

# The Rainy-Day Fund: Decentralized Parametric Insurance for Smallholder Farmers in Kenya

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## Abstract

Smallholder farmers in Kenya face serious challenges due to climate variability, as more than 98% of agriculture depends on rain-fed systems and much of the country's arable land lies in arid and semi-arid regions (ASALs). Frequent droughts, unpredictable rainfall, and extreme weather events have reduced crop yields, threatened food security, and put rural livelihoods at risk. Traditional risk mitigation strategies, including crop diversification and off-farm income, remain insufficient, while irrigation development is limited due to infrastructural and environmental constraints. Weather index insurance (WII) has emerged as a practical solution because it provides affordable, quick, and reliable payouts based on objective weather data, while reducing administrative costs and moral hazard. Building on this idea, the Rainy-Day Fund introduces a decentralized, blockchain-based parametric insurance system. By using smart contracts and mobile payment platforms, it can deliver timely payouts to farmers, strengthen their resilience, and help them reinvest in their farms. This approach not only protects farmers from the financial shocks of extreme weather but also offers a transparent and efficient way to support sustainable agricultural livelihoods.

**Keywords:** Smallholder farmers, Kenya, climate change, weather index insurance, parametric insurance, blockchain, agricultural resilience, arid and semi-arid lands.

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# 1 Goals and Motivation

The goal of the Rainy Day Fund is to design a decentralized parametric insurance solution that can provide smallholder farmers with affordable, fast, and trustworthy protection against climate-related risks. By leveraging blockchain technology, the project seeks to overcome mistrust, high administrative costs, and inefficiencies that have limited adoption of weather index insurance. The motivation lies in addressing urgent climate vulnerabilities, reducing poverty traps, and creating scalable financial safety nets in one of the world’s most underserved insurance markets.

## 2 Introduction

Agriculture is the backbone of Kenya’s economy, contributing approximately 21.3% to the country’s GDP in 2024 (Bank 2024). It is the largest employer in the country, providing livelihoods for over 40% of the total population and more than 70% of the rural population (FAO 2024). Smallholder farmers form the majority of agricultural producers, yet they remain highly vulnerable to climate variability.

Kenya’s Arid and Semi-Arid Lands (ASALs) cover about 89% of the country’s land area, host over 70% of livestock, and are home to around 36% of the population (IUCN n.d. Authority 2021; UNEP-DHI n.d.). Farmers in these regions depend almost entirely on rain-fed crops and livestock, making them extremely vulnerable to droughts and erratic rainfall. The drought between 2020 and 2023, the worst in four decades, illustrates the severity of this risk as farmers faced severe yield losses in many regions, 2.6 million livestock were lost, and 4.4 million people required urgent food assistance (The-Star 2023).

These shocks highlight the fragility of rural livelihoods and the absence of effective financial safety nets to protect farmers. This paper proposes a decentralized, blockchain-based parametric insurance model as a potential solution to bridge this gap. Our guiding research question is: How can blockchain-based weather insurance provide affordable, transparent, and automatic protection for rural farmers in Africa who are exposed to increasing climate risks?

## 3 Problem Analysis

Smallholder farmers in Kenya are uniquely vulnerable to climate risks. About 98% of Kenya’s agricultural systems are rain-fed (Government of Kenya and Fisheries 2017), while irrigation development is limited due to infrastructural and environmental constraints (Wairimu et al. n.d.). Traditional coping strategies such as crop diversification, off-farm work, and borrowing are insufficient to withstand the growing severity of climate shocks. As a result, households often fall into poverty traps, selling livestock or assets after droughts and struggling to recover in later seasons. The drought between 2020 and 2023, considered the worst in four decades, illustrates the magnitude of the challenge as farmers experienced severe yield losses in affected areas, more than 2.6 million livestock died, and about 4.4 million people required urgent food assistance (OCHA 2023). These shocks do not only affect farmers individually but also ripple across Kenya’s economy, since agriculture contributes over 20% of national GDP and supports the majority of rural livelihoods (Bank 2024).

Conventional agricultural insurance is largely absent in Kenya, and where it does exist, it suffers from deep structural weaknesses. High administrative costs make premiums unaffordable

for smallholder farmers (Dominguez Anguiano and Parte 2024). Claims are processed slowly and often manually, which delays payouts and worsens farmers’ financial stress during crises (Chainlink 2021). A lack of transparency around pricing and claims fosters mistrust (Dominguez Anguiano and Parte 2024). Moreover, coverage remains minimal, as fewer than 3% of farmers in Sub-Saharan Africa are insured, leaving more than 97% unprotected (Bank 2022).

Weather Index Insurance (WII) has emerged as a potential tool to address these challenges, because it relies on measurable weather data such as rainfall or temperature thresholds to trigger payouts. This reduces delays, administrative costs, and moral hazard compared to traditional indemnity-based insurance (Jensen et al. 2016; Sibiko et al. 2018). Studies show that WII adoption can reduce poverty, improve household welfare, and encourage investment in improved seeds and fertilizers. Yet despite this potential, uptake remains very limited. Farmers often lack awareness or financial literacy, making WII appear too complex (Janzen et al. 2020). Basis risk remains a major concern, as mismatches between weather station data and on-farm realities can result in payouts that do not reflect actual losses, undermining trust (Jensen et al. 2016). Affordability is another barrier, since many farmers lack liquidity at the beginning of the planting season, precisely when premiums are due.

These systemic shortcomings are reflected in the lived experiences of farmers like *Mary*, a 38-year-old smallholder living in a semi-arid region of Kenya. Mary is married with three children and owns a basic Android phone, but she has no formal insurance. For her, every drought threatens both her harvest and her household income. When she does consider insurance, she struggles to afford premiums upfront, finds products too complex to understand, and doubts that payouts would be delivered fairly or on time. Even if she were to purchase a policy, she fears that unreliable weather data would not capture the realities of her farm. As she puts it, “Why should I pay if they don’t measure my reality?” Mary’s skepticism mirrors the sentiments of millions of smallholder farmers across Kenya who remain excluded from meaningful risk protection.

## **4 Benefits of Blockchain in Insurance**

### **4.1 Blockchain & Decentralized Microinsurance**

Blockchain technology, with its decentralized ledger and automated smart contracts, is particularly well-suited for microinsurance solutions targeting smallholder farmers. By eliminating intermediaries, automating claims, and ensuring transparency, blockchain can reduce operational costs, increase trust, and make insurance accessible even in remote areas (Dominguez Anguiano and Parte 2024; Shetty et al. 2022). Moreover, parametric microinsurance, where payouts are triggered by measurable weather events, benefits from blockchain’s immutable and auditable infrastructure, ensuring rapid and verifiable payments. Despite early adoption challenges, integrating blockchain into agricultural insurance provides a scalable, efficient, and reliable solution to climate risk, bridging gaps in coverage for underserved populations.

### **4.2 Problems with Traditional Insurance**

Traditional insurance faces several critical challenges that limit its effectiveness, particularly in agricultural and microinsurance contexts. Transparency is often lacking, so policyholders cannot easily see how premiums are set, how claims are assessed, or why payouts are delayed. This lack

of clarity fosters distrust between insurers and customers (Dominguez Anguiano and Parte 2024). Claims are also slow and mostly manual, requiring extensive paperwork and human assessment. These delays can worsen farmers’ financial stress during climate shocks (Chainlink 2021; Shetty et al. 2022). High administrative costs associated with record-keeping, fraud checks, and staffing are often passed on as expensive premiums, making insurance unaffordable for smallholder farmers (Dominguez Anguiano and Parte 2024). The reliance on self-reported or incomplete data further raises the risk of fraud and moral hazard, while detecting and preventing fraud requires significant resources (Chainlink 2021; Shetty et al. 2022). Finally, coverage remains extremely limited. In Sub-Saharan Africa, less than 3% of farmers are insured due to logistical, financial, and trust barriers, and the centralized structure of traditional insurance often makes it difficult for rural farmers to access services (Alsdorf and Berkun 2024; Bank 2022).

### 4.3 Blockchain Advantages

Blockchain technology helps address many of the weaknesses in traditional insurance by providing a decentralized, tamper-proof ledger that builds transparency and trust without relying on a central authority (Shetty et al. 2022). Smart contracts can automate claims and payouts, reducing the need for human involvement and lowering administrative costs (Chainlink 2021; Dominguez Anguiano and Parte 2024). Because records on the blockchain are immutable, they cannot be tampered with, which prevents fraudulent claims. Decentralized oracles also supply reliable and verifiable data for triggering insurance events. In addition, blockchain can connect easily with mobile wallets, allowing farmers in remote or underserved areas to access insurance services directly (Dominguez Anguiano and Parte 2024).

### 4.4 Benefits for Parametric & Microinsurance

Applying blockchain to parametric insurance enables automated, event-based payouts, reducing basis risk, enhancing speed, and improving trust among stakeholders (Chainlink 2021; *How blockchain is revolutionizing parametric insurance* 2025; Shetty et al. 2022). For microinsurance, blockchain improves cost efficiency by lowering policy management costs, making it possible to expand coverage to underserved farmers and to explore flexible pricing models (Dominguez Anguiano and Parte 2024; *Blockchain in insurance (preprint)* 2023). Real-world examples such as Etherisc and Arbol already show how this can work in practice, with thousands of farmers receiving rapid payouts without the need for manual claims assessments (Alsdorf and Berkun 2024; Dominguez Anguiano and Parte 2024; *How blockchain is revolutionizing parametric insurance* 2025). The combination of decentralization, automation, and verifiable data ensures that parametric microinsurance is transparent, scalable, and trustworthy (Shetty et al. 2022).

## 5 Target Market & Stakeholders

Smallholder farmers in Kenya, particularly those living in the Arid and Semi-Arid Lands (ASALs), represent the primary target market for decentralized parametric insurance. These regions cover about 89% of the country’s land area, host over 70% of the livestock population, and are home to roughly 36% of the national population (IUCN n.d. Authority 2021; UNEP-DHI n.d.). With more than 98% of agriculture dependent on rain-fed systems, smallholder farmers are disproportionately exposed to climate variability and shocks (Government of Kenya and

Fisheries 2017). Agriculture employs around 40% of Kenya’s total population and over 70% of the rural population, yet fewer than 1% of farmers currently purchase agricultural insurance, leaving the vast majority unprotected (FAO 2024; Ministry of Agriculture 2023).

The stakeholders in Kenya’s agricultural insurance ecosystem are diverse and interdependent. Farmers are the primary end-users, seeking affordable and trustworthy protection against climate risks. Insurers and micro-insurers, such as APA Insurance, UAP, CIC, Jubilee, and Kenya Orient, underwrite and distribute weather-index products, while global reinsurers like Swiss Re provide the financial backing needed for large-scale coverage (Artemis 2017; BASIS 2017). The Government of Kenya, through its National Agricultural Insurance Policy (NAIP), and regulatory agencies such as the Insurance Regulatory Authority (IRA) and the National Drought Management Authority (NDMA), sets regulations and coordinates drought response (African-Climate-Foundation 2024; Ministry of Agriculture 2023). International donors and development partners, including the World Bank, IFC, and FAO, subsidize premiums, and provide technical support, as seen in the Kenya Livestock Insurance Program (KLIP) (Artemis 2017; Bank 2022). Finally, mobile money services such as Safaricom’s M-Pesa make it possible to collect premiums and deliver payouts directly to farmers (*Seeds of growth: Agriculture presents a range of options for insurers* 2017).

## 6 Market Research & Competitor Analysis

Agricultural insurance penetration in Kenya remains extremely low, even though agriculture forms the backbone of the economy. The Government’s National Agricultural Insurance Policy (NAIP) highlights that less than 1% of farmers and pastoralists purchase agricultural insurance, leaving the vast majority of producers exposed to climate shocks without any formal safety net (Ministry of Agriculture 2023). Across Sub-Saharan Africa, the picture is similar. There are about 48 million smallholder farmers, yet fewer than 1.5 million are insured. This means that only around 3% have coverage, leaving 97% unprotected, despite an annual demand estimated at USD 10–14 billion compared to a premium pool of only USD 1–3 billion (Africa 2020). These figures highlight an enormous protection gap, both in Kenya and across the region, where millions of rural households face severe climate risks without reliable financial buffers.

Despite these low figures, recent pilots suggest that demand exists when products are designed to be affordable, transparent, and accessible. For instance, the World Bank-supported One Million Farmers Platform has enabled over 70,000 smallholders across 15 counties to access weather-index insurance, primarily through digital delivery channels and bundled products. This suggests that the barrier is not farmer willingness but the way insurance is designed and distributed (Bank 2022).

On the supply side, Kenya already offers both livestock and crop index solutions. The Kenya Livestock Insurance Program (KLIP) is a leading public-private partnership providing drought insurance in ASAL counties. It is run by a consortium of local insurers led by APA (together with UAP, CIC, Jubilee, Heritage, Amaco, and Kenya Orient) and supported by Swiss Re as reinsurer. KLIP has successfully delivered multi-million-shilling payouts when drought thresholds were met (Artemis 2017; BASIS 2017). KLIP demonstrates proof of concept for index

insurance in Kenya, showing that government support, consortium underwriting, and reinsurer participation can combine to deliver payouts at scale.

In the crop sector, ACRE Africa and Pula are the leading intermediaries. ACRE Africa has developed weather-index products that are increasingly bundled with agronomic services, such as advisory tools and crop-cutting experiments, to improve product value and data accuracy (Africa 2024). Pula, by contrast, has built scale across Africa by bundling insurance with seeds, fertilizer, and other farm inputs, often distributed through governments and value-chain partners. Its use of satellite and remote sensing data has enabled broad coverage, though it continues to face challenges with basis risk and farmer liquidity constraints at planting (*Pula learning session: Zambia case* 2022; UNSGSA 2023).

More recently, blockchain-based models have entered the Kenyan market. Etherisc, in collaboration with ACRE Africa, piloted a “Bima Pima” crop cover in 2021, reaching over 17,000 farmers and delivering the first blockchain-based payouts in Kenya. By embedding smart contracts and decentralized oracles into the insurance process, Etherisc was able to automate claim settlement and reduce administrative overhead (Etherisc 2021). Although small in scale, this pilot shows how blockchain can help reduce long-standing problems in agricultural insurance, especially those related to trust, transparency, and timely payouts.

OKO Finance, for example, has demonstrated in Mali and Uganda how mobile-first, index-based agriculture insurance can be structured using satellite or remote sensing data and delivered through digital channels (ADA and Finance 2021). Although OKO is not known to be active in Kenya at the moment, its model suggests how digital ecosystems could lower distribution costs and expand access to underserved farming populations.

In short, agricultural insurance in Kenya is still underdeveloped, with less than 1% of farmers insured. However, programs like KLIP and private-sector innovators such as ACRE Africa and Pula show that growth is possible. Farmers still face major barriers, including basis risk (Jensen et al. 2016), limited awareness and perceived complexity (Janzen et al. 2020), and upfront liquidity constraints all reduce trust and limit uptake. Early blockchain pilots such as Etherisc’s indicate promising pathways to reduce administrative costs and improve transparency, but scaling such solutions will depend on robust data infrastructure, effective oracles, and farmer-centric design. Overall, the market reflects both a large protection gap and a significant opportunity, as innovative, technology-enabled models that combine affordability, transparency, and mobile integration have the potential to transform risk management for Kenya’s smallholder farmers.

## 7 Business Model

### 7.1 Overview

The Rainy Day Fund is a two-sided parametric insurance marketplace. Farmers obtain seasonal drought protection through ERC-20 policy tokens, while investors provide liquidity to an ERC-4626 vault and receive proportional shares. A smart contract manages issuance, pooling and payouts. The design reduces administrative overhead and shifts pricing and risk allocation to a market-based mechanism.

## 7.2 Problem and Customer Segments

Smallholder farmers in Kenya face recurrent rainfall shocks but lack access to formal insurance. High distribution costs, weak trust in insurers and limited actuarial data block traditional coverage. At the same time, impact-oriented investors seek transparent, uncorrelated instruments. The marketplace connects both groups, while cooperatives, NGOs and telcos provide distribution and trust infrastructure (Cole et al. 2013).

## 7.3 Value Propositions

- **Farmers:** affordable coverage, predictable payouts triggered by rainfall indices, and mobile transactions via M-Pesa.
- **Investors:** standardized exposure to agricultural risk with measurable yield, diversifying traditional portfolios.
- **Partners:** reduced leakage and transparent performance metrics for evaluation and reporting.

## 7.4 Solution Design

Farmers purchase ERC-20 tokens as digital proof of coverage. Investors deposit capital into an ERC-4626 vault and receive fungible shares. Oracle-based rainfall indices determine payout eligibility. Premiums and yields are modeled via a seasonal sealed-bid uniform-price auction functioning as a prediction market: farmer bids and investor offers jointly reveal the market-implied drought probability  $\hat{\pi}$  and equilibrium margin (Hanson 2003; Wolfers and Zitzewitz 2004). In the current prototype, the premium is set by the contract owner at season start (no on-chain auction). The frontend abstracts blockchain logic and is designed for future fiat–stablecoin conversion integration.

## 7.5 Revenue Model

Premiums collected from farmers fund the risk pool. Investor returns correspond to the surplus of premiums over payouts, distributed proportionally through vault shares. The auction internalizes both risk expectations and operational costs into the equilibrium premium, creating endogenous funding for the platform.

The operator may also allocate its own capital into the pool. This dual role enhances credibility and creates an additional revenue stream if claims remain below expectations, though it increases exposure to volatility. A 2–5% operator fee on premiums covers infrastructure, audits, and compliance. Optional reinsurance transfers catastrophic risk to external providers and stabilizes investor yields (Cummins 2009).

ERC-4626 shares accumulate value as premiums flow in and payouts are deducted. Because surpluses are automatically reinvested into vault NAV, long-term investors experience a compounding effect similar to conventional finance. Payouts are not broadcasted indiscriminately; they require a minimal on-chain claim, after which the contract settles automatically if the rainfall index threshold is breached (see Claim Process and Payout Logic).



## 7.6 Cost Structure

Key cost drivers are oracle services, secure data feeds, system audits, regulatory engagement, payment integration, and farmer outreach. Automation keeps administrative costs lower than in conventional microinsurance. Economies of scale further reduce marginal costs as the pool and user base expand.

## 7.7 Channels and Partnerships

Cooperatives, NGOs, and agro-dealers provide farmer onboarding and trust. M-Pesa integration allows direct premium and payout transactions. Oracle providers deliver rainfall indices (Egberts 2017). Reinsurers supply capacity for tail risk. Regulators and development agencies support compliance and market acceptance.

## 7.8 Scalability

The model can expand from Kenyan maize to other crops, regions, and perils such as livestock mortality or flood. ERC standards allow interoperability with DeFi protocols and secondary markets for risk exposure. The prediction-market mechanism improves with scale, as more participants and data sources sharpen price discovery. Modular system design supports adjustments across regulatory environments.

## 7.9 Claim Process and Payout Logic

Farmers must file a minimal on-chain claim (notice-of-loss) during a specified window  $[t_0, t_1]$  after oracle publication. The contract verifies:

1. ownership: policy tokens  $q > 0$  for the epoch,
2. uniqueness: no prior claim from the same address/epoch,
3. eligibility: oracle index  $I$  satisfies  $I \leq \tau$ .

If (1)–(3) hold, the contract transfers  $qL$  to the claimant’s wallet, otherwise the call reverts. In the analytical model, pro-rata rationing and operator fees can be applied; these are not enforced in the current prototype. No off-chain adjusters or discretionary assessments occur.<sup>1</sup>

## 8 Mechanism Design

*Scope note: The following mechanism specifies the market design used in our economic model. The prototype does not implement on-chain bidding (commit–reveal) or automated auction clearing; seasonal premiums are owner-set in the current implementation.*

Premiums and investor yields are discovered through a pre-season sealed-bid uniform-price auction. This single mechanism acts as a prediction market for drought risk, while remaining implementable under smallholder constraints (Wilson 1979; Ausubel and Cramton 2002).

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<sup>1</sup>A claim call is required to (i) prevent automatic transfers to inactive or lost wallets, (ii) avoid dust payouts below gas costs, and (iii) let farmers select their preferred payout rail (e.g. M-Pesa bridge).

## 8.1 Notation

Let  $x$  denote the number of insurance tokens sold, with  $Q$  referring to the total seasonal quantity (so  $Q = x$  at equilibrium). Each token promises a payout  $L$  if drought occurs, represented by the indicator variable  $X \in \{0, 1\}$ . Farmers pay a premium  $p$  per token.

We define  $\hat{\pi}$  as the *market-implied probability of drought*, inferred endogenously from the auction clearing. Premiums decompose into  $\hat{\pi}L$  and the risk margin  $\mu$ . Operational costs are  $F$ , investor capital  $K$ , realized return  $R$ , and expected return  $R^*$ . Farmer inverse demand is  $p_d(x)$ ; investor supply is  $C_s(R)$ . Required reserves are  $C_{\text{req}}(x)$ , with prudential utilization factor  $\theta \in (0, 1]$ .

## 8.2 Auction Process and Clearing Mechanism

At the beginning of each season, farmers submit bids  $(q_i, p_i)$  and investors submit  $(k_j, R_j)$ . Bids are committed via a commit-reveal protocol (Blum 1983; Buterin 2015; Parkes and Seuken 2014), ensuring confidentiality until revelation.

Feasibility requires

$$C_{\text{req}}(x) = xL\theta \leq S(R), \quad x \leq D(p).$$

Expected return for coverage  $x$  at premium  $p$  is

$$R = \frac{px - \hat{\pi}xL - F}{K}.$$

The mechanism adopts the *full coverage rule*: clearing at the maximal feasible  $x^*$ . The clearing premium is

$$p^* = \min\{p_i : \sum_i q_i \geq x^*\},$$

and the corresponding expected return  $R^*$  follows from the cashflow identity. All accepted farmer bids pay  $p^*$ , all investor capital earns  $R^*$ . If demand exceeds feasible coverage, allocations are scaled proportionally:

$$q_i^{\text{alloc}} = \rho q_i, \quad \rho = \frac{x^*}{\sum_i q_i}.$$

## 8.3 Premium Decomposition and the Risk Margin

The clearing premium decomposes into expected actuarial loss and a margin:

$$p = \hat{\pi}L + \mu.$$

Investor cashflow is

$$CF = pQ - XQL - F,$$

with realized return

$$R = \frac{CF}{K}, \quad R^* = \frac{pQ - \hat{\pi}QL - F}{K}.$$

It follows that

$$\mu = \frac{R^*K + F}{Q}.$$

Operational costs  $F$  are deducted transparently by the contract before distribution. They reduce net cashflows, but investors anticipate them when bidding (Bowers et al. 1997).

## 8.4 Joint Market Equilibrium

Auction outcomes satisfy equilibrium conditions:

$$p^* = p_d(x^*), \quad C_s(R^*) = C_{\text{req}}(x^*).$$

For analysis, demand is approximated by an isoelastic form (Mas-Colell et al. 1995; Varian 1992):

$$p_d(x) = Ax^{-1/\varepsilon}, \quad \varepsilon > 0,$$

and supply linearly:

$$C_s(R) = a + bR, \quad b > 0.$$

Seasonal outcomes  $(Q, p)$  are then fitted ex post with a convex bonding curve:

$$p(x) = \max \left( p_{\min}, p_{\min} \left( 1 + \frac{\lambda x}{N} \right)^k \right)$$

providing a tractable approximation for forecasting (Angeris and Chitra 2020; Shiller 2003). This curve is used *only for analysis*, not for live pricing.

## 8.5 Allocation Rules and Fairness

Pro-rata rationing ensures envy-freeness when demand exceeds feasible capacity:

$$q_i^{\text{alloc}} = \rho q_i, \quad \rho = \frac{\bar{Q}}{\sum q_i}.$$

Alternative rules (cutoffs, discriminatory allocations, priority mechanisms) were rejected as less efficient or less fair. Full coverage with pro-rata allocation mobilizes all feasible capacity while minimizing envy.

## 8.6 Limitations and Future Research

Limitations remain. Functional forms for demand, supply and bonding curves require calibration.  $\hat{\pi}$  must be validated against external actuarial or climate models. Uniform-price auctions remain vulnerable to demand reduction. Commit-reveal protocols face risks of collusion or non-reveal failures. Finally, convex pricing could disadvantage liquidity-constrained farmers. Future research should calibrate with field data, add anti-collusion safeguards and test continuous models as counterfactuals.

# 9 Implementation

Overview of implementation goals, strategy and architecture.

The goal for this project is providing a showcase prototype. Therefore, the focus was on providing the most important features, a neat, easy UI and a good test setup to showcase the functionality and laying the groundwork for possible extensions. These extensions and some

of the more advanced features that were not provided in the prototype will be discussed in sections 9.7 and 9.9. It is important to note that the project is not a complete MVP (minimum viable product), due to the constraints when it comes to funding for example Chainlink as provider for weather data or using actual currency as a payment method.

## 9.1 Prototype Scope: Model vs. Implementation

To avoid ambiguity, this subsection summarizes the economic model versus the implemented prototype.

Table 1: Economic Model vs. Prototype Implementation

Feature	Economic Model	Prototype (This Repo)
Premium discovery	Sealed-bid uniform-price auction (commit–reveal)	Owner-set per season (no on-chain auction)
Claims flow	Minimal claim; pro-rata possible; fees deducted	Explicit claim call; no pro-rata; no fees; revert if insufficient funds
Payout automation	Event-based automatic settlement	Automated settlement upon claim call when oracle threshold met
Oracle data	Chainlink or equivalent, multi-source	Mock oracle (AggregatorV3Interface-compatible)
Policy tokens	ERC-20 per season	ERC-20 per season (transferable)
Risk pool	ERC-4626 vault	ERC-4626 vault implemented
Investor redemption	Flexible per design	Restricted to WITHDRAW phase
Fiat/mobile rails	M-Pesa bridge integration	Not implemented (UI designed for future integration)
Reinsurance	Optional	Not implemented
Deployment	Public testnet/mainnet	Local Hardhat network <sup>2</sup> for prototype

## 9.2 Development Process & Strategy

The strategy for the implementation was largely based on a learning process. At first the focus was mainly on exploring the basics of Solidity-based smart contracts and creating an early working prototype. Once this was achieved the focus shifted to code quality, finding efficient and well established solutions to tackle current challenges and, at the end, integrating all of this into an easy-to-use UI.

The most important guidelines and ideas for the implementation were:

- 1 **Division of Work:** The work was divided mostly into two parts. One part was the overarching architecture and product design, including specifically the smart contract development using Solidity, as well as researching existing libraries and standards to implement and use. The other part, equally important, was researching and setting up the tools and frameworks for

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<sup>2</sup>See: <https://v2.hardhat.org/docs>

everything else: the project and testing setup using Hardhat and writing the actual test code, implementing the UI using React, managing the repository, and bug fixing. This division was important for numerous reasons, but especially because it allowed for mutual verification and simultaneously the possibility to truly focus on specific topics.

- 2 **Testing Setup:** The testing setup within Hardhat and using Node.js made finding bugs and testing after changes much more efficient and also allows for neat and compact showcases of the features and working prototype code. An excerpt from this testing setup and what it shows can be seen in figure ??.
- 3 **Research:** Research was an important, continuous process throughout the project, for finding technical solutions but also possible issues with the current state of the project.
- 4 **Usage of AI:** AI was used throughout the project for research purposes, when trying to find fitting libraries, tools and standards, as well as making repetitive tasks, like writing test code more efficient.

An important challenge was to align technical progress with the economic modeling. Once a working prototype was achieved, communication between these two distinct work streams came into focus. Daily synchronization and change management helped in finding ways to implement the most important parts of the business model, whilst simplifying other parts, like using a mock weather oracle, instead of Chainlink as a source of weather data. The strategy during the development process was to implement based on an objective hierarchy:

- 1 Working smart contract with deterministic payouts
- 2 Investment logic
- 3 Investor incentive model (yield / compound interest)
- 4 Tests and code quality
- 5 Working frontend for showcases and manual testing
- 6 ...

These are just the most important tasks that are included in the final prototype. For further necessary steps towards a finished product refer to 9.9.

### 9.3 System (Macro) Architecture

The macro architecture of the system is centered around the RainyDayFund smart contract, which acts as the core of the decentralized insurance platform. It is designed to be extensible for integration with oracles (such as Chainlink), ERC20 tokens as payment and is integrated within a frontend built with React. The architecture emphasizes modularity, and ease of use for both farmers and investors, as well as neat and easy testing and showcasing.

As shown in figure 1 the users (both farmers and investors) own a crypto wallet and connect this to the frontend. The frontend then allows them to easily invest or buy policies for the current season with their crypto funds, by programmatically interacting with the smart contract.

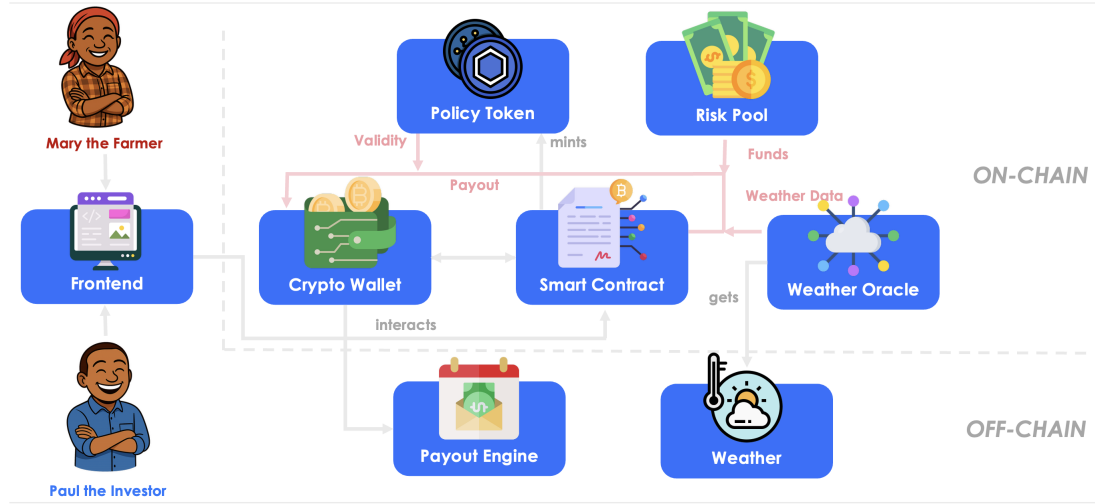


Figure 1: Architectural Overview  
*Source: Author's own.*

The smart contract then mints a policy token for farmers or deposits the investors' funds in the vault, so that they can receive a yield. All funds are stored in a risk pool (in our case the ERC-4626 vault). The farmers can claim their policies at the end of the season and, if all conditions are met, i.e. the weather oracle returns weather data below the threshold and the farmer making the claim actually owns the policy tokens, receive their coverage funds. Investors may withdraw their funds, receiving all the accumulated yield. The **Payout Engine** symbolizes the possibility of transferring out funds from the crypto wallet to widely used mobile-money services, like M-Pesa. This is already a well established process and not included in the project itself, should however be noted, because it allows the farmers to actually immediately use their payouts in their everyday life.

The concrete timeline for the process is based on the crop season and has 5 phases:

1. **Active Phase:** In the active phase policies can be bought and investments can be made. The premium for the current season is set at the beginning by the owner. No claims or withdrawals can be made during this phase.
2. **Inactive Phase:** Now the policies can no longer be bought, but investments can still be made. This allows for a speculative market for the insurance policies, while keeping the possibility of introducing more liquidity from capital investors.
3. **Claim Phase:** The claim phase starts upon the actual crop season ending. Farmers may now try to claim their policies and receive their coverage payouts, while investors have to wait until this phase is over.
4. **Withdrawal Phase:** Now investors may choose to withdraw their capital and receive their yield, while farmers wait until the next season is started.
5. **Finished Phase:** The season is over, unclaimed policies are now invalid and not-withdrawn investments are used as liquidity for the next season, earning yield on the current investment (including the earned yield), creating a compounding effect.

## 9.4 Development Tools & Infrastructure

The development process utilized a modern toolchain centered around the Hardhat framework for smart contract development, deployment, and testing. Initial contract development was performed in the Remix IDE, which enabled rapid deployment and manual testing directly in the browser without requiring local setup. After a working prototype was established, development transitioned to Hardhat, providing a more robust environment with a local blockchain that simulates real network conditions. The frontend was built using React, serving as an interface to test smart contract interactions and demonstrate overall system functionality.

Version control was managed through Git, with collaboration facilitated via a GitHub repository. This setup ensured transparency, accountability, and effective team coordination throughout the project. Deployment was initially planned for the Sepolia Testnet<sup>3</sup>, but the final sprint used only a local network due to recurring issues with contract interaction on Sepolia. This compromise allowed for the delivery of a fully functional prototype that operates predictably without external dependencies.

Development environments included the Remix IDE<sup>4</sup> for Solidity-based work and Neovim for general-purpose coding tasks. All deployment tasks were executed through JavaScript scripts within the Hardhat framework.

## 9.5 Initial Contract Design

The project is built around a Solidity smart contract using the Ethereum Virtual Machine. This central RainyDayFund contract can be called using the front end and holds all the exposed functionality for the consumer. Investors use the `invest()` and `redeemShares()` methods while insurees can buy and claim their policies in batches using the `buyPolicy()` and `claimPolicies()` functions. The contract leverages ERC-20 season policy tokens, enabling simple transfers and season-scoped policy management.

As shown in Figure 2, the initial contract made use of the `ERC-1155 token standard` for the `policyTokens`, to take advantage of the cost-efficient batch operations (Ethereum 2025). To help with testing the (Mock) USDC<sup>5</sup> was created, implementing the ERC20 interface, to emulate the behavior of common stablecoins like USDC, which are used as payment and funding for the risk pool. This allowed for the free minting and full control over the coins and made testing the functionality of the main contract possible, even within the bounds of Remix VM. Therefore, testing was quicker and easier at the beginning, without the need to always deploy on the Sepolia Testnet or an immediate, complete setup, for example with Hardhat.

---

<sup>3</sup>Test network for Ethereum; for more information refer to <https://getblock.medium.com/what-is-sepolia-a-beginners-guide-to-ethereum-test-networks-866663a26698>

<sup>4</sup>An online IDE for developing solidity smart contracts. For documentation see: <https://remix-ide.readthedocs.io/en/latest/run.html#remix-vm>, the IDE can be found at: <https://remix.ethereum.org>

<sup>5</sup>One of the largest stablecoins worldwide, well accessible and low cost, see: <https://developers.circle.com/stablecoins/what-is-usdc>

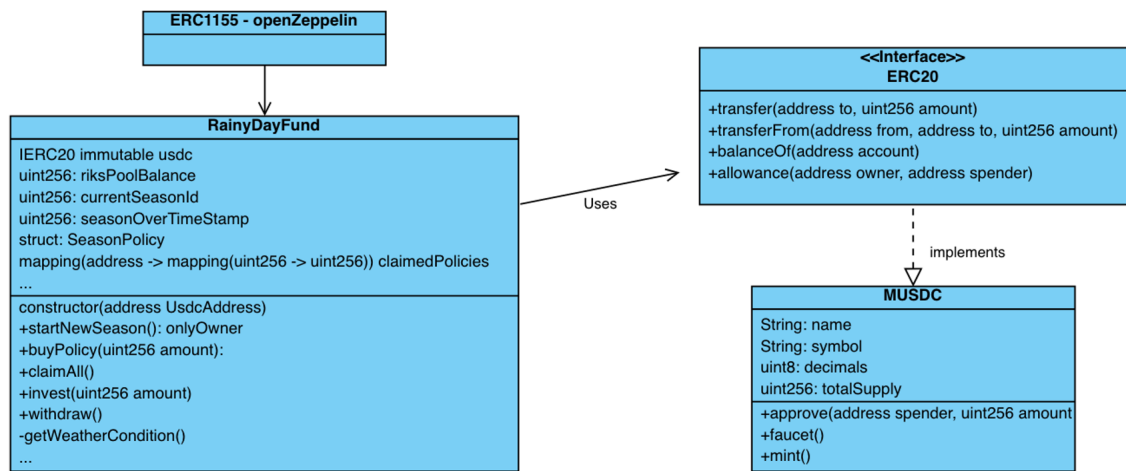


Figure 2: Initial Contract Design  
*Source: Author's own.*

Initially there were multiple issues:

- 1 **Mapping for storing addresses:** Initially, a mapping was used to store who had bought policies and was thereby eligible to claim them. However, there were some issues with this: Firstly, the policies lost all their value when they were resold, because the address of the new owner would not be tracked in the mapping. Moreover, storing all of this data was very gas-inefficient and redundant, because ownership of the policyToken is proof of ownership for the policy.
- 2 **No proper incentive for investors:** It was already planned to give investors an incentive to keep their funds in the risk pool, even after the season would end, to increase liquidity for the next season. The idea to achieve this was to use compound interest or create some other form of yield over time. However, implementing this with the initial setup proved difficult and created vastly unfair results.
- 3 **Weather oracle:** The initial mock-up for the weather oracle was just a number that could be accessed and stored on the contract directly. This was far from the goal of using Chainlink as a decentralized oracle to reliably and transparently access the data.
- 4 **Attack vectors:** Lastly there were some attack vectors, especially for the owner. The `startNewSeason()` function could be used at any point during the season, thus rendering unclaimed policy tokens worthless and not allowing for investment withdrawals to be made.



Addressing these issues of the initial prototype the contract was restructured. The main fixes were:

Table 2: Major Issues and Corresponding Fixes

Issue	Fix
Mapping for storing addresses was gas-inefficient and did not track policy resales	Removed the mapping
No proper incentive for investors and difficulties with implementation	Switched from self-made investment tracking to using the ERC4626 vault
Using Token Standards ERC4626, ERC20 and ERC1155 simultaneously, causing errors with inheritance of the contract	Switched from ERC1155 to only using ERC20 for the policy tokens
Weather Oracle / Chainlink integration	Implementing the proper Chainlink standards for the mock-up weather oracle (Chainlink n.d.)
Attack Vector for Owner	Fixed some issues by including modifiers and properly implementing a state machine (refer to enumeration 5)

## 9.6 Implementation: Final State of the project

The final state of the contract can be seen in Figure 3

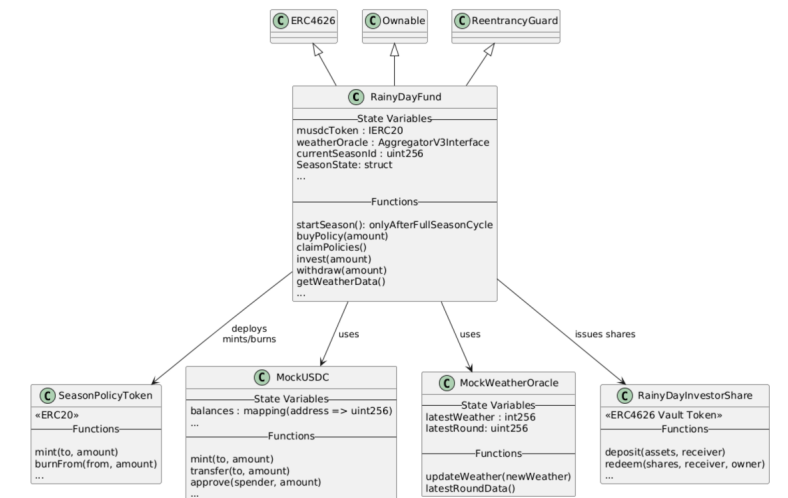


Figure 3: Final Contract Design

*Source: Author's own.*

This class diagram only shows the most important functions and fields of the contract. The full code can be found in the appendix A along with some notes on its functionality.

The constructor takes 2 arguments:

- (1) **usdcAddress:** The address of the stablecoin that will be used for the transactions, here this would be the address of the deployed MockUSDC contract

- (2) **weatherOracle:** The address of the weather data oracle service, here this would be the address of the deployed MockWeatherOracle contract, but in production should be the corresponding Chainlink address.

Both are required to not be zero and used to set the corresponding fields for further use. Then the first season is initialized.

As shown in listing 1, the contract utilizes a SeasonState enum to keep track of the phase that is currently active in the state machine. The `getSeasonState()` method is used as the state machine and utilizes the `getCurrentTime()` method. The choice to implement the time this way, instead of simply using the `block.timestamp` was made to allow for time manipulation in testing. That is why there is a `testingTimeOffset` being added to the timestamp. This offset is calculated and set in a method of its own, that is only used for testing and showcasing reasons and would be removed for production.

```
1  enum SeasonState { ACTIVE, INACTIVE, CLAIM, WITHDRAW, FINISHED }
2  function getCurrentTime() public view returns (uint256) {
3      if (testingMode) {
4          return block.timestamp + testingTimeOffset;
5      }
6      return block.timestamp;
7  }
8
9      function getSeasonState() public view returns (SeasonState) {
10         uint256 currentTime = getCurrentTime();
11         if (currentTime < seasonOverTimeStamp - timeUnit) {
12             return SeasonState.ACTIVE;
13         } else if (currentTime < seasonOverTimeStamp) {
14             return SeasonState.INACTIVE;
15         } else if (currentTime < seasonOverTimeStamp + timeUnit) {
16             return SeasonState.CLAIM;
17         } else if (currentTime < seasonOverTimeStamp + 2 * timeUnit) {
18             return SeasonState.WITHDRAW;
19         } else {
20             return SeasonState.FINISHED;
21         }
22     }
23
24     modifier onlyAfterFullSeasonCycle() {
25         require(getSeasonState() == SeasonState.FINISHED, "Season not fully
finished yet");
26         _;
27     }
28
29     function startNewSeason(uint256 _premium) external onlyOwner
onlyAfterFullSeasonCycle {
30         currentSeasonId++;
31         premium = _premium;
32         seasonOverTimeStamp = getCurrentTime() + 2 * timeUnit;
_initializeSeason(currentSeasonId);
}
```

Listing 1: Excerpt: RainyDayFund.sol - StateMachine

One example of how this gets used, can be seen in the modifier `onlyAfterFullSeasonCycle()`, which requires that the current season state is “FINISHED”. This modifier is for example used for the `startNewSeason()` function, which initializes a new season with the given premium. The function should only be called once the last season has finished, to avoid policies not being claimable or investors not being able to withdraw their funds.

The most important functions for the farmers are `buyPolicy()` and `claimPolicies()`. They allow for purchasing and filing claims while checking all necessary conditions.

```

1  function buyPolicy(uint256 _amount) external nonReentrant returns (uint256
seasonId) {
2      require(_amount > 0, "Amount > 0");
3      require(getSeasonState() == SeasonState.ACTIVE, "Not in active period");
4
5      SeasonPolicy storage policy = seasonPolicies[currentSeasonId];
6
7      uint256 totalPremium = policy.premium * _amount;
8      require(usdc.transferFrom(msg.sender, address(this), totalPremium), "
Transfer failed");
9
10     SeasonPolicyToken(address(policy.policyToken)).mint(msg.sender, _amount);
11     policy.totalPoliciesSold += _amount;
12
13     emit PolicyBought(msg.sender, currentSeasonId, _amount, totalPremium);
14     return currentSeasonId;
15 }
16
17 function claimPolicies() external nonReentrant {
18     require(getSeasonState() == SeasonState.CLAIM, "Not in claim period");
19
20     SeasonPolicy storage policy = seasonPolicies[currentSeasonId];
21     SeasonPolicyToken token = SeasonPolicyToken(address(policy.policyToken)
);
22     uint256 amount = token.balanceOf(msg.sender);
23     require(amount > 0, "No policies to claim");
24
25     (, int256 weather,) = getWeatherData();
26     require(uint256(weather) < 10, "Weather not bad enough");
27
28     uint256 totalPayout = policy.payoutAmount * amount;
29     require(usdc.balanceOf(address(this)) >= totalPayout, "Insufficient
funds");
30
31     require(usdc.transfer(msg.sender, totalPayout), "Payout failed");
32     token.burnFrom(msg.sender, amount);
33
34     emit ClaimMade(msg.sender, currentSeasonId, amount, totalPayout);
35 }
36

```

Listing 2: Excerpt: RainyDayFund.sol - Farmer Functions

The `buyPolicy()` function takes in the amount of `policyTokens` the user wants to buy and returns the current `seasonId`. This id could be used to display metadata about the season in the front end. The amount needs to be above zero and the season needs to be in the active phase. The premium gets calculated based on the amount and the premium stored in the `SeasonPolicy` struct, that gets set at the beginning of the season. After the transfer of the funds the `policyTokens` get minted to the user's wallet and the corresponding event gets emitted.

The `claimPolicies()` function requires the season to be in the claim phase and claims all available `seasonPolicy` tokens in the user's wallet. It checks whether the weather condition is met through the weather oracle with the `getWeatherData()` function and calculates the total payout, based on the fixed payout per token and the amount of tokens. Lastly the payout is made, the tokens are burned and an event gets emitted.

Both functions are secured by a reentrancy guard as a security best practice, because unlike in the prototype setup, in production the stablecoin contract used is not directly controllable and there might be some malicious code or even potential flash loan attacks, where the attacker attempts to manipulate the contract state through rapid sequential interactions. In both cases the tokens are minted/burned only after the transfer was successful to avoid minting/burning should the transfer fail.

Lastly the investment logic is simplified a lot by using the `ERC4626` token vault standard:

```

1  // ERC4626 investment logic
2  function invest(uint256 assets) external nonReentrant onlyDuringSeason {
3      require(assets > 0, "Amount > 0");
4      deposit(assets, msg.sender);
5      emit InvestmentMade(msg.sender, assets);
6  }
7
8  function redeemShares(uint256 shares) external nonReentrant {
9      require(getSeasonState() == SeasonState.WITHDRAW, "Not in withdrawal
10     period");
11     uint256 assets = redeem(shares, msg.sender, msg.sender);
12     emit InvestmentWithdrawn(msg.sender, assets);
13 }

```

Listing 3: Excerpt: `RainyDayFund.sol` - Investor Functions

The `invest()` function simply deposits the assets in the vault, requiring the amount to be above zero and the `redeemShares()` function redeems the user's shares again. All the transfers are handled by the vault implementation. The main customization is the `onlyDuringSeason` modifier for the `invest()` function and the requirement for the "WITHDRAW" phase in the `redeemShares()` function, making sure investments are not made during the claim or withdraw phases and the withdrawals can only happen in the corresponding phase.

Some information about the `SeasonPolicyToken`, `MockUSDC` and `MockWeatherOracle` contracts can be found in the appendix B.

## 9.7 Quality Assurance & Security

Quality assurance focused on comprehensive testing and systematic validation of contract functionality. All tests were written in TypeScript using the Node.js framework with Chai for assertions, enabling early error detection and improving maintainability. To ensure complete testing without reliance on external dependencies, a mock ERC20 token, `MockUSDC`, was implemented to emulate USDC behavior. This approach enabled full control over the testing environment and facilitated the verification of payment and funding logic within isolated virtual machine conditions.

The test setup, shown in Figure ??, emphasizes the importance of robust testing and code coverage in the project. Test coverage reaches nearly 100% for critical functions, allowing bugs to be identified and resolved early in the development cycle. The comprehensive test suite verifies correct contract behavior across a variety of scenarios, including edge cases and potential attack vectors.

RainyDayFund Deployment ✓ Should set the right owner ✓ Should set the correct USDC address ✓ Should set the correct weather oracle ✓ Should initialize with season 1 ✓ Should set correct initial season parameters ✓ Should initialize in ACTIVE state ✓ Should be in testing mode by default ✓ Should initialize season over timestamp correctly ✓ Should reject zero addresses in constructor Testing Mode Functions ✓ Should allow owner to advance through all phases ✓ Should correctly calculate time offset for each phase ✓ Should allow owner to toggle testing mode ✓ Should not allow non-owner to use testing functions ✓ Should return correct current time in testing mode Policy Purchase ✓ Should allow buying policies in ACTIVE state ✓ Should return correct season ID when buying policy ✓ Should reject zero amount purchase ✓ Should reject purchase when not in active period ✓ Should handle multiple policy purchases ✓ Should handle insufficient USDC balance ✓ Should handle insufficient allowance Weather Data and Claims ✓ Should read weather data from oracle ✓ Should allow claiming when weather conditions are met ✓ Should not allow claiming with good weather ✓ Should test weather threshold boundary ✓ Should not allow claiming in wrong periods ✓ Should not allow claiming without policies ✓ Should handle insufficient funds for claims ✓ Should prevent double claiming Investment Functions (ERC4626) ✓ Should allow investments using invest wrapper in ACTIVE state ✓ Should allow investments using direct ERC4626 deposit ✓ Should allow investments in INACTIVE period ✓ Should not allow investments outside ACTIVE/INACTIVE periods ✓ Should reject zero amount investment ✓ Should allow withdrawal during WITHDRAW period using redeemShares ✓ Should allow withdrawal using direct ERC4626 redeem ✓ Should not allow withdrawal outside WITHDRAW period ✓ Should calculate proportional returns with premium income ✓ Should handle ERC4626 preview functions correctly ✓ Should calculate correct share to asset ratios					
63 passing (3s)					
File	% Stmts	% Branch	% Funcs	% Lines	Uncovered Lines
contracts/	98.7	92.31	100	100	
MockUSDC.sol	100	100	100	100	
MockWeatherOracle.sol	100	100	100	100	
RainyDayFund.sol	98.65	92.31	100	100	
All files	98.7	92.31	100	100	

(a) Passing Tests and Coverage

*Source: Author's own.*

## 9.8 Problems and Remaining Questions

During implementation of the `RainyDayFund` contract, a subtle interaction between policy purchases and investor deposits was identified, stemming from the OpenZeppelin ERC4626 vault's design for handling external asset inflows.

Specifically, when policies are purchased before any investments, the USDC premiums are transferred directly into the vault via `buyPolicy()`, increasing `totalAssets()` without minting corresponding RDIS shares. This leaves `totalSupply()` at zero.

Subsequent calls to `invest()`, invoking ERC4626’s `convertToShares()` function to compute share issuance:

$$\text{shares} = \text{assets} \times \frac{\text{totalSupply}() + 10^{\text{decimals offset}}}{\text{totalAssets}() + 1}$$

where the decimals offset is 12 (RDIS<sup>6</sup> at 18 decimals, USDC at 6). The  $10^{12}$  term acts as a “virtual supply” to bootstrap fair pricing and normalize decimals.

With no prior shares, this heavily dilutes the first deposit: for a 1 USDC investment after 9 USDC in premiums,  $\text{shares} \approx 1.11 \times 10^{11}$  raw units, or  $\sim 1.11 \times 10^{-7}$  whole RDIS tokens—appearing as “quasi-null” in the React UI. Later investments face similar dilution until real supply dominates the virtual offset.

This is not a bug but intended ERC4626 behavior (per EIP-4626<sup>7</sup>) to prevent windfalls from external transfers, ensuring atomic fairness: depositors receive exactly their assets’ worth upon immediate redeem. However, it creates order dependence in this flow—invest-first avoids the issue—and cosmetic UI problems, misaligning with the goal of seamless pooling where premiums back the fund and investments capture retained upside ( $\text{NAV}^8 > 1$  on low claims) or share dilution ( $\text{NAV} < 1$  on payouts).

To address this, the following measures are proposed:

1. In `buyPolicy()`, after transferring premiums, mint proportional protocol shares to the owner at the bootstrap rate ( $10^{12}$  per USDC), ensuring whole-scale issuance for all deposits.
2. In `redeemShares()` (WITHDRAW phase only), auto-trigger a one-time redemption of protocol shares on the first investor withdrawal, donating proceeds back as external assets (no new shares minted).

This realizes upside trustlessly: the first withdrawer enables full NAV for all, with negligible extra gas ( $\sim 20k$ ).

Trade-offs include: if no withdrawals occur, retained premiums remain unrealized (fund rolls over); concurrent first withdrawals are serialized fairly by Ethereum. Implementation is deferred due to time constraints and audit needs, and the order dependence is documented and avoided in deployment.

## 9.9 Future Work

The most important next step is the integration of real Chainlink oracles for weather data. The current implementation uses mock data, but production requires reliable, tamper-proof weather information from multiple sources. Deployment on a real network is also necessary. Layer 2<sup>9</sup> solutions such as Polygon or Arbitrum<sup>10</sup> are suitable due to significantly lower gas costs, which is essential for price-sensitive users such as farmers. Cross-chain deployment should also be explored to provide users with additional flexibility.

<sup>6</sup>RainyDayFund Investor Shares - the shares investors get for their capital, as implemented in the ERC-4626 standard

<sup>7</sup>See: <https://eips.ethereum.org/EIPS/eip-4626>

<sup>8</sup>Net Asset Value, refer to e.g. <https://www.investopedia.com/terms/n/nav.asp>

<sup>9</sup>Refer to: (Song et al. 2024)

<sup>10</sup><https://blog.arbitrum.io/a-guide-to-understanding-blockchain-layer-2s/>

The smart contract architecture requires further refinement for production readiness. Upgradeability mechanisms must be introduced to enable future bug fixes and feature additions while maintaining a balance with immutability to preserve user trust. Gas optimization remains a key priority, as the current version functions correctly but is not cost-efficient.

Future functionality may include crop-specific insurance products and multi-season coverage, addressing the limitations of the current single-season model. Additional features such as group policies for farmer cooperatives would further increase system usability.

The frontend requires enhanced usability, particularly for users with limited digital experience. A mobile-first design is essential, as most users will access the platform via smartphones. Offline functionality should also be included to accommodate rural regions with inconsistent internet connectivity.

**Technical priorities include:**

1. Chainlink integration for real weather data
2. Layer 2 deployment for reduced transaction costs
3. Gas optimization and upgradeable contract architecture
4. Mobile-optimized frontend with offline support
5. Multi-language support and simplified user interfaces

More extensive testing on public testnets is planned once deployment issues are resolved. While the current local testing setup provides an effective development environment, testing under real network conditions is essential to uncover issues that may not appear in isolated simulations.

## 10 Conclusion

Blockchain-enabled parametric microinsurance is not a silver bullet for climate risk, but this work shows it can remove long-standing frictions that kept protection out of reach for Kenyan smallholders. The approach begins from a simple premise: if pricing, capital formation, and payouts are automated around objective weather signals, then insurance can become cheaper, faster, and more trustworthy. The design proposes a sealed-bid, uniform-price mechanism for seasonal price discovery alongside tokenized coverage and a pooled ERC-4626 vault, and a test-covered prototype was implemented that executes end-to-end flows with deterministic, auditable logic. The auction mechanism remains part of the model and is not yet implemented on-chain.

Three results stand out.

First, automation meaningfully reduces operational complexity: premiums, coverage, and payouts are settled by code with transparent rules and verifiable data, minimizing discretion and delays.

Second, market-based clearing aligns farmer affordability and investor return ex ante, translating beliefs about drought into prices and capacity in a way that scales with participation.

Third, modularity matters: by standardizing payments, tokens, and oracles, the system can plug into mobile rails (e.g., M-Pesa bridges), real weather feeds, and reinsurance capacity without redesigning core contracts.

Important limitations remain. Basis risk must be reduced through better indices (multi-source rainfall, satellite vegetation, crop models) and local calibration. Real oracle infrastructure, L2 deployment, gas optimization, and upgrade paths are prerequisites for production. Governance and consumer protection (fair disclosures, dispute windows, orderly season transitions) must be specified and audited. Finally, the ERC-4626 interaction between external premiums and share issuance requires a production-grade policy to avoid confusing UX and to preserve fair NAV accounting.

The path forward is practical and testable: pilot one crop and county with a cooperative partner, integrate Chainlink (or equivalent) multi-source weather feeds, settle on a conservative claim threshold with an appeal buffer, and distribute through trusted local channels. Use donor or public co-funding to subsidize early seasons, measure realized basis risk and take-up, and iterate the auction parameters with real demand data. On-chain transparency should be paired with mobile-first UX and multilingual support to build confidence.

In sum, the Rainy-Day Fund demonstrates that decentralized infrastructure can make parametric insurance simpler, fairer, and more credible for farmers like Mary—converting climate shocks into predictable cashflows when they matter most. With robust data, careful governance, and field partnerships, the prototype can evolve into a resilient safety net that scales beyond a single crop or region while remaining transparent and accountable by design.

The entire project can be found in the GitHub repository.

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## A Smart Contract Code

This appendix contains the full source code for the smart contracts implemented in this project. These contracts form the core of our decentralized parametric insurance system.

### A.1 RainyDayFund.sol

The main contract that implements the decentralized parametric insurance system. It handles policy issuance, claims processing, and investment management.

```

1  // SPDX-License-Identifier: MIT
2  pragma solidity ^0.8.28;
3
4  import "@openzeppelin/contracts/access/Ownable.sol";
5  import "@openzeppelin/contracts/utils/ReentrancyGuard.sol";
6  import "@openzeppelin/contracts/token/ERC20/ERC20.sol";
7  import "@openzeppelin/contracts/token/ERC20/extensions/ERC4626.sol";
8  import "@openzeppelin/contracts/token/ERC20/extensions/IERC20Metadata.sol";
9
10 interface AggregatorV3Interface {
11     function latestRoundData() external view returns (
12         uint80 roundId,
13         int256 answer,
14         uint256 startedAt,
15         uint256 updatedAt,
16         uint80 answeredInRound
17     );
18 }
19
20 contract RainyDayFund is ERC4626, Ownable, ReentrancyGuard {
21     IERC20 public immutable usdc;
22
23     uint256 public currentSeasonId;
24     uint256 public seasonOverTimeStamp;
25     uint256 public constant timeUnit = 30 days;

```

```

26     uint256 premium = 9 * 10**6; // 9 USDC
27
28     AggregatorV3Interface public weatherFeed;
29
30     // Testing variables for time control
31     uint256 public testingTimeOffset;
32     bool public testingMode;
33
34     enum SeasonState { ACTIVE, INACTIVE, CLAIM, WITHDRAW, FINISHED }
35
36     struct SeasonPolicy {
37         uint256 creationTimestamp;
38         uint256 payoutAmount;
39         uint256 premium;
40         uint256 totalPoliciesSold;
41         ERC20 policyToken;
42     }
43
44     mapping(uint256 => SeasonPolicy) public seasonPolicies;
45
46     event PolicyBought(address indexed farmer, uint256 seasonId, uint256
amount, uint256 totalPremium);
47     event ClaimMade(address indexed farmer, uint256 seasonId, uint256 amount,
uint256 totalPayout);
48     event InvestmentMade(address indexed investor, uint256 amount);
49     event InvestmentWithdrawn(address indexed investor, uint256 amount);
50     event NewSeasonStarted(uint256 seasonId, uint256 premium, uint256
payoutAmount);
51     event TimeAdvanced(uint256 newTimestamp, SeasonState newState);
52
53     constructor(address _usdcAddress, address _weatherOracle)
54     ERC4626(IERC20Metadata(_usdcAddress))
55     ERC20("RainyDay Investor Shares", "RDIS")
56     Ownable(msg.sender)
57     {
58         require(_usdcAddress != address(0), "USDC address zero");
59         usdc = IERC20(_usdcAddress);
60
61         require(_weatherOracle != address(0), "Weather oracle zero");
62         weatherFeed = AggregatorV3Interface(_weatherOracle);
63
64         currentSeasonId = 1;
65         _initializeSeason(currentSeasonId);
66         seasonOverTimeStamp = getCurrentTime() + 2 * timeUnit;
67
68         // Enable testing mode by default for local testing
69         testingMode = true;
70     }
71
72     // Testing function to get current time (can be offset in testing mode)
73     function getCurrentTime() public view returns (uint256) {
74         if (testingMode) {

```

```

75         return block.timestamp + testingTimeOffset;
76     }
77     return block.timestamp;
78 }
79
80 // Testing function to advance time manually
81 function advanceToNextPhase() external onlyOwner {
82     require(testingMode, "Not in testing mode");
83
84     SeasonState currentState = getSeasonState();
85     uint256 nowBlock = block.timestamp;
86     if (currentState == SeasonState.ACTIVE) {
87         uint256 target = seasonOverTimeStamp - timeUnit + 1; // +1 to ensure
inside the next phase
88         testingTimeOffset = target - nowBlock;
89     } else if (currentState == SeasonState.INACTIVE) {
90         uint256 target = seasonOverTimeStamp + 1;
91         testingTimeOffset = target - nowBlock;
92     } else if (currentState == SeasonState.CLAIM) {
93         uint256 target = seasonOverTimeStamp + timeUnit + 1;
94         testingTimeOffset = target - nowBlock;
95     } else if (currentState == SeasonState.WITHDRAW) {
96         uint256 target = seasonOverTimeStamp + 2 * timeUnit + 1;
97         testingTimeOffset = target - nowBlock;
98     } else {
99         // already finished, do nothing
100         emit TimeAdvanced(getCurrentTime(), getSeasonState());
101         return;
102     }
103
104     emit TimeAdvanced(getCurrentTime(), getSeasonState());
105 }
106
107 // Testing function to set testing mode
108 function setTestingMode(bool _enabled) external onlyOwner {
109     testingMode = _enabled;
110     if (!_enabled) {
111         testingTimeOffset = 0;
112     }
113 }
114
115 function _initializeSeason(uint256 seasonId) internal {
116     SeasonPolicyToken policyToken = new SeasonPolicyToken(
117         string(abi.encodePacked("RainyDay Policy Season ", _toString(seasonId
))),
118         string(abi.encodePacked("RDP", _toString(seasonId))),
119         address(this)
120     );
121
122     seasonPolicies[seasonId] = SeasonPolicy({
123         creationTimestamp: getCurrentTime(),
124         payoutAmount: premium * 4,

```

```

125     premium: premium,
126     totalPoliciesSold: 0,
127     policyToken: policyToken
128 });
129
130     emit NewSeasonStarted(seasonId, premium, seasonPolicies[seasonId].
payoutAmount);
131 }
132
133     function getSeasonState() public view returns (SeasonState) {
134         uint256 currentTime = getCurrentTime();
135         if (currentTime < seasonOverTimeStamp - timeUnit) {
136             return SeasonState.ACTIVE;
137         } else if (currentTime < seasonOverTimeStamp) {
138             return SeasonState.INACTIVE;
139         } else if (currentTime < seasonOverTimeStamp + timeUnit) {
140             return SeasonState.CLAIM;
141         } else if (currentTime < seasonOverTimeStamp + 2 * timeUnit) {
142             return SeasonState.WITHDRAW;
143         } else {
144             return SeasonState.FINISHED;
145         }
146     }
147
148     modifier onlyAfterFullSeasonCycle() {
149         require(getSeasonState() == SeasonState.FINISHED, "Season not fully
finished yet");
150     }
151 }
152
153     modifier onlyDuringSeason() {
154         require(
155             getSeasonState() == SeasonState.ACTIVE ||
156             getSeasonState() == SeasonState.INACTIVE,
157             "Season not active anymore");
158     }
159 }
160
161     function startNewSeason(uint256 _premium) external onlyOwner
onlyAfterFullSeasonCycle {
162         currentSeasonId++;
163         premium = _premium;
164         seasonOverTimeStamp = getCurrentTime() + 2 * timeUnit;
165         _initializeSeason(currentSeasonId);
166     }
167
168     function buyPolicy(uint256 _amount) external nonReentrant returns (
uint256 seasonId) {
169         require(_amount > 0, "Amount > 0");
170         require(getSeasonState() == SeasonState.ACTIVE, "Not in active period")
;
171

```

```

172     SeasonPolicy storage policy = seasonPolicies[currentSeasonId];
173
174     uint256 totalPremium = policy.premium * _amount;
175     require(usdc.transferFrom(msg.sender, address(this), totalPremium), "
Transfer failed");
176
177     SeasonPolicyToken(address(policy.policyToken)).mint(msg.sender, _amount
);
178     policy.totalPoliciesSold += _amount;
179
180     emit PolicyBought(msg.sender, currentSeasonId, _amount, totalPremium);
181     return currentSeasonId;
182 }
183
184 function claimPolicies() external nonReentrant {
185     require(getSeasonState() == SeasonState.CLAIM, "Not in claim period");
186
187     SeasonPolicy storage policy = seasonPolicies[currentSeasonId];
188     SeasonPolicyToken token = SeasonPolicyToken(address(policy.policyToken)
);
189     uint256 amount = token.balanceOf(msg.sender);
190     require(amount > 0, "No policies to claim");
191
192     (,int256 weather,) = getWeatherData();
193     require(uint256(weather) < 10, "Weather not bad enough");
194
195     uint256 totalPayout = policy.payoutAmount * amount;
196     require(usdc.balanceOf(address(this)) >= totalPayout, "Insufficient
funds");
197
198     require(usdc.transfer(msg.sender, totalPayout), "Payout failed");
199     token.burnFrom(msg.sender, amount);
200
201     emit ClaimMade(msg.sender, currentSeasonId, amount, totalPayout);
202 }
203
204 function getWeatherData() public view returns (uint80 roundId, int256
weather, uint256 timestamp) {
205     (roundId, weather,,timestamp,) = weatherFeed.latestRoundData();
206 }
207
208 // ERC4626 investment logic
209 function invest(uint256 assets) external nonReentrant onlyDuringSeason {
210     require(assets > 0, "Amount > 0");
211     deposit(assets, msg.sender);
212     emit InvestmentMade(msg.sender, assets);
213 }
214
215 function redeemShares(uint256 shares) external nonReentrant {
216     require(getSeasonState() == SeasonState.WITHDRAW, "Not in withdrawal
period");
217     uint256 assets = redeem(shares, msg.sender, msg.sender);

```

```

218     emit InvestmentWithdrawn(msg.sender, assets);
219 }
220
221 function totalAssets() public view override returns (uint256) {
222     return usdc.balanceOf(address(this));
223 }
224
225 // minimal utility
226 function _toString(uint256 value) internal pure returns (string memory) {
227     if (value == 0) return "0";
228     uint256 temp = value;
229     uint256 digits;
230     while (temp != 0) { digits++; temp /= 10; }
231     bytes memory buffer = new bytes(digits);
232     while (value != 0) { digits--; buffer[digits] = bytes1(uint8(48 + value
233 % 10)); value /= 10; }
233     return string(buffer);
234 }
235 }
236
237 contract SeasonPolicyToken is ERC20 {
238     address public immutable rainyDayFund;
239     modifier onlyRainyDayFund() { require(msg.sender == rainyDayFund, "Only
240 fund"); _; }
241
242     constructor(string memory name, string memory symbol, address _fund)
243     ERC20(name, symbol) {
244         rainyDayFund = _fund;
245     }
246
247     function mint(address to, uint256 amount) external onlyRainyDayFund {
248         _mint(to, amount); }
249
250     function burnFrom(address from, uint256 amount) external onlyRainyDayFund
251     { _burn(from, amount); }
252 }

```

Listing 4: RainyDayFund.sol - Main Insurance Contract

## A.2 MockUSDC.sol

A mock implementation of the USDC stablecoin for testing purposes. It implements the ERC20 interface and provides additional minting functionality.

```

1 // SPDX-License-Identifier: MIT
2 pragma solidity ^0.8.20;
3
4 import "@openzeppelin/contracts/token/ERC20/ERC20.sol";
5
6 contract MockUSDC is ERC20 {
7     constructor() ERC20("Mock USDC", "mUSDC") {
8         _mint(msg.sender, 1_000_000 * 10 ** decimals());
9     }

```



```

10
11     function mint(address to, uint256 amount) external {
12         _mint(to, amount);
13     }
14 }
15

```

Listing 5: MockUSDC.sol - Mock Stablecoin for Testing

### A.3 MockWeatherOracle.sol

A mock implementation of a weather data oracle that conforms to Chainlink’s AggregatorV3Interface for standardized data feeds. This contract simulates weather data for testing the insurance system.

```

1  // SPDX-License-Identifier: MIT
2  pragma solidity ^0.8.28;
3
4  contract MockWeatherOracle {
5      int256 public latestWeather;
6      uint80 public latestRound;
7
8      constructor(int256 _initialWeather) {
9          latestWeather = _initialWeather;
10         latestRound = 1;
11     }
12
13     function updatePrice(int256 _newWeather) external {
14         latestWeather = _newWeather;
15         latestRound += 1;
16     }
17
18     function latestRoundData()
19         external
20         view
21         returns (
22             uint80 roundId,
23             int256 answer,
24             uint256 startedAt,
25             uint256 updatedAt,
26             uint80 answeredInRound
27         )
28     {
29         return (
30             latestRound,
31             latestWeather,
32             block.timestamp,
33             block.timestamp,
34             latestRound
35         );
36     }
37 }
38

```

## B Contract Architecture Analysis

The smart contracts presented above form the foundation of our decentralized parametric insurance system. Each plays a specific role in the ecosystem:

### B.1 RainyDayFund

This is the core contract of the system and implements several key components:

1. **Policy Management:** Handles the issuance of policy tokens to farmers and tracks active policies.
2. **Season States:** Implements a state machine for managing different phases of the insurance season (active, inactive, claim, withdraw, finished).
3. **Claims Processing:** Processes claims by verifying policy ownership and weather conditions.
4. **Investment Management:** Allows investors to provide liquidity to the risk pool and earn returns.
5. **Weather Data Integration:** Interfaces with the weather oracle to retrieve data for claims verification.

The contract employs several important design patterns:

- **ERC4626 Tokenized Vault:** For managing investments and yield generation.
- **ERC20 Policy Tokens:** For representing insurance policies as transferable assets.
- **Non-reentrant Guards:** To prevent reentrancy attacks during financial transactions.
- **Owner Controls:** To manage system parameters and seasonal transitions.
- **State Machine:** To enforce the correct sequence of operations based on the current season state.

### B.2 MockUSDC

This contract simulates a stablecoin for testing purposes. In a production environment, this would be replaced with a real stablecoin like USDC. The mock implementation provides:

- Standard ERC20 functionality for token transfers and allowances
- Additional minting capability for testing purposes
- Initial supply of 1,000,000 tokens for the contract deployer

### B.3 MockWeatherOracle

This contract simulates a weather data oracle, conforming to Chainlink’s AggregatorV3Interface standard. In production, this would be replaced with actual Chainlink oracles providing real weather data. The mock implementation provides:

- Storage for weather data values
- Functions to update weather data (for testing purposes)
- Standard interface conformance to ensure compatibility with the main contract

## C AI Usage Overview

Table 3: AI Usage Table

AI-based Tool	Type of Use	Affected Parts of the Work
ChatGPT	Proof-Reading, fixing typos and improving sentence structure as well as fixing LaTeX compilation errors	ResearchPaper.pdf
ClaudeAI	Finding and Fixing coding errors	Testing suite, App.jsx
Grok/xAI	Finding and Fixing coding errors, suggestions for tech-stack	Solidity Contracts