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ECLAC SUBREGIONAL HEADQUARTERS FOR THE CARIBBEAN

Exploring the notion of a Caribbean emissions trading scheme

Financing the greening of Caribbean economies

Sheldon McLean

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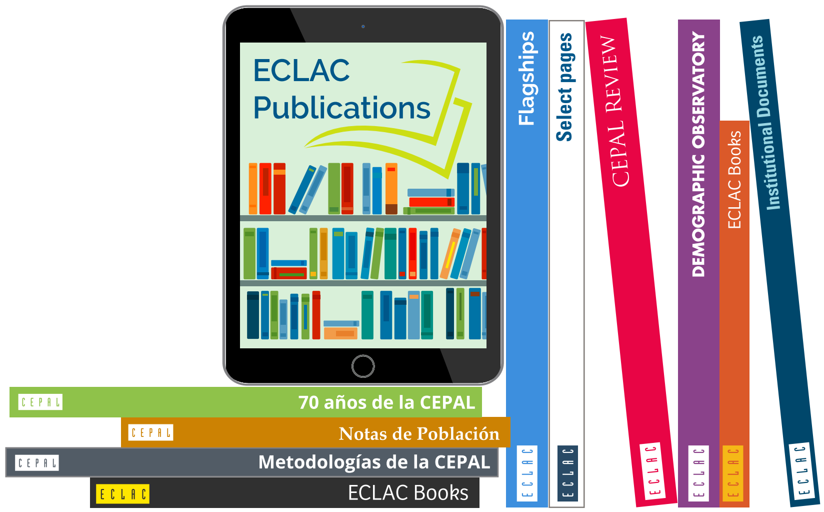

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Abstract

Between 2000 and 2019 the Caribbean Community produced between 0.11 and 0.16% of global emissions. However, despite being only minor emitters these countries find themselves highly exposed to the impact of climate change, increasingly vulnerable to floods, droughts, rising temperatures, rising sea-levels, hurricanes and coral bleaching etc. Furthermore, CARICOM Member States[1] have submitted their Nationally Determined Contributions (NDCs)[2] to the United Nations Framework Convention for Climate Change (UNFCCC). The subregion has, however, lagged behind in the receipt of grant and concessionary support for its climate change adaptation and mitigation needs. Accordingly, one market-based modality, which may be useful a tool for generating the necessary resources for implementing Caribbean NDCs is the development of a regional emissions trading scheme (ETS). Presently, no such market-based mechanism exists in the subregion.

This paper therefore represents exploratory research that considers the structure and function of ETS schemes which can be useful for leveraging implementation of Caribbean NDCs. However, for such an ETS to be a success, its framework must be structured carefully. Key factors which must be considered in its design are the size of the emissions cap for the countries, the sectors that will be involved, the Greenhouse gases (GHGs) to be covered, a monitoring, reporting and verification framework for the GHG emissions, the emissions allowances allocation system, and an emissions allocations reserve. The fact that NDCs may of necessity become increasingly ambitious will also have to be considered when designing a regional scheme. The revenue that is generated from the auctions can be retained by the ETS regulator to assist in offsetting its operational costs. Surplus revenue can be used to finance other climate change adaptation and mitigation projects. However, the distribution of the surplus revenue that accrues from such auctions will need to be carefully calibrated given the heterogeneity in size, industrial development and levels of emissions across Caribbean countries.

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1 All the CARICOM Member States, except Montserrat, submitted their INDCs to the UNFCCC.

2 The Intended Nationally Determined Contributions (INDCs) are the voluntary plans that the countries submitted to the UNFCCC to reduce their greenhouse gas (GHG) emissions. Upon the ratification of Paris Agreement, countries INDCs became their NDCs (Nachmany & Mangan, 2018).

The paper also posits that a bespoke ETS, complemented by the implementation of other climate change adaptation and mitigation projects, would likely assist the countries of the subregion in achieving their NDC targets, while contributing to the international community's overall goal of limiting global temperature rise to 1.5°C. ECLAC proposes to build on this initial research through scenario analyses and a game theory framework, to provide additional insights into the structure, elements, and mechanics of an optimal ETS for the subregion.

Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) was established in 1992 to facilitate the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UN 1992, 9).[3] [4] With its adoption, the international community acknowledged that while all countries contribute to and are affected by climate change, the industrialized countries bear a greater responsibility for the acceleration and increasingly devastating impact of the phenomenon. (Yu & Zhu, 2015). The principle of "common but differentiated responsibility" has remained a fundamental tenet of subsequent discourse on the shared obligation and commitment of States Parties to multilateral environmental agreements, including the first major international treaty to mobilize collective action to address climate change, the Kyoto Protocol.

The Kyoto Protocol, which was agreed to by Parties of the UNFCCC at the third session of the Conference of the Parties (COP 3) in 1997, effectively operationalized the UNFCCC as it committed Annex I countries (comprising industrialized countries and countries in transition) to reduce their greenhouse gas (GHG) emissions.[5] The Kyoto Protocol therefore created a framework to facilitate GHG emission reduction action. The Protocol established Assigned Amount Units (AAUs), which were allowances assigned to countries to emit GHGs comprising one metric ton of carbon dioxide equivalents (CO_2eq). The Protocol also allowed the AAUs to be traded. Countries with unused AAUs therefore could sell these to Annex I countries that produced more GHG emissions than their alloted quota afforded them. This eventually led to the development of the cap and trade system. The European Union (EU) was the first to create a cap and trade system. It placed limits on the amount of GHGs that its regional

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3 The UNFCCC was signed by 154 nations on June 4, 1992, during the Earth Summit in Rio de Janeiro, Brazil. It entered into force on March 21, 1994.

4 The Preamble of the 1992 UNFCCC asserts "that the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions" (UN 1992, 2).

5 The annex I countries initially consisted of thirty-eight developed countries. In contrast, the non-annex I consisted of developing countries.

producers can emit annually. A key component necessary for ensuring the effectiveness of the cap and trade system is the price of the emission allowances.

Then, if regulated entities emitted more greenhouse gases (GHGso than allowed), they could purchase carbon credits to offset their emission reduction commitments.The Twenty First Conference of the Parties (COP 21) sought to stimulate global collective action for countries to reduce their GHG emissions. This led to countries submitting national action plans referred to as Intended Nationally Determined Contributions (INDCS) prior to COP 21.[6] Article 6.2 of the Paris Agreement[7] allows for the bilateral cooperation among Parties to achieve their Nationally Determined Contributions (NDCs)[8] through the trading of Internationally Transferred Mitigation Outcomes (ITMOs) (Schwieger et al., 2019). At the national level, countries are considering the development of carbon pricing instruments, such as emissions trading, crediting, and carbon taxes among their policy-mix designed to support achievement of their NDCs. It is in this context that the possibility of using market mechanisms for climate finance is being explored.

Between 2000 and 2019 the Caribbean Community (CARICOM) Member States[9] produced between 0.11 and 0.16% of global emissions (World Bank, 2023). However, despite being only minor emitters these countries find themselves highly exposed to the impact of climate change, increasingly vulnerable to floods, droughts, rising temperatures, rising sea-levels, hurricanes and coral bleaching etc. Furthermore, CARICOM Member States[10] have submitted their Nationally Determined Contributions (NDCs)[11] to the United Nations Framework Convention for Climate Change (UNFCCC). The subregion has, however, lagged behind in the receipt of grant and concessionary support for the implementation of its NDCs. This must be viewed against the fact that the subregion's high debt burden has limited fiscal space to adequately finance adaptation and mitigation strategies (ECLAC, 2016). This is particularly germane since there were NDCs that were conditional on the receipt of the required technical and financial support from the international community It is important to note that either conditional or unconditional commitments may be applied to the NDCs. Table 1 displays the dates the INDCs were submitted and when the Paris Agreement was ratified.

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6 For several years the international climate change negotiations were in deadlock due to the Annex classification problem. This problem is where the Annex I (developed) countries became upset that the non-Annex I (developing countrieso did not have any emission reduction commitments. In fact, the United States (US), an Annex I country, was perturbed that China, a non-Annex I country and its major competitor in international trade, did not have legally binding GHG emission reduction obligations (Charles, 2019).
On February 16, 2005, the Kyoto Protocol entered into force on February 16, 2005. Its first commitment period covered 2008 to 2012. At the seventeenth Conference of Parties (COP 17) in Durban, South Africa, in 2011, Parties agreed to an extension of the Kyoto Protocol, which resulted in the second commitment period covering 2012 to 2020. In COP 17, Parties also agreed to negotiate a new climate change agreement that would replace the Kyoto Protocol (Charles, 2019).
Prior to COP 21, Parties were encouraged to submit action plans to the UNFCCC which outlined their intension to pursue GHG emission reduction action. These action plans were referred to as Intended Nationally Determined Contributions (INDCs). The INDCs were all voluntary, non-legally binding, and were based on countries national circumstances. The INDCs of each country immediately became their Nationally Determined Contributions (NDCs) upon the Paris Agreement's entry into force in 2016 (Charles, 2019).

7 The Paris Agreement arose out of the twenty-first Conference of the Parties (COP 21) in 2015.

8 The NDCs are plans voluntary plans and commitments submitted by countries to reduce their GHG emissions in various sectors. They were submitted by countries as they agreed to the Paris Agreement.

9 The CARICOM Member States include member states are Antigua and Barbuda, Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, and Trinidad and Tobago.

10 All the CARICOM Member States, except Montserrat, submitted their INDCs to the UNFCCC.

11 The Intended Nationally Determined Contributions (INDCs) are the voluntary plans that the countries submitted to the UNFCCC to reduce their greenhouse gas (GHG) emissions. Upon the ratification of Paris Agreement, countries INDCs became their NDCs (Nachmany & Mangan, 2018).

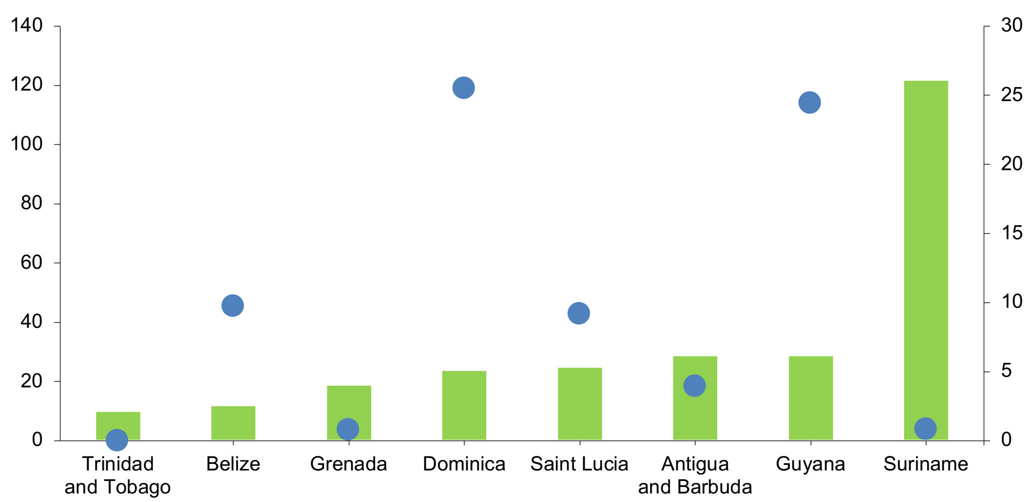
Table 1
Caribbean ratification of their NDCs

Country	Submission date	Ratification date of Paris Agreement
Antigua and Barbuda	19 October 2015	21 Sep 2016
Bahamas	November 2016	22 Aug 2016
Barbados	September 2015	22 April 2016
Belize	April 2016	22 Apr 2016
Dominica	November 23, 2015	21 Sep 2016
Grenada	18 September 2015	22 Apr 2016
Guyana	29 September 2015	20 May 2016
Haiti	30 September 2015	31 Jul 2017
Jamaica	September 2015	10 Apr 2017
Montserrat		
Saint Kitts and Nevis	12 December 2015	22 Apr 2016
Saint Lucia	18 November 2015	22 Apr 2016
Saint Vincent and the Grenadines	18 November 2015	29 Jun 2016
Suriname	September 2015	13 Feb 2019
Trinidad and Tobago	6 August 2015	22 Feb 2018

Source: UNCC (2023); UNTC (2023).

The first[12] Caribbean NDCs identify the cumulative climate mitigation and adaptation financing needs of these countries between 2015 and 2030. The size of the financing needs ranges from 10% of 2021 GDP in Trinidad and Tobago to 175% of 2021 GDP in Haiti. Countries have also received climate financing commitments from various sources. The size of the commitments received between 2010 and 2015, relative to the total financing range from 0.0% in Trinidad and Tobago to 25.5% in Dominica. No country has so far received more than 26% in pledges from donors; disbursements lag even further behind commitments. In these circumstances, the median financing gap for Caribbean countries with respect to NDC implementation, is in excess of US$800 million. See figure 1.

Figure 1
The Caribbean NDCs financial needs (2015–2030) and commitment estimates (2010–2015)
Total financial needs (per cent of GDP); Total financing needs (per cent of total financing needs) [right axis]



Source: Economic Commission for Latin America and the Caribbean (ECLAC), on the basis Mohan, Preeya S. 2022. Implementing nationally determined contributions under the Paris agreement: an assessment of climate finance in Caribbean small island developing states.

12 It should be noted that by 2022, most Caribbean countries submitted their second NDCs to the UNFCCC.

The situation is becoming increasingly worrisome as the Global Stocktake (GST),[13] which will review countries' progress on achieving their NDC targets, is due in 2023. Therefore, the Caribbean may need to pursue innovative, sustainable mechanisms for financing its NDCs implementation. Accordingly, one market-based modality, which may be useful a tool for generating the necessary resources for implementing Caribbean NDCs is the development of a regional emissions trading scheme (ETS).This however would need to be complemented by non-market approaches. Presently, no such market-based mechanism exists in the subregion. This may be partially atributable to the fact that CARICOM countries, classified as non-Annex I countries under the Kyoto Protocol, have no emission reduction commitments, as well as the inherent complexity of and attendent robust legislative framework that this would reguire to function effectively.

This notwithstanding, it may be useful to explore the merit of the carbon market system in facilitating GHG emission reduction action in the CARICOM SIDS, while simultaneously generating revenue for crucial adaptation and resilience building initiatives. This notwithstanding, given that CARICOM Member States are low emitters of GHGs, some businesses may be reluctant to participate in any ETS.Such a scheme can only be successful if the subregion has the necessary political will and private sector buy-in. The intuition here may be that any potential mandatory ETS would have to be structured properly to ensure that CARICOM's firms are not placed at an international trade competitive disadvantage. This study therefore is intended solely to explore the utility of an emissions trading scheme in assisting Caribbean SIDS in achieving their NDC targets. Section I examines the history of the cap and trade system. Section II considers the mechanics of the carbon market. Section III examines the features of an optimal emmissions trading scheme for the Caribbean which may facilitate the achievement of the NDCs of the CARICOM Member States. Section IV concludes the paper.

[13] The Global Stocktake is an important component of the Paris Agreement and is designed to assess progress towards the Agreement's long-term goals and targets. The GST is meant to take stock of the collective progress made by countries in achieving the Paris Agreement's goals and to identify areas where further action is needed. The GST is to be conducted every five years, with the first one taking place in 2023. The stocktake will assess progress made by countries in reducing greenhouse gas emissions, adapting to the impacts of climate change, and providing support to developing countries. It will also consider the adequacy and effectiveness of the overall collective efforts and support provided to achieve the long-term goals of the Paris Agreement.

I. Mechanics of a carbon market

An emissions trading scheme can facilitate a reduction in GHG emissions. However, to work effectively it must be structured carefully. Most importantly, the ETS should have an overall GHG emissions reduction goal for the targeted city, state, region, country or group of countries, with all partcipants working towards reducing their GHG emissions by a specified percentage or amount over a period of time. To achieve the overall predetermined goal, identified stakeholders would be required to participate in the ETS. Here a distinction can be made between a mandatory ETS and a voluntary ETS. This section of the paper will therefore be dedicated to exploring the mechanics of the functioning of an ETS while examining these two variations of the ETS.

A. Mandatory ETS

Under a mandatory ETS, stakeholders producing GHG emissions in specific sectors would be required to reduce these emissions. The ETS should at its inception, specify which sectors should be covered by the program. Electricity generation, transportation, and heavy industrial production tend to be the highest GHG emission sectors. Therefore, it is not uncommon to see the aforementioned sectors targeted by countries' ETSs.[14] The agriculture sector, and the forestry sector can also produce GHG emissions, and they are targeted by some ETSs.[15] [16]

It is imporatant to note that a necessary antecendent to the establishment of an ETS is often the conduct of a study of the emissions for the various sectors. The results of this analysis will in turn detail the quantum of GHG emissions produed by each sector annually, how much GHG emissions are produced by each company, and what are the GHGs emitted. The study should also assess the feasibility of reducing GHG emissions for each stakeholder. The latter is necessary in order to avoid policy makers

[14] The ETS in the EU, Kazakhstan, New Zealand, Québec, South Korea include the electricity generation, transportation, and heavy industrial production sectors.

[15] For example, the ETS in Kazakhstan, New Zealand and Québec include the agriculture sector.

[16] Carbon credits earned from negative net emissions through land use, land use change, and forestry (LULUCF) activities are referred to as Removal Units (RMUs).

creating *ad hoc* and unrealistic reduction targets. Furthermore, the results of the study can be used used as a benchmark for cross-comparision with the the monitoring, reporting and verification system that would be subsequently instituted to verify the stakeholders' emissions and compliance.

The ETS should also clearly indicate which GHGs are to be covered by the program. Some ETS may cover multiple GHGs, thus, stakeholders would be required to reduce the CO_2eq (carbon dioxide equivalent) of the GHGs. For example, the EU ETS covers carbon dioxide, nitrous oxide, and perfluorocarbons (EC 2020a). Many ETSs target only carbon dioxide, such as the US's Regional Greenhouse Gas Initiatiive (RGGI).[17] Therefore, the stakeholders would be required to solely reduce carbon dioxide emissions. Stakeholders participating in the mandatory ETS, whom are also referred to as regulated entities, would be required to cover all their emissions with emission allowances. In other words, at the end of the year, the stakeholders would be required to surrender emission allowances for each ton of CO_2eq of GHG emitted. The ETS also places a cap or a limit on the amount of GHG emissions that the stakeholders in specific sectors would be allowed to produce each year. The emissions cap could be gradually reduced over time to encourage the reduction of GHG emissions over time. The aformentioned stakeholders would be comprised of private sector companies that are emitters of GHGs. These stakeholders usually operate within the highest emitting sectors, which have been identifed in countries NDCs. If the emissions are in excess of the cap, then the stakeholders would face two options. The first option would be to purchase emission allocations to cover their excess GHG emissions. The second, would be to pay a fine for the excess emissions.

The emission allocations can be (and are commonly) allocated through a regulator at the ETS. In turn, the emission allocations can either be distributed freely to stakeholders in the target sectors, or they can be distributed through an auction system. In the auction system, stakeholders bid for the emission allowances, and pay the winning bid price for their emission allocations. While stakeholders may prefer a free allocation system as it allows them to obtain the emission allocations gratis, an auction system is more attractive for the state since it generates revenue from the distribution of the emission allowances. Furthermore, the accrued revenue can be used by the government to finance crucial climate change adaptation, mitigation and resilience building projects. Emission allowances can be distributed on a quarterly, semi-annual, or annual basis. Regardless of the frequency of distribution selected, it is important that the ETS regulator stays within the predetermined distribution limit for a particular year.

Moreover, stakeholders that produce less GHG emissions than their cap, may sell their extra emission allowances and conversely, stakeholders that produce more emissions than their cap may purchase the required extra emission allocations. These emission allocations may be traded on the ETS. Thus, the ETS may function as an exchange to facilitate the trading of the emission allowances, a key element of which would be the price of of the latter. As the emission allowances would be traded on the ETS, its price would be marked to market daily. This means that its price can fluctuate daily as the market dynamics change. A key component necessary for ensuring the effectiveness of the cap and trade system is the price of the emission allowances. Changes in the market price of the emission allowances can stimulate varying actions by stakeholders. For example, if the market price of emission allowances settles at a level that is too soft, this would effectivlely remove the incentive from the stakeholders to reduce their GHG emissions. Instead, they will, more likely than not, opt to purchase the emission allowances rather than pursue GHG emission reduction action. However, if the price of the

[17] The Regional Greenhouse Gas Initiative (RGGI) is a regional emissions trading scheme in the United States that aspires to reducing greenhouse gas emissions, particularly carbon dioxide (CO_2), from the power sector. Established in 2009, the RGGI currently includes ten states: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, Vermont, and New Jersey. The RGGI is considered as a regional emissions trading scheme as each state has autonomy and its own laws.

GHG emission allocations settles higher than the per unit price of the fine, then it would be rational for the stakeholders with excess emissions to pay the fine rather than purchase the emissions.

The price of the emission allowances will be determined by its demand and supply. Demand is primarily influenced by the cap imposed by the ETS regulator, and the extent to which the stakeholders reduce their GHG emissions. For instance, if the cap is set too high, then many businesses will achieve their GHG emission reduction targets, thus reducing the need and demand for extra emission allowances. If the cap is set too low, then many businesses will be unable to achieve their GHG emission reduction targets, thus resulting in a high demand for the extra emission allowances. If regulated entities largely pursue sufficient GHG emission reduction action, they will achieve their targets, and thus there may be weak demand for the emission allowances. However, if the regulated entities do not pursue GHG emission reduction action, then they will exceed their cap, thus resulting in a high demand for extra emission allowances.

An excess supply of emissions allocations has the potential to erode its price. This was clearly illustrated by the EU's experience with the EU ETS, which will be examined in some detail later in the paper. To ensure price stability, the government can consider implementing an allowance reserve. The allowance reserve can either remove or store excess emission allowances depending on the peculiar market ccircumstances. To this end, when the price of the emission allowances declines to a trigger price, the regulator could be authorized to remove excess emission allowances into the reserve. This can be done through two modlaities. For instance, the regulator can choose to reduce the number of emission allowances available in the next emission distribution cycle. Alternatively, the regulator can opt to purchase emissions allocations at the ETS and stores them in the reserve. The emissions reserve can also be used to prevent the emissions allocation prices from escalating. When the market price of the emission allowances rises above a trigger price, the regulator may release extra emission allowances to increase the supply on the market. This can be done at the next distribution event, or through open market operations.[18]

Monitoring, reporting, and verification systems are often, of necessity, embedded into ETS. In order for the ETS regulator to know that a regulated entity[19] has exceeded its emissions limit, there must be a built-in system for quantifying and monitoring the GHG emissions. The regulator may require these stakeholders to undertake GHG emission audits on an annual basis. To ensure the validity of the audits, the regulator may require the audits to be conducted by an accredited firm. For example, the ANSI National Accreditation Board (ANAB)[20] operates according to ISO 14065:2013[21] - greenhouse gases. The ANAB also accredits organizations providing third-party validation and verification GHG reductions and removals. Therefore, it would be logical for the government to enact legislation to allow for the GHG emission verification to be conducted by a firm that has been accredited by the ANAB or another appropriate credible institution.

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[18] Open market operations refer to regulators participating in the market by buying and selling the emission allowances to manipulate its price.

[19] The regulated entities are the stakeholders that would be required to reduce the GHG emissions would be companies. These would be companies from the highest emitting sectors that were identified in countries NDCs.

[20] ANAB is a non-governmental organization, which is a wholly owned subsidiary of American National Standards Institute, Inc. (ANSI), which is a non-profit organization.

[21] Specifies principles and requirements for bodies that undertake validation or verification of greenhouse gas (GHG) assertions.

B. Voluntary ETS

As mentioned earlier, apart from the mandatory ETS, there are also voluntary ETSs. With a voluntary ETS there is non-mandatory participation by the stakeholders on the exchange. The stakeholders are not mandated to purchase emission allowances to cover their GHG emissions. Instead, they may purchase emissions allowances as a means of improving their public image, or they may want to contribute to the global fight to reduce GHG emissions. Therefore in this variation of the ETS, there exists neither a cap on GHG emissions nor a fine for excess GHG emissions. Several voluntary ETS exist. Some examples are the American Carbon Registry (ACR), the Climate Action Reserve (CAR), the Climate Registry, the Gold Standard, Verra's Verified Carbon Standard, and the World Bank Forest Carbon Partnership Facility (ANAB, 2020). In view of the fact that CARICOM Member States are low emitters of GHGs, some businesses may be reluctant to participate in any ETS. If the subregion has the necessary political will and private sector buy-in. The intuition here is that any potential mandatory ETS would have to be structured properly to ensure that CARICOM's firms are not placed at an international trade competitive disadvantage.

II. Introduction to emissions trading

A. The European Union Emission Trading Scheme

As indicated earlier, the first international carbon market was developed in the European Union (EU) (EC, 2020a). The European Union Emission Trading Scheme (EU ETS) was launched in 2005 to help facilitate the achievement of the EU's Kyoto target of 20% reduction of GHG in 2020 relative to 1990 (de Alegría et al., 2017).[22]

The main features of the EU ETS are the emission cap, which is a ceiling on the maximum amount of GHG emissions allowed to be produced regulated entitiesand the trading of EU Emission Allowances (EUAs) to cover the GHG emissions in excess of the cap. The cap has decreased over time to encourage the total GHG emissions to decline. The EUAs were originally allocated by the EU without cost, but eventually auctions were introduced (Hepburn et al. 2006). The trading system offers flexibility to businesses as they may either choose to alter their production processes to reduce their GHG emissions, or they may purchase EUAs to offset their GHG emissions.[23] The price of the carbon credits is a key component of the system. As alluded to in the previous section, if the carbon credits prices are lower than the average cost of reducing the GHG emissions, then the producer would be incentivized to purchase the carbon credits. Alternatively, if the carbon credits prices are higher than the average cost of reducing the GHG emissions, then the producer would be incentivized to pursue GHG emission reduction action.

It is noteworthy that implementation of the EU ETS was divided into four phases: Phase I (2005–2007), Phase II (2008–2012), Phase III (2013–2020), and Phase IV (2021–2028). Phase I was intended to be a pilot phase to test the practicality of the system. During this phase the EU allowed its member States to allocate as many EUAs as they desired based on historic emissions, a process referred

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22 The EU Directive 2003/87/EC established the EU ETS in 2003. In January 2005, the Directive took effect, effectively launching the EU ETS.

23 When regulated entity, which is a business with a GHG emission reduction commitment, produces 1 ton of CO_2eq, it must 'surrender' or give back 1 emissions allowance back to the regulator.

to as grandfathering. Businesses in the power and heavy industrial sectors were given GHG emission limits, and thus were required to purchase EUAs to cover their excess GHG emissions,[24] or pay a fine of €40 per ton of CO_2eq (carbon dioxide equivalent).[25] A monitoring, reporting and verifying (MRV) system was also created to track the progress made in achieving the GHG emissions reductions.

The success of Phase I lay primarily in the pathway it created for the establishment of carbon credit prices, and the subsequent reduction of approximately 200 million tons of CO_2 of emissions across the EU in 2006. However, by 2007, it became apparent that too many EUAs were being allocated, resulting in an oversupply of the carbon credits. This oversupply caused a decline in the EUA prices (Caney and Hepburn 2011; Schwieger et al., 2019). In Phase II, the EU reduced the EUAs by 6.5% relative to 2005 in an attempt to trigger a rebound in the carbon credit prices. The EU also allowed up to 10% of the total EUAs to be issued through auctions rather than being given out gratis. Additionally, the penalty for non-compliance was increased to €100 per ton of CO_2eq. During this Phase the EU also allowed businesses to offset their GHG emission requirements with CERs and ERUs.[26] However, these additional carbon credits, the 2008/2009 global economic recession, as well as the decreased GHG emissions, facilitated an excess supply of carbon credits, preciptatiing a crash in their prices.

Consequently, recognizing the inherent weakness in the EU ETS which led to the prevailing depressed EUA prices, the EU introduced more changes in Phase III. These modifications included increased auctions and the introduction of the Market Stability Reserve which was introduced in 2015 in an effort to mop-up excess supply of EUAs (EC, 2020c). In light of these changes, approximately 40% of the EUAs were issued mainly through auctions in Phase III. To ensure that auctions occurred in a transparent and non-discriminatory manner, they were guided by the EU ETS Auctioning Regulation. The free allocation of the EUAs was restricted to the heavy industries other than power, and were based on benchmarks. For the years 2019 to 2023, excess EUAs are to be placed in the reserve by decreasing the number of allowances that the member States may auction. Additionally, 900 million EUAs that were back-loaded[27] over the period 2014 to 2016 were added to the Market Stability Reserve (EC, 2020b).

While Phase IV commenced in January 2021, the legislative framework of the EU ETS was revised in 2018 to facilitate the achievement of the EU's 2030 emission reduction targets and the EU's commitments under the Paris Agreement. The revisions included:

- increasing the annual reductions in the EUAs;
- strengthening the Market Stability Reserve;
- continuing the free allocation of some EUAs; and
- encouraging the heavy industry and power sectors to transform by using processes that generate less GHG emissions (EC, 2020a).

In 2022, the EU introduced the Fit for 55 package, which is a set of proposals to revise the EU legislation to ensure that its policies are aligned with its climate goals. With respect to the EU ETS, the Fit for 55 package introduces the following new provisions:

- The expansion of the program to include emissions from maritime transport.

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[24] Presently, the GHG covered by the EU ETS are carbon dioxide (CO_2), nitrous oxide (N_2O), and perfluorocarbons (PFCs). Nitrous oxide was included from Phase II (EC 2020a).

[25] Participation in the EU ETS is mandatory for the businesses producing GHG emissions in the following sectors, oil refineries, steel works and production of iron, aluminium, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids, and bulk organic chemicals. The aviation sector is scheduled to be included in the EU ETS from 2023 (EC 2020a).

[26] An emission reduction unit (ERU) is generated by a joint implementation project. A certified emission reduction (CER) is generated from a clean development mechanism project activity.

[27] The backloaded EUAs are the allowances that were supposed to be issued but were postponed for auctioning at a later date. In 2014, 400 million EUAs were postponed. In 2015, 300 million EUAs were postponed. In 2016, 200 million EUAs were postponed (EC 2020c).

- The gradual phasing-out of free allowances for some sectors.
- The implementation of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). This includes the aviation sector in the EU ETS.
- The increase of funding for the modernization and the innovation funds.
- The revision of the market stability reserve (EC, 2023).

Apart from the EU ETS, the Fit for 55 package introduced several new mechanisms. This includes the following:

- The decision on the notification of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) offsetting requirements. CORSIA is a global scheme for offsetting CO_2 emissions from international aviation, in which EU member states participate.
- The proposal for a social climate fund whose goal is to address the social and distributional impact of the new emissions trading system for buildings and road transport.
- The proposal for the carbon border adjustment mechanism (CBAM). This seeks to ensure that the EU ETS is in full compliance and synchronized with the EU's international trade rules.
- The land use, land-use change and forestry (LULUCF) regulations. These regulations effectively incorporate the forestry sector in the ETS. It creates a legally binding commitment for the EU member states to reduce emissions through the use of the forestry sector.
- The introduction of progressive EU-wide emissions reduction targets for cars and vans for 2030 and beyond, including a 100% reduction target for 2035 for new cars and vans.
- The proposal for new EU rules on methane emissions. The proposal aims to track and reduce methane emissions in the energy sector.
- The proposal for the ReFuelEU Aviation to reduce the aviation sector's emissions. This can be done through using biofuels and electrofuels.
- The proposal for the FuelEU Maritime to reduce the GHG intensity of the energy used on-board by ships by up to 75% by 2050.
- The revision of the renewable energy directive. This seeks to increase the EU target of at least 32% of energy mix from renewable energy sources by 2030 to at least 40%.
- A revision of the EU energy efficiency directive was proposed as part of the Fit for 55 package. Its main goal is to reduce final energy consumption at EU level by 11.7% in 2030, compared to projections made in 2020.
- The revision of the energy performance of buildings directive to make all new buildings zero-emission buildings by 2030.
- The hydrogen and decarbonised gas market package which introduces a new regulatory framework for dedicated hydrogen infrastructure and markets and integrated network planning.
- The revision of the taxation of energy products and electricity (EC, 2023).

The foregoing suggests that the development of emission trading schemes is an iterative process, and the lessions learned from the EU's experience have been useful in the shaping of ETSs in other jurisdictions. These lessons can also be instructive in guiding other countries and regions interested in introducing carbon markets. The rest of this chapter will therefore be dedicated to a consideration of other carbon markets, the features of which the author believe could provide useful information for Caribbean (and Latin America) countries in designing an appropriate ETS.

B. Other carbon markets

Apart from the EU ETS, several other countries have developed carbon markets. In an attempt to broaden the appreciation of the varied structure, operational modality, sectoral focus and other defining features of functional ETSs, examples of a few other of these schemes will be examined hereunder.

1. China

China launched a national emissions trading scheme in 2021, following its success in managing in several pilot ETS in various of its cities, namely Beijing, Chongqing, Guangdong, Hunan, Shanghai, Shenzhen, and Tianjin. The national emissions trading scheme is scheduled to be established in Shanghai and will be operated by an independent trading institute. It is envisaged that the national scheme will cover as many as 10,000 emitters from the petrochemicals, chemicals, building materials, steel, ferrous metals, paper-making, power-generation, and aviation sectors (Brittlebank, 2016; Xu & Stanway, 2021). The national emission trading scheme is intended to be compulsory, therefore GHG emitters operating in the aforementioned sectors would be required to participate.

In contrast to the EU ETS, China's national ETS does not set an emissions cap. Instead, it includes carbon intensity limits for every unit of electricity a power plant produces. Carbon intensity is a measure of the amount of carbon dioxide (or equivalent) emitted per unit of energy produced, and it is calculated by dividing the total emissions from a power plant by the total amount of electricity it generates.

Under the National ETS, power plants are required to meet carbon intensity benchmarks or limits, which are based on the type of fuel they use and the efficiency of their operations. If a power plant emits less carbon dioxide than the benchmark or limit, it can sell its unused carbon allowances to other entities that need them. On the other hand, if a power plant emits more carbon dioxide than the benchmark or limit, it must purchase additional allowances or face penalties (Farand 2021). The carbon emissions allowances closed in 2021 at 54.22 yuan (US$8.52) per tonne, up 13% on the opening price (Luyue, 2022).

2. Kazakhstan

Kazakhstan launched its national emissions trading scheme in January 2013. The program covers GHG emissions produced by businesses operating in the energy, transport, heavy industry, agriculture, and waste sectors. The emissions trading scheme was operationalized through 3 phases. Phase I (2013), or pilot stage, included the power generation, oil and gas mining, metallurgy, and chemical industries. Phase II (2014-2015) covered the same industries but was suspended over the period 2016 to 2017 in order to facilitate the development of a monitoring, reporting, and verification system, and the establishment of emission allocation rules. Phase III encompassed all the aforementioned sectors as well as the cement, lime, gypsum, and brick industries. The emissions cap for Phase III was set at a 5% reduction by 2020 from 1990 levels. The country has an NDC target of 15% unconditional reduction in GHG from 1990 levels by 2030. Therefore, this may evolve into a new cap in future phases. The average price of the emission allowances was US $1.14 per ton of CO_2eq in 2019 (ICAP, 2021a).

Kazakhstan's emissions trading scheme finds its relevant to the Caribbean context in several ways. Firstly, it serves as a pertinent example of how a developing country can go about implementing an emissions trading scheme across a range of sectors. Secondly, it highlights that an ETS can be implemented in phases. Thirdly, it shows that the establishment of clear emissions allocation rules are central to the a well functioning market for carbon credits.

3. New Zealand

The New Zealand Emissions Trading Scheme (NZ ETS) was launched in 2008. At the program's inception, it was restricted to emissions from the agriculture sector. The emission allowances were allocated freely, and there was no cap on the domestic emissions. In 2010 the scheme was expanded to include the energy, industrial processing, and liquid fossil fuels sectors. In 2013 it was further broadened to cover the waste sector (ICAP, 2021b).

In June 2020, the Government of New Zealand completed several reforms to its ETS. These included:

- The phasing down of the free allocation of the emissions allowances for the industrial sector.[28]
- The introduction of auctioning as a system to allocate emissions.
- The introduction of an auction reserve price as a price floor.
- Plans to establish a cap on emissions (ICAP 2021b).

The average price of the NZ ETS emission allowances was set at US $16.33 per ton of CO_2eq in 2019 (ICAP, 2021b).

4. Quebec

Québec, a province of Canada, introduced its emission trading scheme in 2012. The program covered GHG emissions from the transportation, heavy industry, construction, agriculture, waste, and power generation sectors. The program allowed participation by mandatory emitters as well as stakeholders voluntarily seeking to reduce their emissions. The initial cap for the first compliance period (2012-2014), was 23.20 million tons of CO_2eq. The cap was increased to 65.30 million tons of CO_2eq in the second compliance period (2015-2017) to accommodate the expansion of the program's scope GHGs (EDF and IETA, 2015).[29]

Presently, the GHGs covered by Québec's ETS are carbon dioxide, methane (CH_4), nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons, sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) (EDF & IETA, 2015).

In the case of Quebec, the emission allowances are distributed by both free, and auction systems. The former is utilized to distribute emissions from the cement production, chemical and petrochemicals, metallurgy, mining and pelletizing, pulp and paper, petroleum refining, and power generation sectors. The remaining emissions allowances are then distributed through auctions.

In January 2014, Québec officially linked its emission trading system with the system in California. The resulting emissions trading system is presently the largest in North America (EDF & IETA, 2015; ICAP, 2021c). It is also the first emissions trading system to be operated by subnational jurisdictions of different countries (ICAP, 2021c). In 2020, Québec's ETS was conditioned by a price floor of $16.34 CAD, while California price floor was $16.68 USD. Both ETS allow the price floor to increase by 5% plus inflation each year (Galdi et al., 2020). In 2022, the emissions allowance price in California and Quebec, grew to US $28 per ton.

5. South Korea

South Korea Emission Trading Scheme was launched in 2015. Phase I (2015-2017) of the scheme was relatively broad in its sectoral coverage of GHG emissions, with the power generation, industry (iron and steel, petrochemical, cement, oil refinery, nonferrous metals, paper, textile, machinery, mining, glass, and ceramics), buildings, waste, and transportation (domestic aviation) sectors all falling under the scheme's scope (ICAP, 2021d). The emissions cap was set at 540 million in 2015, 560 million in 2016, 567 million tons of CO_2eq in 2017. Additionally, in the first phase emissions allowances were freely allocated.

[28] The Government of New Zealand intends to decrease the free allocation system by 1% per year between 2021 and 2030, increasing to 2% in 2030-2040, and 3% in 2040-2050 (ICAP 2021b).

[29] The scope was expanded in 2015 to include emissions from fuel. This applied to the transportation sector. Only the first distributors of fuel are covered under the cap (EDF and IETA 2015).

There was a gradual shift towards the use of auctions to distribute a share of emission allowances in subsequent phases. Accordingly, in Phase II (2018-2020) 97% of the emissions allowances were freely allocated, while 3% were distributed through auctions. The emission cap was changed to 548 million tons of CO_2eq throughout Phase II. Whilst in Phase III (2021-2025) 90% of the emissions allowances are scheduled to be freely allocated, and the remaining 10% to be allocated via the auction process. The average price of South Korea's ETS emission allowances was US $25.59 per ton of CO_2eq in 2019 (ICAP, 2021c).

6. United States

Several states in the United States namely, Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont, and Virginia jointly operate the Regional Greenhouse Gas Initiative (RGGI).[30] The RGGI, which was established in 2005, is a mandatory emissions trading scheme. The RGGI requires hydrocarbon-fueled power plants with a capacity greater than 25 megawatts (MW) to obtain emission allowances for each ton of carbon dioxide they emit annually (C2ES, 2019). The number of emissions allowances is decreased each year so that the region's power plants produce fewer carbon emissions over time. Allowances in the RGGI are distributed quarterly by each state through auctions. Notably, the revenue generated from the auctions is used by the states to fund energy efficiency investments and other GHG emission reduction projects.

Like other emission trading schemes, the RGGI was administered over several phases. In Phase I (2009-2011) 395 million emissions allowances were auctioned. The emission allowances price ranged between US$1.86 and US$3.35, generating US$922 million in total revenue for all the states. The states operated under a Model Rule which allowed each state to implement regulations to govern the stakeholders participating in the program. At the end of Phase I, New Jersey withdrew from the program (C2ES, 2019). At the commencement of Phase II (2012-2014), the cap was allowed to accommodate the departure of New Jersey. The Model Rule was also updated in February 2013 (RGGI 2018), lowering the 2014 carbon dioxide cap to 91 million tons.[31] This development caused the emission allowance price to rise to as high as US$3.21 per ton of CO_2eq at the next auction (C2ES, 2019).

In 2012 the RGGI program was reviewed. Following this review, the states introduced a Cost Containment Reserve (CCR) to help control the emission allowances prices and prevent it from escallating. The CCR is comprised of additional emission allowances. Therefore, if prices rose excessively, the states may release additional emission allowances from the CCR to reduce prices. The trigger price for states to tap in the CCR was US$4 in 2014, US$6 in 2015, US$8 in 2016, US$10 in 2017, and scheduled to increase by 2.5% annually thereafter (C2ES, 2019). During Phase III (2015 to 2017), the RGGI was reviewed (2016). Following this review, the states announced plans for an overall cap reduction of 30% between 2020 and 2030. The trigger price for the CCR was set to US$13 in 2021, increasing by 7% per annum. A new mechanism called the Emissions Containment Reserve (ECR) was developed and planned to take effect from 2021. The ECR would act as a mechanism to ensure a price floor. If the emission allowances prices fell too low, then the states could withhold up to 10% of their annual allowances. The trigger price for the ECR is US$6 in 2021, increasing by 7% per annum (C2ES, 2019). During Phase IV (2018 to 2020), however, New Jersey rejoined the RGGI (2020).

7. Mexico

In January 2020, Mexico launched a pilot ETS. It covers direct CO_2 emissions from fixed sources in the energy and industry sectors emitting at least 100,000 tCO_2 per year, which represents around 40% of the country's greenhouse gas (GHG) emissions (ICAP, 2023). The ETS' main objective is to provide a public policy mitigation instrument that contributes to Mexico's national mitigation goals, including its

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30 The founding states of the RGGI were Connecticut, Delaware, Maine, New Hampshire, New Jersey, New York, and Vermont. Maryland, Massachusetts, and Rhode Island joined in 2007 (C2ES 2019).

31 The new cap took effect from January 2014.

Nationally Determined Contributions (NDC). The ETS aims to enhance the quality of emissions data and build capacity in emissions trading, ultimately improving the design of the operational phase from 2023 onwards (ICAP, 2023).

During the pilot phase (2020-2022), companies received free allowances based on their historical emissions. New entrants received free allowances based on their verified emissions in the year in which they first crossed the 100,000 tCO_2 threshold. By the end of 2022, there have been no auctions in the Mexican ETS Pilot. Secondary trading of the emissions allowances can only take place via negotiation between participants on an over-the-counter market. The sectors covered by the scheme include heavy industry and power (ICAP, 2023). There are three reserves in the scheme, which are filled each year with allowances additional to the cap. The auctions reserve (equivalent to 5% of the cap) is for regular auctions, which have not yet happened. The new entrants' reserve (equivalent to 10% of the cap) is for new entrants as well as increases in production among existing regulated entities. The general reserve (equivalent to 5% of the cap) is for ex-post adjustment allocation for entities with higher emissions relative to their baselines. These reserves function as safeguards to avoid economic impacts on regulated entities (ICAP, 2023).

Mexico's pilot ETS poses no economic impact on regulated entities. Instead, non-compliant entities face the risk of losing the opportunity to bank unused allowances into subsequent compliance periods within the Pilot. This means that entities that if they do not meet their emissions targets during the Pilot they will not be able to carry forward unused allowances to the operational phase of the ETS, which could limit their flexibility in meeting future emissions targets. Additionally, non-compliant entities receive fewer allowances in the first allocation of the operational phase of the ETS, which is a further disincentive for non-compliance. For each allowance not delivered during the Pilot, entities will receive two fewer allowances in the first allocation of the operational phase (ICAP, 2023).

8. Brazil

On May 19, 2022, the Brazilian Federal Government published Decree No. 11,075/2022 ("Decree"), which establishes the National Greenhouse Gas Emissions Reduction System ("Sinare"), whose purpose is to serve as a single center for recording emissions, removals, reductions and offsets of GHG, and certified emission reduction credits' trade, transfers and transactions. Therefore, the Decree also allows for the systematic operationalization of the carbon market (Bezerra et al., 2022).

Notablely, Sinare is not an ETS, but rather a registry system for recording and trading carbon credits. Nevertheless, it is an important step towards the operationalization of the carbon market in Brazil. The Sinare registry allows sectors such as electric energy, urban public and cargo transport, manufacturing, and agriculture to register their carbon footprints and participate in the voluntary carbon market. This will help Brazil to become a major player in the market, especially given the country's potential for surplus Emissions Reductions (ERs) from the Amazon Jurisdictional Reducing Emissions from Deforestation and Forest Degradation (J-REDD+) programs (Riva et al., 2022). The J-REDD+ program is included as a mechanism under Article 5 of the Paris Agreement, to reduce emissions from deforestation and forest degradation in developing countries. It provides financial incentives for developing countries to reduce carbon emissions by preserving their forests. Brazil is one of the countries with the largest area of tropical forests, and the Amazon region alone covers approximately 60% of the country's territory. Therefore, Brazil's participation in the J-REDD+ program has the potential to generate a significant number of carbon credits, which can be traded in the voluntary carbon market.

It is important to note that Brazil is also well-positioned to benefit from the Article 6 mechanism under the Paris Agreement, which facilitates cooperation between countries striving to reach their NDCs. Brazil's success in reducing emissions from Amazon forest loss and degradation will be crucial in capitalizing on the revenue earning potential of the carbon market.

9. Chile

On 13 June 2022, Chile published its Climate Change Framework Law. The law provides a framework for a range of policies, including sectoral mitigation and adaptation plans, that will enable Chile to reduce its greenhouse gas emissions and build resilience to the impacts of climate change (ICAP, 2022). Article 14 of the law sets out the requirements for the Ministry of Environment to specify GHG emission limits for a range of sources, based on a system of emission standards set by technology, sector, or activity. This approach will enable regulated entities to identify the most cost-effective ways to reduce their emissions and promote the development of new low-emission technologies. The potential for the establishment of aggregate emission limits or caps could create a market for emission allowances that could be traded among regulated entities, and thus establish a potential future ETS (ICAP, 2022). Article 15 allows regulated entities that perform better than their standard to have their surplus emission reductions certified, which can then be used by other regulated entities to comply with their respective emission standards. This type of system could serve as a precursor to the development of tradable performance standards, where entities that perform better than their standards can receive certificates that can be sold to entities that do not meet their standards (ICAP, 2022).

Article 37 provides a basis for the development of market, fiscal, and financial-based instruments to achieve the objectives of Chile's NDC and Long-Term Strategy (ICAP, 2022). This hints at the development of a tradable performance standard system, though details of the potential instruments are yet to be defined. Thus far the paper has considered the evolution and mechanics of the carbon market and demonstrated that the process of developing emission trading schemes can be iterative in nature, often requiring a phased approach to implementation; as well as presented a myriad of possible structures and defining features of ETSs, which could be useful in facilitating emssions reduction in the Caribbean pusuant to the achieving its NDCs. Accordingly, in order to add another important layer to the discussion, an examination of the salient features of of an optimal emissions trading scheme for the Caribbean will be undertaken in the next section.

III. Examining the features of an optimal Caribbean emissions trading scheme

This section will seek to utilize the earlier survey of individual and regional ETSs to engage in a determination of the most suitable structure of a subregional (Caribbean and/or Latin America and the Caribbean) emissions trading scheme. In addition, an attempt is also made to add to its versatility through the design of a robust model for forecasting carbon credit prices (using EU prices) which would be crucial to the success of any subregional ETS. Specifically, a three (3) step forecasting model, which combines Empirical Mode Decomposition, Particle Swarm Optimization and Support Vector Regression will be employed.

It is important to commence the discussion with a consideration of the subregions GHG emissions. As alluded to earlier The CARICOM Member States are not major GHG emitters. Table 2 displays the anthropogenic carbon dioxide emissions for select Caribbean countries as well as select global economies with high per capita carbon emissions.

An examination of table 2 reveals that the only CARICOM Member State with a high per capita carbon emissions rate is Trinidad and Tobago (T&T). This is due to the presence of a petrochemical industry in the country as well as a small population size of approximately 1.3 million people.[32] With the significant hydrocarbon discoveries and extraction in Guyana, coupled with its relatively small population, we shoud expect Guyana's per capita carbon emmisison levels to gradually, but significantly, increase.

[32] The petrochemical industry is typically a high GHG emitting industry.

As such, a more appropriate reflection of the carbon dioxide emissions would be absolute emissions.[33] Table 3 illustrates absolute anthropogenic carbon dioxide emissions for select Caribbean economies and select global economies with high absolute CO_2 emissions. This reveals that all the CARICOM Members States, including T&T, have low absolute anthropogenic carbon dioxide emissions compared to major industrialized economies around the world.

Table 2
Per capita CO_2 emissions, 2019
(Metric tons per capita)

Country	CO_2 emissions
Select CARICOM member and associate member States	
Antigua and Barbuda	5.64
Bahamas, The	7.02
Barbados	4.46
Belize	1.64
Dominica	2.38
Grenada	2.68
Guyana	3.56
Haiti	0.29
Jamaica	2.98
Saint Kitts and Nevis	5.23
Saint Lucia	3.02
Saint Vincent and the Grenadines	2.48
Suriname	4.41
Trinidad and Tobago	11.31
Curacao	37.73
Sint Maarten	19.46
Select global economies with high CO_2 emissions	
Bahrain	22.26
Brunei Darussalam	15.95
Kuwait	20.86
Luxembourg	15.31
New Caledonia	16.01
Saudi Arabia	14.61
United Arab Emirates	20.50
Qatar	32.76
United States	14.67
CARICOM member State average	4.07
World average	4.44

Source: World Bank (2023).

Table 3
Absolute CO_2 emissions, 2019

Country	CO_2 emissions *(Kt)*	Emissions relative to the world *(Percentage)*
	CARICOM member States	
Antigua and Barbuda	1 220	0.00
The Bahamas	3 160	0.01
Barbados	3 790	0.01
Belize	1 550	0.00
Dominica	230	0.00

33 Absolute emissions refer to the total amount of GHGs that a country or entity releases into the atmosphere. In comparison, per capita emissions, refer to the amount of GHG emissions of country divided by its populations. This reveals the average amount of emissions produced per person.

Country	CO_2 emissions (Kt)	Emissions relative to the world (Percentage)
	CARICOM member States	
Grenada	2 390	0.01
Guyana	5 680	0.01
Haiti	10 500	0.02
Jamaica	9 970	0.02
Saint Kitts and Nevis	350	0.00
Saint Lucia	880	0.00
Saint Vincent and the Grenadines	340	0.00
Suriname	4 460	0.01
Trinidad and Tobago	28 340	0.06
Select global economies with high absolute CO_2		
Brazil	1 057 260	2.28
Canada	736 930	1.59
China	12 705 090	27.45
Germany	749 710	1.62
India	3 394 870	7.33
Indonesia	1 002 370	2.17
Iran	893 720	1.93
Japan	1 166 510	2.52
Korea, Republic of	698 460	1.51
Mexico	653 870	1.41
Russian Federation	2 476 840	5.35
Saudi Arabia	723 150	1.56
South Africa	555 430	1.20
United States	6 001 210	12.97
CARICOM total	72 860	0.16
World total	46 287 620	100.00

Source: World Bank (2023).

Notably, Curacao's and Sint Maarten's CO_2 emissions were reported at 37.73 Mt/capita and 19.46 Mt/capita respectively. This was higher than the other countries in the region, including T&T. However, this results from the countries having oil and heavy industries which are high emitters of GHGs, while having small population sizes. A further examination of table 2 suggests that collectively, the CARICOM Member States emitted approximately 0.16% of world emissions in 2019. T&T's absolute carbon dioxide emissions accounted for less than 1% of the world's total carbon dioxide emissions. This is exceedingly small, relative to other emitting countries such as China, the United States, and India, which accounted for 27.45%, 12.97%, and 7.33% of the world's total emissions, respectively. Although the CARICOM Member States are low GHG emitters, they enjoined the international community in becoming signatories to the Paris Agreement, thereby agreeing to pursue action to reduce their GHG emissions. The CARICOM Member States Nationally Determined Contributions (NDCs) highlighted the sectors in which they intend to reduce GHG emissions.[34]

The CARICOM Member States NDCs are very diverse with respect to targets, quantification of targets, and approaches to achieving these targets. Some are of the view that this particular outcome of the the COP negotiations as requiring corrective action, since no standardization, as it were, was mandated for the submission of INDCs to the UNFCCC. Nevertheless, COP 21 was a tremendous success as it induced both Annex I and non-Annex I countries to pursue GHG emission reduction action. Two similarities can be observed from the CARICOM Member States NDCs. The first is the willingness to pursue GHG emission reduction action by implementing renewable energy projects. The second, is that while the implementation of the NDCs is conditional upon the receipt of international support there are also unconditional obligagtions.

[34] Full table of CARICOM Member States' INDCs can be found in annex 2.

As mentioned earlier in the paper, although US$100 billion per year in climate finance from 2020 onwards was pledged, this target has not been met and what funds are available, are largely inaccessible to many small developing, climate vulnerable economies in the Caribbean. It is not surprising therefore that there is increasing support for the notion of the establishment of the Caribbean Resilience Fund (CRF), which has be proposed by ECLAC, as well as a Loss and Damage Fund and a prposal for the establisment of a Green Bank to be based in Barbados.With respect to the former, the CRF is intended to be a special purpose financing vehicle for leveraging long-term, low-cost development financing for the Caribbean for investment in adaptation and mitigation initiatives, as well as faciltating the reduction of GHG emmisisons artiuclated in NDC targets of Member States. More particularly, a finnancing window of the CRF will be dedicated to climate resilience builing, including diversifying the subregion's energy sources and lowering the cost of energy.

Accessing climate finance funds, such as the Green Climate Fund (GCF), requires the interested country to establish a National Designated Authority (NDA), and seek GCF Accredited Entity status for one of its local institutions from the GCF. The GCF Accredited Entity is distinct from the NDA. The NDA's purpose is to act as an intermediator between the developing country and the GCF. In comparison, the GCF Accredited Entity performs as the institutional mechanism to channel the GCF financial resources to specific projects and programs. The GCF has two categories of Accredited Entities; Direct Access Entities (DAEs), and International Access Entities (IAEs). The DAEs are national or regional organizations that are nominated by the developing country's NDA. Whereas the IAEs are international agencies, such as United Nations (UN) agencies, multilateral development banks, international financial institutions, and regional institutions, which may coordinate climate change projects in developing countries (Charles, 2019). Institutions seeking to become a GCF Accredited Entity as DAEs must first be nominated by the NDA. The GCF only considers NDA-recommended institutions that are compliant with the GCF policies on financial standards, environmental and social safeguards, and gender. Then the institution may undergo GCF readiness support, where it is trained to develop the institutional capacity to implement GCF-funded projects. This training may take a minimum of 2 years. After completing the training, the institution may apply for accreditation through the GCF's Online Accreditation System (OAS). Once all the relevant information is submitted, the GCF may review the application, and may take up to six months to make its accreditation decision (Charles, 2019).

This process is not automatic as the GCF may still deny the accreditation. Even if the GCF grants accreditation, it may have conditions attached. The GCF also has a fit-for-purpose system to categorize projects. The categories are Category C (no or minimal risk), Category B (medium risk), and Category A (high risk). This fit-for-purpose system has implications for the projects in which the DAEs may be authorized to implement. In fact, the GCF has four funding categories: (i) micro – which has a financial limit of US$10 million, (ii) small – which has a financial range of US$10 million to US$50 million, (iii) medium – which has a financial range of US$10 million to US$250 million, and (iv) large – which provides funding in excess of US$250 million (Charles, 2019). Clearly, gaining GCF Accredited Entity status is no easy task. In the CARICOM region, the only institutions to have obtained it are the Caribbean Community Climate Change Center (CCCCC), the Caribbean Development Bank (CDB), the Department of the Environment – Antigua and Barbuda, and the Protected Areas Conservation Trust (PACT) – Belize. This nowithstanding, these institutions are only authorized to implement relatively small projects, with the risk up to Category B (Charles, 2019).

In view of the foregoing, a viable option for partially offsetting the finacing needs for achieving NDC targets may be the development of an emissions trading scheme within the Caribbean Community. The rest of this chapter will examine this notion more closely through a consideration of possible elements of the potential structure of a emissions trading scheme in the Caribbean Community.

A. Structure of the potential emissions trading scheme in CARICOM

If the CARICOM Member States were to seriuosly consider moving in the direction of establishing and implementing an emissions trading scheme to facilitate the reduction of the GHG emissions to achieve their NDC targets, there are several issues surrounding the ETS that will arise, which would require careful consideration.

1. Mandatory or voluntary

The first issue that should be considered is whether or not a potential ETS should be mandatory or voluntary. Under a mandatory scheme, stakeholders producing GHG emissions in particular sectors would be mandated to participate. They would be required to obtain emissions allocations to cover each ton of CO_2eq of GHG that they produce. In contrast, under a voluntary system, no stakeholder will be forced to participate. Instead, only the stakeholders that desire to contribute to the global fight against climate change may choose to participate.

In view of the fact that CARICOM Member States are low emitters of GHGs, some businesses may be reluctant to participate in any ETS. They may hold the view that climate change is a challenge caused by the high GHG emitting countries and that they should not be 'forced' to reduce their emissions. This line of thinking would be consistent with the prevailing view that underpinned the deadlock in the international climate change negotiations for many years. Furthermore, the CARICOM Member States are also highly vulnerable to climate change, and extreme weather conditions. The hurricanes that have devastated countries in the region[35] within the past few years highlight just how precariuos this challenge is becoming, and the urgent need for remedial action. Furthermore, the voluntary ETS may not encourage a large enough participation to facilitate a reduction in the GHG emissions in the CARICOM Member States. For this reason, the author shares the view that a mandatory ETS represents the more logical choice, provided that the subregion has the requisite political will and private sector[36] buy-in.

Notably, GHG emission reduction action carries a cost. Firms will have to adopt new technologies and processes to make production cleaner and reduce emissions. This will inevitably necessitate the acquisition of new technologies and machinery, as well as re-training of workers. Increased cost of production will make firms less cost-competitive in international trade. Therefore, climate mitigation strategies have the potential to negatively impact net exports, the balance of payments, and the Gross Domestic Product (GDP) of small developing economies of the Caribbean. The intuition here is that any potential mandatory ETS would have to be structured properly to ensure that CARICOM's firms are not placed at an international trade competitive disadvantage.

2. Regional or national

The previous discusssion raises another critical question. Should the ETS be regional or national? Individual Member States can opt to implement a national ETS. However, collective action to reduce GHGs in the subregion may be better achieved through a regional Scheme. The experience in the United States with the Regional Greenhouse Gas Initiative as well as the European Union with the EU ETS, demonstrates that regional collaboration can be both feasible and practical albiet not entirely friction-free. Individual member states may retain the flexiility to either partcipate or opt out. Within all of this, despite the relative success of ETSs achieved in the US and the EU, it is imperative to recall that RGGI

[35] These hurricanes include Dorian in 2019, and Irma and Maria in 2017.

[36] Private sector firms in high emitting sectors, such as power generation, cement production, and transportation, are likely to be significant contributors to GHG emissions. In fact, countries NDCs already identified the high emitting sectors. Therefore, private sector firms in high emitting sectors identified in the NDCs are likely to be regulated entities in the ETS. To comply with the ETS, these firms will need to hold sufficient allowances to cover their emissions, either through allocation from the ETS regulator or through purchasing allowances from other regulated entities.

has had substantial challenges —with states pulling out and rejoining, depending on the government in office— which is extremely disruptive to the scheme and to all players, and undermines credibility. It is increasingly clear that any serious consideration of instituting a regional ETS would have to be initiated at the level of a meeting between the Heads of Governments of CARICOM Member States and would require agreement among same to pursue such an initiative. Member States would need to discuss and agree on (and calibrate) both national and regional GHG reduction goals. It is this quantification of GHG emission that will be used to set the cap on emissions.

The ETS regulator would be responsible for administering the regional ETS in each participating country. Collectively, the Member States may work towards the achievement of the regional GHG emission reduction goal, with a built-in mechanism for regulation and monitoring. Notably, for the regional emissions trading scheme to be effective, there must be an agreed regional approach with legislation, regulations, rules and procedures. Firstly, it is essential to have a shared understanding among the participating countries of the scheme's objectives, targets, and scope. The scheme's design must be tailored to suit the specific regional context, taking into account regional characteristics such as the GHGs covered, the sectors included, the private sector firms crowded-in, etc.

Once the objectives and targets have been agreed on, the rules and procedures for the scheme must be developed. These rules and procedures typically include the allocation and distribution of allowances, monitoring and verification of emissions, reporting requirements, and compliance and enforcement. Furthermore, the rules and procedures should provide clarity on the trading process, including the rules for buying and selling allowances, the types of entities eligible to participate in the market, and the trading platform's operation. This will help ensure that the market operates transparently and efficiently. Moreover, it would be important to establish an effective governance structure to oversee the scheme's operation and ensure that it is functioning as intended. For this reason, an independent regulator should be established at the ETS. The regulator acts as an independent body that monitor compliance and enforce the rules of the scheme.

3. Size of the cap

Given that individual Member States produce different volumes of GHG emissions, in the establishment of the ETS, it should be agreed that individual countries be allowed differing caps on their emissions. The particpating member States can set respective emissions caps to help them achieve their NDCs. For example, T&T’s NDC stated the government’s intention to achieve a 15% reduction in CO_2 emissions from a business-as-usual (BAU) baseline from the power, heavy industry, and transport sectors by 2030. In comparison, Jamaica stated its intention to reduce GHG emissions by 25.4% unconditionally 28.5% conditionally compared to the BAU by 2030.

The Member States should also stagger the implementation of any regional GHG emission reduction target over a period of time. Since most countries highlighted the year 2030 as the date for the achievement of some results, then this date could be specifed as the target date in the ETS. As countries gradually enhance their commitments in their NDCs, the cap can gradually grow to reflect the new commitments. So there could be a cap set for 2030, and for 2050. To ensure that the ETS remains relevant and effective in the long run, the Member States will need to work together to regularly review and update the emissions caps to reflect any changes in their NDCs. The ETS governance structure should facilitate this process by providing a platform for dialogue, consultation, and decision-making among the participating countries.

4. Sectors

Consideration also has to be given to which sectors should be covered by the ETS. There is a school of thought that suggests that NDCs should not guide an ETS, since an ETS should be uniform in scope and coverage across the region, regardless of NDCs of individual member states, which in any event would have to be updated from 2030 and would move toward being economy-wide. It would be natural to cover CO_2 from power production in the first instance. Further, the EU ETS has a fixed coverage and scope; with coverage and scope varying across member States. Furthermore, the quantum allocated to each country varies, based on historical emissions and projected needs. The EU ETS covers 3 GHGs (CO_2, N_2O and PFCs), while RGGI covers just CO_2. From the Caribbean's perspective, for example, subregional governments may wish to ensure that a regional ETS provides a tool for levergaing financing for the implementation of their NDCs, which may necessitate some measure of variable geometry in sectoral coverage across countries.

This study therefore recommends that the Caribbean countries should start the ETS with one or few sectors, possibly those that are common across member states' NDCs. This nothwistanding, Caribbean governments may opt to agree on a set of sectors and a compendium of GHGs that would be initially covered by the regional ETS which may not be guided by NDCs. Then as time passes more sectors could be included in the ETS as the regional NDCs, climate objectives and climate policies evolve. In fact, the recent Fit for 55 package which was passed by the EU in December 2022 saw the EU align its ETS with its climate change policies and objectives.

5. Greenhouse gases

Since carbon dioxide is the most common anthropogenic GHG emission, it would be natural for member States to target this gas. Other GHGs which are targeted in other ETS include methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, and nitrogen trifluoride. It would be logical for the potential regional ETS to start with 1 GHG. Carbon dioxide can be this gas. As time progresses, the ETS can be reviewed and more GHGs can be included.

6. Auction versus free allocation

The emission allocations in an ETS can be distributed either through free allocation of the emission allowances by the regulator at the ETS or auctioning of the emissions allocations. Free allocation involves the regulator providing some or all of the emission allowances to regulated entities for free. One potential advantage of free allocation is that it can provide certainty to regulated entities regarding their future allowance allocations, which can facilitate long-term planning and investment. However, free allocation can also lead to windfall profits for firms that receive allowances for free. Additionally, free allocation may not provide sufficient incentives for regulated entities to invest in low-carbon technologies or reduce emissions beyond the level required by the ETS. In contrast, auctioning involves the regulator selling the emission allowances to regulated entities through a competitive bidding process. This approach can provide more efficient price signals to encourage investment in low-carbon technologies and to reduce emissions beyond the level required by the ETS. Auctioning can also generate revenue for the ETS regulator that can be used to support further climate action or to offset the costs of the ETS.

The experience of the EU ETS showed that an ETS can be initaited with emissions allowances being distributed for free based on grandfathering. It would be logical for the first set of emissions allowances to be distributed in this manner, at least in the first year. However, given that the ETS regulator would have operational costs, and many Caribbean governments have limited fiscal space, increasing public debt burdens, and would be reluctant to taken on additional recurrent subventions, the ETS regulator would need to become self-sufficient. Therefore, the ETS regulator would need to generate revenue to offset their costs. As such, this study recommends that from the second year, a hybrid of free allocation based on historic emisisons (or grandfathering) as well as auctions should be used. Eventully, the percentage of emissions allowances distributed through auctions should be increased until the free allocation system is phased out.

7. Amount of emissions allocations

The experience of the EU ETS highlights the need to safegaurd against the distribution of too many emissions allowances, which in turn will place downward pressures on the price. Moreover, a price that is too low will remove the incentive for emission reduction and inturn render the ETS ineffective in reducing GHG emissions as stakeholders will merely compensate for high emissions bypurchasing emissions allowances. The EU also allowed the emissions allowances to be rolled over and saved (EC 2020b). Therefore, unused emission allowances in one year could be used to offset GHG emissions in future years.

Moreover, emission allocations distributed should match the GHG emissions cap. So if the cap for the region for the first year is 66,497 kt, then only 66,497 thousand emission allocations should be distributed in the first year. If the potential regional ETS allows the rolling over of the emissions allocations, then it would be useful to also have an emissions reserve with a built-in trigger-price. Notably, before at the start of the ETS there will be no performance data. For this reason, the ETS should be implemented in phases. The first phase should be a pilot or trail state to determine how effective the ETS is working and if there too much emissions is allocated. If there is a surplus of emissions allowances, then this can be reduced in the next phase through the distribution of lower-levels of allowances.

8. Non-compliance penalties

In order to create an incentive for stakeholders to reduce their GHG emissions, a penalty should be charged to stakeholders for non-compliance with their assigned caps. The objective of the penalty should be to create a sufficient incentive to stimulate GHG emission reduction action, rather than punish local stakeholders. To this end, the penalty should also not be excessive and should be linked to the number of emissions per ton of CO_2eq (carbon dioxide equivalent). Therefore, the non-compliant regulated entities[37] would pay more in penalties as they produce more GHG emissions. The emission allowances prices at the EU ETS fluctuated between US$30 and US$40 in 2020. Perhaps, therefore, a penalty fee can be set at approximately US$50 per ton of CO_2eq at the inception of the potential regional ETS.[38]

9. Emissions allocations reserve

The incorporation of an emissions allocation reserve into any subregional ETS will be important to ensure price stability. The emissions allocations reserve will provide an effective tool for ensuring that the market price of the emissions allocations does not fluctuate excessively (i.e. fall too low or rise too high). While it is not rational for the price of the emission allocations to rise above the carbon penalty fee,[39] it is still a possible occurrence if speculation occurs on the ETS. In fact, financial speculation can cause bubbles, jumps, or unexpected crashes.[40] Therefore, this study recommends the creation of an

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[37] These stakeholders would be the companies with GHG emission reduction commitments that are included as regulated entities in the ETS.

[38] The ETS regulator will enforce the non-compliance penalty fee.

[39] Note, the carbon penalty fee is the fee for non-compliance in the ETS. In other words, if a regulated entity produces more GHG emissions than allowed, if they do not have sufficient emissions allowances to cover their emissions, then they should pay a fee to the ETS regulator.

[40] In financial economics, financial speculation refers to the practice of buying and selling financial assets, with the intension to profit from short-term fluctuations in their prices.
A bubble in financial economics refers to a situation where the price of a financial asset becomes disconnected from its underlying value, leading to a rapid increase in price followed by a sudden drop.
Jumps in financial economics refer to sudden, large movements in the price of an asset or a financial market. Jumps can occur for a variety of reasons, including unexpected news or events, changes in market sentiment, or technical factors.
Unexpected crashes in financial economics refer to sharp declines in the prices of financial that are sudden and unexpected. Crashes can occur due to a variety of factors, including changes in economic conditions, geopolitical events, or market sentiment.
Overall, financial speculation, bubbles, jumps, and unexpected crashes are all important concepts in financial economics that help to explain the behavior of financial markets.

emissions reserve to help keep the emissions allowances prices within normal or acceptable limits. Alternatively, consideration can be given to merely having auction price floors and ceilings.

10. Monitoring, reporting and verification system

In order to ensure that GHG emissions are declining, the governments must have a system in place to monitor the emissions. In fact, an ETS would not be feasible without a monitoring, reporting, and verification system. The system will involve stages for monitoring, reporting, and verification of emissions. The monitoring of emissions in an ETS will be partially performed by the regulated entities. This is can be done through the use of emissions monitoring systems, such as sensors or other measurement devices, which track the quantity and type of greenhouse gases emitted by the regulated entity. The regulatory body overseeing the ETS may outline specific monitoring methods. The next stage involves the reporting of the emissions. Reporting of emissions involves submitting the monitoring data to a regulatory body responsible for overseeing the ETS. Regulated entities are typically required to submit their emissions reports annually, and the reports should include a detailed breakdown of emissions sources, the methods used for measuring emissions, and any offsets or credits used to comply with the ETS requirements.

The next stage involves the verification of the emissions. This should be carried out by an independent third-party auditor. The auditor's role is to verify the accuracy of the reported data and assess whether the regulated entities have complied with the emissions cap. The ETS regulator will specify the qualifications and accreditation requirements for auditors and may maintain a list of approved auditors that regulated entities must use. As such, the regulated entities would be responsible for submitting their emissions reports to the regulator, and the regulator will review these reports and use an independent auditor to verify the emissions. Once verification is required, the regulated entity will typically be responsible for engaging and paying for the services of the auditor. The auditor will perform an independent assessment of the emissions data and submit a report to the ETS regulator. The ETS regulator will use the verification report to assess the compliance of the regulated entity with the ETS rules.

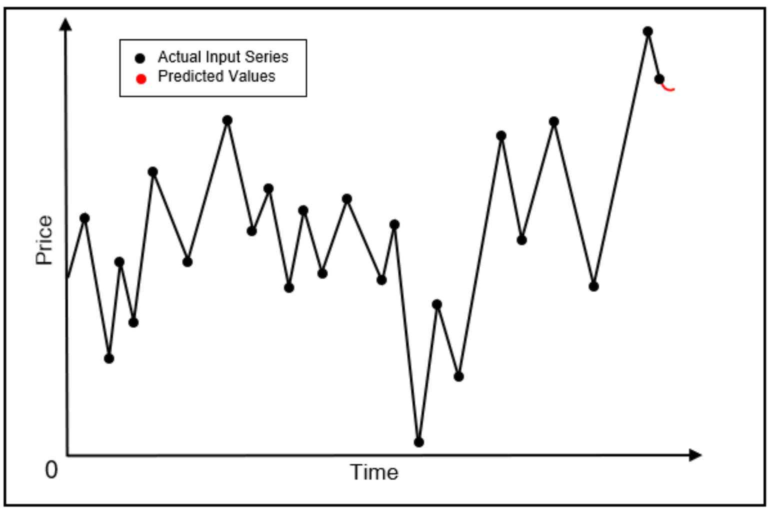
11. The carbon credit price

The price of the emissions allowances will influence the extent to which stakeholders will reduce their GHG emissions. This study therefore recommends that some of the emissions allowances can be distributed for free. Eventually auctions can be used, and the free allocation can be gradually phased out. Through auctions, the market price of emissions allowances at each initial public offering will send a signal regarding what is the cost of abatement . This may encourage businesses to recognize the negative external costs of their GHG emissions thereby setting the stage for businesses to take the first step towards internalizing the negative externality from their GHG emissions. Regulated entities requiring additional emissions allowances to purchase them and stakeholders with surplus emission allowances to sell them, which may create some interesting market dynamics. If the market price of the emissions allowances on the ETS is higher than the cost of reducing the GHG emissions, then it would be rational for some stakeholders to reduce their GHG emissions then sell the extra emissions allowances. In fact, since the cost of production will vary among firms in industries, the free trade of emissions allowances should incentivize the most efficient firms to reduce their GHG emissions, and the least efficient firms to purchase the emissions allowances.

At the time of writing, no ETS exists in the CARICOM region. Therefore, there are no prices for emissions allocations presently in the CARICOM region. Nevertheless, the prices of the emissions allocations are displayed using the price of the emissions allocations (carbon credits) on the EU ETS as a proxy[41] in this instance, in order to test the model and demostrate that it forecasts prices with a high degree of predictive accuracy. This a particularly useful tool for market regulators in ordee to determine how effective the carbom market will be. Diagram 1 illustrates the carbon credit prices on the EU ETS[42] It also provides a forecast of the prices. A forecast on the carbon credit prices is produced since the future prices of the emissions allocations should be of interest to stakeholders with an emissions cap[43] Stakeholders can therefore compare the costs of reducing their GHG emissions to the future market price of the emissions allocations. If the future price of the emissions allocations rises to certain thresholds, then it may incentivize stakeholders to reduce their emissions and sell their surplus emissions allocations on the ETS at a profit.

The forecast of the future prices should also be of interest to the potential regulator at the ETS as it can provide an outlook of the emissions allocations prices. If the forecast suggests that prices would decline precipitiously, then the regulator at the ETS may make preparations to remove some emissions allocations into the emissions allocations reserve. If the forecast suggests that the emissions allocations prices may rise too high, then the regulator at the ETS may add some emissions allocations from the emissions allocations reserve.

Diagram 1
European Union's carbon credit price trend and predictions



Source: Economic Commission for Latin America and the Caribbean (ECLAC).

41 There should be cognizance that the EU is under a stringent cap, which produces expensive allowances. However, price data are readily available.

42 An Empirical Mode Decomposition Particle Swarm Optimization Support Vector Regression (EMD-PSO-SVR) has been used to provide the n-step ahead out-of-sample forecast. The detailed methodology for the forecast can be found in annex 3 and annex 5. Notably, the EMD-PSO-SVR is consistent with the present status of univariate forecasting methodologies which use a decomposition method to first decompose the time series, then apply a machine learning model to forecast each decomposition. The forecasted decompositions are then summed to produce the overall out of sample forecast.

43 See annex 2 and annex 3 for the methodology.

IV. Conclusion

Globally, countries have demonstrated a willingness to pursue GHG emission reduction action. These pledges have been expressed in their NDCs. Although the CARICOM Member States have low GHG emissions, they demonstrated their commitment to the fight against climate change as they have also submitted NDCs to the UNFCCC. However, the Caribbean may need to pursue innovative mechanisms for both facilitating and financing of its NDCs implementation. Accordingly, a market-based modality may be useful in this regard. Presently, no such market-based mechanism exists in the subregion. The CARICOM Member States in looking towards the market-based mechanisms to facilitate the achievement of their NDCs, should seriuosly consider developing a Caribbean regional emissions trading scheme (ETS). It is expected that some businesses may be reluctant to participate in a mandatory ETS, which covers sectors outlined in each member states NDCs, since the CARICOM Member States GHG emissions are exceptionally low. However, if the CARICOM Members States are committed to pursuing action to reduce their GHG emissions as expressed in their NDCs, then the regional ETS may be a feasible mechanism to stimulate GHG emission reduction action. The governments of the CARICOM Members States would, however, need to meet to decide whether or not the subregion should adopt a regional ETS.

Assessing the interest and commitment of the private sector to engage in a ETS is crucial for the success of such an initiative. The private sector, particularly small and medium enterprises (SMEs), plays a significant role in contributing to greenhouse gas emissions, and their participation in an ETS is critical to achieving emissions reduction targets. To determine the interest and commitment of the private sector in a regional ETS, administering a survey is an effective way to gather information. The survey should be designed to gather information on the following: awareness and knowledge of emissions trading schemes; perceived benefits of participation; barriers to participation; and preferences for the ETS design. As seen in the case studies of several countries, a pilot of the ETS was rolled out before a larger intitiative was implemented. Therefore, testing a pilot phase of a regional ETS before considering it at the CARICOM level is a prudent approach. A pilot phase can provide valuable insights into the practicalities of implementing an ETS, highlight potential challenges, and inform the design of the final ETS. The pilot phase can also provide an opportunity to assess the readiness of the private sector to participate in an ETS and gather feedback on the potential impacts of the ETS on businesses, particularly small and medium enterprises. This information can be used to refine the ETS design and develop appropriate support mechanisms for regulated entities. Furthermore, conducting a pilot at the national level can also help to build capacity and strengthen the institutional frameworks necessary for the successful implementation of an ETS. This can involve training and capacity building for regulatory authorities and the private sector, as well as establishing monitoring, reporting, and verification systems.

After the pilot, a larger regional ETS can be rolled out. The overall objective of the mandatory ETS may be to meet the collective targets of all the Member States. Each Member State can be responsible for working on their own targets as specified in their NDCs. More importantly, in order for the ETS to be a success, it must be structured properly. Critical factors which must be considered in its design are the size of the emissions cap for the countries, the sectors that will be involved, the GHG to be covered, a monitoring, reporting and verification framework for the GHG emissions, the emissions allowances allocation system, and an emissions allocations reserve. All the aforementioned factors can influence the market price of the emissions allocations, which in turn will function as the market mechanism to stimulate the climate mitigation action. The three (3) step forecasting model introduced in the paper, which combines Empirical Mode Decomposition, Particle Swarm Optimization and Support Vector Regression, is also crucial since future prices would be of interest to a potential subregional ETS regulator. The revenue that the governments may generate from the auctions at the ETS can be used to finance other climate change adaptation and mitigation projects. Collectively, the ETS, as well as the implementation of other climate change adaptation and mitigation projects can assist countries in achieving their NDC targets, and help the international community move a step closer to reaching its overall goal of limiting global temperature rise to 1.5°C.

This notwithstanding, this paper represents an initial exploration of the notion that an ETS can be a useful tool for leveraging implementation of Caribbean NDCs. The authors therefore intend to build on this initial body of work through scenario analyses and a game theoretical framework, which may provide additional insights into the optimal features of a Caribbean-wide ETS.

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Annexes

Annex 1
A Cursory review of relevant progress of climate change negotiations as it relates to carbon credits, emissions trading schemes and climate finance.

The origins of the climate change negotiations can be traced to the First Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 1990 (Houghton et al. 1990). The policy makers' summary asserts "*We are certain of the following:there is a natural greenhouse effect which already keeps the Earth warmer than it would otherwise be; and emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide. These increases will enhance the greenhouse effect, resulting on average in an additional warming of the Earth's surface. The main greenhouse gas, water vapour, will increase in response to global warming and further enhance it".*[44]

These findings were so profound that they persuaded the international community to meet, resulting in the formation of the UNFCCC in 1992, and the annual Conference of the Parties (COP) from 1995'.

A. COP meetings

During the first 3 COPs, the Parties agreed that the stabilization of the emissions from the industrial countries was important. In fact, the Parties discussed Quantifiable Emissions Limitations and Reduction Obligations (QELROs) which set GHG emissions reduction targets for countries. Thus, when the Kyoto Protocol was signed at COP 3 in Kyoto, Japan, Parties agreed to the establishment of legally binding GHG emission reduction commitments for industrialized countries (Annex I countries). The 38 Annex I countries were required to reduce their GHG emissions by 5.2% below their 1990 levels. The first commitment period for the Kyoto Protocol covered 2008 to 2012. In 2012, the Protocol was amended to facilitate a second commitment period for 2013 to 2020.

The next major milestone occurred in COP 6 in 2000 where the US lobbied for the inclusion of market-based mechanisms in the Protocol, as well as the imposition of GHG emission reduction commitments upon its international trade competitors. In November 2000, COP 6 in The Hague, Netherlands, was suspended without reaching an agreement (Vrolijk 2000). This was followed by the US withdrawal from the Kyoto Protocol in 2001.

The market-based mechanisms, namely the Emission Trading Scheme (ETS), the Joint Implementation Mechanism, and the Clean Development Mechanism (CDM) emerged from COP 7 at Marrakech, Morocco, in 2001. The ETS created the framework for carbon markets. Annex I countries

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[44] In addition, the report indicated that 'We calculate with confidence that: some gases are potentially more effective than others at changing climate, and their relative effectiveness can be estimated Carbon dioxide has been responsible for over half the enhanced greenhouse effect in the past and is likely to remain so in the future; atmospheric concentrations of the long-lived gases (carbon dioxide, nitrous oxide and the CFCs) adjust only slowly to changes in emissions. Continued emissions of these gases at present rates would commit us to increased concentrations for centuries ahead. The longer emissions continue to increase at present day rates, the greater reductions would have to be for concentrations to stabilize at a given level; and the long-lived gases would require immediate reductions in emissions from human activities of over 60% to stabilize their concentrations at today's levels, methane would require a 15-20% reduction'. It also predicted that 'based on current model results, we predict: 'under the IPCC Business-as-Usual (Scenario A) emissions of greenhouse gases, a rate of increase of global mean temperature during the next century of about 0 3°C per decade (with an uncertainty range of 0 2°C to 0 5°C per decade), this is greater than that seen over the past 10,000 years. This will result in a likely increase in global mean temperature of about 1°C above the present value by 2025 and VC before the end of the next century. The rise will not be steady because of the influence of other factors." (Houghton et al., 1990, VI)'.

with emission reduction commitments were allowed to purchase AAUs, to offset their commitments. The AAUs were essentially, carbon credits.

Additionally, the Clean Development Mechanism allowed Annex I countries with emission reduction commitments to achieve part of their Kyoto targets by implementing emission reduction projects in non-Annex I countries. For every ton of GHG emission avoided within a CDM project, the project developers may earn a carbon credit called a Certified Emission Reduction (CER). Projects implemented by Annex I countries in non-Annex I countries under the Joint Implementation may earn a carbon credit called Emission Reduction Units (ERUs). Each ton of GHG saved and certified as a CER or ERU gives the owner of the carbon credit the right to emit a ton of GHG elsewhere. In other words, the CERs and the ERUs could be used to offset GHG emission requirements. Both the CERs and ERUs could be traded in carbon markets (de Alegría et al., 2017). Therefore, stakeholders' GHG emission reduction commitments could be offset by purchasing the carbon credits.

Fortuitously, three climate finance funds were developed as a result of COP 7. These were: (i) the Least Developed Countries (LDCs) Fund; (ii) the Special Climate Change Fund; and (iii) the Adaptation Fund (Mace, 2005; Bulkeley & Newell, 2015; Charles, 2016). These funds helped mobilize finance to fund climate action in various countries.

At COP 15 held in Copenhagen, Denmark, in 2009, Parties aspired to create a successor treaty to the Kyoto Protocol. Unfortunately, there was a deadlock at the Conference, over the extending legally binding GHG emission reduction commitments to both Annex I and non-Annex I countries. Additionally, the US negotiators were reluctant to accept any legally binding climate action treaty since Congress approval was required to approve the agreement. Furthermore, the US Congress was unwilling to approve of any legally binding climate action treaty if similar GHG reduction constraints are not imposed on China (Falkner, 2016).

Concerned that the Kyoto Protocol may expire in 2012 with no replacement agreement, at COP 17 in Durban, South Africa, in 2011, Parties agreed to an extension of the Protocol to 2017 and potentially 2020. The second commitment was confirmed through the "Doha Amendment to the Kyoto Protocol" in COP 18 at Doha, Qatar, in 2012. Parties also agreed to negotiate a successor to the Kyoto Protocol.

In 2015, at COP 21, Parties agreed to the a climate change treaty, the Paris Agreement,[45] which sought to encourage global collective action to limit global temperature rise to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C by the end of the century. The Paris Agreement broke the deadlock in negotiations between the Annex I and non-Annex I countries to pursue GHG emission reduction action. This was achieved by encouraging countries to voluntarily submit their own plans to reduce their GHG emissions. The Paris Agreement was very appealing to many developed countries as it is not legally binding and also succeeded in persuading large GHG emitting non-Annex I countries such as China, India, Brazil, South Africa, and Indonesia to pursue some GHG emission reduction action.

To achieve the overall goal of limiting global temperature rise, parties were encouraged to submit their INDCs.[46] Given that there is an unequal distribution of technical and financial capacity among the countries, the developed countries pledged to provide support to developing countries to help achieve their NDCs. Moreover, US$100 billion per year in climate finance from 2020 onwards was pledged by

[45] 196 countries became Party to the Paris Agreement. The Paris Agreement entered into force on November 4, 2016. The Agreement applies from 2020, and the first global review of progress made, the Global Stocktake, is scheduled to occur in 2023 (C2ES, 2021).

[46] The idea for the NDCs rose out of COP 19 in Warsaw in 2013. Parties were encouraged to submit their INDCs in advance of COP 21 (C2ES, 2021).

donor countries and agencies at COP 21.[47] Given that there a multiple climate finance funds under the UNFCCC, the pledged climate finance were to be channeled through a multiplicity of mechanisms.[48]

The Twenty Seventh Conference of the Parties (COP27) to the United Nations Framework Convention on Climate Change (UNFCCC) was held in Sharm el-Sheikh, Egypt, in 2022. COP27 was framed as the "implementation COP", which would lead to action. It was expected to make progress on "loss and damage".[49] The industrialized countries are mainly in opposition to loss and damage finance. They are of the view that loss and damage finance would expose them to never-ending litigation.[50] While many industrialized countries are in favour of an insurance mechanism to address loss and damage, many insurers and reinsurers are unwilling to take on the weather risk for SIDS as they have a high probability of filing claims due to their high likelihood of experiencing extreme weather events (Charles, 2021).

Hence, by far, the most significant outcome of COP27 was the agreement to establish a Loss and Damage Fund for Vulnerable Countries. The Fund is to be dedicated to developing countries to respond to loss and damage. Notably, Parties have agreed to establish a 'transitional committee' in the Twenty Eighth session of the Conference of the Parties (COP 28) in 2023 in Dubai, the United Arab Emirates, to determine the modality for operationalizing the funding arrangements. Another major outcome of COP 27 was the progress made on adaptation. Parties agreed to move forward on the Global Goal on Adaptation into COP 28 and complete the first Global Stock-take (2021 – 2023). Deliberations were also held on setting a new collective quantified goal on climate finance in 2024. The expectation is that emphasis will be placed on SIDS as the new climate finance goal is set.

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47 The US$100 billion per year in climate finance is an old pledge that originated from COP 15, in Denmark in 2009.

48 The climate finance funds under the UNFCCC include the Least Developed Countries Fund (LDCF), the Special Climate Change Fund (SCCF), the Adaptation Fund (AF), and the Green Climate Fund (GCF). The GCF is presently the lead agency for financing adaptation and mitigation action in developing countries. The LDCF and the SCCF are under the jurisdiction of the Global Environment Facility (GEF) (Amerasinghe et al., 2017).

49 Loss and damage refers to the permanent loss or repairable damage caused by climate change. It includes the loss and damage caused by the increase in the frequency and intensity of extreme weather events such as hurricanes, tropical cyclones, tornadoes, and heat waves. It also includes the effects of slow-onset events such as sea-level rise, ocean acidification, and desertification. More importantly, loss and damage refers to the effects that goes beyond adaptation and mitigation.

50 Presently, the climate science (Geography, Meteorology, Climatology) cannot link any country's GHG emissions to any extreme weather event. Therefore, no industrialized country wants to be held legally liable for loss and damage in any country (Charles 2021). Furthermore, countries are weary about agreeing to mobilizing loss and damage finance as it could lead to increase costs for their private sector, which could negatively impact their competitiveness as they participate in international trade.

Annex 2

Table A1
List of CARICOM member States's NDC pledges

Country	Emission reduction target	RE target	EE target	NDC tools	Primary sectors
Antigua and Barbuda		(1) by 2030, achieve an energy matrix with 50 MW of electricity from RE, (2) by 2030, produce 100% of electricity demanded for water sources from off-grid RE		Conditional: (1) by 2020, establish EE standards for the import of vehicles, (2) construct a WTE plant by 2025. Unconditional: (1) create a legal/policy framework for low carbon development, (2) update building codes	Energy, health, tourism, agriculture, waste, water, transportation, and forestry
The Bahamas	Conditional: 30% of 2030 BaU	(1) 30% of RE in the energy mix by 2030		(1) Create a legal/policy framework for RE, (2) PPP for RE, (3) lower import duty on hybrid cars, (4) establish an EE building code, (5) tax vehicle imports based on fuel consumption and engine CC, (6) establish a National Forestry Estate	Energy, forestry, and transport
Barbados	Conditional: 30% of BaU by 2030	RE to produce 65% of peak demand by 2030	(1) 22% reduction in BaU by 2029, (2) in non-electricity, a 22% reduction in BaU by 2029	(1) Tax incentives to encourage the import of hybrid vehicles	Energy, industry, waste, and agriculture
Belize	Conditional: 20% reduction in transport fuel use	Increase RE to 85% of the energy mix by 2030		(1) Protect forests, (2) reduce wood fuel consumption, (3) protect mangrove, (4) develop transport policy, (5) develop a sustainable energy action plan, (6) promote EE, (7) develop solid waste policy	Energy, solid waste management, and transport
Dominica	Conditional: 44.7% of 2014 emissions reduction by 2030	(1) Geothermal power generation: 39.3 Gg, (2) solar PV for Hotel Sector: 0.24 Gg, (3) solar PV for schools, universities, hospitals, etc.: 0.86 Gg, (4) off-grid RE backup	5.2 Gg from streetlights	(1) RE investment in geothermal, solar PV, off-grid micro-hydro, and wind, (2) replace all gov vehicles with hybrids,	Energy, transport, manufacturing, construction, residential, agriculture, fisheries, forestry, and solid waste

Country	Emission reduction target	RE target	EE target	NDC tools	Primary sectors
		for Ross University: 1.71 Gg, (5) promoting hybrid vehicles: 12 Gg, (6) RE-powered mini-grids: 2.92 Gg, (7) reduce CH4 emissions from landfill: >11 Gg		(3) policy to encourage the import of hybrids, (4) replacing streetlights in Portsmouth with LED fixtures, (5) implement an EE retrofits program, (6) develop an EE building code, (7) implement an educational awareness program	
Grenada	Conditional: 30% of 2010 emission reduction by 2030	(1) 10 MW solar, 15 MW geothermal, 2 MW wind by 2025, (2) landfill CH4 capture	(1) Building retrofits (20% reduction), (2) building codes (30% reduction), (3) EE in hotels (20% reduction)	(1) Building codes, (2) transport fuel tax, (3) EE standards	Electricity, transport, waste, and forestry
Guyana	Conditional: (1) avoid deforestation: 48.7 Mt CO_2; (2) energy: 100% renewable power supply by 2025	Conditional: Energy: 100% renewable power supply by 2025		(1) Forestry policies, (2) building codes, (3) net metering, (4) remove import duty on RE equipment, (5) conduct energy audits, (6) public education, (7) RE for new townships	Energy, and forestry
Haiti	Conditional: 26% of BaU by 2030; Unconditional: 5% of BaU by 2030	Conditional: 60 MW hydro (24.5%), 50 MW wind (9.4%), 30 MW solar (7.5%) and 20 MW biomass (5.6%)	Reduce fuelwood consumption by 32% by 2030, distribution of 1M low-consumption lamps		Energy, agriculture, forestry, land, and waste
Jamaica	10% of BaU by 2030	Increase RE to 20% of the energy mix by 2030		(1) Implement climate change policy, (2) implement energy policy, (3) scale up RE	Energy, and transport
Saint Kitts and Nevis	Conditional: 35% of BaU by 2030	35 MW geothermal, 1.9 MW solar, 7.6 MW wind, 0.5 MW WtE	(1) Reduce electricity losses by at least 50%, (2) 5% reduction in national energy consumption, (3) 5% reduction in fuel consumption		Electricity, and transport
Saint. Lucia	Conditional: 23% of BaU by 2030	35% of the energy generated using RE by 2025, and 50% by 2050		(1) Implement EE buildings, (2) improve EE in transport	Energy, and transport
Saint Vincent and the Grenadines	22% of BaU by 2025	50% of energy supply from geothermal	22% reduction in electricity consumption compared to the BaU by 2025	(1) New building code, (2) reduce import duties on low emission vehicles,	Energy, industry, agriculture, and waste

Country	Emission reduction target	RE target	EE target	NDC tools	Primary sectors
				(3) labelling of appliances	
Suriname		(1) 168 MW hydropower plant, (2) 62 MW from geothermal, (3) a biofuel project to blend ethanol in gasoline, (4) 25% RE generation by 2025		Policy/and laws	Energy, and forestry
Trinidad and Tobago	15% of BaU by 2030			(1) 15% reduction of BaU in the 3 priority sectors, (2) implement a forestry policy, (3) implement an environmental policy, (4) implement a climate policy, (5) consider RE projects	Conditional: power, industry, Unconditional: transport

Source: UNFCCC (2018); Charles (2022).
Note: Trinidad and Tobago has a renewable energy target of 10% of total electricity by 2021. However, this was not expressed as an INDC or NDC.

Annex 3

A.1 Empirical Mode Decomposition

The Empirical Mode Decomposition (EMD) is a technique that can be used to decompose signals and time series. It is appropriate for time series that are non-stationary and non-linear. It is based on the assumption that the original signal or time series is composed of multiple oscillations in the frequency domain. This may be expressed as

$$x(t) = \sum_n x_n(t) + r(t) \qquad (01)$$

where $x(t)$ is the signal; $x_n(t)$ is the IMFs; and $r(t)$ is the residual.

The EMD seeks to identify the various oscillatory modes, also referred to as intrinsic mode functions (IMFs), and separate these IMFs from the original signal. In other words, the EMD goes into the frequency domain and breaks up the original time series into multiple IMFs while remaining in the time domain. This results in each of the IMFs being of the same length to reflect the same time domain. (In Matlab, increasing the length of the signal increases the number of IMFs).

The EMD algorithm applies the decomposition to a time series into its component IMFs obeying two properties:

(i) The number of local minima and maxima of an IMF differs by at most 1.

(ii) The mean of an IMF is 0.

The second property is the stationary condition for the IMF (Zeiler et al., 2010).

The EMD is comparable to other time-frequency decomposition methods, such as the Fourier Transform and wavelet decomposition. However, the EMD framework is advantageous to the other methods as it is easier to reconstruct. In fact, as all the IMFs are of the same length, they can be reconstructed into the original time series by adding all the IMFs and the residual. In contrast, complex transformations have to be applied to the Fourier Transform and the wavelet transform to reconstruct the original signal. For this reason, the EMD framework is often the preferred decomposition methodology used in decomposition-based forecasting methodologies.

A.2 Particle Swarm Optimization

Particle Swarm Optimization (PSO) is an optimization technique that is based on the swarming behaviors exhibited by birds, insects, and fish. The technique is used to determine optimal or near-optimal solutions to location problems. More specifically, it attempts to solve a problem by taking a population or group of candidate solutions, also referred to as particles, and shifting these particles around in the search-space towards the optimal position (Kennedy & Eberhart, 1995).

The optimization process commences with a swarm comprised of *N* particles. Each particle has a position vector and a velocity vector. This may be denoted by

$$x_i = (x_{i1}, \ldots, x_{id}) \qquad (02)$$

$$v_i = (v_{i1}, \ldots, v_{id}) \qquad (03)$$

where x_i denotes the position vector, v_i denotes the velocity vector, i=1,...,d are the number of dimensions in the vector.

Each particle is conscious of its own best (*ob*) and the global best (*gb*) position in the D-dimensional search space. The modified velocity and position of each particle is computed with the following equations.

$$v_{id}^{k+1} = \omega v_{id}^{k} + c_1 r_1 (ob - x_{id}) + c_2 r_2 (gb - x_{id}) \quad (04)$$

$$x_{id}^{k+1} = x_{id}^{k} + v_{id}^{k+1} \quad (05)$$

where $k+1$ denotes the new velocity or position, k is the previous velocity or position, ω is a weight, c_1 is the cognition factor, c_2 is the social learning factor, the *c* shows the pull of each particle toward the *ob* and gb positions, r_1 and r_2 are uniformly distributed random numbers in the 0 to 1 range.

The weight which determines the balance between global and local explorations is estimated by the formula:

$$\omega = \omega_{min} - (\omega_{max} - \omega_{min}) * \frac{iter}{iter_{max}} \quad (06)$$

where ω_{max} is the maximum weight, ω_{min} is the minimum weight, $iter$ represents the current iteration, and $iter_{max}$ denotes the maximum iteration (Wang et al. 2010; Liu et al. 2018; Rastgoufard and Charalampidis 2018).

A.3 Support Vector Regression

The Support Vector Regression (SVR) is a supervised learning machine learning model.[51] It is also an extension of the Support Vector Machine (SVM) Model (Drucker et al., 1997). If a research objective is to classify data, the SVM uses a hyperplane and support vectors to perform the classification.

The hyperplane can be a line, which may be linear or non-linear, that is used to separate the data. The support vectors are the boundaries that define the soft margin which indicates an interval range in which estimation errors may be tolerated.

If the data is linear and can be divided into 2 categories, a liner hyperplane can be used as the threshold to perform the separation. This hyperplane is denoted by:

$$w^T z + b = 0 \quad (07)$$

where *w* is the n-dimension weight, *z* is the training data (z_i $were$ $i = 1, 2, 3, \dots, n$), and *b* is the bias that allows some misclassification.

The hyperplane must satisfy 2 conditions. First, the misclassification error (denoted by b) must be kept to a minimum. Second, the distance of the hyperplane to the support vectors (hence the soft margin) should be at a maximum (Shrivastav and Ramudu 2020). The soft margin may be specified as:

$$w^T z + b \begin{cases} \geq 1 \; for \; y_i = 1 \\ \leq 1 \; for \; y_i = -1 \end{cases} \quad (08)$$

where y_i denotes the support vectors that form the boundary of the soft margin.

Therefore, in the application of the SVM a hyperplane is used to separate the data. In the cases where the data is not linearly separable, a Kernel Function is used to transform the data, then the hyperplane is used to perform the separation. The Kernel Function is necessary to transform the data into a higher dimension, to make it separable. The support vectors would be used to determine the soft margin and level of tolerance for the classification errors.

Ullrich et al. (2007) note several Kernel Functions can be used.

Linear: $k(x, x') = \langle x, x' \rangle$ (09)

Polynomial: $k(x, x') = \langle x, x' \rangle^{degree}$ (10)

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[51] Supervised learning machine learning models are models that learns from an example to determine the function that is appropriate to map input to output. in contrast, unsupervised learning models do not learn patterns from the data. Example of unsupervised learning models include principal component analysis, and factor analysis.

Polynomial: $k(x, x') = (scale * \langle x, x' \rangle + offset)^{degree}$ (11)

Laplace: $k(x, x') = \exp(-\sigma \, \|x, x'\|)$ (12)

Gaussian Radial Basis: $k(x, x') = \exp(-\sigma \, \|x, x'\|^2)$ (13)

Hyperbolic $k(x, x') = \tanh(scale * \langle x, x' \rangle + offset)$ (14)

Bessel $k(x, x') = \frac{Bessel_{v+1}^{n}(\sigma\|x, x'\|)}{(\|x, x'\|^{-n(v+1)})}$ (15)

The SVR operates on a similar principle. The SVR is an approximation of the regression function within a margin utilizing a set of support vectors.

The SVR can map linear and non-linear functions. Let a linear case be represented by:

$$y_i = w^T x_i + b \quad (16)$$

where *w* is the weight vector, *b* is the intercept (constant) of the regression model, and x_i is the input vector or matrix.

Let a non-linear representation be denoted by:

$$y_i = w^T \Phi x_i + b \quad (17)$$

where Φ is supposed to denote a non-linear parameter.

The *w* and *b* parameters are estimated by minimizing the function:

$$r(C) = C \frac{1}{N} \sum_{i=1}^{N} L_\varepsilon(d_i, y_i) + \frac{1}{2} \|\omega\|^2 \quad (18)$$

where

$$L_\varepsilon(d, y) = \begin{cases} |d - y| - \varepsilon \; if \; |d - y| \geq \varepsilon \\ 0 \quad\quad otherwise \end{cases} \quad (19)$$

where *C* is the regularized constant that determines the trade-off between the empirical risk and the regularization term; ε is referred to the tube size which states the approximation accuracy placed on the training data points; $L_\varepsilon(d, y)$ denotes the ε-insensitive loss function. *C* and ε are also user-determined parameters.

A.4 Particle Swarm Optimization -Support Vector Regression- (PSO-SVR)

In the PSO-SVR, the PSO is used to determine the optimal parameter values of the SVR model (Wang et al., 2010). These parameters that may be optimized are the regularization parameter *C*, the tube size of insensitive loss function ε, and the kernel function parameter *K*. It is important that the appropriate values of these parameters are determined in order to prevent overfitting or underfitting. Therefore, the integration of the PSO into the SVR should improve the quality of the SVR.

Liu et al. (2018) applied the PSO-SVR via the following steps.

Step 1 – initialization

In the first step, there is an initialization of the parameters for the regularization parameter *C*, the tube size of insensitive loss function ε, and the kernel function parameter *K*.

Step 2 – fitness evaluation

In the second step, the aforementioned parameters are inserted in the SVR. The SVR is run and a forecast is generated. The mean squared error is used to assess the performance of the model and the model fit.

Step 3 – update of own best

For each particle, compare its present fitness/objective value with the objective value of its own best. If the current iteration is better and exceeds that of its own best, then the own best is updated and replaced with the current objective value.

Step 4 – update of global best

For each particle, compare its present fitness/objective value with the objective value of the global best. If the current iteration is better than the global best, then the global best is updated with the current objective value.

Step 5 – update of velocity and position

Update the velocity and position of each particle using Equations (04) and (05).

Step 6 – stop criteria

The aforementioned processes are repeated in the stipulated order until the maximum iteration is reached. Annex 3 illustrates a flow chart of the PSO-SVR.

Annex 4
PSo-SVR algorithm sequence

Unfortunately, the Matlab code that was utilized by Wang et al. (2010), and Liu et al. (2018) was not publicly available. As a result, this study applied the PSO-SVR slightly differently. The algorithm used for the PSO-SVR in Matlab 2018b in this study takes the following sequence.

- **Step:1** Read the excel file.
- **Step:2** Define the parameters, input series, and next day target output.
- **Step:3** Give the parameters as input to PSO.
- **Step:4** Optimize Regularization parameter (*C*) and Kernel function (*K*) through the PSO.
- **Step:5** Input optimized parameters to SVR.
- **Step:6** Calculate the mean squared error (MSE).
- **Step:7** Perform cross-validation.
- **Step:8** Plot the required graphics.
- **Step:9** Get input from the user to predict no. of values.
- **Step:10** Predict the new value based on the optimized SVR model.

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