# Global Warming and The Bahamas

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## INTRODUCTION

Climate change indicates both physical and operational risks for any economy, thereby causing desolation to smaller island nations, like The Bahamas. The build-up of greenhouse gases ($CO_2$) in the atmosphere damages the ozone layer, which results in more exposure from the sun. The damage causes environmental changes–being a catalyst for physical disasters such as hurricanes, tornadoes, droughts and bushfires. Data regarding the global atmospheric concentration of greenhouse gases (GHGs), such as $CO_2$ shows that the concentration has risen by about 48.0% since 1850 (NASA, 2021). This $CO_2$ exposure results from typical everyday industrial activities that release the gases into the atmosphere, thereby releasing excess heat energy. Since the 1970s, it has been observed that more than 90.0% of the rest of the trapped heat has been absorbed into the oceans. Progressively, the oceans have warmed up over the past century, but the rise in ocean temperature is still accelerating. It is estimated that the top part of the ocean is warming up about 24.0% faster than it did a few decades ago, and that rate is likely to climb in the future (Borunda, 2019).

The Bahamas' location in the Atlantic Hurricane Belt increases the country's vulnerability to these severe weather events. Currently, over 80.0% of the country's landmass is within 5.0 feet (1.5 m) of mean sea level and this is detrimental to both the population and the economy, since the majority of the coastal areas are inhabited with smaller bodies of water housing our exotic sea life. As demonstrated in Table 1, four major hurricanes have struck the Bahamas since 2012, despite the country's smaller 'carbon footprint' relative to other countries that contribute on a larger scale to climate change (Goodman, 2019). Over the years, the value of damages and losses are projected to increase. The 12 major hurricanes that have struck The Bahamas between 1980 and 2018 have had profound effect on the country's well-being, and its economy, as they have caused an accumulated $2.5 billion in damages, equivalent to 30.0% of the country's GDP (Hartnell, 2018). The most significant hurricane, Dorian, resulted in damages of 1.0% of GDP. Dorian became a major alert for the Bahamian community, as more citizens became aware of the catastrophic effects of climate change, and demand solutions in mitigating global temperature.

**Table 1: Hurricanes and The Bahamas 2012-2020**

| Hurricane | Year | Score | Damage ($BSD) | Losses ($BSD) | GDP (%) |
|---|---|---|---|---|---|
| Sandy | 2012 | 2 | $702.8 million | - | 0.9 |
| Joaquin | 2015 | 4 | $104.8 million | $9.7 million | 0.11 |
| Matthew | 2016 | 4 | $373.9 million | $145.5 million | 1.1 |
| Irma | 2017 | 4 | $32.3 million | $86.9 million | 0.4 |
| Dorian | 2019 | 5 | $2.5 billion | $717.3 million | 1.0 |

## The Model

The global warming model for the Bahamian economy is based on Hassler et al (2020) and Nordhaus and Boyer (2000) model. The model examines the linkages between the world economy, carbon emissions and global warming, against the backdrop of a small country that contributes low amounts of emissions. Furthermore, the model evaluates the impact of climate change on the future well-being of citizens and the economy, as well as assesses the effectiveness of taxation on carbon to combat the growth of the global temperature, and the subsequent benefit captured by The Bahamas.

## Model Results

The primary finding is that if the oceanic temperature continues to increase, The Bahamas would be severely impacted. If global warming continues to proliferate, the welfare of Bahamian citizens would fall by over 4.0% in equivalent-consumption terms over a lifecycle. The model evaluates several alternative policies: ad valorem tax, per unit tax, carbon cap and trade; and different scenarios, like an increase in the expected number and intensity of hurricanes that directly hit The Bahamas, which the model assumes is highly correlated with oceanic temperature. Assuming no change in the current trend of global temperatures, welfare in The Bahamas would decline by an additional 1.5% on average.

## Climate Analysis

The usage of fossil energy sources generates $CO_2$ emissions. A parameter $g_j$ measures how unclean the energy source $j$ is. Fossil energy sources have $g_j = 1$ and purely green energy sources have $g_j = 0$. Total emissions from region $i$ in period $t$ is given by $M_{i,t} =$

$$\sum_{j=1}^{n} \boldsymbol{gjej, i, t}$$

When following Golosov et al (2014) model, the law of motion for atmospheric excess stock of carbon $S_t$ is given by $S_t =$

$$\sum_{s=0}^{\infty} (1 - \mathrm{ds}) \sum_{i=2}^{r} Mi, t - s$$

$$1 - d_s = \varphi L + (1-\varphi L)\ \varphi 0\ (1-\varphi)^s$$

These indicators measure carbon depreciation from the atmosphere. It suggest that $\varphi L$ remains in the atmosphere forever. The interesting concept of this model is how the climate interacts with the economy. The assumption is that $CO_2$ levels directly impact the productivity (technology shock) of the economy through a log linear specification:

$$A_{i,t} = \exp(z_{i,t} - \gamma_{i,\ t} S_{t-1})$$

where $z_{i,t}$ is a stochastic productivity trend, $\gamma_{i,\ t}$ is a region-specific parameter that determines how climate-related damages depend on the amount of $CO_2$ levels. The value of $\gamma$ can be calibrated to match the frequency of hurricanes that impact The Bahamas. It can predict, over long-horizons, how much economic damage The Bahamas will incur from climate change through this parameter. Finally note that $S_{t-1}$ enters with a lag, which suggests that pollution today will impact the economy a decade from now. This is justified as the current damage to the environment due to global warming cannot be reversed given current technology.

The climate system is assumed to follow the DICE/RICE model of Nordhaus described in Nordhaus and Boyer (2010):

$$T_t = T_{t-1} + \sigma_1 \frac{\mathrm{n}}{\ln 2} \ln\left(\frac{St-1}{S0} - \varkappa Tt - 1 - \sigma_2 (T_{t-1} - \mathrm{T}^{\mathrm{L}}{}_{t-1})\right)$$

$$\mathrm{T}^{\mathrm{L}}{}_t = \mathrm{T}^{\mathrm{L}}{}_{t-1}\ \sigma_3 (T_{t-1} - \mathrm{T}^{\mathrm{L}}{}_{t-1})$$

Where $T_t$ is the global mean temperature in the atmosphere (and upper layers of the ocean) and $\mathrm{T}^{\mathrm{L}}{}_t$ is the mean temperature in the deep ocean. Both are measured as deviations from their pre-industrial levels.

## Government

According to Krusell et al (2020), a key factor in their study was that the analysis of the consequences of climate change related policies were not uniformly optimal across regions. Hence, in the present study, two different scenarios of a carbon tax $\Gamma_{i,t}$, the ad valorem tax and per unit taxes were considered. The ad valorem taxes, the cost of energy services provider of used energy sources in the region $i$ is $(1+ \Gamma_{i,t} g_j)\, Pj, i, t$, and $\Gamma_{i,t}, g_j, + P_{j,i,t}$ with per unit taxes. The government handles this taxes by using a budget constraint.

The government budget constraint is given by (per unit taxes):

$$\Gamma_{i,t(}W_{i,t}L_{i,t} + R_{i,t}\, K_{i,t)} = \Gamma_{i,t} \sum_{k=1}^{n} gk^{e}k, i, tPk, i, t$$

## Calculation of Welfare

The welfare was calculated by using the resource constraint below:

$$Y = C + I + G$$

The current calculation reduces the consumption proportionally to the change in temperature.

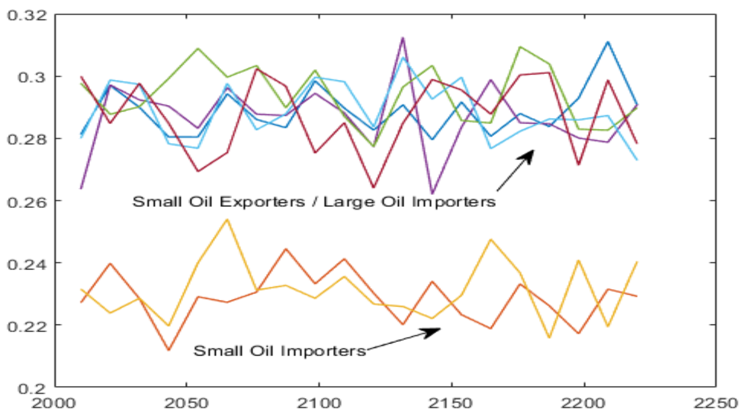
In the counterfactuals of models, it tested how global temperature and utility respond with different parameters. Specifically, the initial carbon levels and taxes were modified.

## Comparison across Country Types

With regard to Hassler et al. (2020), the model allows for regional heterogeneity, as the most important distinctions are small versus large economies; and oil producers (exporters) versus oil consumers (importers). In this analysis, regions can only trade in oil and cannot share global-warming risk.

As shown in Hassler et al., the percentage GDP losses incurred from a unit increase in the atmospheric carbon concentration are significantly different across country types, with large economies benefiting from oil subsidies and with less developed economies that are not oil producers, being most impacted.

**Graph 1: Growth Rates Across Country Types: Status Quo**




## Hurricane Stimulation

In this analysis, it was assumed that the chance of a hurricane making landfall in The Bahamas depends directly on oceanic temperature via a beta distribution.

The probability of a hurricane is given by:

$$1 - ß\ ( 16 - S, 1 )$$

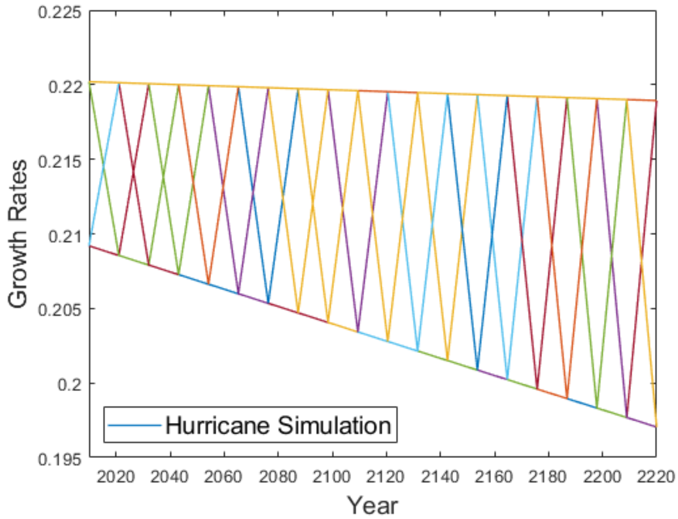
where *s* is the *increase* in global temperature, determined endogenously in the model.

The mean of this process is 0.94, with *s* = 0**,** which is calibrated as a conservative estimate to a 6.0% chance of a hurricane each period. In this regard, it was assumed that the economic impact increases linearly, with global temperature rising from 5.0% of GDP, for *s* – 0, to 10.0%, for *s* – 10.

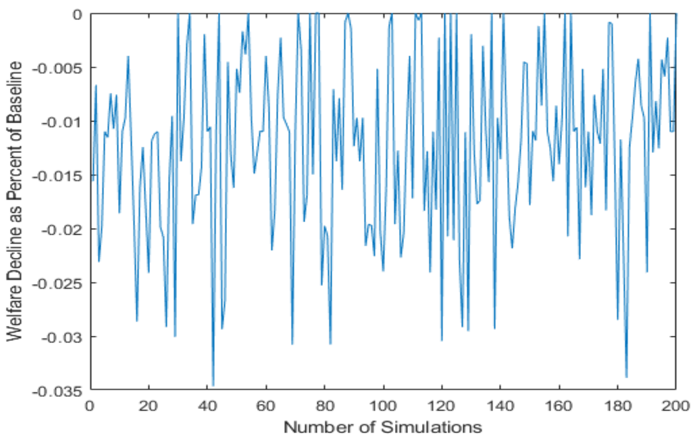
## Hurricane Simulation: Results

In the results, GDP annual growth rate in the Bahamas averaged 1.09% from 1990 until 2021. The baseline was set to 1.4, to reflect the slightly higher growth rate from 2000-2021. Under the "no taxation" scenario, growth rates fall from a potential 1.4 to 1.2, which suggests a seemingly slight decline in growth, but this would have significant implications due to the long-run feature of the model. Gaining two percentage points in growth over a 100-year horizon implies that GDP would be higher by a factor of nearly 7! Further, lifetime welfare has a possibility of declining to 3.5%, with reference to Lucas welfare cost of business cycles at 0.05%. Again, while these annual percentages seem small, they accumulate over a lifetime.

**Graph 2: Estimate of Decade Growth Rates: Hurricane Simulation**




**Graph 3: Estimate of Decline in Welfare: Hurricane Simulation**




## Calibration

To obtain the desired results, the model was calibrated to Bahamian data. It set $r = 2$ to consider only the oil-consuming and the oil producer regions, since the base assumption only considers the Bahamas. Subsequently, the Bahamas imports most of the goods, so it was assumed that oil producing region that sells to the Bahamas would be among the OPEC countries.

## Calibrated Parameters

The parameters were taken from previous literature. Since the literature regarding climate change in The Bahamas specifically is limited, the parameters that were well suited to small open economies were selected, in order to make the model applicable to The Bahamas, with the exception of the discount factor which was calculated specifically for The Bahamas. Table 2 below provides a justification for the calibration based on the literature. The number of different fuel imports into the energy production equation for the region is set to $n = 3$. Oil is the first fuel option in the region, followed by coal and green energy. In the final-good production function, the share of capital $\alpha = 0.3$ was set using the study (Krusell 2018) of consequences of uncertainty and the fuel income share (share of energy services). The production of energy services was calibrated as follows: for the elasticity parameter, meaning the substitution of the three sources of fuel, Stern 2012 finding was used, with $p$ **=** -0.058. To calibrate the λ's the methods of Glolosov et al (2014) were used, whereby the authors used the price of coal and some carbon content to make assumptions on the units of coal versus other energy sources. The same assumptions were made for oil and green energy. Then from the authors Krussell (2018), a ratio of oil to coal was estimated in order to obtain the λ**'s** then a normalization was done to ensure that λ summed to 1. The same assumptions were made for the remaining parameters.

## Results

For the results, similar to Hassler et al (2018), different tax scenarios were applied to the global temperature and the utility of The Bahamas. In Particular, the cases of no tax, per unit tax and ad valorem tax were reviewed. As stated before, the ad valorem tax is a charge based on the value of a product. In terms of the study, this tax is imposed on the value of region one's oil purchased by the oil consumers. Meanwhile, per unit tax can be described as a fixed amount that is charged for every unit of oil purchased by the oil consumers. The results are displayed in below in Figure 1.

**Table 2: Calibrated Parameters**

| Symbol | Variable Name | Value | Source |
|---|---|---|---|
| β | Discount Factor | 0.91 | Ramirez and Wright (2017) |
| α | Share of Capital | 0.30 | Hassler and Krusell (2018) |
| ν | Share of Energy Services | 0.03 | Hassler and Krusell (2018) |
| p | Elasticity Parameter | -0.058 | Stern (2012) |
| $\lambda_1$ | Share of Oil | 0.355 | Golosov et al (2014) |
| $\lambda_2$ | Share of Coal | 0.102 | Golosov et al (2014) |
| $\lambda_3$ | Share of Green | 0.543 | Golosov et al (2014) |
| $A_2$ | Coal Technology | 7693 | Hassler and Krusell (2018) |
| $A_3$ | Green Technology | 1311 | Hassler and Krusell (2018) |
| $L_1$ | Labour Share Oil | 1 | Hassler and Krusell (2018) |
| $L_2$ | Labour Share Coal | 0.004 | |
| $L_3$ | Labour Share Green | 0.0001 | Hassler and Krusell (2018) |

**Figure 1: Effect of Taxation on Mean Temperature**

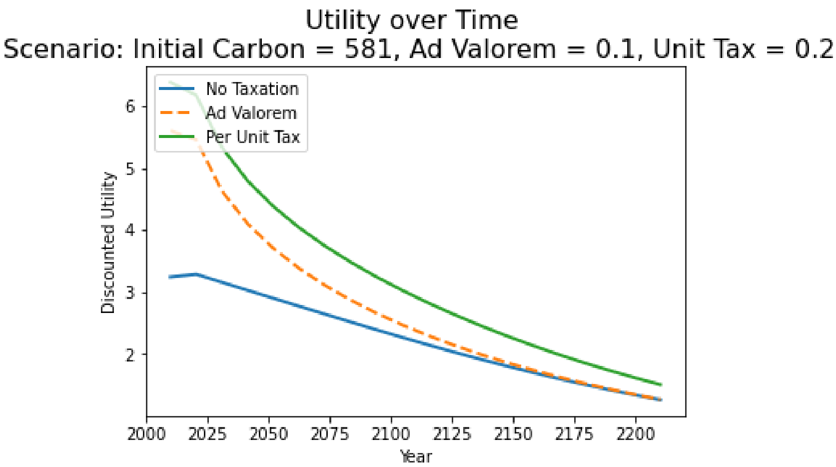



Figure 1 shows the effect of the different taxation scenarios on global temperature. An increase in the temperature would disapprove that there is an improvement in the level of climate change. Overall, the results reveal that the global temperature increases in every case, but to a lesser degree when the ad valorem tax is imposed. This indicates that a carbon tax could be a useful tool in the fight against climate change, thus co-signing the results of the studies discussed in the literature review. However, the per unit tax can be consider the better tool because it surpasses the ad valorem tax at curbing the growth in global temperature. This is not surprising because it is possible that a per unit tax could be more costly to oil consumers than an ad valorem tax. Our reason is the fact that the price of oil can fluctuate frequently due to a plethora of reasons. Since the ad valorem tax is tied directly to the value of oil, if the price of oil falls over the period, the tax collected from it will decrease. With regard to per unit tax, even if the price of oil falls, the amount charged remains the same which can act as a deterrent in purchasing oil.

In theory, the per unit tax leads to a shift in purchases across product quality grades because they cause consumers to either purchase less of a particular good, which is known as quantity substitution, or purchase higher quality versions of the good, which is referred to as quality substitution (Hoffer and Nesbit 2018, 143). In another explanation, per unit taxation generates more government revenue, which the government can use to finance public goods that benefit society. For example, the government could improve their region's transportation, which is likely to encourage more people to take busses, thereby decreasing the number of cars on the road, and thus, the level of carbon emissions in the city. It is estimated that approximately 20.0% of the emissions reductions needed to slow rising temperatures, need to come from trips avoided or trips shifted from buses.

The counterfactuals of our models, to test how global temperature and utility respond with different parameters were examined. The initial carbon levels and taxes were modified. In Figure 2, the results of models, following the adjustment of carbon to 750, instead of our original 581 and raising the ad valorem to 0.2, while lowering the unit taxes to 0.1, were presented. The results now show a minor difference to the baseline scenario, as the lower unit taxes lead to slightly higher global temperature even with a larger initial carbon level.

Growth in global temperature does decline in the face of a tax in all our scenarios. It is the view that this is because a tax may not be enough to completely slow the advancement of climate change.

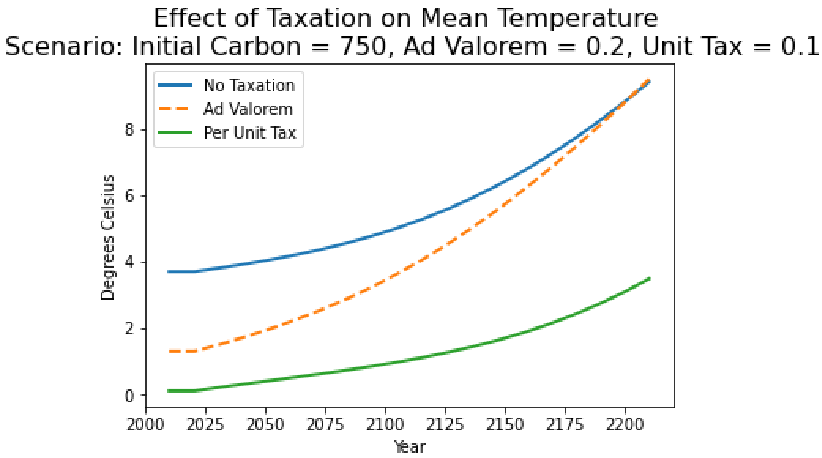



**Figure 2: Effect of Taxation on Mean Temperature**

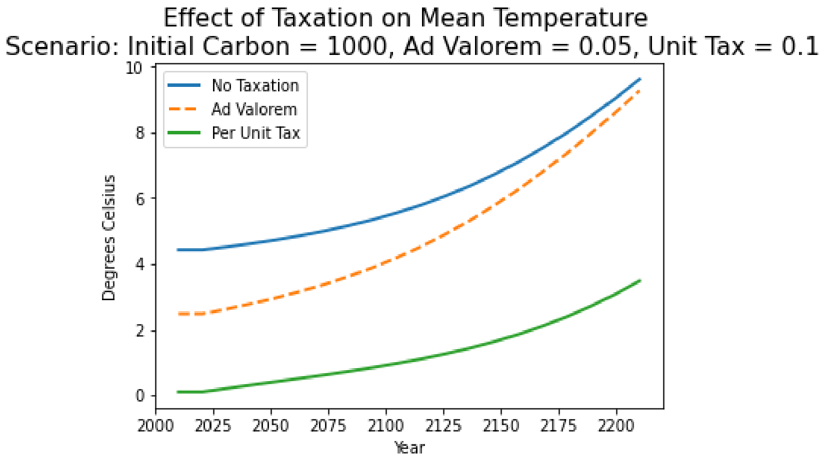



**Figure 3: Effect of Taxation on Mean Temperature**

Referencing Krusell and Smith (2020), it can be inferred that The Bahamas is a part of the 44.0% of the regions that did considerably gain from the tax. In Hassler and Krusell (2012) study, the authors concluded that the tax was only significantly effective when it was imposed on oil producing countries. Therefore, since The Bahamas is only an oil consumer, the country may not have as much influence in slowing the progression of climate change, as a country that is an oil producer. Nevertheless, the imposition of a tax is better than no tax at all, so the study advocates for the imposition of any form of carbon taxation, especially a per unit tax which appears to be the more impactful form of tax scenario.

Regarding utility, Figure 4 shows the utility over time in the same scenarios discussed previously. According to observations, the most utility is lost when there is no tax imposed. Less utility is lost in the tax scenarios, which implies that taxes could provide benefits to reduce some of the losses that The Bahamas may incur if the tax is not implemented. However, more utility is lost in the per unit tax scenario, in comparison to the ad valorem tax scenario. Therefore, the ad valorem taxes are more beneficial in terms of welfare, than the per unit taxes in an economy with monopolistic competition. Reason being the profit-maximizing price of the monopolist is lower under ad valorem taxation relative to when unit taxation is imposed, which implies that ad valorem taxes causes less distortion or deadweight loss, which results in greater equilibrium output, thereby making them welfare superior to unit tax (Hamilton, 1999). In this study, ad valorem taxes are a function of the price of oil, which is partially under the control of Region 1. Intuitively, ad valorm taxation eliminates a portion (Equal to the ad valorem tax rate) of a Region 1's incentive to limit its output level in order to raise prices (Auerbach, Hines, and National Bureau of Economic Research (Cambridge, Etados Unidos 2001). This form actually manages to achieve a degree of Pareto Efficiency, which means that there is no change that could lead to improved satisfaction for some agents without other agents losing if there's no scope for further Pareto improvement. (Blackordby and Murty 2007).

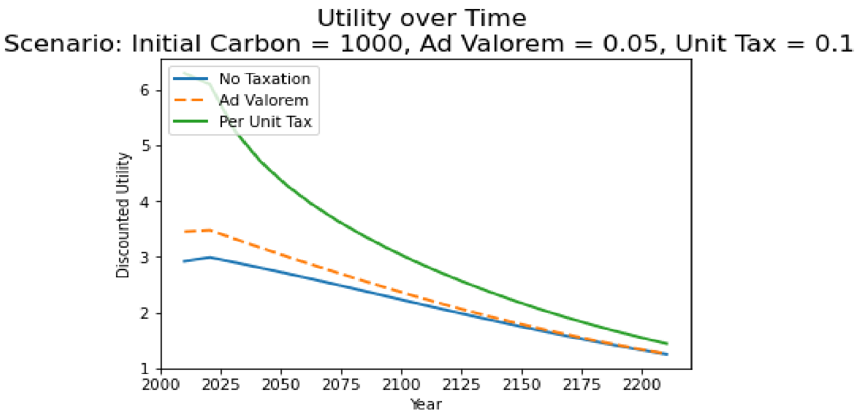



**Figure 4: Utility in The Bahamas overtime with a Carbon Tax**

The counterfactuals of our model were presented to test how utility responds with different parameters. In figures 6 and 7, we present the results of the models, following changes in the initial carbon level, ad valorem and unit taxes. There is less utility loss when no tax is imposed vis-à-vis the model with original parameter.

## Conclusion

Climate change is serious and the most important issue today. The Bahamian government has enacted policies which address these concerns of climate change. In 2005, the government developed a National Policy for Adaption to Climate Change, which assesses the level of vulnerability of The Bahamas to climate change by each sector of the economy, which includes coastal, marine resource and fisheries, terrestrial biodiversity resources, agriculture and forestry, human settlements and human health, water resources, the energy and transportation, and tourism, finance and insurance industries. These policies include actions for addressing impacts and a plan of action to include the expansion of coastal monitoring and data collection in order to aid in decision making. The government also mentioned the development of a comprehensive National Land Use Management Plan, and the promotion of alternative fishery and resource use activities. Further, the government proposed the establishment of a National Energy Policy to provide tax incentives for the usage of renewable energy, such as solar, wind and wave energy, which is in line with the Kyoto Protocol, which is an international agreement that aims to lower emissions in the atmosphere. The Bahamas has also joined member countries to reduce carbon emissions, so much that global warming is limited to well below 2 degrees Celsius above pre-industrial levels, while pursuing efforts that limit the temperature increase even further to 1.5 degrees Celsius.

In the finding of this study, it was noted that, following the imposition of both the ad valorem and per unit carbon taxes, the growth in global temperature declines. However, the per unit tax seems to be more effective in combating climate change, because the progression of global temperature decelerates more, following the imposition of this tax relative to the other tax. This is perhaps due to the fact that the ad valorem tax may not generate as much revenue as the per unit tax. When the value of the initial carbon level and tax rates are adjusted, the general results do not change, which led to the conclusion that the results are credible. Taxes can help to reduce dome climate change, however, The Bahamas may not be able to curb climate change as much as a region that produces non-renewable forms of energy. So, the taxes are effective only up to a certain point.

However, global temperature will continue to rise and there will be some lost utility. In this paper the recommendations include, improving the country's urban drainage infrastructure to mitigate any potential flooding from a storm. Further, it would be prudential for New Providence's southern mangroves to be restored, as they are a natural protection against storm surges, in addition to the coral reefs. In addition, seawalls should be routinely upgraded. With regard to the beach issue, extensive sand fencing options should be pursued to keep the sand on the beaches and away from the streets. There should also be a barrier dune between the beaches and the roads wherever possible. These dunes need to be maintained periodically. Each dune should have a salt tolerant native vegetation species next to it in order to stabilize it.

Further, more native plants should be planted in general, as they bind to the sand, thereby providing another method to keep sand trapped on the beach. Another, more extreme long term option is the relocation the roads so that they are further away from the beaches, in order for walls and dunes to be created. In addition, shorelines should be extended outwards, similar to Baha Mar reclamation of the shoreline (Sealey 2012).

In addition, the majority of the country's infrastructure is located on the coastline, inclusive of is tourism substructure, such as hotels, restaurants, roads, airports and docks, hence, it is suggested that these properties require a higher building code standard than inland properties (Hartnell, 2018). Specifically, it has been recommended that all the elements from the foundation to roof be anchored, in addition to reinforcing the foundation-to-wall, wall-to-floor, floor-to-floor and wall-to-roof connections, as this type of design will allow dwellings to resist high wind forces as a unit (ECLAC, 2020).

In conclusion, the effects of climate change will not disappear in the near term, so it is important that methods are explored to combat the growth in carbon emissions and the global temperature.

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