Received: 11 November 2023 | Revised: 11 May 2024 | Accepted: 13 July 2024 | Published online: 22 July 2024

RESEARCH ARTICLE

Green and Low-Carbon Economy
2024, Vol. 00(00) 1–12
DOI: 10.47852/bonviewGLCE42022046

BON VIEW PUBLISHING

Addressing Loss and Damage from Climate Change Through Tokenized Rainfall Futures

Don Charles[1,*] and **Sheldon McLean**[2]

[1] *Independent Researcher, Trinidad and Tobago*

[2] *Economic Commission for Latin America and the Caribbean, Trinidad and Tobago*

Abstract: The objective of the study was to explore how finance to cover the cost of loss and damage from climate change can be mobilized through weather derivatives. More specifically, a futures contract was considered as the derivative to mobilize the financing. To integrate the recent advancements in finance and technology, tokenized weather derivatives can be considered.

This study contributes to the literature as it proposes a pricing mechanism for the proposed loss and damage futures. The futures price should be a function of the contract size, the difference between the expected rainfall in the future, and the threshold or long-run average rainfall. This pricing approach is adopted since it allows the price to rise when excess rainfall occurs, which in turn is responsible for loss and damage. Therefore, the forecast of the rainfall should be of significant interest of the economic agent seeking to hedge the loss and damage with the futures.

A long short-term memory (LSTM) model was used for forecasting. The LSTM performed better than traditional linear models such as the autoregressive integrated moving average and exponential generalized autoregressive conditional heteroscedasticity models, as it can capture the non-linear dynamics of the rainfall data.

Keywords: loss and damage, climate change, long short-term memory, forecasting, futures

1. Introduction

The most extreme category of Atlantic hurricanes is Category 5, and they are supposed to rarely occur. However, over the period from 2016 to 2019, there was at least one Category Five Atlantic hurricane in each year [1]. In fact, that was the longest streak for consecutive Category Five Atlantic hurricanes. Nine Atlantic hurricanes, including Camille, Allen, Andrew, Isabel, Ivan, Dean, Felix, Irma, and Maria, experienced multiple instances of reaching Category 5 intensity. This entails initially achieving Category 5 status, subsequently weakening to Category 4 or lower, and then regaining Category 5 hurricane strength [2]. Table 1 [3] displays the Category 5 Atlantic hurricanes from 1955 to the present in 2023.

When these Category 5 hurricanes make landfall, they typically cause a lot of damage to the affected country. For instance, in September 2019, Hurricane Dorian struck the Abaco Islands (in the Bahamas) as a Category 5 hurricane. The hurricane caused flooding and mass destruction, including destroying houses and buildings, damage to the island's airport and hospital, downed power lines, and damage to other public infrastructure [4]. The cost of the damage to the Bahamas (the islands of Abaco and Grand Bahama) from Hurricane Dorian was estimated at US$3.4 billion, which is approximately a quarter of the country's GDP [5]. In the aftermath of hurricanes, tropical cyclones, and other extreme weather events, the governments of the affected country are typically tasked with the responsibility of replacing the damaged public infrastructure. While it is true that many countries affected by extreme weather events typically receive some aid, this aid is only sufficient to partially offset the costs of the immediate relief and recovery effort. Greater finance is required to replace the damaged public infrastructure. Since Caribbean governments generally do not have surplus funds waiting for them in these emergency situations, they tend to turn to debt financing.

However, the Caribbean region is already one of the most indebted regions in the world. Several countries' debt-to-GDP ratios stand close to 100% [6]. Additionally, several countries' debt-to-GDP ratios are over 60%, which is the upper limit for sustainable debt for a developed country [7].

However, as low absolute emitters of greenhouse gases (GHGs), the Caribbean did not cause this climate change problem. But they are affected by climate change, which is the effect from the negative externality of the GHG emissions. There is a need for the highest GHG emitting countries to internalize the negative externality of their GHG emissions. However, no industrialized country wants to be held liable for climate change on any extreme weather event in any country.

While the international community is debating at the Conference of the Parties, there is an urgent need to mobilize finance to address the loss and damage from climate change for Caribbean small island developing states. In this regard, weather derivatives emerge as a potential solution. Weather derivatives are an attractive option as they can be used to mobilize finance,

---

[*] **Corresponding author:** Don Charles, Independent Researcher, Trinidad and Tobago. Email: don.charles@my.uwi.edu

Table 1
Category 5 Atlantic hurricanes since 1955

1955 – Janet	1988 – Gilbert	2007 – Dean
1961 – Esther	1989 – Hugo	2007 – Felix
1961 – Hattie	1992 – Andrew	2016 – Mathew
1966 – Inz	1988 – Mitch	2017 – Irma
1967 – Beulah	2003 – Isabel	2017 – Maria
1969 – Camille	2004 – Ivan	2018 – Michael
1971 – Edith	2005 – Emily	2019 – Dorian
1977 – Anita	2005 – Katrina	2019 Lorenzo
1979 – David	2005 – Rita	2022 – Ian
1980 – Allen	2005 – Wilma	2023 – Lee

which can be used to offset losses while the country is held legally liable for climate change.

The objective of the study is to explore how finance to cover the cost of loss and damage from climate change can be mobilized through weather derivatives. To integrate the recent advancements in finance and technology, tokenized weather derivatives can be considered.

The novelty in this research is the application of weather derivatives to address loss and damage from climate change. The second contribution is this study adds to the literature on weather derivatives, which currently contains scares literature. The third contribution is the application of tokenization to weather derivatives.

The rest of the study is structured as follows. Section 2 provides a literature review on weather derivatives. Section 3 outlines the data and methodology used for the analysis. Section 4 presents the results of the analysis. Section 5 furnishes a discussion on the pricing of the loss and damage futures. Section 6 concludes this study.

2. Literature Review on Weather Derivatives

Unpredictable changes in weather can cause financial losses for several economic agents. To hedge against possible losses, derivative instruments called weather derivatives come into play [8].

A derivative is an asset that holds no value on its own and derives its value from another asset called an underlying [9]. It consists of a contract between two parties and can be used to hedge a position in the underlying asset.[1] Derivatives are typically traded on standardized financial markets called exchanges or through private and customized market arrangements called over-the-counter (OTC) markets [11]. There are different types of derivatives, namely futures, forwards, options, and swaps [12].

A futures contract involves two parties agreeing to buy and sell a specific amount of an asset at a predetermined price, with the delivery of the asset scheduled for a future date known as the maturity date [13]. In practice, when futures are traded on exchanges, there is usually no actual delivery of the asset; instead, the contract is typically liquidated by the maturity date.[2] In comparison, a forward contract is an agreement where two parties agree to buy and sell a specific amount of an asset in the present. Payment for the asset is made, and the delivery of the asset occurs at the maturity date. Forward contracts are often traded on OTC markets [10, 14].

An option is a contract that gives a trader the right (not the obligation) to buy or sell an asset at a predetermined price on a specific date. The predetermined price is referred to as the strike price. The right to purchase the option at the strike price is called a call option, while the right to sell the option at the strike price is called a put option. Options are used for hedging because if the price of the asset moves unfavorably in the future, the option holder can execute the option to mitigate or eliminate potential losses from changes in the asset's price [15]. A swap is a contract where two economic agents agree to exchange cash flows from specific financial instruments [10].

In the context of weather, derivatives can be used to hedge against commonly occurring adverse weather conditions [16, 17].[3] They were originally designed to hedge against temperature, but eventually, derivatives have been created to hedge against excess wind, snow, hail, excess or deficit rainfall, or a combination of different adverse weather conditions. Notably, in contrast to traditional financial derivatives used to hedge against price risk, weather derivatives are employed to hedge against potential losses in output due to unfavorable weather conditions [18].

Weather derivative contracts are based on weather indices that track the weather conditions at specific locations measured by meteorological stations. Therefore, meteorological data are essential for the design of weather derivatives. Like financial derivatives, weather derivatives can be manifested as futures, options, and swaps [8].[4]

The next subsection reviews the history of the use of weather derivatives.

2.1. History of the use of weather derivatives

The first weather derivative was used in 1996 as a contract traded OTC between Aquila Energy and Consolidated Edison. The contract was a forward contract where Consolidated Edison would purchase electricity at an agreed-upon price from Aquila, and the delivery of the electricity supply was scheduled for a future date. However, the contract included a clause for mitigating risk in the weather [19].

After that, the El Niño events of 1996 to 1998 and the corresponding warm winters caused a reduced demand for heating, which, in turn, reduced the revenues for electricity companies in the United States (US) in that year. Subsequently, in 1997, Koch Energy and Enron entered into a forward contract to supply electricity but included a clause to mitigate against risks from temperature [19]. Later in 1999, the first standardized future contract for temperature was traded on the Chicago Mercantile Exchange (CME). The exchange acted as the clearinghouse[5] ensuring settlement and liquidity and eliminating Herstatt risk [8].[6] Trading of weather derivatives on the exchange also increased the transparency of transactions and encouraged the spread of weather derivatives to regions outside of the US. In fact, the CME

---

[1] Alternatively, traders that have no interest in the underlying can trade the derivative as they aspire to profit from the changes in price. These types of traders are referred to as speculators [10].

[2] For example, if an economic agent sold a futures contract, they would receive a payment for the asset in the present, but the delivery is scheduled for a future date. At this point in time, the contract is considered as open as the entire transaction has not been completed. When the maturity date arrives, the contract expires and the exchange closes the contract. This is done by forcing the economic agent that originally sold the asset to buy it back at the present price.

[3] In contrast, weather insurance is used to mitigate the loss of extreme weather events which have a low probability of occurring.

[4] Since the underlying weather derivative is the index of meteorological data, there will be no delivery at maturity. Therefore, weather derivatives are always liquidated by the maturity date. Hence the reason why forwards are not appropriate contracts for weather derivatives.

[5] The clearing house performs as the buyer for all sellers and the seller for all buyers. This ensures the settlement of all transactions.

[6] Herstatt risk is also referred to as settlement risk. It is the risk that a transaction will not be completed because one party of the transaction is unable to settle the transaction [20].

has weather derivatives for 47 cities across the US, Canada, Europe, Australia, and Asia [19].

The CME weather derivatives were initially based on different temperature indices, namely heating degree days (HDDs) and cooling degree days (CDDs). However, as it expanded to include more weather conditions, it developed more indices. After the weather index was defined, the weather derivative was specified by various elements: (i) the contract type, which can be futures, options, or a swap; (ii) the contract period; (iii) the meteorological station from which the weather data are recorded; (iv) the tick size, which determines the dollar amount associated with each weather index; (v) the maximum payout, which protects parties from extreme weather events [19].

Mexico also used weather derivatives. For instance, it launched weather derivative insurance for farmers in 2003. The insurance was created to insure against droughts (deficit rainfall) affecting four crops, namely corn, barley, beans, and sorghum. The insurance mainly affects corn since over 80% of the cultivated land is devoted to corn. Agroasemex, a state-owned agency, provides coverage to farmers. Also, the farmers are the beneficiaries of claims; they do not pay premiums to Agroasemex. Instead, the federal government covers 70% of the cost of the premium while the state government pays the remaining 30%. Agroasemex reinsures their risk[7] with the reinsurance company Partner RE, thus spreading their risk internationally [21].

The methodology for the weather derivative insurance was structured as follows. First, Agroasemex estimated a liability (loss) index for each crop. Then, it estimated a weather index for different weather conditions for which it intends to provide coverage. To establish the relationship between the loss and the weather conditions, it estimated a basic regression when the liability index is regressed on various weather indices. The aggregation of the various liability indices was used as the index to measure their risk exposure for reinsurance. Therefore, this aggregated loss index was used as the underlying for a weather derivative to hedge their risk [22]. A futures with a call option was used as the weather derivative, as the strike price associated with the option guarantees a minimum profit margin from trading the derivative.

While Mexico's weather derivatives have often been integrated with weather insurance, it is important to distinguish that weather insurance is not the same as a weather derivative. In parametric weather insurance, the insurer provides coverage for specific weather conditions referred to as named perils. An index is used to track the performance of the weather conditions, and when it passes a threshold, it acts as a trigger for the insurer to make a payment to the policyholder. In contrast, a derivative does not trigger a payout when an event occurs. Instead, the trader of the derivative can profit from changes in its price, which in turn can be used to offset the potential loss caused by adverse weather conditions.

European countries such as France, the United Kingdom (UK), and Germany have experimented with weather derivatives. For instance, in July 2001, the London International Financial Futures and Options Exchange issued six exchange-traded futures contracts based on indices of the mean of daily average temperatures (Mean DATs) in London, Paris, and Berlin. Each contract was worth £3,000 for every degree Celsius of temperature change. The futures were cash-settled, meaning that no physical delivery of a commodity occurred. Instead, the contracts' value was settled in cash based on the difference between the actual temperature (as measured) and the reference index value [23]. European weather derivatives cannot be liquidated before their expiration date [24]. Several countries in the Asia-Pacific region have shown interest and traded weather derivatives. For instance, in Japan, the Tokyo Commodity Exchange entered the weather derivatives market as it launched weather futures and options contracts. There are contracts based on temperature indices for various cities in Japan, allowing businesses to hedge against temperature-related risks. South Korea, through the Korea Exchange (KRX), also established a weather derivatives market. KRX offers temperature-based futures and options contracts. In Australia, the Australian Securities Exchange provides weather futures and options linked to temperature indices. While Asia-Pacific weather derivatives do allow for the hedging of risk of various stakeholders, Asian markets have a more limited set of derivative contracts than North American and European markets [18].

An important aspect of the weather derivative is the relation between the price of the derivative and the value of the weather index. This relation will inform the hedging position. For instance, if as temperature rises, the price of the weather derivative increases, then a farmer seeking to hedge against high temperatures would take a long position since if the temperatures are higher than expected, there should be a rise in the futures price which would allow for offsetting some of the loss from reduced yields. Likewise, if there is an inverse relation between the price of the derivative and the value of the weather index, then the farmer would hedge temperature rises by taking a short position.

The next subsection reviews how weather derivatives are priced.

2.2. Pricing of weather derivatives

The pricing of weather derivatives is challenging due to the underlying weather conditions being non-tradable in markets. Therefore, traditional pricing models like the Black-Scholes pricing model, which is applied to financial derivatives, cannot be applied. Instead, alternate methods have been developed to price weather derivatives. They can be categorized as burn analysis, index modeling, and daily modeling [18, 19].

Historical burn analysis involves the estimation of the average discounted payoff of a weather derivative based on its historical performance. It does not consider the dynamics of weather conditions.

The second approach of index modeling relies on weather indices such as HDD, CDD, climate accumulated temperature, deficit rainfall days (DRD), excess rainfall days(ERD), etc. However, this approach has several limitations, including each index requiring a new model, and modeling temperature indices directly can result in information loss; some indices, such as HDD and CDD, are bounded by zero [18, 19].

The third approach is modeling the actual data. This involves modeling the weather data (at the highest available frequency) to price derivatives. This approach is advantageous; for example, for a temperature derivative, a single model can be fitted to the temperature data, and it can be used to price high and low-temperature derivatives. There are two approaches to weather data modeling. The first is based on the assumption that the data follows a continuous process. Thus, a mean-reverting and continuous diffusion stochastic differential equation can be used to model the weather data and price the derivative. The second approach is based on the assumption that the data follows a discrete process. This is a relatively accurate assumption to reflect potential sharp changes in the weather data. Models such

---

[7] This means that the local insurance company pays a premium to a larger and international insurance company. Thus, the local insurance company is a policyholder. If the named peril occurs, the local insurance company files a claim and receives a payout from the larger insurance company. Then, the local insurance company can use this payout to pay the claims of their farmer policyholders.

as the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model are often used to model the weather data [18, 19].

Thus, regardless of which methodology is used, the pricing of a given weather derivative is inherently related to weather forecasting [19].

The next section will review the data and methodology which will inform how the proposed weather derivative to address loss and damage from climate change can be priced.

3. Data and Methodology

Every region does not experience the same weather; subsequently, they do not face the same weather risks. The Caribbean region has a tropical climate and is vulnerable to loss and damage caused by extreme weather events (such as tropical storms and hurricanes) and slow onset events (such as sea level rise).

In the Caribbean, climate change is being manifested by the increase in the frequency of tropical storms and hurricanes. These events are often associated with excess rainfall. Therefore, for the purposes of this study, the weather derivative that is being considered to address the loss and damage will be linked to excess rainfall.

The next subsection considers the rainfall data for the estimation of the weather derivative.

3.1. Data

Ideally, the data to model the excess rainfall should come from the meteorological stations in each country. However, the author does not have access to such data for each country. Therefore, for simplicity, data are collected from the World Bank database. The data collected are the available data on precipitation in Dominica, and it covers the 2000 to 2020 period at the monthly frequency. The data are displayed in Tables 2A and B [25].

Notably, weather derivatives on rainfall frequently use an index based on rainfall for pricing. An index is used to measure DRD and another for ERD. However, this study adopts the weather data modeling approach where the actual data are modeled to price the derivative. Thus, Dominica's precipitation data are used in this study's example to show how the weather derivative for loss and damage from climate change can be priced.

The next subsection outlines the pretesting methodology.

3.2. Methodology: Pretesting

To investigate the non-linearity of data, the Hurst exponent is used. The Hurst exponent is a statistical method used to investigate the long-range dependence and self-similarity in time series data. If time series data exhibit structural breaks or non-linearity, it may affect the self-similarity properties [26, 27]. The Hurst exponent ranges from 0 to 1, and its interpretation is as follows:

- If $H < 0.5$, the time series is mean-reverting (anti-persistent). This means it tends to reverse direction and move back towards a central point.
- If $H = 0.5$, the time series follows a Brownian motion (random walk). It has no trend and behaves like a purely random process.
- If $H > 0.5$, the time series is persistent (trending). It has a tendency to continue in the same direction.

The Hurst exponent test is used in conjunction with the Rescaled Range (R/S) Analysis plot to determine non-linearity. A straight line in the log-log plot indicates self-similarity. If the plot shows a straight line, it suggests long-range dependence and self-similarity in the data.

If the line is close to 45^o (slope around 0.5), it indicates a Brownian motion, which is characteristic of a random walk. A slope greater than 0.5 (above 45^o) suggests persistence or a trending behavior. A slope less than 0.5 (below 45^o) suggests anti-persistence or mean reversion.

The next subsection discusses the regression techniques used in this study.

3.3. Methodology: Regression

The equation for the price of a rainfall futures contract can specified as follows:

$$P = C * [E(R) - LA] \tag{1}$$

where P is the price of the rainfall futures contract, C is the contract size or value per unit of rainfall (e.g., dollars per millimeter of rainfall), $E(R)$ is the expected rainfall during the contract's reference period, LA is the rainfall threshold specified in the contract. For the purposes of this study, let LA be equal to the long-run average of the rainfall. This will be the last column of Table 2A.

In this equation, the price is determined by the difference between the expected rainfall during the contract's reference period and the predefined rainfall threshold. If the expected rainfall is above the threshold, then the economic agent may incur a loss. This is because more rain fell than long-run average, resulting in excess rainfall. However, this loss can be offset by the futures price will increase by the amount $[E(R) - LA]$. Thus, since there is a positive relation between the rainfall and the price of the futures, the economic

Table 2A
Precipitation of Dominica (mm)

Dominica	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Long-run average
Jan	88.59	84.27	48.28	39.08	47.67	115.63	86.75	60.06	53.50	72.62	46.71	**58.34**
Feb	50.09	158.95	36.24	44.73	48.08	58.40	31.20	31.41	59.54	38.80	9.37	**39.25**
Mar	29.50	39.96	53.93	21.27	63.52	22.89	41.05	35.95	48.91	27.61	24.78	**39.56**
Apr	35.89	34.22	97.50	34.30	42.91	37.80	31.90	21.69	54.75	57.92	49.23	**53.62**
May	44.60	27.24	61.27	39.02	159.20	75.97	43.52	30.99	48.16	96.56	94.61	**70.61**
Jun	45.68	125.55	52.52	67.87	73.60	291.62	116.81	81.25	70.60	80.56	114.12	**78.11**
Jul	90.59	169.55	73.37	**109.81**	152.51	175.54	126.14	108.15	121.06	114.01	172.37	**108.35**
Aug	112.81	17.53	75.36	**119.68**	90.39	141.39	131.84	**233.24**	132.79	82.13	153.55	**125.61**
Sep	128.18	62.58	120.82	77.74	124.84	107.15	127.79	95.57	223.24	101.46	173.43	**136.05**
Oct	81.03	36.39	152.30	**167.20**	188.30	191.44	196.18	**189.86**	203.44	80.16	261.38	**144.44**
Nov	128.59	24.69	69.84	**220.35**	271.10	214.59	76.63	49.90	82.61	106.67	119.55	**133.36**
Dec	59.65	61.57	44.10	54.14	76.27	49.61	84.22	60.95	66.59	46.54	77.63	**77.09**

Table 2B
Precipitation of Dominica

Dominica	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	202.20	37.33	47.34	54.94	50.22	32.35	41.54	79.27	40.41	60.80
Feb	116.32	38.22	34.87	46.01	59.37	34.45	38.34	58.24	24.06	46.21
Mar	44.05	52.39	22.66	20.72	48.32	70.95	60.00	30.18	28.80	49.63
Apr	86.53	83.12	120.95	39.94	46.69	46.42	69.14	55.41	36.22	24.29
May	179.15	153.36	135.00	61.49	17.64	71.97	**86.74**	63.49	96.39	21.44
Jun	220.96	30.47	86.75	39.83	36.47	61.71	**86.58**	59.10	85.26	61.49
Jul	101.36	109.11	109.67	63.67	47.99	131.65	**89.13**	69.67	131.49	125.85
Aug	99.43	203.52	154.51	122.01	**136.63**	80.56	**139.66**	95.17	151.39	107.62
Sep	268.44	70.32	135.18	124.03	63.94	193.01	**268.84**	99.60	98.77	104.80
Oct	78.41	278.89	155.30	111.87	94.49	124.67	109.88	108.96	101.59	230.36
Nov	43.38	57.78	54.98	176.86	**154.06**	234.28	60.42	195.55	97.49	161.52
Dec	204.51	55.73	114.43	63.85	61.93	102.61	85.89	53.63	91.37	51.51

agent can hedge the excess rainfall by taking a long position, and liquidating the futures when the excess rainfall occurs.

The contract size is typically specified by the exchange where the contract is traded and represents the monetary value associated with a unit change in rainfall. For example, if C is \$3,000 per millimeter, then a change in rainfall of one millimeter above the threshold would result in a payout of \$3,000.

The expected rainfall $E(R)$ can be estimated by forecasting the rainfall over a 12-month period. Several models can be used for univariate forecasting, such as the Autoregressive Integrated Moving Average (ARIMA) and the GARCH family. However, the aforementioned models are based on the assumption of linearity and normality. But rainfall data exhibit seasonality. In fact, in the Caribbean, there is a higher chance of occurrence tropical storms or hurricanes which are associated with excess rainfall during the August to October period. Therefore, the forecasting model should perform well if the linearity and normality assumptions do not hold.

The forecasting can be performed with a long short-term memory (LSTM) model. A LSTM is an artificial neural network (ANN) model, which attempts to learn the pattern of data by processing it through a structure of layers and neurons in a manner similar to the human brain. Data enter a first layer that consist of several nodes called an input layer and then are transferred to a hidden layer. At the hidden layer, the training is performed and the model tries to learn the pattern of the data. The LSTM is advantageous over the basic ANN as its pattern recognition and forecasts are influenced by what it has learnt from over long sequences. LSTMs can selectively remember and forget information as needed, which assists in its pattern recognition and forecasting ability. After the LSTM learns the pattern in the hidden layer, the data are transferred to the output layer, where it produces a forecast. Therefore, an LSTM can be used for univariate forecasting of time series.

For comparison, the results of the LSTM model are compared to the results of an ARIMA model and an Exponential-GARCH (EGARCH)[8] model.

An ARIMA model is a univariate time series model that is to predict future values of a time series from its past values. It consists of three components, namely (1) an autoregressive (AR) component, which models the relationship between the variable's current value and its previous values; (i) integrated (I), which applies a differencing transformation to the time series to accounts for non-stationarity; and (3) moving average, which models the dependency between the current value and past forecast errors.

The next section displays the results of the modeling and the pricing of the weather derivative.

4. Results

4.1. Pretesting

Before applying the forecasting methodology, pretests are performed for normality and linearity. The Jarque-Bera test is performed for normality.[9] The Jarque-Bera test statistic was 75.51 with a probability value of 0.0000. Since the probability of the test statistic was less than the 10%, 5%, and 1%, then the null hypothesis is rejected suggesting that the rainfall time series for Dominica is not normally distributed.

Next, the Hurst exponent and the R/S Analysis tests are applied for non-linearity.

As can be seen from Figure 1, the log-log plot was not straight (linear) and angled at 45o. Additionally, the Hurst Exponent was 0.02 which was less than 0.5, suggesting that Dominica's rainfall data are mean-reverting and non-linear.

The non-linearity and non-normality results justify the use of the LSTM model for the regression as it can work well with both linear and non-linear data.

The next subsection displays the regression results.

4.2. Regression results

The LSTM is applied to Dominica's rainfall data. This will be useful for the pricing of the rainfall futures. The forest results are presented in Figure 2.

Figure 2 displays the LSTM findings. The discussion of this outcome follows the diagnostics. Many diagnostic tests are run in order to evaluate the LSTM model's predictive accuracy.

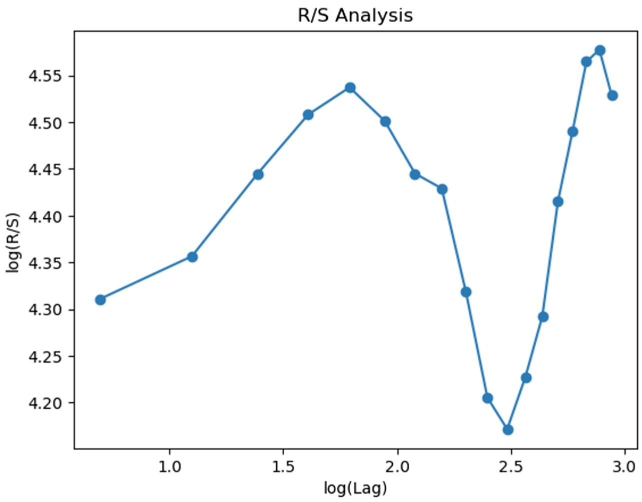
Figure 3 displays the fit of the regression with the confidence interval bands. As can be seen in Figure 3, the actual data fall within the confidence bands for most of the regression; however, there were periods where the actual rainfall exceeded the forecasted rainfall by an amount greater than 1.96 standard deviations away from the forecasted value. However, this result is

---

[8] An EGARCH model is a univariate time series model that is used to predict the conditional variance of a variable [28]. It is a modification from the traditional GARCH model to account for size of shock leverage effects and sign of shock leverage effects [29].

[9] The Jarque-Bera test assesses the normality of data by jointly testing for no skewness and no excess kurtosis in the null hypothesis.

Figure 1
R/S analysis of Dominica's rainfall.



Note: Hurst Exponent: 0.021742899223071495

sensible as there are times when the excess rainfall is significantly more than the long-term average.

Next, Figure 4 shows the results of the Bland-Altman Plot. The results show the majority of the residual data points fall within the confidence interval. However, a few data points fall outside of the upper limit of the confidence interval. This shows that there are periods where the rainfall may be significantly higher than the long-run average.

The next subsection compares the results of the LSTM to other models.

4.3. Comparison of the LSTM to other models

Next, the point estimates of the LSTM forecast are displayed in Table 3. It is also compared to the results from an ARIMA forecast. The forecasts are compared to demonstrate the difference in the predictive capacity of the models.

As can be seen from Table 3, the forecast of the LSTM model is below the long-run average. It also fluctuates similar to the long-run average data. In contrast, the ARIMA produces a linear forecast of the rainfall data. The ARIMA forecast displays no fluctuation to match the variation in precipitation in the different seasons. Thus, the ARIMA model is not appropriate for modeling the rainfall data. The EGARCH model also produces forecast; however, it forecasts the conditional variance. Therefore, the square root of the EGARCH estimates is taken as the forecasted estimates for the rainfall data. The EGARCH forecasts are also linear. Therefore, the LSTM model is more appropriate to model the rainfall data than the ARIMA and EGARCH models.

4.4. Limitations of the LSTM

Similar to other neural networks, the LSTM model has a number of drawbacks. One significant drawback is that, like the majority of neural networks, the LSTM is a "black box" model. This indicates that they do not provide coefficients or marginal effects between the input and the output.

Second, LSTMs like other neural networks are non-deterministic models. This implies that the model may yield somewhat different results each time it is trained or used. The sequence in which the data are given during training is one of the elements that might cause the variations, as can the random weight initialization. Because of this non-deterministic nature, the results may vary with each iteration.

Despite this, LSTMs and other neural networks are still used due to their high predictive accuracy.

The next section furnishes a discussion and explains how the futures can be priced.

5. Discussion

Before discussing how the proposed loss and damage futures can be priced, this study reminds the reader of the distinction between weather futures and weather insurance. In weather insurance, the economic agent that purchases the instrument is a policyholder, and the economic agent that offers the instrument is the insurer [18]. Additionally, in parametric insurance, when an adverse weather event occurs, it acts as a trigger for the insurer to provide the policyholder with an agreed sum of money called a payout. In financial futures, there is no payout; instead, the price of the futures may change. However, the trader of the futures

Figure 2
12-month forecasts of Dominica's rainfall

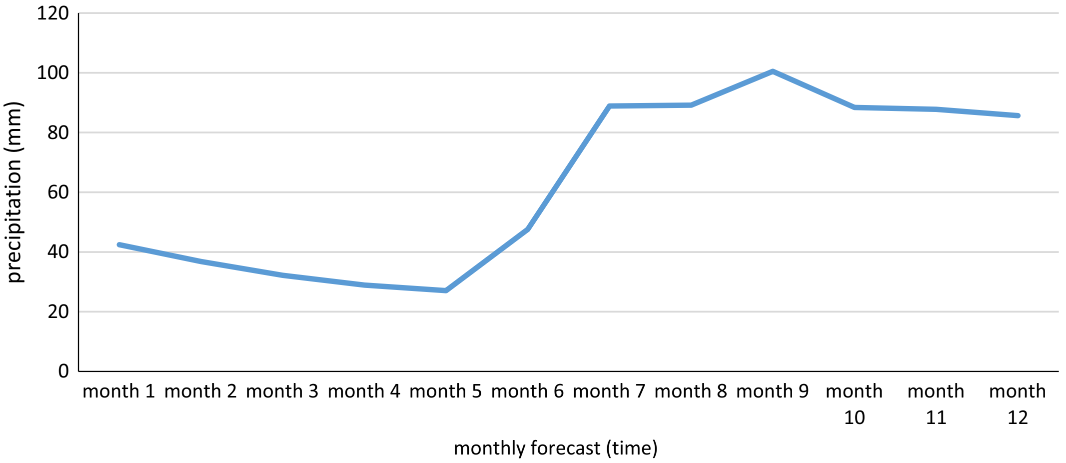


Figure 3
Fit of the regression with the confidence interval bands

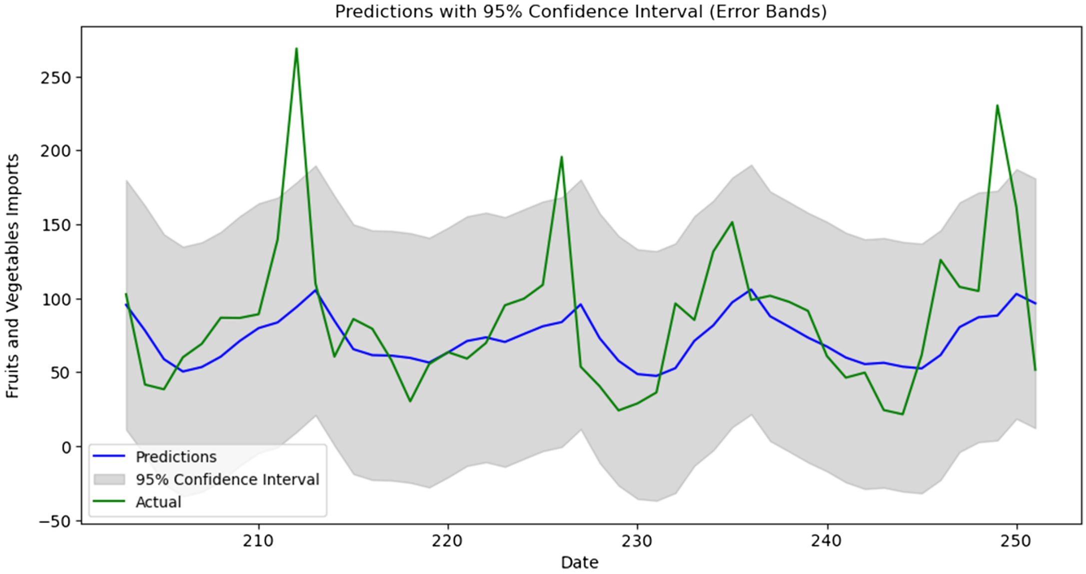
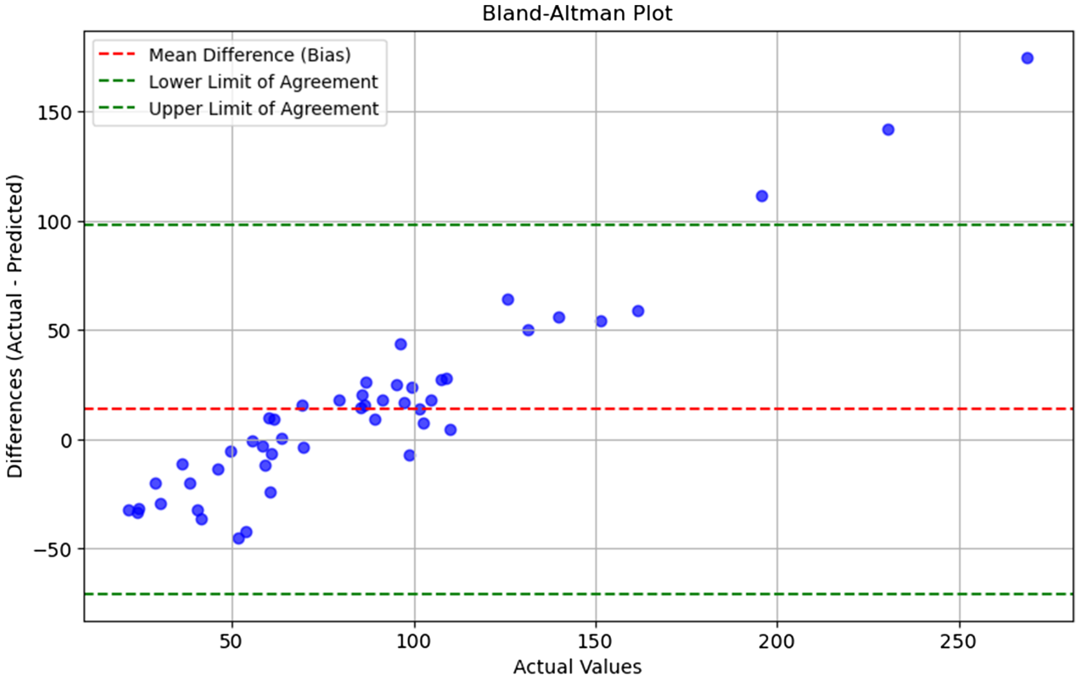


Figure 4
Bland-Altman plot



contract may buy and sell the futures and try to profit from its change in price. This profit from the change in the price of the futures can be used to offset the potential loss that may be incurred in the underlying. The same principle can be applied to weather futures, where the economic agent tries to profit from the change in the price of the futures, which, in turn, may be used to offset the loss caused by the adverse weather event.

Nevertheless, weather insurance is often used in conjunction with weather derivatives, especially in the reinsurance market. The reinsurance company may trade the futures to make a profit, which it may use to help offset some of the costs when its policyholders file claims.

The next subsection discusses the features of the proposed loss and damage futures.

Table 3
Comparison of the forecast results of the LSTM, ARIMA, and EGARCH model

Monthly forecast	LSTM	ARIMA	EGARCH (Variance)	EGARCH (square root)	Long-run average
Month 1	42.45787	74.8968	8757.61	93.5821	58.34
Month 2	36.78764	83.2429	6639.24	81.48153	39.25
Month 3	32.19664	86.2023	5701.513	75.50837	39.56
Month 4	28.90559	87.2326	5243.605	72.41274	53.62
Month 5	27.05541	87.572	5007.692	70.76504	70.61
Month 6	47.57077	87.6639	4882.529	69.8751	78.11
Month 7	88.87428	87.6672	4815.048	69.39055	108.35
Month 8	89.15891	87.6388	4778.342	69.12555	125.61
Month 9	100.4909	87.599	4758.278	68.98028	136.05
Month 10	88.40893	87.5552	4747.283	68.90053	144.44
Month 11	87.74656	87.5099	4741.248	68.85672	133.36
Month 12	85.6375	87.464	4737.932	68.83264	77.09

5.1. Features of the proposed futures

This study proposes that rainfall-based futures to address loss and damage from climate change should contain the following terms which are standard for similar weather derivatives.

The first feature is the contract size. The contract size is simply an index number that needs to be converted into a monetary value by a “multiplier.” The multiplier is called lot size of the contract. This is necessary for determining the value of a futures contract. If the net value of a rainfall index is 150 points, and the lot size is 1000, then the contract value is $150,000. Alternatively, if the rainfall data are used in place of an index, then if the rainfall data are 150 mm and the lot size is 1000, then the contract value may be $150,000.

Note that the contract size is similar to the “lot size” which is used in financial derivatives. 1000 is a common lot size for many futures.

The second feature is the product description. The rainfall index or rainfall data should be specific to a geographical location. In other words, if the rainfall futures is being developed for Dominica, then it can only use rainfall data or an index of rainfall data for Dominica and not data from other Caribbean countries. Each country that is considering a weather futures should obtain separate futures since their rainfall data will be different.

The third feature is the tick size. The tick size is the predetermined decimal applied to each index point. For instance, if the decimal is decided to be 0.1, then the tick size of the contract will be (=$1000*0.1 = $100 per contract).

The fourth feature is the mode of settlement. For the rainfall futures, the mode of settlement should be a compulsory cash basis. This is because unlike other futures such as oil futures, rainfall indices are not physically deliverable.

The fifth feature is the contract month. While it is possible for futures to have short maturity periods before they expire, this study argues that the proposed loss and damage rainfall futures should be 12 months in duration. This argument is made as it gives the futures price time to fluctuate during the 12 months in the year as the rainfall fluctuates. Furthermore, if the futures expires at the end of the calendar year, then it would expire when the biggest risk from extreme weather events would have subsided in the Caribbean.

The sixth feature is ticker symbols. It is standard for futures traded on exchanges to have ticker symbols. Therefore, a ticker can be developed for the rainfall futures. As the rainfall futures can be based on rainfall days (RD) then an appropriate ticker can be RDX.

5.2. Pricing of the futures

A methodology is required for pricing the rainfall futures. Note, in the case of weather derivatives, a methodology can be derived to price each instrument.

The equation for the price of a rainfall futures contract can be derived based on the parameters and assumptions of the contract. The price (P) of a rainfall futures contract can be estimated as follows:

$$P = C * (E(R) - LA) \tag{2}$$

where

P is the price of the rainfall futures contract; C is the contract size or value per unit of rainfall (e.g., $ per millimeter of rainfall); E(R) is the expected rainfall during the contract’s reference period; LA is the long-run average rainfall. It is also the rainfall threshold or strike level specified in the contract.

In this equation, the price is determined by the difference between the expected rainfall (E(R)) during the contract’s reference period and the predefined rainfall threshold (LA). If the expected rainfall is above the threshold, the price of the futures rises. The rise in the price of the futures allows for the economic agent holding the rainfall futures to offset the potential loss that is caused by the excess rainfall.

Note, given the structure of Equation (2), if the expected rainfall (E(R)) is less than the predefined rainfall threshold (LA), then $(E(R) - LA)$ will be less than 0. Therefore, the futures would be worthless if the rainfall is less than the long-run average rainfall. The futures only gains value when the rainfall is more than the long-run average, resulting in excess rainfall.

To circumvent this problem Equation (2) is modified.

$$P = C * [(E(R) - LA) + LA] \tag{3}$$

if $E(R) < LA$ then the Equation (3) is modified to

$$P = C * [(0) + LA] \tag{4}$$

Equations (3) and (4) ensure that the futures will contain a minimum price.

To illustrate the pricing of the futures, consider an example. Assume that the rainfall $E(R)$ in August was 150 mm. Assume that the long-run average for August was 125.61 mm. Then, the excess rainfall $(E(R) - LA)$ was 24.39 mm. Therefore, $[(E(R) - LA) + LA]$

equates to 150 mm. Assume that the lot size is 1000, then the contract value should be \$150,000. Therefore, if the economic agent only bought 1 contract ($C = 1$) then they could receive \$150,000 at the liquidation of the contract in August.

However, if the rainfall in August was 89.16 mm (which is equivalent to the LSTM forecast), then since $E(R) < LA$, Equation (4) should be used to price the futures. This would result in the futures being \$125,610.

Assume that the economic agent bought the futures at price that was determined by the long-run average. In other words, assume that the purchase price was LA. Thus, they paid \$125,610 per lot for the contract. Therefore, the profit margin for the futures in any month will be dependent upon the price the economic agent purchased the futures at the inception, and the rainfall during the rainy season as it affects the price of the futures. This is determined by $(E(R) - LA)$. This pricing framework would allow the economic agent to profit from the trade of the futures in the rainy season (where the risk of excess rain is the highest).

To offset the loss of the loss and damage caused by excess rainfall, the economic agent would have to purchase sufficient lots of the futures contract. For example, if the excess rainfall caused \$5 million in damage, then the economic agent should have purchased $5{,}000{,}000/24{,}390 = 205$ lots of the futures contract to perfectly offset their loss.

An alternative scenario can be derived for the pricing of the futures. This is presented in the next subsection.

5.3. Alternative pricing of the futures

At the inception, the proposed loss and damage futures can be priced in accordance with Equations (3) and (4). However, once the futures are traded on an exchange, there is a possibility for the pricing dynamics to change. This is due to changes in the demand and supply for the futures on the exchange by traders and speculators are likely to have an impact on the futures price.

In fact, the expectation that the price of the futures should rise especially when the rainfall in a given month is higher than the long-run average may cause the futures to enter temporary speculative bubbles. Thus, the price of the futures can rise to levels that are significantly higher than what can be explained by the market fundamentals. This is likely to occur if futures are traded on an exchange since many traders on exchanges exhibit herding behavior, following the crowd without analyzing the underlying fundamentals. This can cause large jumps (price increases).

Notably, speculative behavior and jumps are also associated with risk. Latecomers to the jump may expect price to continue to rise, but as the bubble bursts there may be a sharp and quick decline in the futures price. This may cause traders who took a long (buying) position on the market to incur losses.

To leverage the recent advancements in financial technology, the futures can be issued through tokenization. This is discussed in the next subsection.

5.4. Tokenization

Tokenization refers to the process of converting ownership rights or assets into digital tokens which are recorded on a distributed ledger technology platform or blockchain.[10] Physical assets and financial assets can be tokenized. For physical assets, tokenization involves representing the rights of ownership of the asset in a digital format called a token, which in turn is managed on the blockchain. This type of tokenization is referred to as “off the chain” as the physical asset exists off the blockchain. For financial assets, the asset lacks a physical property; thus, it exists only on the blockchain. This type of tokenization is referred to as “native” as the asset exists only on the blockchain [30].

For the proposed loss and damage futures, tokenization involves issuing these futures contracts as tokens, each of which represents the rights of a loss and damage futures contract. The futures contracts will be native to the blockchain as it exists only on the blockchain. However, there are two approaches to issuing the futures.

The first is where the futures is issued in the traditional manner, than tokens are created to represent the futures contracts. The second approach is where the futures contracts are issued directly on the blockchain. The futures is registered on a distributed ledger and is denominated in a major currency, or a crypto currency which is then traded on the exchange. The second approach eliminates a step of the first approach.

This study argues that the loss and damage futures should be tokenized as tokenization brings several advantages. One of the key benefits is increased accessibility. Through digital tokens, a broader range of participants, including retail traders (individuals) and institutions, can easily access and trade these futures without the need for a traditional broker.

Second, tokenization allows for fractional ownership of weather futures. Investors can buy and sell fractions of these contracts through tokens, making it easier to manage their exposure to specific weather events without the necessity of entering full contracts. In other words, fractionalization allows a trader to purchase a fraction of the lot of the futures (which is less than 1000) rather than the full contract (which is 1000). This fractionalization allows small-scale retail traders to trade the futures.

The third benefit is the increased participation by various sizes of traders allows for increased liquidity. Sufficient liquidity on the market allows for smaller bid-ask spreads and facilitates more efficiency on the market. Liquidity will be important for the loss and damage futures as it will allow economic agents to mobilize funds when the adverse weather event occurs and they want to liquidate their futures contracts.

The fourth benefit is the transparency and security offered by blockchain technology. Blockchains are transparent, immutable, and secure, making it easy for traders to verify the transactions for the futures. This reduces the risk of errors, disputes, or fraud and ensures the integrity of the contracts. Furthermore, smart contracts[11] can be embedded into the futures, to automate and streamline various aspects of the trading and settlement process. For example, a smart contract can be used to fill orders when a buyer agrees to go long and a seller agrees to go short at the same price.

Notably, tokenization is a relatively new phenomenon, and it is being piloted for financial and physical assets. In the European Union (EU), the DLT Pilot Regime, which is a financial technology (fintech) sandbox, allows DLT entrepreneurs to operate with exemption from the full range of the EU’s financial requirements. This allows the entrepreneurs to operate freely and test the application of their business ventures while allowing the EU’s legislators to gain experience on tokenized financial instruments [31].

The tokenized financial instruments which have emerged in the sandbox include equities, bonds, and crypto currencies. However, there is scope for all financial assets, including futures, to be

---

[10] A token is asset or something of value that is recorded and managed on a distributed ledger technology platform or blockchain. Financial assets such as futures, options, swaps, stocks, etc. can all be converted into tokens, which in turn are managed on a blockchain.

[11] Smart contracts are algorithms which implement the conditions of a contract when conditions are met. For example, a smart contract can be used as an algorithm to make a futures contract expire when a particular maturity date arrives without the need for a market maker at the exchange to manually expire the contract.

tokenized as tokenization is essentially the digital representation of the asset on the distributed ledger.

According to a study by Schaub et al. [32], in 2017 only 5 tokenized securities were issued. This volume grew to more than 100 by 2020. European tokenization is estimated to grow by approximately 81% per year and is expected to reach a value of 918 billion euros by 2026.

The next subsection discusses the challenges and feasibility of large-scale implementation of rainfall futures.

5.5. Practical challenges and feasibility of large-scale implementation

Tokenized rainfall futures can be implemented at a large-scale. However, there are several practical challenges in the exercise, and thus it requires careful consideration.

The first challenge is the availability of meteorological data for the estimation of the futures price. This is important because according to Equations (3) and (4), the expected rainfall and long-run rainfall are required to determine the price of the futures. If these data are unavailable, then the futures cannot be constructed.

Second, the meteorological data for the affected location should match the futures. If the rainfall data at the location do not match the futures, then basis risk occurs as the futures would not offset the risk of loss associated with the bad weather occurring at particular locations. Therefore, a region consisting of multiple countries should have rainfall futures for each country since they will all have different rainfall data.

The third challenge is the tendency for weather derivatives traded on financial markets to be affected by speculation. If this occurs, speculation can cause jumps in the price of the weather derivatives. This can result in the derivatives being decoupled from the weather and no longer functioning as a hedging instrument.

The fourth challenge is the likelihood for adverse weather events to occur after the futures contract has been liquidated. In the face of climate change, some countries may face multiple extreme weather events in 1 year. However, after a futures contract is liquidated, the economic agent loses coverage against risk until another contract is created. In the interim between the liquidation of contracts, the economic agent is not covered if they are affected by another extreme weather event.

The fifth challenge is the lack of awareness of weather derivatives and other instruments by the affected stakeholders to hedge the risk of extreme weather events. This information asymmetry can result in the low uptake of weather derivatives, especially by the stakeholders most affected by the weather risks. This problem can be addressed through public information campaigns.

Despite these challenges, weather derivatives are used by stakeholders to address weather risks. In fact, many reinsurers use weather derivatives to spread risk and mobilize the required financial resources to make payouts.

The next section concludes this study.

6. Conclusion

This study sought to explore how a weather derivative can be used to mobilize finance to cover the cost of loss and damage from climate change, specifically considering futures as the derivative to mobilize financing. As is standard with futures contracts, they should have several features such as a contract size, a tick size, a mode of settlement, a ticker symbol, and a contract duration. Given that these are weather futures, each should be specific to a geographical location to ensure that the futures finances are linked to the weather conditions at specific locations.

An important feature that arises is the pricing of the futures. This study contributes to the literature by proposing a pricing mechanism for the proposed loss and damage futures. The futures price should be a function of the contract size, the difference between the expected rainfall in the future and the threshold or long-run average rainfall, with the exact pricing equations expressed as Equations (3) and (4). This pricing formula ensures that the minimum price of the futures will be proportional to the long-run average rainfall. The futures price may rise if the expected rainfall exceeds the long-run rainfall, resulting in excess rainfall. This pricing approach is adopted since it allows the price to rise when excess rainfall occurs, which, in turn, is responsible for loss and damage.

The economic agent can offset potential loss and damage from climate change and excess rainfall by trading the rainfall futures. If excess rainfall occurs, the price of the futures should rise. If the economic agent had taken the long (buying) position before the price rises, they could make a profit from the liquidation of the futures contract when excess rainfall occurs. To ensure that this profit can offset the potential cost of loss and damage caused by climate change, the economic agent should buy sufficient contract lots. To determine the number of contract lots to purchase, the economic agent needs to estimate the cost of loss and damage and the potential profit margin as the futures price rises above its initial price. Both of the aforementioned factors (the estimate of loss and the futures price when excess rainfall occurs) are dependent upon forecasts of the rainfall. Therefore, the economic agent seeking to hedge loss and damage caused by excess rainfall should be interested in the forecasts of the rainfall.

This study used the LSTM artificial neural network model to forecast rainfall. The LSTM model is better than traditional linear models such as ARIMA and GARCH as it can capture the non-linear dynamics of the rainfall data, making it an empirical contribution. Additionally, this study proposes the use of tokenization to issue the proposed loss and damage futures, contributing to the literature by recommending tokenization for its benefits such as high security for transactions, enhanced liquidity through fractionalization, and an opportunity to manage futures contracts through automation and smart contracts.

Indeed, the proposed loss and damage futures provide a risk management tool for economic agents exposed to such climate-related risks. Moreover, the proposed futures also supports the transition to a low-carbon economy as the finance for the liquidation of the futures can be used to fund projects in building climate resilience. Therefore, the proposed loss and damage futures play a dual role in mitigating financial risks associated with excess rainfall and promoting climate-resilient projects, aligning with the broader goals of a low-carbon economy.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The data that support the findings of this study are openly available at https://docs.google.com/spreadsheets/d/1psAtdbC9xTkM4tDB_t26mQ9Z5UVxz6gW/edit?usp=drive_link&ouid=105704881634710280082&rtpof=true&sd=true

Author Contribution Statement

Don Charles: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, resources, data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Sheldon McLean:** Writing – original draft, Writing – review & editing.

References

[1] Klotzbach, P. J., Wood, K. M., Bell, M. M., Blake, E. S., Bowen, S. G., Caron, L. P., . . . , & Truchelut, R. E. (2022). A hyperactive end to the Atlantic hurricane season October–November 2020. *Bulletin of the American Meteorological Society*, *103*(1), E110–E128. https://doi.org/10.1175/BAMS-D-20-0312.1

[2] Klotzbach, P. J., Schreck III, C. J., Compo, G. P., Bowen, S. G., Gibney, E. J., Oliver, E. C., & Bell, M. M. (2021). The record-breaking 1933 Atlantic hurricane season. *Bulletin of the American Meteorological Society*, *102*(3), E446–E463. https://doi.org/10.1175/BAMS-D-19-0330.1

[3] National Hurricane Centre. (2023). *NHC data archive*. Retrieved from: https://www.nhc.noaa.gov/data/

[4] Wilchcombe, J., Nishi, R., Simmons, J., Widlansky, M., & Tsurunari, Y. (2021). Field survey on storm surge by catastrophic hurricane Dorian in the Bahamas 2019. *Journal of Japan Society of Civil Engineers, Ser. B3 (Ocean Engineering)*, *77*(2), I_289–I_294. https://doi.org/10.2208/jscejoe.77.2_I_289

[5] Looney, R. E. (2020). Caribbean natural disasters and country/regional responses. In R. E. Looney (Ed.), *Handbook of Caribbean economies* (pp. 140–158). UK: Taylor & Francis.

[6] McLean, S., & Charles, D. (2018). Caribbean development report: A perusal of public debt in the Caribbean and its impact on economic growth. *Studies and Perspectives (ECLAC Subregional Headquarters for the Caribbean)*.

[7] Tran, N. (2018). Debt threshold for fiscal sustainability assessment in emerging economies. *Journal of Policy Modeling*, *40*(2), 375–394. https://doi.org/10.1016/j.jpolmod.2018.01.011

[8] Chaudhary, K., & Mittal, V. (2022). Weather derivatives: A study on need and impediments in India. *International Journal of Creative Research Thoughts*, *10*(5), e379–e386.

[9] Wigan, D. (2009). Financialisation and derivatives: Constructing an artifice of indifference. *Competition & Change*, *13*(2), 157–172. https://doi.org/10.1179/102452909X417033

[10] Jarrow, R. A., & Chatterjea, A. (2019). *Introduction to derivative securities, financial markets, and risk management*. Singapore: World Scientific Publishing Company.

[11] Banks, E. (2005). *Exchange-traded derivatives*. Germany: Wiley.

[12] Chisholm, A. M. (2010). *Derivatives demystified: A step-by-step guide to forwards, futures, swaps and options*. Germany: Wiley.

[13] Manjushree, S. (2020). A derivative is a risk hedging tool from investor perspective. *Shanlax International Journal of Commerce*, *8*(3), 39–44. https://doi.org/10.34293/commerce.v8i3.3131

[14] Bacon, R., & Kojima, M. (2008). *Coping with oil price volatility. Energy sector management assistance program*. Energy Security Special Report No. 005/08. Retrieved from: https://www.esmap.org/sites/esmap.org/files/8142008101202_coping_oil_price.pdf

[15] Zhang, J., & Huang, W. (2021). Option hedging using LSTM-RNN: An empirical analysis. *Quantitative Finance*, *21*(10), 1753–1772. https://doi.org/10.1080/14697688.2021.1905171

[16] Salgueiro, A. M. (2019). Weather index-based insurance as a meteorological risk management alternative in viticulture. *Wine Economics and Policy*, *8*(2), 114–126. https://doi.org/10.1016/j.wep.2019.07.002

[17] Weagley, D. (2019). Financial sector stress and risk sharing: Evidence from the weather derivatives market. *The Review of Financial Studies*, *32*(6), 2456–2497. https://doi.org/10.1093/rfs/hhy098

[18] Cui, H., Zhou, Y., Dzandu, M. D., Tang, Y., & Lu, X. (2019). Is temperature-index derivative suitable for China? *Physica A: Statistical Mechanics and its Applications*, *536*, 120959. https://doi.org/10.1016/j.physa.2019.04.195

[19] Cui, K. (2014). *Weather derivatives: Modelling, pricing and applications*. Doctoral Dissertation, University of Calgary.

[20] Wandhofer, R. (2019). *Technology innovation in financial markets: Implications for money, payments and settlement finality*. Doctoral Dissertation, University of London.

[21] Fuchs, A., & Wolff, H. (2011). Concept and unintended consequences of weather index insurance: The case of Mexico. *American Journal of Agricultural Economics*, *93*(2), 505–511. https://doi.org/10.1093/ajae/aaq137

[22] International Research Institute for Climate and Society. (2021). *Appendix 2. Case studies of agricultural weather risk management*. Retrieved from: https://iri.columbia.edu/~deo/insurancereading/Managing%20Ag%20Production%20Risk_Appendix%202_FINAL.doc

[23] Buckley, N., Hamilton, A., Harding, J., Roche, N., Ross, N., Sands, E., . . . , & Whitlow, H. (2002). *European weather derivatives*. Retrieved from: https://www.actuaries.org.uk/system/files/documents/pdf/european-weather-derivatives.pdf

[24] Jones, T. L. (2007). Agricultural applications of weather derivatives. *International Business & Economics Research Journal*, *6*(6), 1–8. https://doi.org/10.19030/iber.v6i6.3377

[25] World Bank. (2023). *Dominica*. Retrieved from: https://climateknowledgeportal.worldbank.org/country/dominica/climate-data-historical

[26] Qian, B., & Rasheed, K. (2004). Hurst exponent and financial market predictability. In *IASTED Conference on Financial Engineering and Applications*, 203–209.

[27] Vogl, M. (2023). Hurst exponent dynamics of S&P 500 returns: Implications for market efficiency, long memory, multi-fractality and financial crises predictability by application of a nonlinear dynamics analysis framework. *Chaos, Solitons & Fractals*, *166*, 112884. https://doi.org/10.1016/j.chaos.2022.112884

[28] Epaphra, M. (2016). Modeling exchange rate volatility: Application of the GARCH and EGARCH models. *Journal*

of Mathematical Finance, *7*(1), 121–143. https://doi.org/10.4236/jmf.2017.71007

[29] Abdalla, S. Z. S. (2012). Modelling exchange rate volatility using GARCH models: Empirical evidence from Arab countries. *International Journal of Economics and Finance*, *4*(3), 216–229. http://dx.doi.org/10.5539/ijef.v4n3p216

[30] Mounira, B. (2023). Securities tokenization: The third wave of financial market evolution – World Bank Bond-i case study. *Algerian Scientific Journal Platform*, *8*(1), 1169–1184.

[31] McCarthy, J. (2022). Distributed ledger technology and financial market infrastructures: An EU pilot regulatory regime. *Capital Markets Law Journal*, *17*(3), 288–306. https://doi.org/10.1093/cmlj/kmac009

[32] Schaub, B., Kreitmair, M., & Richter, J. (2021). *Tokenization in Europe—Current state and future outlook*. Retrieved from: https://plutoneoam.medium.com/tokenization-in-europe-current-state-and-future-outlook-feeac85fb2c3

How to Cite: Charles, D., & McLean, S. (2024). Addressing Loss and Damage from Climate Change Through Tokenized Rainfall Futures. *Green and Low-Carbon Economy*. https://doi.org/10.47852/bonviewGLCE42022046