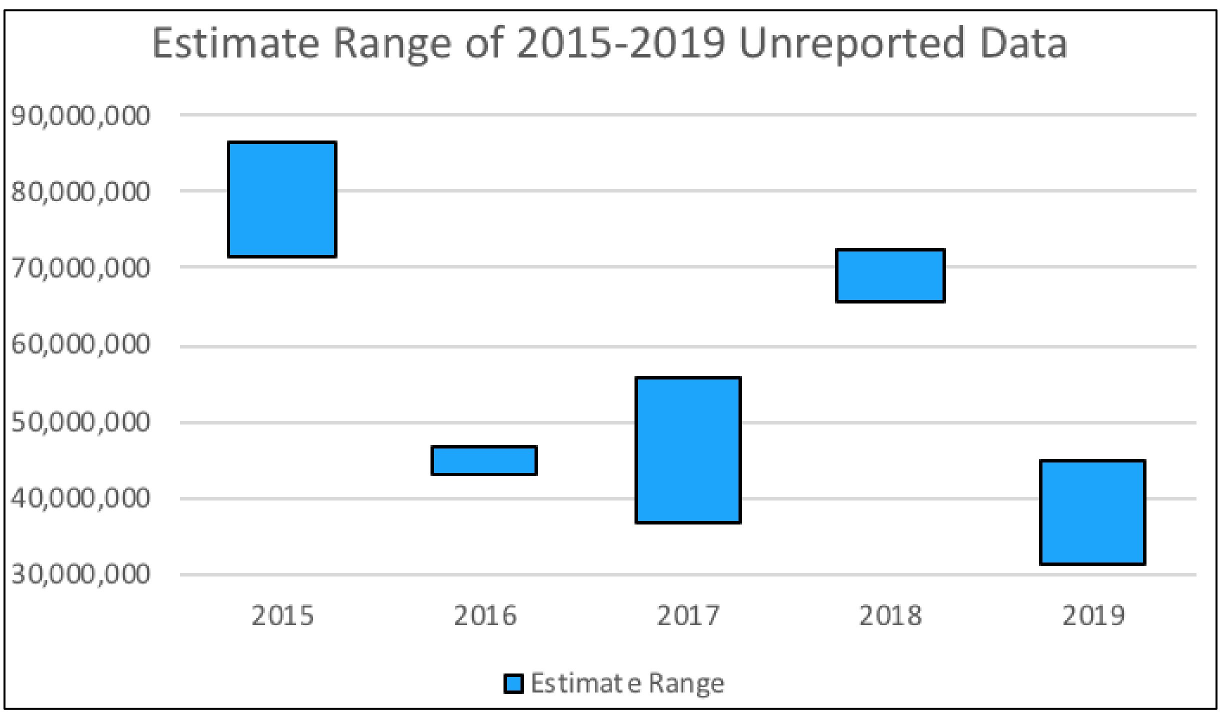
Below is a chart explaining our key takeaways and assumptions from analyzing the company and aggregate data together.

Key Takeaway	Key Assumption from Takeaway
308 companies did not report any emissions from 2015 to 2019	Emissions were not significant enough to report
No reported company data for Buildings and Land Use	Emissions from Buildings & Land Use is mainly from civilians and/or sources that do not track and report their carbon emissions
More emissions classified as Other sector than the government reported for total aggregate emissions	Companies mislabeled their emission as "other" when it actually fits into another sector
95.1% of aggregate data reported by companies, excluding Buildings & Land Use sector	The small portion of non-reported emissions comes from companies that did not report all of their emissions

We then found a rough estimate of each year's missing data by compiling the total emissions for each year from the same companies that had 0's in one given year. For example, the same companies that had 0 emissions reported in 2015, had 86,333,106 reported in 2016.

	2015	2016	2017	2018	2019
2015 Data Not Reported	0	86,333,106	71,720,102	84,162,064	80,477,048
2016 Data Not Reported	44,149,922	0	44,557,686	46,525,683	43,045,940
2017 Data Not Reported	41,648,357	55,655,420	0	52,563,828	36,566,047
2018 Data Not Reported	72,269,786	70,413,517	69,580,214	0	65,557,161
2019 Data Not Reported	38,448,646	44,832,426	31,100,602	42,157,209	0

By taking the minimum and maximum of each year's data not reported, we were able to form an estimated range for the unknown data for each year which can be seen in the graph below.



Data Limitations

- ❑ Vital environmental information such as temperature, sea-level, coastline, air pollution, etc.
- ❑ Individual company financial statements
- ❑ Accuracy and completeness of company emission data

Assumptions

Assumption	Rationale
Pullanta's risk free rate is 1.51%	This rate is the most recent U.S. Treasury Bill interest rate for a one-year Treasury Bill
The 2019 data given is not reliable	The data was estimated through mid-year reporting
The Buildings & Land Use sector cannot be regulated through our program	We are not given the specific parties accountable for this sector's emissions due to lack of company reporting
California and Pullanta are comparable parties	They are both developed states with comparable GDP to emission ratios

Risk Management

RCD Tool

With the implementation of a carbon credit program, Pullanta is faced with a variety of risks. Some of the risks are described below using a risk categorization and definition tool (RCD):

Risk Category	Risk Sub-Category	Description
Strategic	Strategy	Carbon Credit Program fails to reduce emissions as intended
Strategic	Competitor Action	Competitors price carbon credits in an unsustainable manner
Strategic	Propaganda	Biased information released by groups in the attempt to sway public opinion
Strategic	Regulatory	New policies and regulations implemented affecting the Carbon Credit Program
Operational	Technology	Carbon emissions not recorded and calculated correctly
Operational	Technology	New development and availability of cost-effective carbon reduction alternatives
Operational	Technology	Companies lack the innovation and technology to continuously meet carbon emission standards
Operational	Temperature	Increased carbon emissions due to rise in temperature
Operational	Corruption	Companies submit incorrect emission readings
Operational	Industrial Accident	Unintentional release of large amounts of carbon emissions
Financial	Market	Unexpected change in the economy
Financial	Market	Cap on carbon emissions is too high or too low
Financial	Market	Price of carbon credits is too high or too low

Figure 4 shows the RCD tool for risks associated with implementing a carbon credit program

Impacts

The risks mentioned in the RCD tool are making a substantial impact on our carbon credit program. There are two key takeaways that we have implemented accordingly into our program. One is there must be a floor and ceiling on the price of carbon credits to ensure the primary and secondary market for carbon credits stays reasonable and sustainable. The second is there must be laws and regulations put in place by the Pullanta Government to penalize companies that do not follow the program.

In pricing we also took into consideration how Pullanta's citizens would view the program. The graphs below show a shocking revelation that higher carbon prices actually lead to more trust in politicians and lower corruption perception.

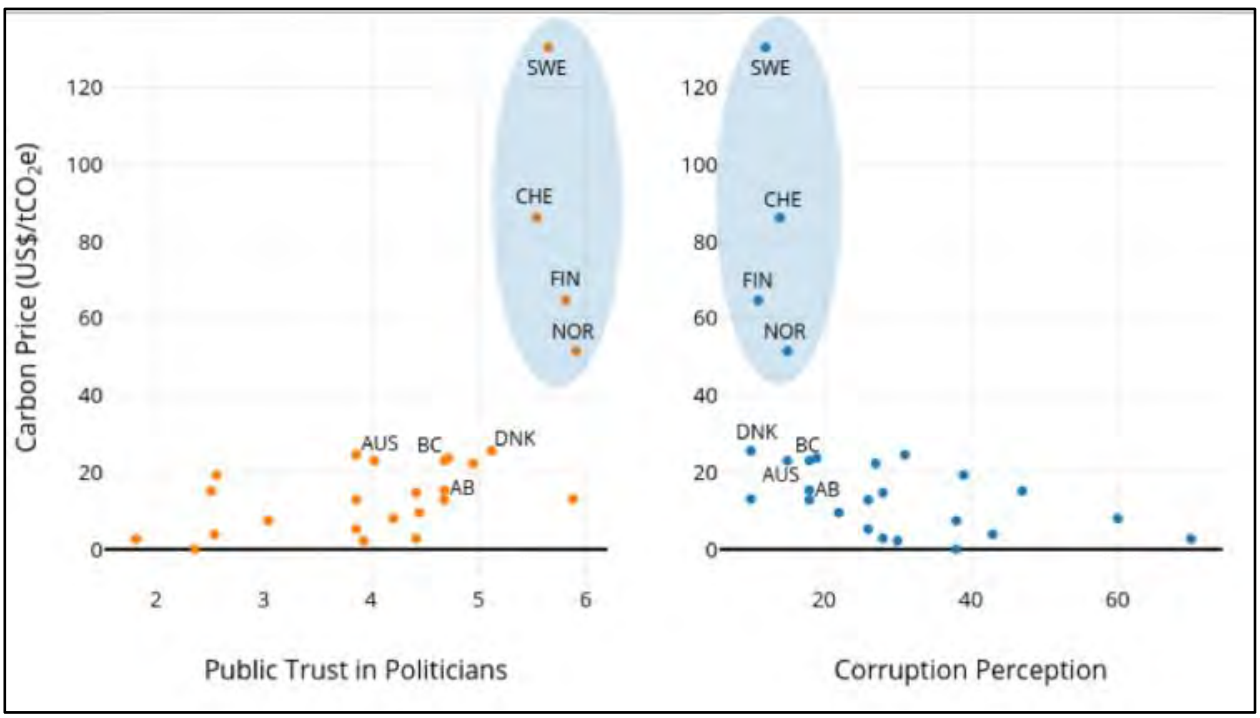


Figure 5 Social Impact of Carbon Price
Source: Our World in Data (Funke & Mattauch, 2018)

Costs

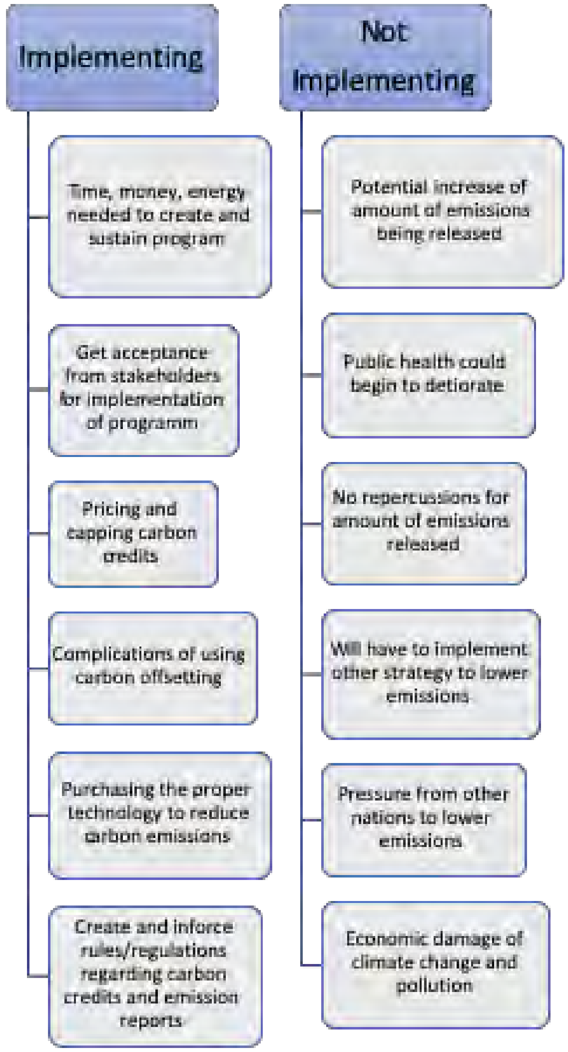


Figure 6 describes the financial and non-financial costs of implementing or not implementing the carbon credit program

Alternative Approaches

Two of the most commonly discussed alternative approaches to a carbon credit program are carbon tax and carbon capture and storage (CCS). Sweden has been able to decrease emissions by over 25% since implementing a carbon tax in 1991 (Funke & Mattauch, 2018). CCS is a relatively new innovation, still being worked on and improved.

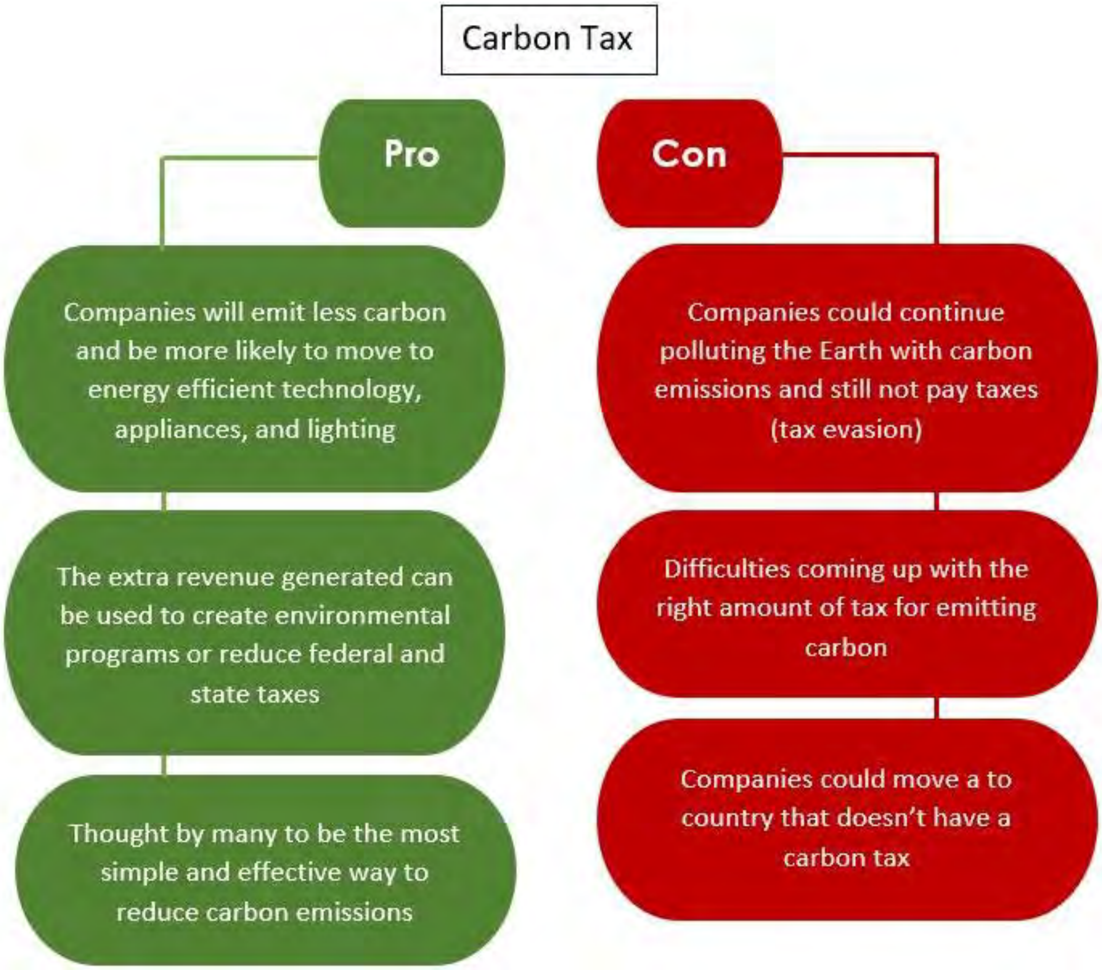


Figure 7 describes our first alternative approach to a carbon credit program
Sources: How Carbon Tax Works (Dowdey), Economics Help (Pettinger et al.)

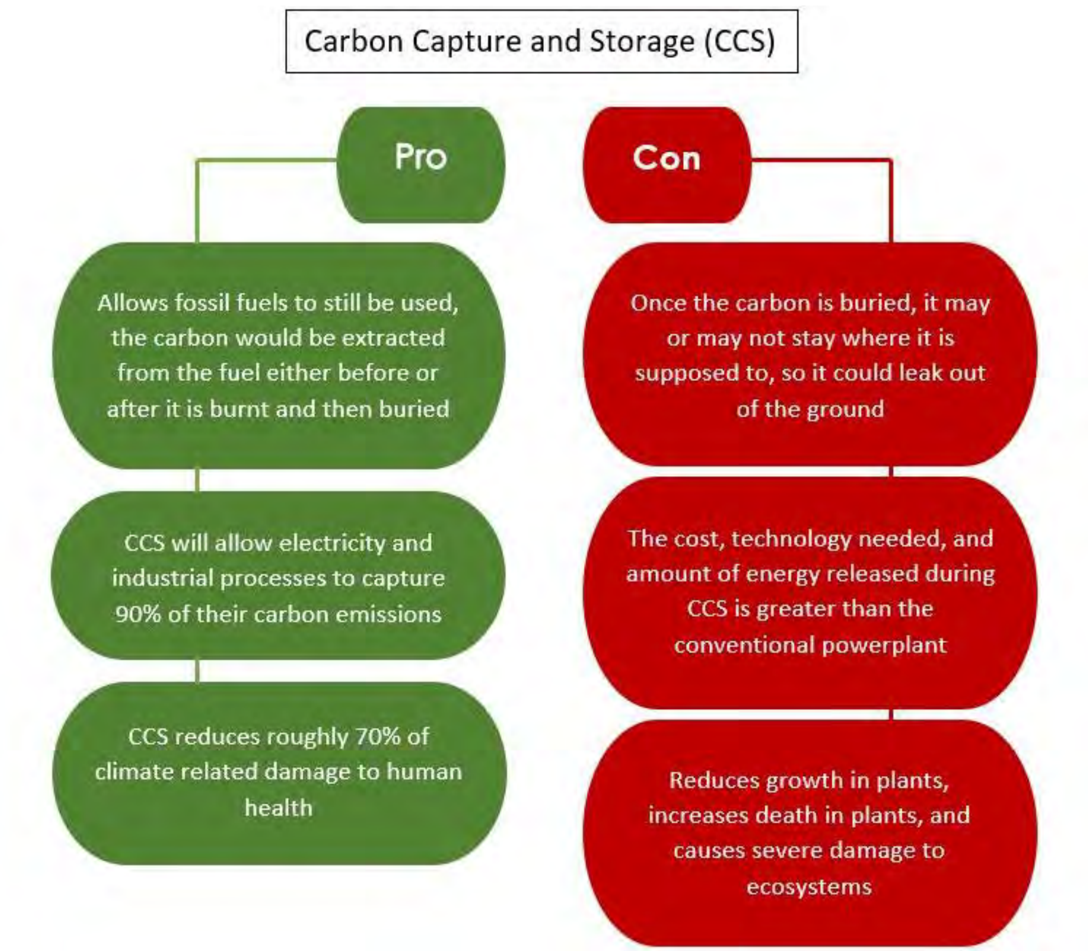


Figure 8 describes our second alternative approach to a carbon credit program
Sources: World Coal Association, Climate Vision, Alternative Energy

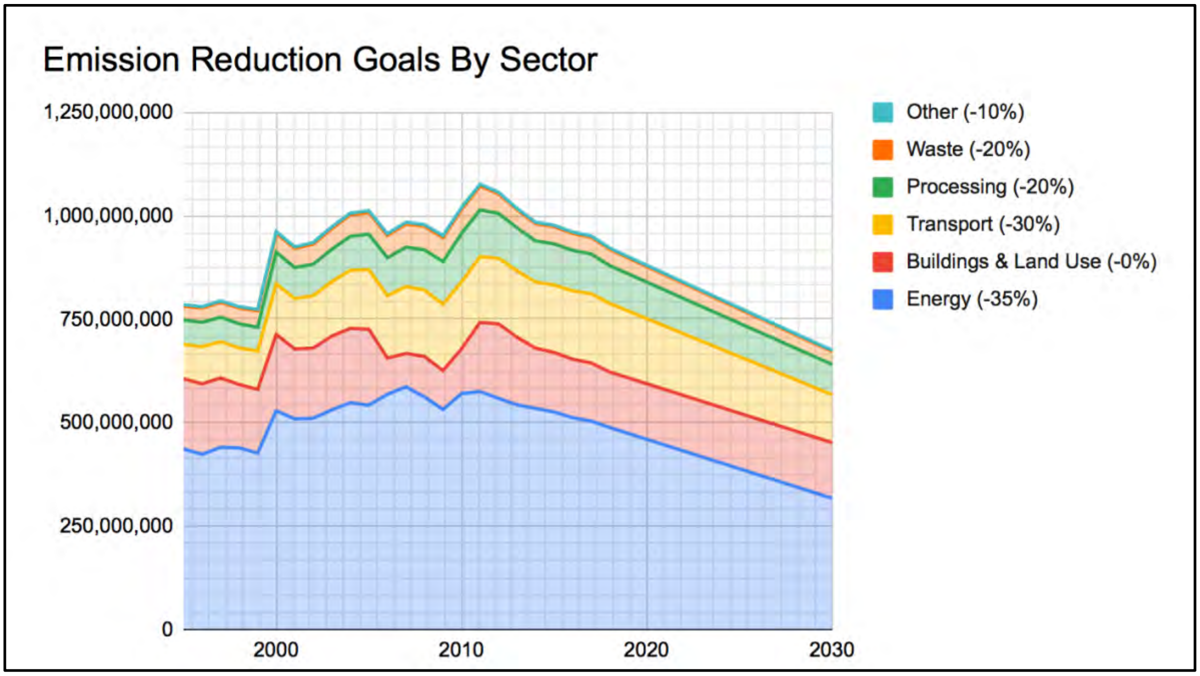
Plan

Overview

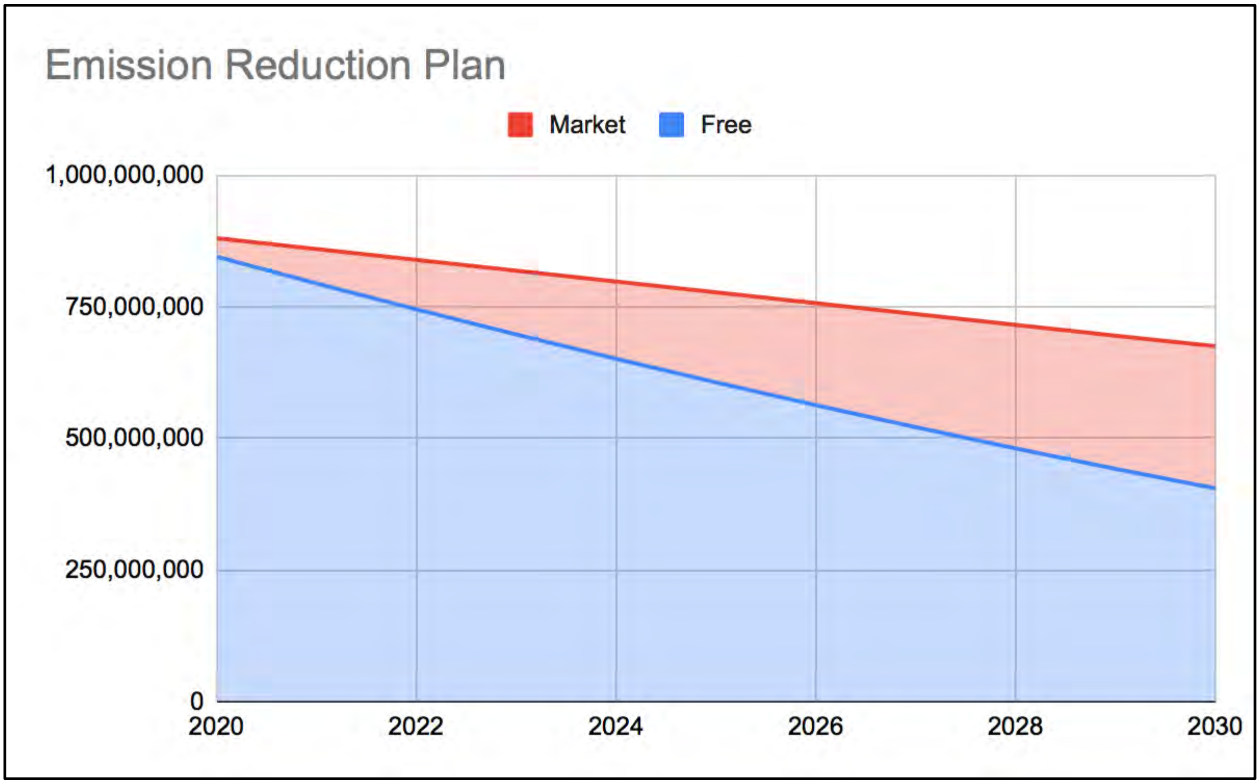
Our Carbon Credit Program will focus on reducing each company's greenhouse gas emissions per year through 2030. Each sector then has their own reduction goal to meet by 2030. The Energy, Manufacturing, and Construction sector will have the greatest emission reduction since they have the largest proportion of emissions and capability to implement renewable energy sources to replace carbon emissions. Due to our lack of company data in the Buildings & Land

Use sector, we felt that our carbon credit program would not regulate this sector sufficiently enough to rely on any reduction goals. We assume that this sector will either decrease or stay constant because their emissions have decreased annually since 2012. The table below shows each sector's goals and how they contribute to the total reduction of emissions through 2030.

Year	Energy	Buildings & Land Use	Transport	Processing	Waste	Other	Total
2019	474,060,325	134,355,788	161,547,327	89,946,748	38,383,635	2,952,456	901,246,279
2020	459,818,170	134,355,788	157,405,088	88,422,227	37,724,007	2,927,087	880,652,366
2021	445,576,014	134,355,788	153,262,849	86,897,706	37,064,380	2,901,718	860,058,453
2022	431,333,858	134,355,788	149,120,609	85,373,184	36,404,752	2,876,349	839,464,540
2023	417,091,703	134,355,788	144,978,370	83,848,663	35,745,124	2,850,979	818,870,628
2024	402,849,547	134,355,788	140,836,131	82,324,142	35,085,497	2,825,610	798,276,715
2025	388,607,391	134,355,788	136,693,892	80,799,621	34,425,869	2,800,241	777,682,802
2026	374,365,235	134,355,788	132,551,653	79,275,100	33,766,241	2,774,872	757,088,889
2027	360,123,080	134,355,788	128,409,414	77,750,579	33,106,613	2,749,503	736,494,976
2028	345,880,924	134,355,788	124,267,175	76,226,057	32,446,986	2,724,134	715,901,063
2029	331,638,768	134,355,788	120,124,935	74,701,536	31,787,358	2,698,764	695,307,150
2030	317,396,613	134,355,788	115,982,696	73,177,015	31,662,130	2,739,870	675,314,112



To reach each sector's reduction goal, we will implement a system in which a certain amount of carbon is free to each sector while the rest must be bought as carbon credits. Starting in 2020, each sector will be given 96% of their total allotted carbon emissions for free. Each year companies will be paying an increasing percentage of their previous year's emissions. This means companies will only have to pay for 4% of their 2019 emissions. For the next 10 years this will increase annually by 3.6% until reaching 40% in 2030, causing companies to rely more on the use of carbon credits. This gives companies time to explore more environmentally conscious options and gradually become less dependent on the use of carbon. Below is a graph to visualize our Emission Reduction Plan.



Due to the fact that we plan to reduce each sector by a different percentage, we decided to manage each sector individually rather than grouping them together. Since we are not holding citizens accountable for reporting their carbon emissions, we do not expect them to purchase any carbon credits, thus they will all be given for free to the Buildings and Land Use sector. The carbon credits allocated per sector are determined by both the size of the sector and their particular emission goal.

Carbon Credits Given Per Sector

Year	Energy	Buildings & Land Use	Transport	Processing	Waste	Other	Total
2020 (96.0%)	441,425,443	134,355,788	151,108,884	84,885,338	36,215,047	2,810,003	850,800,503
2021 (92.4%)	411,712,237	134,355,788	141,614,872	80,293,480	34,247,487	2,681,187	804,905,051
2022 (88.8%)	383,024,466	134,355,788	132,419,101	75,811,388	32,327,420	2,554,197	760,492,360
2023 (85.2%)	355,362,131	134,355,788	123,521,571	71,439,061	30,454,846	2,429,034	717,562,431

2024 (81.6%)	328,725,230	134,355,788	114,922,283	67,176,500	28,629,765	2,305,698	676,115,264
2025 (78.0%)	303,113,765	134,355,788	106,621,236	63,023,704	26,852,178	2,184,188	636,150,859
2026 (74.4%)	278,527,735	134,355,788	98,618,430	58,980,674	25,122,083	2,064,505	597,669,215
2027 (70.8%)	254,967,140	134,355,788	90,913,865	55,047,410	23,439,482	1,946,648	560,670,333
2028 (67.2%)	232,431,981	134,355,788	83,507,541	51,223,911	21,804,374	1,830,618	525,154,213
2029 (63.6%)	210,922,257	134,355,788	76,399,459	47,510,177	20,216,760	1,716,414	491,120,855
2030 (60.0%)	190,437,968	134,355,788	69,589,618	43,906,209	18,997,278	1,643,922	458,930,783

Carbon Credits On The Market Per Sector

Year	Energy	Buildings & Land Use	Transport	Processing	Waste	Other	Total
2020 (4.0%)	18,392,727	0	6,296,204	3,536,889	1,508,960	117,084	29,851,863
2021 (7.6%)	33,863,777	0	11,647,977	6,604,226	2,816,893	220,531	55,153,402
2022 (11.2%)	48,309,392	0	16,701,508	9,561,796	4,077,332	322,152	78,972,180
2023 (14.8%)	61,729,572	0	21,456,799	12,409,602	5,290,278	421,945	101,308,197
2024 (18.4%)	74,124,317	0	25,913,848	15,147,642	6,455,731	519,912	122,161,451
2025 (22.0%)	85,493,626	0	30,072,656	17,775,917	7,573,691	616,053	141,531,943
2026 (25.6%)	95,837,500	0	33,933,223	20,294,426	8,644,158	710,367	159,419,674
2027 (29.2%)	105,155,940	0	37,495,549	22,703,169	9,667,131	802,855	175,824,643
2028 (32.8%)	113,448,943	0	40,759,633	25,002,146	10,642,612	893,516	190,746,850
2029 (36.4%)	120,716,511	0	43,725,476	27,191,359	11,570,598	982,350	204,186,295
2030 (40.0%)	126,958,645	0	46,393,078	29,270,806	12,664,852	1,095,948	216,383,329

Carbon credits will first be available to companies through various financial instruments that will be offered at the beginning of each year. Every carbon credit that is not bought through these financial instruments will be auctioned off in a quarterly auction described below. Carbon credits will be reset at the end of each year. Companies will be regulated to ensure they purchase no more than 2% over their allotted percentage, through the auction or financial instruments. For example, in 2020 companies can only purchase 6% of their previous year's total emissions in carbon credits since they are allotted 4%. This is to ensure that no one company can monopolize carbon credits on the secondary market.

Carbon Credit Auction

- Each company must register and submit their reported emissions prior to start
- Held the first Wednesday of every February, May, August, and Novemeber
- Sealed bid format with a price floor and ceiling set
- Only mulitples of 100 and 1000 are sold
- Remaining carbon credits from each auction will roll over to the next auction until no more are left for the year
- Once concluded, the carbon credits will be sent to the respective companies
- All proceeds, minus expenses, will be invested in consumer benefit programs such as energy efficiency, renewable energy, energy bill assistance, and other greenhouse gas reduction programs

Pricing

To price our carbon credits we used parties that have correlated emissions data with Pullanta. These parties were California and Quebec (both under the same cap and trade program). Below is a matrix plot showing a .89 correlation between California's and Pullanta's GDP divided by total emissions. This strong correlation tells us California's cap and trade program is a quality reference to use when forming our plan.

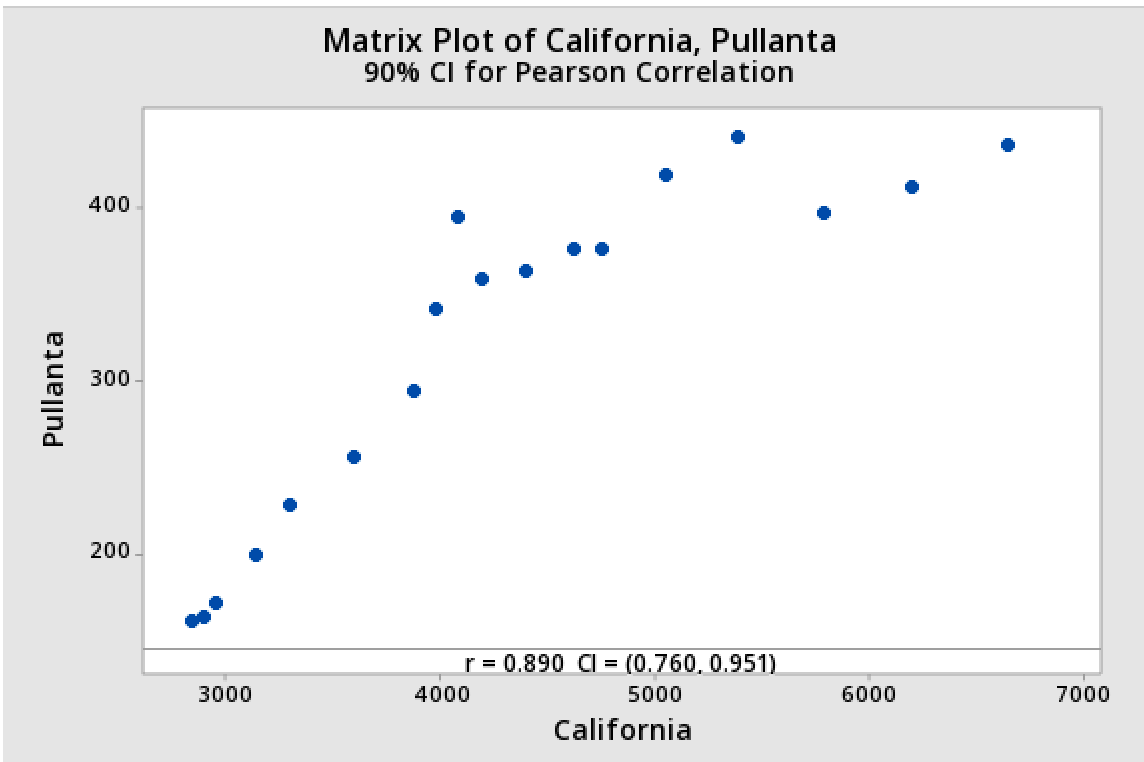


Figure 9 shows the correlation between California and Pullanta
Source: Minitab 2019

Since we will be holding a quarterly auction to sell the carbon credits we needed to price a floor and ceiling, as prices will be driven by the market. The first floor and ceiling price is comparable to the related parties and then adjusted for the GDP, population, and land size of Pullanta. The floor is raised 5% each year, while the ceiling is raised 5% until 2025 and then a hard ceiling of Ᵽ75 is used until 2030. This 5% increase was influenced by California's pricing method (Sutter, 2018). This way carbon credits will slowly increase in price, but the market will be stable. The carbon credits will then sell for market value during the auction and in the secondary market.

Secondary Market

- Designed for companies that need to buy or sell extra carbon credits
- Will incentivise companies to reduce emissions by having an extra way to retain profit
- Profit will be purely kept by the company selling the carbon credits
- Must not sell for higher than the ceiling price set for that year

Annual Floor/Ceiling of Carbon Credits

Year	Floor (Ᵽ)	Ceiling (Ᵽ)
2020	27.25	58.33
2021	28.61	61.25
2022	30.04	64.31
2023	31.55	67.53
2024	33.12	70.90
2025	34.78	74.45
2026	36.52	75.00
2027	38.34	75.00
2028	40.26	75.00
2029	42.27	75.00
2030	44.39	75.00

Figure 10 above shows the prices used for the floor and ceiling until 2030

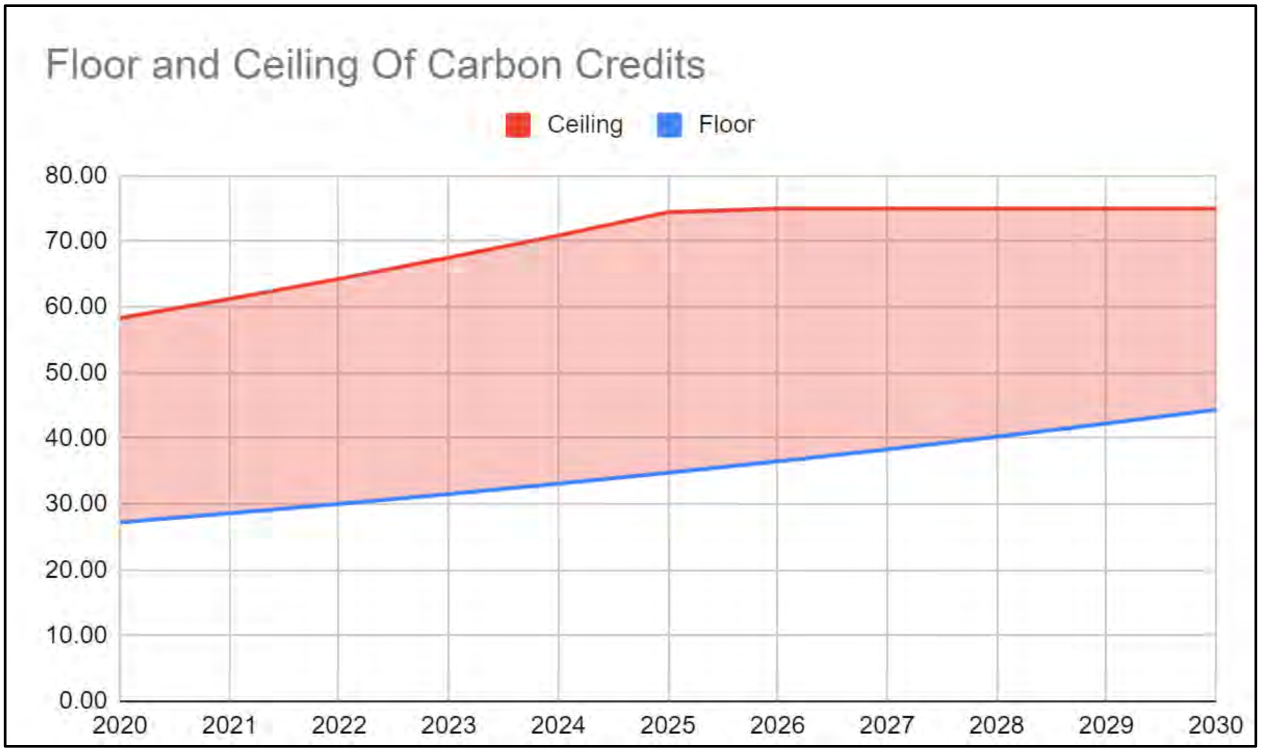


Figure 11 shows the price floor and ceiling set for carbon credit prices in the market

Social Cost

Without having access to data such as Pullanta's temperature, sea-level, and other various factors we cannot come to an accurate price for the social cost of carbon (SCC). Due to this, the next best estimate is using the average global SCC. Using a 3% discount rate, Resources for the Future, calculated the global cost of carbon to be $50 which equates to Ƥ83.33 (Rennert & Kingdon, 2019). The SCC is different than our carbon credit price simply because Ƥ83.33 would be unreasonable for companies to pay given Pullanta's GDP. Our research suggests a 3% discount rate is the most sufficient rate despite the fact that raising that rate would cause our carbon credits to be more similar in price to the SCC (FRED, 2020). Below is a graph showing the range of values of the SCC using different discount rates.

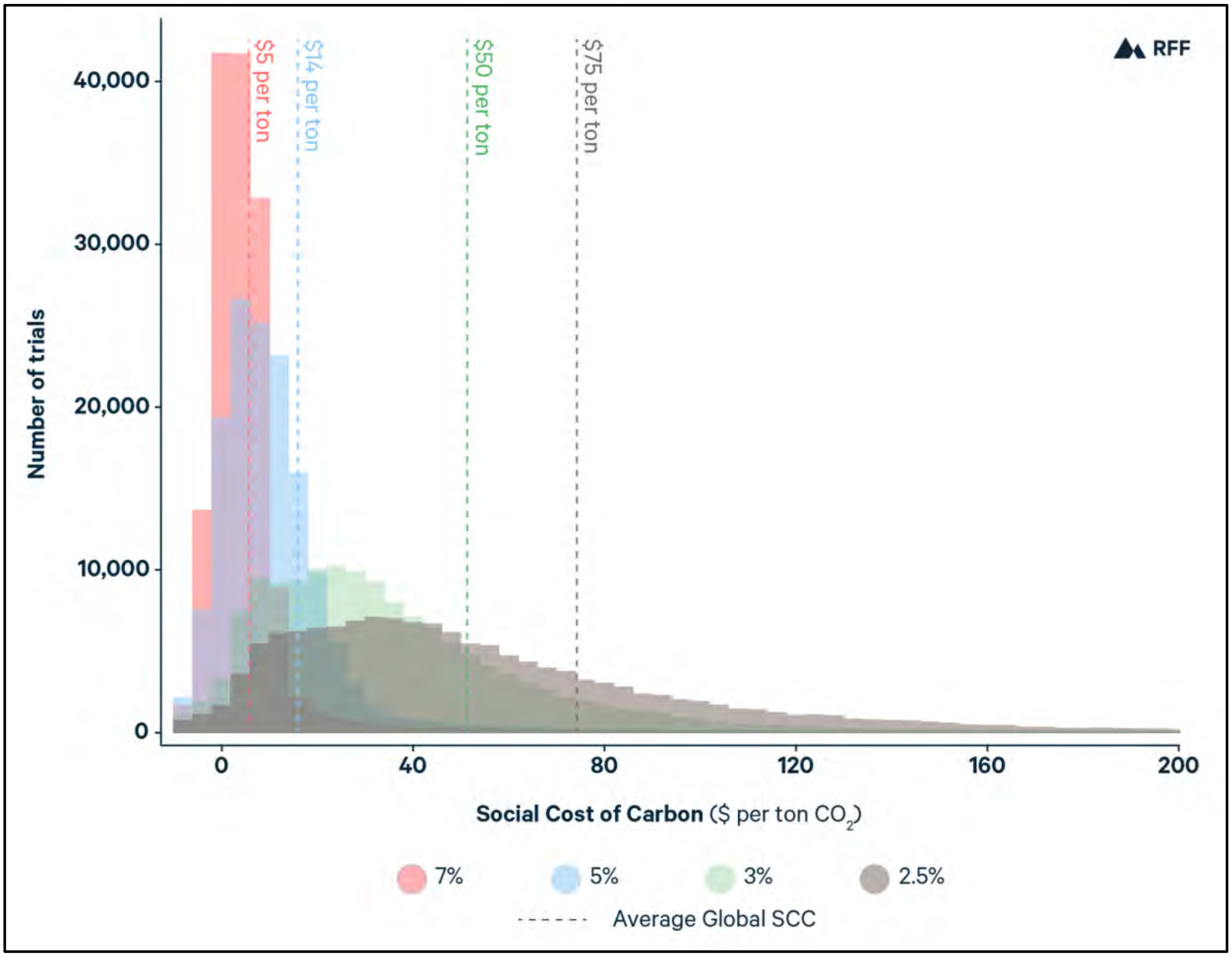


Figure 12 shows the social cost of carbon from the different models ran by the United States Government
Source: Resources for the Future

Implementation

Revenue

The Department of Environmental Concerns will be receiving money from our program in the following ways:

1) Auction Revenues
2) Cash inflow from bonds
3) Transaction fees from futures
4) Fines collected

5) Money from reinvestment

Since carbon credits will be bought and sold using market price it is impossible to know how much revenue we will receive from the program each year. As the carbon credit market expands each year, revenue will continue to increase significantly.

Rules and Regulations

Modelling

Model Comparison

There were several different models under consideration for our program. We tested an Inverse Gaussian distribution as well as a Log Gamma distribution. For both of these distributions we tested multiple combinations of potential parameters. Prior to the testing, we found that Population and Land Area both were highly correlated with GDP so we were able to eliminate them as potential parameters. After testing, we narrowed it down to 3 potential models as shown below.

	MODEL	Parameters	P Values	AIC	Best Model
1	Log Inverse Gaussian	GDP	4.45e-06	968.47	X
		Energy Use	.000334		
2	Log Gamma	GDP	9.13e-06	967.35	✓
		Energy Use	.000383		
3	Log Inverse Gaussian	GDP	.000287	978.54	X
		Forested Land	.052385		

Although all of these models have their own strengths, we decided that Model 2 was most suitable for our needs. We quickly were able to eliminate Model 3 since it has both the highest P value and AIC value. Due to the fact that both Models 1 and 2 had extremely similar P values, we felt that the difference in AIC value was more significant in measuring the accuracy of the model.

Independent Variable Predictions

GDP:

Using a linear regression model, we projected the GDP of Pullanta each year until 2030.

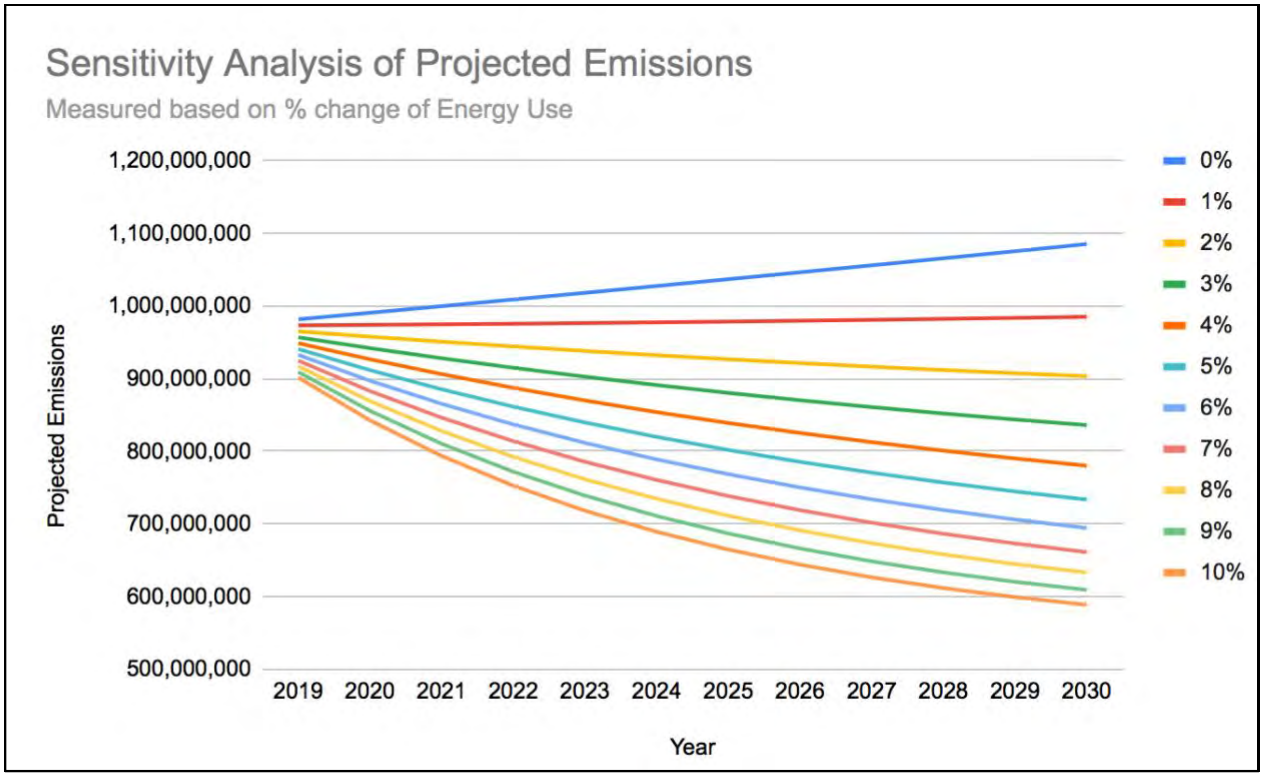
Year	GDP (Ᵽ)
2019	790,063,000,000
2020	814,952,000,000
2021	839,841,000,000
2022	864,729,000,000
2023	889,618,000,000
2024	914,507,000,000
2025	939,396,000,000
2026	964,284,000,000
2027	989,173,000,000
2028	1,014,060,000,000
2029	1,038,950,000,000
2030	1,063,840,000,000

Energy Use:

In order to hit our projected carbon emission reduction goals, a 7% change in energy use per year starting in 2019 is required. If no change occurs, projected emissions will reach 1,085,372,279 tonnes by 2030, a staggering 410,058,167 over our goal.

Sensitivity Analysis

The table below shows how sensitive the projected emissions will be.



Total Emissions Predictions

We use a log gamma general linear model to predict the total emissions from 2019 through 2030. The equation for our formula is:

$$\hat{Y} = \exp(19.56287 + 3.665244e\text{-}13X_1 + 3.67096e\text{-}5X_2)$$

X_1: Energy Use

X_2: GDP

Assuming our program will be successful in decreasing energy use by 7% each year, we predict total emissions will decrease to 661,223,275 tonnes (28.32% decrease from 2018 levels) by 2030, as shown in the graph below.

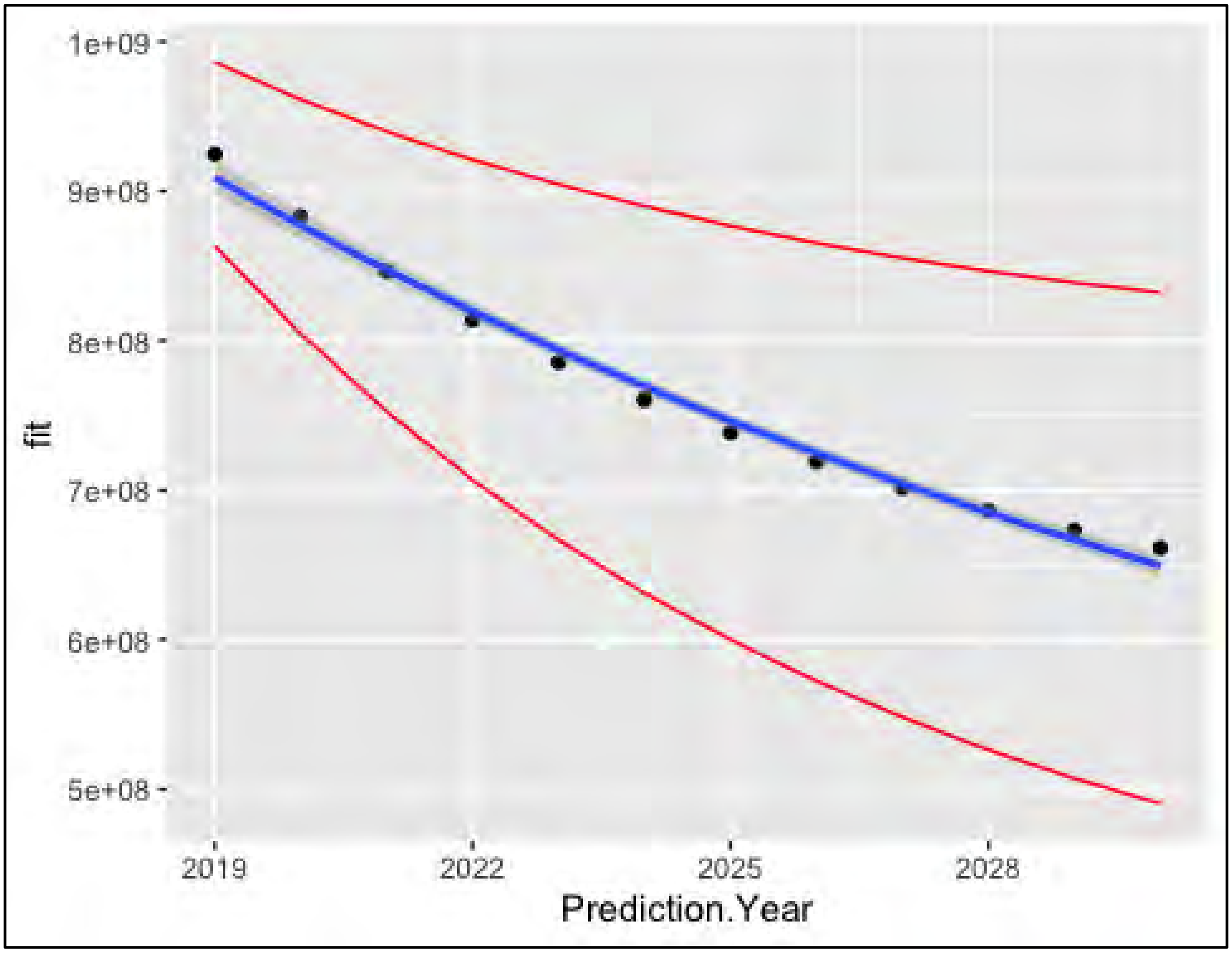


Figure 13 shows the fitted values for projected emissions using the gamma model. The red lines represent the upper and lower bounds of the 90% confidence interval.

Financial Instruments

Tools

Financial Instrument	Description
Bond 1 ***1,500,000 available***	❏ 5-year bond ❏ Company pays X immediately *(*See Bond 1 Pricing*)* ❏ 5 annual coupons of 3 carbon credits each distributed to company at the end of each year ❏ Company receives Ꝑ6000 at the end of 5 years

Bond 2 ***5,000 available***	❏ 1-year bond ❏ Company pays X immediately *(*See Bond 2 Pricing*)* ❏ Zero coupons ❏ Company receives 1000 carbon credits at the end of the year
Future	❏ an obligation to sell or buy a carbon credit at a later date at an agreed-upon price ❏ a company "posts" a carbon credit future contract where they must sell a carbon credit at a certain price at a later date (marked to market with intermediary daily) ❏ Pullanta's Department of Environmental Concerns receives a Ƥ.02 transaction fee from both sides of the trade

Figure 14 shows our financial instruments that will be released along with carbon credits
Our total emission goals are considered when establishing availability of each bond
Source: FXCM

Bonds Summary

Both bonds are subject to price changes each year. These changes will be reflected by the change in the floor price used for our auction (see Figure 10). Each year, the value of a carbon credit used to price our bonds will be 10% higher than the floor price that year. We believe this will entice companies to purchase our bonds, forcing more carbon credits into the market to keep the Futures market active as well. We will use an interest rate of 1.51% to discount cash flows. Using a price of Ƥ29.80 for carbon credits, the present value of future cash flows for Bond 1 in 2020 is Ƥ6041.21, which we will use for our current price of Bond 1. A breakdown of the pricing for each year of purchase is displayed below:

Bond 1 Pricing

Year	Monetary Value of CC Coupons (Ᵽ)	Bonds bought in 2020	Bonds bought in 2021	Bonds bought in 2022	Bonds bought in 2023	Bonds bought in 2024	Bonds bought in 2025	Bonds bought in 2026	Bonds bought in 2027	Bonds bought in 2028	Bonds bought in 2029	Bonds bought in 2030
2020	89.93	88.59										
2021	94.42	91.63	94.42									
2022	99.14	94.78	97.67	99.14								
2023	104.10	98.04	101.03	102.55	104.10							
2024	109.30	101.41	104.50	106.08	107.68	109.30						
2025	114.77		108.09	109.72	111.38	113.06	114.77					
2026	120.51			113.50	115.21	116.95	118.72	120.51				
2027	126.53				119.17	120.97	122.80	124.65	126.53			
2028	132.86					125.13	127.02	128.94	130.88	132.86		
2029	139.50						131.39	133.37	135.38	137.43	139.50	
2030	146.48							137.96	140.04	142.15	144.30	146.48
PV of Coupons		474.46	505.70	530.99	557.54	585.42	614.69	645.42	532.84	412.44	283.80	146.48
PV of Ᵽ6000 Face Value		5,566.82	5,566.82	5,566.82	5,566.82	5,566.82	5,566.82	5,566.82	5,650.88	5,736.21	5,822.82	5,910.75
Price of Bond 1		6,041.28	6,072.52	6,097.81	6,124.36	6,152.24	6,181.51	6,212.24	6,183.72	6,148.65	6,106.63	6,057.23

Bond 1 will only pay carbon credit coupons through 2030, meaning all bonds sold starting in 2027 will mature on December 31, 2030.

Bond 2 Pricing

Year	Value of 1 Carbon Credit (Ᵽ)	Value of 1,000 Carbon Credits (Ᵽ)	Price of Bond 2 (Ᵽ)
2020	29.98	29,975.00	29,529.11
2021	31.47	31,473.75	31,005.57
2022	33.05	33,047.44	32,555.84
2023	34.70	34,699.81	34,183.64
2024	36.43	36,434.80	35,892.82
2025	38.26	38,256.54	37,687.46
2026	40.17	40,169.37	39,571.83
2027	42.18	42,177.84	41,550.42
2028	44.29	44,286.73	43,627.94
2029	46.50	46,501.06	45,809.34
2030	48.83	48,826.12	48,099.81

Bond 2 will be available every year through the existence of our program.

Design

All financial instruments are made so companies are incentivized to use a decreased amount of carbon credits every year at a minimal cost. The bonds allow the companies to use carbon by sacrificing only the opportunity cost of investing that money. Companies can also benefit from investing in carbon futures depending on the market and interest rates. However, in some economic situations, companies may lose money by investing in carbon futures relative to an investment in carbon credit bonds.

Analysis

Both bonds will be available to buy through a standardized online program that will be made available to each company. This program will automatically ensure companies do not receive more carbon credits in their bonds than they are allotted each year. The carbon credits administered will be deducted from that year's total carbon credits on the market for each individual sector. The money received from the purchase of each bond will be invested from the time of the purchase to the time of maturity. This money will then be used to invest in consumer benefit programs.

The future contracts will be bought and sold using the same standardized online program mentioned above. This will be used as a way companies can hedge against the risk of a falling or rising rate of carbon credits. No new carbon credits will be sold, this is purely a secondary market tool for the benefit of the companies involved in the program.

Conclusion and Recommendation

Through our research and comparison of other successful carbon credit programs and analysis of Pullanta’s data, MWC has been able to form a program specific for Pullanta’s needs. Our program fits a log gamma general linear model to determine the required energy use reductions to meet our emission goals as well as gradually requiring companies to purchase more carbon credits each year through the use of financial instruments and a carbon credit auction.

We recommend that the Department of Environmental Concerns implements MWC’s carbon credit program to successfully reduce Pullanta’s emissions 25% by 2030. Our plan will not only reach Pullanta’s desired carbon reduction goals but will also bring in revenue to fund additional climate change mitigation efforts and provide the foundation to create a long-lasting safe and healthy environment for Pullanta.

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**References 1, 5 and 11 are the images used on the title page*

Appendix

Model Testing Code:

```
emissiondata2 <- read.csv("~/Documents/emissiondata2.csv")

View(emissiondata2)

library(MASS)



#inversengaussian with log

head(emissiondata2)

summary(model1)

model2<- glm(Total
~GDP+Forested.Land+Energy.Use,family=inverse.gaussian(link="log"),data
=emissiondata2)

summary(model2)

model3<-glm(Total ~
GDP+Energy.Use,family=inverse.gaussian(link="log"),data=emissiondata2)

summary(model3)


model1 <- glm(Total ~ GDP + Forested.Land,
family=inverse.gaussian(link="log"),data=emissiondata2)



> summary(model7)



Call:

glm(formula = Total ~ GDP + Energy.Use, family = Gamma(link = "log"),

    data = emissiondata2)



Deviance Residuals:

      Min         1Q     Median         3Q        Max

-0.083094  -0.051811   0.006261   0.040618   0.119444
```

```
Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.956e+01  2.263e-01  86.460  < 2e-16 ***
GDP         3.665e-13  6.394e-14   5.732 9.13e-06 ***
Energy.Use  3.671e-05  8.770e-06   4.186 0.000383 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Gamma family taken to be 0.003549105)

    Null deviance: 0.227611  on 24  degrees of freedom
Residual deviance: 0.077486  on 22  degrees of freedom
  (2 observations deleted due to missingness)
AIC: 967.35

Number of Fisher Scoring iterations: 4

#nextmodeltest

> summary(model3)

Call:
glm(formula = Total ~ GDP + Energy.Use, family = inverse.gaussian(link
= "log"),
    data = emissiondata2)
```

```
Deviance Residuals:
       Min          1Q      Median          3Q         Max
-2.576e-06  -1.498e-06   2.108e-07   1.434e-06   4.342e-06

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.951e+01  2.312e-01  84.373  < 2e-16 ***
GDP         3.858e-13  6.389e-14   6.039 4.45e-06 ***
Energy.Use  3.830e-05  9.028e-06   4.242 0.000334 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for inverse.gaussian family taken to be
3.942926e-12)

    Null deviance: 2.5084e-10  on 24  degrees of freedom
Residual deviance: 8.6744e-11  on 22  degrees of freedom
  (2 observations deleted due to missingness)
AIC: 968.47

Number of Fisher Scoring iterations: 1
```

Emission Prediction Code:

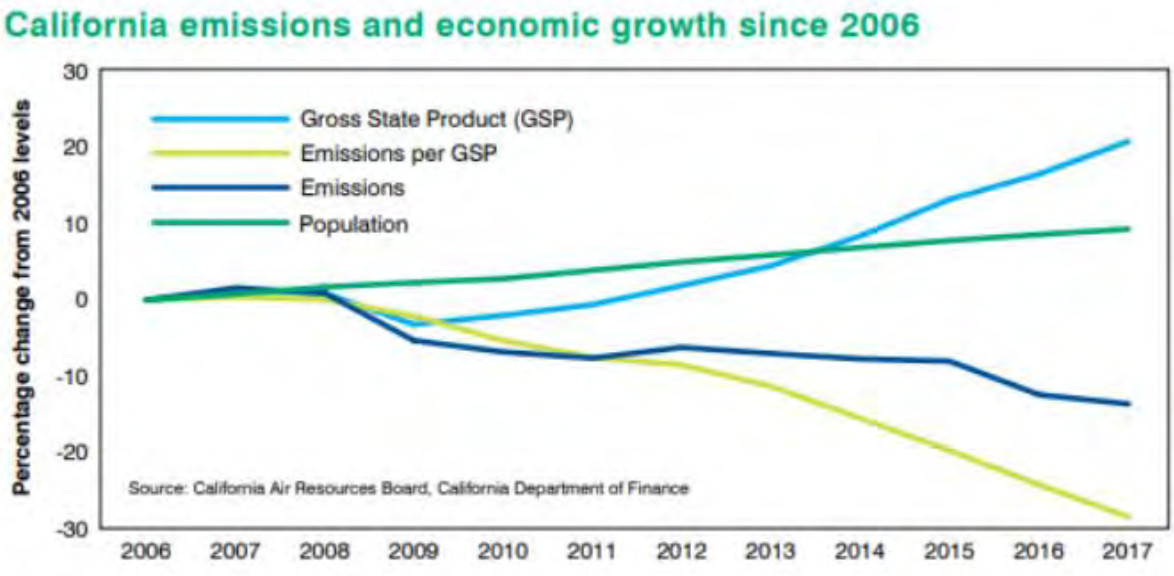
```
emission.data <- read.csv("D:/GA/MATH 498/emission data.csv")
View(emission.data)
library(MASS)

#Model for emission
```

```r
model1<-glm(Total~ Energy.Use+GDP ,data=emission.data,
family=Gamma(link="log"))
summary(model1)

#model for GDP(timeseries)
GDPmodel<-lm(GDP~Year, data=emission.data)
summary(GDPmodel)

#Predict GDP
Prediction <- read.csv("D:/GA/MATH 498/Prediction.csv")
options(digits=12)

data<-data.frame(Year=Prediction$Year)
show(data)

data$pred <-predict(GDPmodel,newdata=data,type="response")
data

#predict emission

data2<-data.frame(Energy.Use=Prediction$Energy.Use,
GDP=Prediction$GDP)
show(data2)

data2$Emission <-predict(model1,newdata=data2,type="response")
data2
```

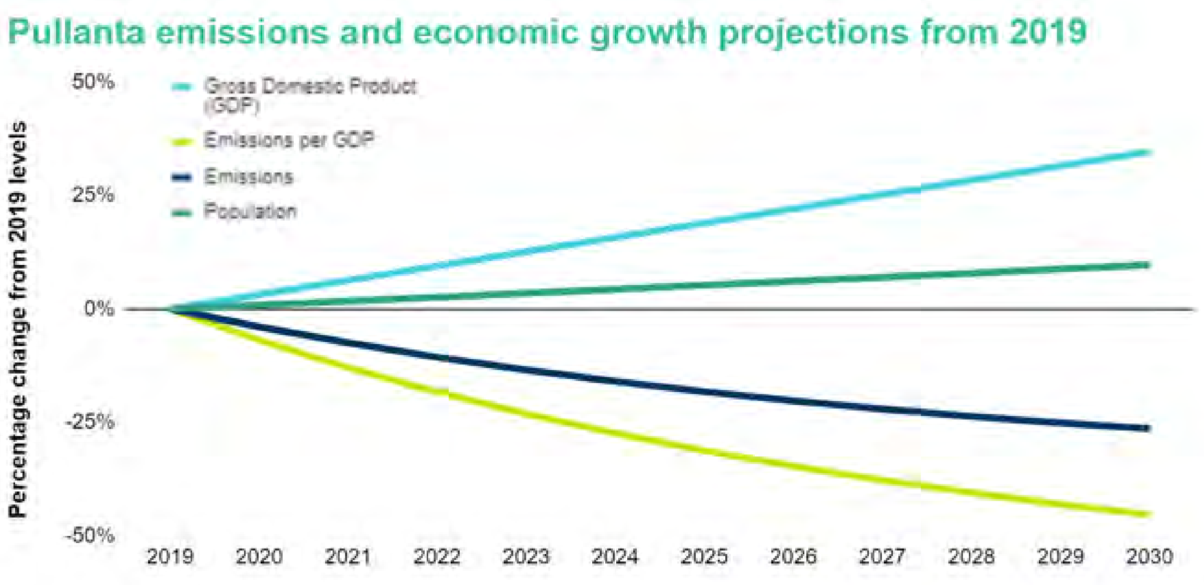
Confidence Interval Code:

```
#predict emission

data2<-data.frame(Energy.Use=Prediction$Energy.Use,
GDP=Prediction$GDP)
show(data2)

preds <-predict(model1,newdata=data2,type="link",se.fit=TRUE)
preds

#confidence interval of prediction
critval= 1.95;
upr <- preds$fit + (critval * preds$se.fit)
lwr <- preds$fit - (critval * preds$se.fit)
fit <- preds$fit

View(upr)
View(lwr)

#graph
install.packages("ggplot2")
library(ggplot2)


preddata<- data.frame(Prediction$Year,fit,upr,lwr)
preddata

ggplot(data=preddata, mapping=aes(x=Prediction.Year,y=fit)) +
geom_point() +
  stat_smooth(method="glm", method.args=list(family=Gamma)) +
  geom_line(data=preddata, mapping=aes(x=Prediction.Year, y=upr),
col="red") +
  geom_line(data=preddata, mapping=aes(x=Prediction.Year, y=lwr),
col="red")
```

California Program Comparison



Source: California's cap-and-trade program step by step (Sutter)



The above graphs compare the changes in emissions and economic growth for California and Pullanta over a 10-year span. The results of our plan appear to mirror California's success at the 10-year mark.

CALIFORNIA CAP-AND-TRADE PROGRAM
SUMMARY OF CALIFORNIA-QUEBEC JOINT AUCTION SETTLEMENT PRICES AND RESULTS
Conducted from November 2014 through November 2017

Auction Name	Total Current Auction Allowances Offered	Total Current Auction Allowances Sold	Current Auction Settlement Price	Total Advance Auction Allowances Offered	Total Advance Auction Allowances Sold	Advance Auction Settlement Price
November 2017 Joint Auction #13	79,548,286	79,548,286	$15.06	9,723,500	9,723,500	$14.76
August 2017 Joint Auction #12	63,887,833	63,887,833	$14.75	9,723,500	9,723,500	$14.55
May 2017 Joint Auction #11	75,311,960	75,311,960	$13.80	9,723,500	2,117,000	$13.57
February 2017 Joint Auction #10	65,104,273	11,673,000	$13.57	9,723,500	701,000	$13.57
November 2016 Joint Auction #9	87,069,495	76,960,000	$12.73	10,078,750	1,020,000	$12.73
August 2016 Joint Auction #8	86,278,410	30,021,000	$12.73	10,078,750	769,000	$12.73
May 2016 Joint Auction #7	67,675,951	7,260,000	$12.73	10,078,750	914,000	$12.73
February 2016 Joint Auction #6	71,555,827	68,026,000	$12.73	10,078,750	9,361,000	$12.73
November 2015 Joint Auction #5	75,113,008	75,113,008	$12.73	10,431,500	10,431,500	$12.65
August 2015 Joint Auction #4	73,429,360	73,429,360	$12.52	10,431,500	10,431,500	$12.30
May 2015 Joint Auction #3	76,931,627	76,931,627	$12.29	10,431,500	9,812,000	$12.10
February 2015 Joint Auction #2	73,610,528	73,610,528	$12.21	10,431,500	10,431,500	$12.10
November 2014 Joint Auction #1	23,070,987	23,070,987	$12.10	10,787,000	10,787,000	$11.86

Auction Name	Total Current Auction Allowances Offered	Total Current Auction Allowances Sold	Current Auction Settlement Price	Total Advance Auction Allowances Offered	Total Advance Auction Allowances Sold	Advance Auction Settlement Price
August 2014 Auction #8	22,473,043	22,473,043	$11.50	9,260,000	6,470,000	$11.34
May 2014 Auction #7	16,947,080	16,947,080	$11.50	9,260,000	4,036,000	$11.34
February 2014 Auction #6	19,538,695	19,538,695	$11.48	9,260,000	9,260,000	$11.38
November 2013 Auction #5	16,614,526	16,614,526	$11.48	9,560,000	9,560,000	$11.10
August 2013 Auction #4	13,865,422	13,865,422	$12.22	9,560,000	9,560,000	$11.10
May 2013 Auction #3	14,522,048	14,522,048	$14.00	9,560,000	7,515,000	$10.71
February 2013 Auction #2	12,924,822	12,924,822	$13.62	9,560,000	4,440,000	$10.71
November 2012 Auction #1	23,126,110	23,126,110	$10.09	39,450,000	5,576,000	$10.00

Looking at California’s auction report, we notice the carbon credit allowances offered per auction are almost always completely sold (California Air Resources Board, 2019). We thus expect to see similar results in Pullanta’s auction.