Climate change mitigation & adaptation in the Caribbean: Resilience and energy security lessons and experiences

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In the present work we peer into stories of in the Caribbean archipelago, concluding that the Caribbean is diverse and vast and we must therefore take advantage of several independent streams of resources, and delve deeper into numerical and quantitative engineering and economics analyses, to successfully implement climate change mitigation, climate change adaptation, climate resilience and energy security in our region. Given the diversity of Caribbean states, we also assert that the end of the fossil fuel era for Caribbean oil producers must not harm their economies, if their petroleum industries are re-purposed in ways that do not harm the atmosphere, but continue to ensure economic stability. Finally we also conclude that if the most effective climate change mitigation effort is reduced energy consumption by average citizens, then pervasive organized crime and heightened street violence, which hamper personal climate change mitigation measures for many individuals, must be dispelled from the Caribbean.

Key words: Climate Change; Caribbean; Mitigation; Adaptation; Trinidad and Tobago; Barbados

1. Introduction

The Caribbean region, which we can call for a moment, the fictitious continent of Archipelagic America, is primarily oceanic (see Figure 1), boasts a population of thirty million (McEvoy 2001) and a surface area of 1,063,000 square miles (Ogden, J. C. and Menzies, R. J. 2019).

It is as varied as it is vast. From the difficult mountainous terrain of Dominica to the booming solar power industries of Barbados and Antigua, to wind energy's success in Jamaica, to the fear in the eyes of Puerto Ricans after hurricane Maria, we see various realities, challenges and successes in the regional battles with climate and energy. Across the language barriers, historical barriers, and cultural barriers, there are seven loose definitions of the Caribbean Williams & Bunkley-Williams (2021). There are the British West Indies which heavily influence CARICOM, the Spanish speaking Caribbean territories, Cuba, Puerto Rico, Dominican Republic, etc, the Francophone Caribbean, namely French Guiana, Guadeloupe, Haiti, Martinique, etc, the Dutch territories such as Aruba, Curacao, etc, the US territories in the Caribbean Sea such as Puerto Rico and the U.S. Virgin Islands, and finally the Greater Caribbean Region,

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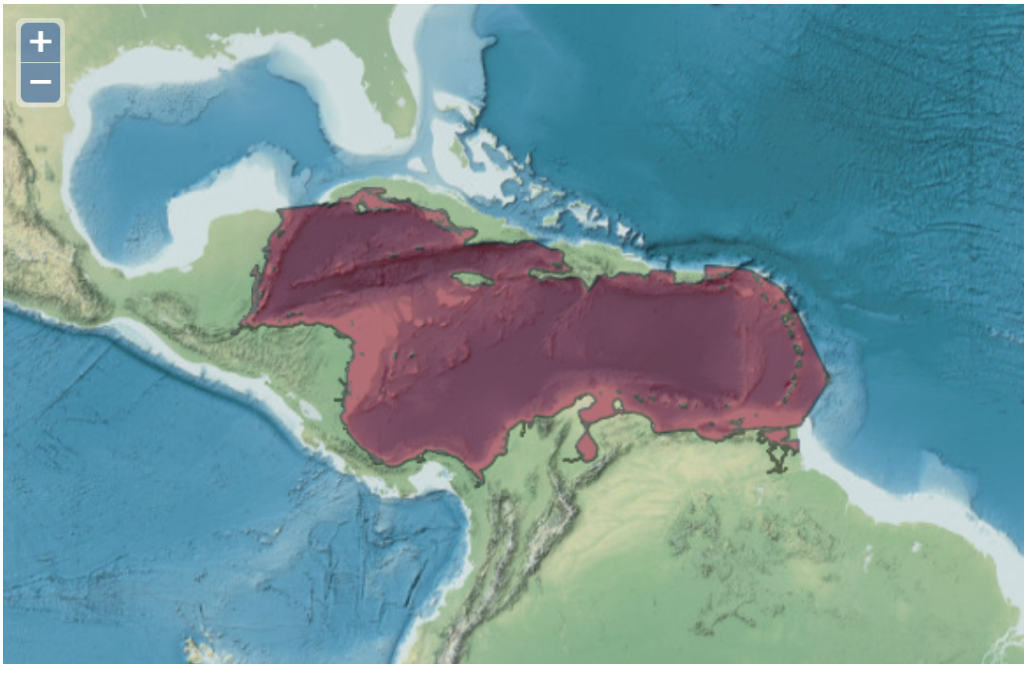

FIGURE 1. Boundaries of the Caribbean Sea (Marine Regions 2021).

covering territories that touch the Gulf of Mexico and Central America. Depending on the issue at hand, there can be great benefits from that diverse configuration. In terms of climate change mitigation, climate resilience and climate adaptation resources, these seven loose definitions of the Caribbean actually point towards seven distinct streams of helpful resources to the Caribbean region. These seven streams should be more strategically exploited.

Regional Organizations such as Caribbean Community Climate Change Centre, Caribbean Centre for Renewable Energy and Energy Efficiency, CARICOM, and the Caribbean Development Bank (to name a few) exert magnanimous efforts around climate change mitigation & adaptation in the Caribbean, towards climate resilience and energy security. But alas, there is a leaky pipeline between the massive streams of resources flowing towards the Caribbean, and its climate resilience outcomes. Comparing for example current hurricane landfall outcomes in Archipelagic America with hurricane landfall in North America, repeatedly we find increasing hurricane severity and thus increasing damages in USD per capita in Archipelagic America, in contrast with a century of sustained damages in USD per capita in North America (Weinkle *et al.* 2018). This speaks to the different outcomes of climate change mitigation & adaptation efforts in North America compared to those in Archipelagic America. Adaptation programs in the Caribbean are usually internationally supported and can for example be funded by facilities such as the Global Environment Facility (GEF) or the Green Climate fund, executed through entities such as the World Bank, while overseen by regional bodies such as the Organisation of American States. However, in a survey of 89 reports on the outcomes of such programs, in 2019 Thomas identifies repeated deficiencies in rigorous connections between the range of appraised adaptation options and the actual climate hazards, and their associated impacts, vulnerability, and risk. Within these documents

glaring deficiencies in quantitative information about hazards and their impacts are also identified (Thomas *et al.* 2019). These deficiencies characterize the leaky pipeline between the source of funding and the climate hazard outcomes of the average Caribbean citizen. We must negotiate greater levels of support flowing into the Caribbean region (Bert Wilkinson 2021), but we must also fix the leaking pipeline to improve the status of climate change adaptation and resilience outcomes in the Caribbean. There is a very real concern that Caribbean nations stand on the front-lines of global climate change, and Caribbean regional global warming threats are deemed immediate and urgent (Shultz *et al.* 2020; Greig *et al.* 2020; Zegarra *et al.* 2020; Francis & Nair 2020; Barclay *et al.* 2019; Walcker *et al.* 2019; Cloos & Ridde 2018; Hu & Smith 2018). To stand powerfully on these front-lines, the challenges of Climate Change Mitigation, Climate Change Adaptation, climate resilience and energy security must be met not only with an influx of funding (Bert Wilkinson 2021), but also with strategically positioned human resources possessing the primarily quantitative, evidence-based and analytical skills to close the leaky pipeline. Because of the infancy of analytical, numbers-based climate change mitigation and adaptation analyses applied to the Caribbean region (Drakes *et al.* 2020; Mercer *et al.* 2012; Thomas *et al.* 2019), this shift can best happen if it is lead by teams of highly skilled Caribbean nationals trained to tackle quantitative questions using data capture and data science methods alongside economics and engineering analyses to produce tangible, measurable solutions.

2. Climate change mitigationand the Caribbean

The Intergovernmental Panel on Climate Change (IPCC), the United Nations body for assessing the science related to climate change, defines Climate change mitigation as any effort which serves to reduce the unnatural excess of greenhouse gas emissions in the atmosphere (IPCC 2021). In the Caribbean region, where most nations are small island developing states or SIDS, the massive impacts of climate change have already wreaked major havoc (Shultz *et al.* 2020; Greig *et al.* 2020; Zegarra *et al.* 2020; Francis & Nair 2020; Barclay *et al.* 2019; Walcker *et al.* 2019; Cloos & Ridde 2018; Hu & Smith 2018). In response to an unfolding situation, several regional renewable energy targets (CARICOM 2021a) have been outlined by the Caribbean Community (CARICOM 2021). From a global standpoint, such targets are primarily and powerfully symbolic, as global climate change is arguably driven by the emissions of larger countries with bigger populations (Althor *et al.* 2016; Nakamura & Mufson 2014; Stern 2006). More importantly, these targets allow for the idea of energy independence for many Caribbean nations, the majority of whom are currently net importers of fossil fuels, thus at the mercy of fluctuations in global oil prices. Due to the colossal man-made increase in atmospheric carbon dioxide, current climate change mitigation activities constitute a marathon and not a sprint.

Climate change mitigation must comprise primarily of two changed societal behaviors: (1) Greater energy efficiency in all practices (Ürge-Vorsatz & Metz 2009; Robèrt *et al.* 2007), alongside (2) a shift from fossil fuels to renewable sources of energy (Johnsson *et al.* 2019). This is not a unique need for the Caribbean region, but Climate Change mitigation activity is globally everybody's responsibility (Kang *et al.* 2020; Rong 2010; Chandler *et al.* 2002). The Caribbean is however, at the mercy of the international community's decisions about climate change mitigation, given thei small size compared to the rest of the world, and their current distressful experiences of climate related disasters (Shultz *et al.* 2020; Greig *et al.* 2020; Zegarra *et al.* 2020; Francis & Nair 2020; Barclay *et al.* 2019; Walcker *et al.* 2019; Cloos & Ridde 2018; Hu & Smith 2018).

Thus, energy efficiency or energy consumption reduction, which will serve as the most important industrial Climate Change mitigation activity anywhere in the world (Worrell *et al.* 2009), has to be a primary target throughout the Caribbean region's industries. Beyond industry though, if average daily human practices incorporate walking, bicycling, carpooling, using public transit and even supporting car-free districts instead of driving alone, climate change mitigation can be further facilitated by the concept of energy efficiency filtering down to individuals' personal transportation decisions Scarinci *et al.* (2017). However, there are strong links between perceived social order and climate-friendly human activities. For example, in Trinidad and Tobago, where crime is the top public concern (Chadee *et al.* 2017), many persons opt out of public transit and walking and prefer to drive privately as a personal safety measure (Francke 2013). If violent street crime is a daily reality in Trinidad and Tobago, and several other Caribbean regional examples where similar concerns pervade (O'Neal, Eugenia 2020; Hill & Morris 2017; Ayres 1998; Sutton *et al.* 2017; De Albuquerque & McElroy 1999; Imbusch *et al.* 2011), Climate Change mitigation is tied to crime control and a general sense of public safety from randomized violent street crime.

Assessing the the Caribbean region's shift from fossil fuels to renewable sources of energy, the Caribbean Centre for Renewable Energy and Energy Efficiency (CCREEE) has published a sequence of Energy report cards (Victoria Healy and Laura Beshilas and Kamyria Coney and Gary Jackson 2021*a*), and the United States of America's National Renewable Energy Laboratory (NREL) has also included the Caribbean region in their suite of Energy snap shots (Victoria Healy and Laura Beshilas and Kamyria Coney and Gary Jackson 2021*b*; Victoria Healy and Laura Beshilas and Kamyria Coney 2021; Victoria Healy and Laura Beshilas and Kamyria Coney and Gary Jackson 2021*c*,*d*). Looking at these assessments, the infancy of the Caribbean's climate change mitigation activity can be clearly seen. Barbados, which has set the ambitious renewable energy goal of being fossil fuel free by 2030, surpassed its C-SERMS target (CARICOM 2021) in its locally written energy policies (Government of Barbados, Ministry of Energy and Water Resources 2019). However, Climate Change mitigation is analytical before being technological (Thomas *et al.* 2019) and certainly not just about blind technology importation outside of a wider strategic implementation framework which considers energy efficiency measures, assesses various forms of available renewable energy resources, and then implements in a streamlined sustainable manner which includes long term plans for maintenance and upkeep (Ikejemba & Schuur 2020). In Barbados, a recently implemented BNOCL solar PV program designed to bring solar PV to thousands of Barbadians (Sheena Forde-Craigg 2021) has been halted for several months as the electric grid swiftly became over-inundated with the sudden influx of solar power in several densely populated areas of Barbados. Climate change mitigationpolicy must be written and implemented alongside a technical understanding of the mechanics of RE systems and detailed engineering-led, economics-based needs analyses to avoid program failure. These practices will also inform Climate Change Adaptation efforts which require similar levels of understanding and rigor.

3. Climate Change Adaptation

Caribbean regional viability requires a more dire global end-of-century goal of a 1.5^oC rise in global temperatures, compared to the international community's widespread stipulated target not to go past a 2^oC rise in global temperatures (Knutti *et al.* 2016; Randalls 2010). In the absence of this, Climate Change Adaptation is now the critical lower bar for which the Caribbean region must achieve viability (United Nations 2021).

Climate change adaptation refers to any action taken to prepare for and adjust to both the current effects of climate change and its predicted future impacts (The European Commission 2021). In the Caribbean, expected climate change effects include increased hurricane severity (Tompkins 2005; Lugo 2000), rising temperatures, erosion, flooding, drought, storm surges (Robinson & Wren 2020), falls in vegetative agricultural yield because of increased drought (Herrera *et al.* 2018), and reduced yields from dairy farming due to increasing livestock water requirements and heat stress (Lallo *et al.* 2018).Thus, in several economic sectors, the Caribbean region must adapt ahead of and amid these climate change symptoms.

Surveys of Caribbean climate change adaptation policy documents show ad hoc approaches (Thomas *et al.* 2019; Mercer *et al.* 2012) and a deficiency in the quantification of regional climate hazards and their impacts (Thomas *et al.* 2019). Thus, there are very few quantitative/numerical assessments of climate adaptation needs, such as seen in the work of (Drakes *et al.* 2020), in which a quantitative link is demonstrated between an IPCC-specified climate scenario, RCP 4.5 (Intergovernmental Panel on Climate Change 2021) and water resource management in Barbados. Going forward, an increase in similar quantitative Climate change adaptation efforts in the Caribbean region can lead to many areas of bolstered climate resilience.

4. Climate resilience

Climate resilience is the ability to withstand weather and climate-related hazards (US Climate Resilience Toolkit 2021; Tyler *et al.* 2016; Tyler & Moench 2012; Friend & Moench 2013; Bahadur & Tanner 2014). The US Government's Climate Resilience Toolkit stipulates climate resilience requires exploring hazards, assessing vulnerability & risk, investigating Options, prioritizing & planning, and taking action (US Climate Resilience Toolkit 2021). In the Caribbean, these stipulated steps must be adopted as a guide for exploring more evidence-based, numerical approaches to climate challenges, leading via data capture and data analysis to full climate resilience. At present our uniquely tourism-dependent economies (Mackay & Spencer 2017) produce a heightened need for mobility justice (Sheller 2021) and other facets of human security (Jerez Columbié & Morrissey 2020), in achieving climate resilience. Caribbean regional climate resilience efforts also cover many internationally applicable areas such as insurance as a measure for human security in achieving climate resilience (Surminski *et al.* 2016), species' conservation across shifting geophysical settings (Anderson *et al.* 2014) when species are migrating due to climate change (Gail Karlsson 2019), climate resilience when agricultural crops are threatened, thus securing the relevant economic and food security (Kahiluoto *et al.* 2019), conservation of the coastal environment and marine biological communities in the changing climate (Bates *et al.* 2019; Jevrejeva *et al.* 2020), and the equalization of access to climate resilience financing (Ayers *et al.* 2011).

Climate resilience experts stipulate that in urban settings, resilience requires consideration of social justice and human security outcomes so that the most vulnerable can avoid poverty in the tendrils of climate change (Tyler & Moench 2012; Tyler *et al.* 2016; Friend & Moench 2013; Bahadur & Tanner 2014). Thus, several Caribbean nations have set out to write integrated resource and resilience plans as a planning tool for renewable energy roll out, but also as a measure to achieve climate resilience in the energy and social sectors. The recently written Barbados IRRP has raised concerns given that it stipulates a solar-power dominated power grid for Barbados in 2030 despite the difficulty of the April 2021 experience of volcanic ash inundation from the La Soufrière

volcano into Barbados. Experts stipulate biofuel as a dispatchable form of fuel that should be included as widely as possible in any resilience effort. This solution would certainly bring emergency sources of power to a fossil fuel free Barbados which suffers under the weight of another volcanic ash influx in a primarily solar powered context. The impact of hurricane winds and falling debris on solar PV installations or wind turbines is also a concern as Barbados is not outside the hurricane path (Robert Edison Sandiford, and Kate Chappell 2021). All these potential sources of power outages are considered in building climate resilience. Internationally funded Caribbean climate resilience work such as (CNG Media 2021) needs to foster greater strategic alignment between climate resilience activity in the Caribbean region, and climate resilience activity prescribed by international experts (Thomas *et al.* 2019; Mercer *et al.* 2012).

Part of the resilience effort must be the ability to minimize power interruptions in the wake of natural hazards such as storms and floods. In many places around the developing world, owning a generator and power storage technology have become a status symbol among the wealthy, whose power remains uninterrupted during natural hazards. However, nationwide implementation of the right ratios of the various modes of Renewable Energy can bolster this type of climate resilience for all persons who depend on the electric grid. Such climate resilience issues of equalization and human security in the context of the Caribbean are inextricably linked to energy security.

5. Energy Security

Energy security, or a nation's uninterrupted access to the energy it needs, touches on climate change mitigation & adaptation in the Caribbean, along seven major dimensions: Energy availability, infrastructure, energy prices, societal effects, environment, governance, and energy efficiency (Ang *et al.* 2015). In the Caribbean, primarily comprised of small island developing states (SIDS), where energy access currently primarily depends on foreign fossil fuel supplies and is therefore costly, energy security is in actual crisis (Niles & Lloyd 2013).

In the shift away from fossil fuels, energy security warrants a multi-faceted approach toward energy, where multi-modal renewable energy sources provide options and alternatives in the face of climate hazards and other possible difficulties (Li *et al.* 2016). For example, beyond hurricanes and volcanic ash, we can consider one renewable energy impact of drought. Because of climate change, increased drought causes lower river flow rates which in turn causes reduction in hydroelectric power sources. This is something to guard against in the case of Belize, whose electric grid is 52% hydroelectric powered (Healy *et al.* 2021), and in Suriname, whose electric grid is 60 % hydroelectric powered (CCREEE 2018).

6. Lessons and Experiences in Barbados and Trinidad

Indeed, Archipelagic America is as varied as it is vast, and as seen in all the practical examples of the previous sections, we do not have to traverse very far to illustrate this point. Comparing Barbados with Trinidad and Tobago, two great examples which actually share a Maritime border, we find two very distinct experiences of Climate change Mitigation, climate adaptation and resilience, and energy security. While Trinidad lucked out in the primordial lottery system for nations and sits on profitable oil and gas reserves,

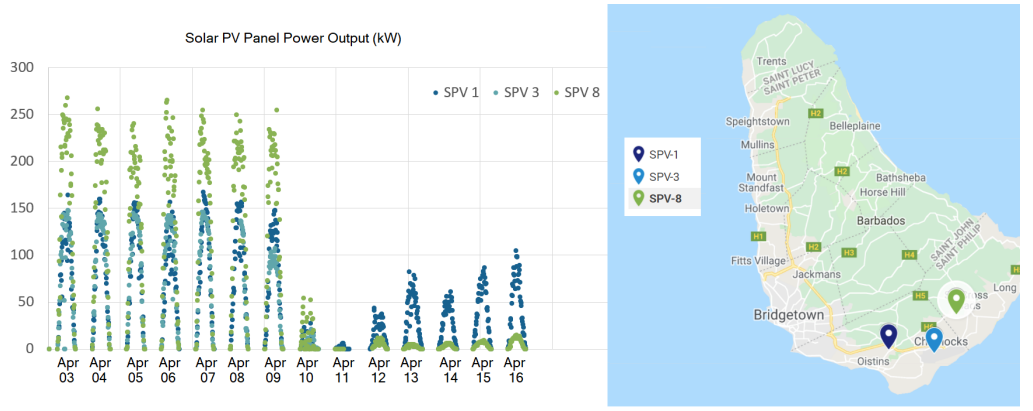

FIGURE 2. Commercial Solar photo-voltaic panel output power on the Barbados south coast before and after the April 9th 2021 eruption of the La Soufrière volcano Henry *et al.* (2021)

Barbados won that same primordial lottery for the best beaches in a massive nationwide spread of flawless postcards waiting to happen.

Wile Trinidad now struggles with the possibly harsh economic fall-out of the end of the fossil fuel era, Energy access came to the fore in Barbados during 2021, which has been an unprecedented year for the citizens of Barbados, battling two major natural disasters (Sandy Deane 2021) in the context of the unfolding COVID 19 pandemic.

6.1. *La Soufrière volcanic eruption*

Barbados does not have volcanoes, but she is still vulnerable to volcanic ash-fall due to volcanic activity in the nearby volcanic island of St. Vincent. The La Soufrière volcano poses energy supply issues in St. Vincent (electric grid disruption (Patrick Oppmann 2021)) as well as Barbados (solar panel obstruction (Henry *et al.* 2021)). In Barbados' efforts towards being fossil fuel free by 2030, solar power is expected to supply the majority of the needed electric power ('Barbados Ministry of Energy Small Business and Entrepreneurship' and IDB 2021). This raises concerns in the context of the April 10 2021 incident where Barbados was covered in ashes from the La Soufrière volcanic eruption (BC Pires 2021) and solar panels under-performed (Henry *et al.* 2021) for over 10 days (see Figure 2).

The recently published Barbados Integrated Resource and Resiliency Plan ('Barbados Ministry of Energy Small Business and Entrepreneurship' and IDB 2021), without considering the volcanic eruption, stipulates a primarily solar-powered Barbados in 2030. Thus, in that scenario, it is implied that massive, high-stakes, resilience measures **must be implemented** on a nationwide scale to defend against ash-fall experiences in Barbados during future La Soufrière volcanic eruptions which occur after 2030.

6.2. *Hurricane Elsa*

On July 2 2021, a Category 1 hurricane, Elsa, battered Barbados, taking several roofs off homes, and causing damage to 700 roofs (Robert Edison Sandiford, and Kate Chappell 2021; Fabian Belgrave 2021). As the first hurricane that made landfall in Barbados in 74 years, there was widespread relief that it was only rated Category 1. However, as one personally assessed the conditions of the roads, the widespread fallen trees tangled up in damaged electric wires, amid precariously long and pervasive electricity and water outages, it became clear that greater nationwide hurricane resilience measures must be immediately taken.

6.3. *Lessons and Experiences from Trinidad and Tobago facing the end of the fossil fuel era*

Speaking of nationwide resilience, the combination of poverty and oil are not historically associated with resilience, especially where oil is established as the primary industry in a developing territory (Myers & House 2005; Conrad & Jagessar 2018). As a developing country with an oil-based economy, Trinidad and Tobago's oil and gas industry has provided over 120 years of benefits to its nationals (Furlonge & Kaiser 2010). Now, tottering to find bearings in a moment when the entire world is shifting away from fossil fuels, oil-dependent developing nations like Trinidad and Tobago are left with very few options. A clear answer is the notion that *rich nations need to give extra financial support to poorer countries* (Sir Ronald Sanders 2021) to help them to sustainably divest from an economy built on the burning of fossil fuel.

Trinidad and Tobago has a petroleum-based economy which must be diversified via renewables like biofuel (as a transition technology to move away from oil and gas in the changing world) and a bolstered, sustainable petro-chemicals manufacturing sector. This is because biofuels, which are fluid fuels, utilize much of the same technologies (with required adjustments) as are used now during the dying the fossil fuel era. Trinidad and Tobago, heavily oil dependent, logically hesitates as she weighs the potentially crippling cost of abandoning all fossil fuel assets and transitioning to renewable energy (Mercure *et al.* 2018; Murto & Nese 2002; Neville 2020; Andrew Gioannetti 2021). The hope of swapping out the current fossil fuels with newly emerging biofuels can benefit countries like Trinidad since they can partially avoid the abandonment of many fossil fuel assets like fuel pipeline networks, diesel engines, CNG cars, etc Robèrt *et al.* (2007); Henry *et al.* (2020); Corro *et al.* (2019), as the Caribbean region transitions away from the fossil fuel era. For economic sustainability, the Oil and Gas transition in Trinidad and Tobago should be centered around the strategic replacement of a fossil-fuel-driven economy with an organic-chemicals-driven economy (Rahman & Khondaker 2012; Vázquez-López 2020) and the replacement of the fluid fuels transmitted in all the physical assets of the fossil-fuel era with biofuels (Henry *et al.* 2020). There is great promise in scaled up production of non-grid and non-transportation petroleum products, and useful organic chemicals that do not burden the carbon content of the atmosphere. Such a transition can only succeed with great financial input, strategic analysis, and remains an urgent challenge for the leadership of Trinidad and Tobago to pursue as the international pressures increase around renewable energy transition. Trinidad and Tobago can join Barbados in leading the Caribbean regional replacement of fossil fuels by using locally sourced substrates Henry *et al.* (2020) as biofuel.

7. Conclusion - Coordination, Streamlining, and moving powerfully forward

In light of the vastness of the Caribbean and the various streams of resource flowing towards the Caribbean region, the opportunity must be met with great effort. In this time of global crises, where we witness the international scientific community come together with governments, media, and the data analytics communities to fight the COVID pandemic, we in the Caribbean must take a similar approach to fight the climate crisis. We must haste the end of ideological silos, and foster a Caribbean region where the seven Caribbean definitions reach across language and historical barriers and relate to each other, and where communities with petroleum expertise and communities with renewable

energy experience unlock various challenges in collaboration with each other towards the same end goal - resilience for the lowest common denominator across the Caribbean nations. It requires, for example, that the sound of the energy space in Barbados and the sound of the energy space in Trinidad eventually harmonize with each other, where at present there appears to be dissonance.

For all our Caribbean nations, experiencing the harshness of hurricanes, temperature increases, sea level rises, drought and flooding, Caribbean viability requires the end of the era where burning fossil fuels dominate global energy. However, as smaller countries like Trinidad and Tobago mitigate this problem by redirecting their petroleum industry, mitigation activity should not render them to poverty, and this is where international support alongside local and regional strategic Economic and Engineering activity are needed.

Important measures highlighted in the present study can be summarized as follows:

- The Caribbean is diverse and vast. We must take advantage of several streams of resources, but do not assume one blanket solution fits all nations
- More numerical and quantitative analysis will ensure climate change mitigation, climate adaptation, climate resilience and energy security in our region. We must bring together regional teams of engineers and economists in a way that remedies the leaky pipeline between the present influx of resource and climate outcomes
- The end of the fossil fuel era for Caribbean oil producers must not harm their economies. The petroleum industry must be regionally re-purposed in ways that do not harm the atmosphere to continue to ensure economic stability
- The most effective climate change mitigation effort is reduced energy consumption by average citizens. Organized crime and street violence hamper personal climate change mitigation measures for many individuals living in the Caribbean and we need to stamp it out of our region as a part of the regional climate change mitigation effort.

Again, the Caribbean region, which we can call for a moment, the fictitious continent of Archipelagic America, is primarily oceanic, boasts a population of thirty million and a surface area of 1,063,000 square miles. It is our home.

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