Analysis of Implementing a Smart Contract in Weather Insurance using Chainlink Oracles

Bachelor Thesis

Submitted in partial fulfillment of the requirements for the degree of Bachelor of Science

Author

Aeberhard Elia Andreas

Gmeindhusplatz 4
5223 Riniken

Matriculation Number: **19-925-957**

Email: elia.aeberhard@uzh.ch

Supervisor

Prof. Dr Claudio J. Tessone

Blockchain & Distributed Ledger Technologies

Department of Informatics

University of Zurich

Date of Submission: [Date]

Executive Summary

This thesis explores the potential of blockchain technology in improving traditional weather insurance systems. These traditional models often face limitations, such as inefficiencies, lack of transparency, high administrative costs and limited accessibility. By leveraging blockchain technology, smart contracts and decentralized oracles, we propose a blockchain-based prototype, which addresses these limitations and introduces an innovative approach for weather insurance. With the prototype we aim to automate key processes, such as policy creation, eligibility checks and payouts, increasing the efficiency and transparency compared to traditional weather insurance models. With the use of external weather data sources and decentralized oracles, this thesis presents how weather data can be integrated onto the blockchain environment and used in a blockchain-based system. The proposed system also utilizes decentralized applications as the interface for user interaction, enabling the data exchange between the users of the system and the smart contract, which manages the core logic of the system. We then present different real-world application scenarios of the prototype and identify its key limitations, including scalability issues, regulatory challenges and user adoption. Despite these challenges, the thesis highlights the opportunities of blockchain-based insurance systems to redefine traditional insurance models and concludes that while the prototype is suitable for small-scale applications, more research is needed for a large-scale system.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Weather-related disasters are among the most significant challenges of the 21st century. Their frequency and severity continue to increase steadily due to climate change, causing destruction and substantial economic losses for individuals, businesses and governments. Insurance has long been the primary tool to reduce the financial impact of such disasters, providing a safety net that promotes stability. However, traditional insurance is increasingly struggling to address the scale and complexity of modern and future climate risks, which are expected to increase due to greenhouse gas emissions (Van Aalst 2006; Monasterolo 2020; Jones and Mearns 2005).

Traditional weather insurance systems struggle with inefficiencies such as manual claim assessments, systemic risk and a lack of transparency and trust, which highlight the limitations of these systems and underscore the need for innovative solutions to address the growing modern and future climate risks. By leveraging key features such as decentralization, transparency and automation, a blockchain-based weather insurance system is able to overcome the inefficiencies of traditional models (Salem et al. 2021; Omar et al. 2023). This thesis aims to address the limitations of traditional models in modern and future climate risks by utilizing key features of blockchain technology in a prototype and evaluates its feasibility in practical applications such as the renewable energy sector and disaster relief efforts.

1.1 Background

In 2016, global disasters accounted for USD 175 billion in economic losses. USD 54 billion of these losses were insured, resulting in uninsured losses of USD 121 billion (Swiss Re Institute 2017). These losses highlight the importance of weather insurance in providing financial protection for individuals, businesses and governments. However, the significant gap between insured and uninsured losses highlights the insufficiency of current insurance solutions in addressing the scope of climate-related risks. For comparison, international humanitarian assistance reached USD 28 billion in 2015, making the uninsured losses of 2016 over four times that amount (Initiatives 2016).

Predictions suggest a worsening of these losses due to intensifying climate risks. Insurance premiums are projected to increase by more than 5 percent and property losses from natural disasters could rise by up to 60 percent by 2040. These escalating costs reflect the growing frequency and severity of extreme weather events, including hurricanes, floods, droughts and wildfires. This increased probability of extreme weather events is also expected to lead to higher weather insurance premiums, highlighting the significant challenges posed by intensifying climate risks (Cho 2022; Tucker 1997).

1.1.1 Existing Weather Insurance

Traditional weather insurance primarily consisted of crop insurance. The policy in this type of contract was typically conducted bilaterally between an individual or business and the insurance company. If a loss occurred on the crop of the individual or business due to weather conditions, an assessment had to be done by the insurance company and the insurance payout sum was determined based on the specific circumstances (Michler et al. 2022).

Crop insurance has several major problems associated with it. One of these problems is the manual process of analyzing and determining the loss in monetary terms by an insurance company representative. Other problems include systemic risk, where many insurance holders in the same region are at risk of being affected by extreme weather conditions simultaneously and asymmetric information, where insurance holders behave more riskily than they normally would because they know they are insured (Makki 2002).

A more modern approach to weather insurance, compared to traditional crop insurance, is weather-based index insurance. The key difference is that weather-based index insurance relies on a measurable variable (such as a temperature drop below a certain threshold or a specific amount of rainfall) and the underlying weather data is provided by a reference weather station. The goal is for the criteria (e.g., the temperature threshold) to reflect the financial loss experienced by the insurance holder, such as the loss of a cornfield due to adverse weather conditions (Kajwang 2022).

1.1.2 Key Limitations in Existing Weather Insurance

Despite the advancements in traditional weather insurance, several challenges continue to reduce its effectiveness and accessibility. The following subsections explore these challenges and elaborate on how blockchain technology can be used in a weather insurance system to address them.

Administrative Costs

In traditional crop insurance, administrative costs make up 35% to 40% of the insurance outlays, while the remaining portion goes toward other costs such as the insurance payout and reinsurance costs (Glauber 2004). The majority of these administrative costs consist of loss assessment, monitoring, claims and underwriting expenses.

In index insurance, administrative costs are significantly lower than in crop insurance because the payouts are based on predefined weather indices rather than assessing individual losses. This index-based insurance model also reduces moral hazards since the payouts are triggered by weather events rather than individual actions. Kusuma et al. (2018) propose a weather-based index insurance for rice in Indonesia. It is designed to be cost-effective by basing the insured amount on the cost of inputs (e.g., seed and fertilizer) rather than covering individual revenue losses.

In section 1.2, this thesis will discuss how smart contracts can be used to lower administrative costs through automated processes even further than weather-based index insurance.

Systemic Risk

A key limitation of existing weather insurance is the systemic risk it poses. Xu et al. (2010) explain how weather risk is systemic in nature, meaning that weather-related events like droughts or floods often affect entire regions rather than isolated areas. In such events, a large number of insurance holders would file claims simultaneously, making it difficult for the insurance company to pay out all these claims at the same time. The study further shows that systemic risk is one of the key reasons why existing weather-based insurance markets have struggled and often require government subsidies, especially in the case of crop insurance. This thesis will examine how a blockchain-based weather insurance solution could further reduce systemic risk by creating more decentralized risk pools.

Lack of Transparency and Trust

The reliance of the insurance industry on trust is well established (Courbage and Nicolas 2021). Trust plays a key role in fostering collaboration between insurance providers and policyholders, ensuring a smooth execution of transactions and minimizing disputes. Guiso (2012) further finds that in low-trust environments, transaction costs and subsequently, insurance premiums are unusually high. For example, Gennaioli et al. (2022) found that in countries with a low trust index in financial markets, the percentage of rejected claims can rise to as much as 35%, while globally, the average hovers around 20%. These statistics underline the importance of maintaining high levels of trust to promote activity, cost-effectiveness and fairness in insurance systems.

Due to the immutability and public nature of blockchain, it offers a trustworthy foundation by preventing fraudulent activities such as altering transactions, falsifying claims or tampering with data (Ahmad 2024). Transactions recorded on the blockchain are tamper-proof and stored transparently across a worldwide network of nodes, through which all participants can independently verify the relevant information (Eigelshoven et al. 2021). However, Hawlitschek et al. (2018) note that completely trust-free systems may not be possible, as they may still rely on trusted intermediaries, particularly for off-chain data integration. By providing fraudulent data, intermediaries can compromise the entire system, as a smart contract running on the blockchain cannot validate external data. In our system, we will also use intermediary entities, such as Chainlink and Google Cloud Platform (GCP) Datasets (see section 2.3). While these intermediaries introduce potential vulnerabilities, we will discuss later in the thesis how to mitigate such vulnerabilities to ensure a trustworthy system (K. M. Khan et al. 2022).

1.1.3 Oracles

Blockchain oracles serve as intermediaries between on-chain smart contracts and off-chain data sources and enable smart contracts to access and use real-world information (Caldarelli 2022). By fetching, verifying and transmitting external data to the blockchain, oracles allow smart contracts to make decisions and execute their logic based on up-to-date information (Pasdar et al. 2023). In this thesis, we will utilize such oracles to integrate real-world weather data into a blockchain-based weather insurance system.

1.2 Smart Contracts in Insurance

Smart contracts are emerging as an innovative technology in the insurance industry, offering the potential to automate processes, enhance transparency and improve trust among its users. In this section, we explore two notable examples: AXA's Fizzy and Lemonade. These case studies highlight the potential of blockchain-based solutions and their real-world applicability.

1.2.1 Early Applications: Fizzy and Lemonade

In 2017, the insurance company AXA launched Fizzy, a flight insurance product based on smart contract technology. It was one of the earliest examples of the adoption of blockchain technology in the insurance industry. Fizzy was quite simple: a customer entered their flight details and paid a premium for the insurance. Later, Fizzy used an oracle to check wether the flight had been delayed by more than two hours and, if so, automatically triggered a payment (Hoffmann 2021).

Another example is Lemonade, a pioneering company in the InsuranceTech industry. It uses a combination of artificial intelligence and smart contracts to identify, analyze and streamline claims processes automatically. A customer can buy a policy via Lemonade's app, where the smart contract defines and enforces the terms of the coverage. When an insured event, such as theft or damage, occurs, the customer can file a claim directly through the app. Lemonade's AI then immediately reviews the claim, validates the circumstances and triggers the smart contract to execute the payout. This process is seamless and transparent and can be completed within minutes, in contrast to the lengthy and often cumbersome claim handling of traditional insurance, where multiple intermediaries, approvals and other entities are involved. (La Barbera 2023; Tardieu et al. 2020).

1.3 Technical and Regulatory Challenges of Smart Contracts

Gatteschi et al. (2018) express concerns that blockchain technology, including smart contracts, is still being explored and not yet ready for its benefits to become more evident. While the technology offers significant advantages, its adoption in industries like insurance is often hindered by technical and regulatory challenges.

1.3.1 Technical Challenges

In the insurance industry, a significant challenge is the technical readiness of smart contracts. These contracts depend on oracles, external data sources that provide real-world information necessary for their operations. Oracles serve as the bridge between off-chain and on-chain data, delivering critical inputs such as weather data, flight delays or other metrics relevant to insurance claims. The reliability of a smart contract depends on the accuracy and integrity of the data provided by these oracles, which are essential to the system. However, oracles can also introduce vulnerabilities, such as data corruption or tampering, which undermine the trustworthiness of the system (Sheldon 2020; Al-Breiki et al. 2020).

Apart from oracle vulnerabilities, there are also concerns about the scalability of smart contracts, especially on the Ethereum blockchain. With a high volume of data and transactions, the performance of the system can degrade due to computational and storage limitations. The Ethereum blockchain often faces challenges with transaction throughput, latency and high gas fees, which reduce the potential for implementing a blockchain-based insurance system at scale (D. Khan et al. 2021; Chauhan et al. 2018).

Other technical issues include the lack of standardization in the development and implementation of smart contracts and the fact that their code is vulnerable to bugs that can be exploited by malicious actors. The immutability of a smart contract once deployed on the blockchain underscores the need for extensive testing, auditing and monitoring to ensure the security of a blockchain-based insurance system (Chen et al. 2019).

1.3.2 Regulatory Challenges

Another important point to consider is the variety of regulatory issues associated with smart contracts. These challenges originate from inconsistencies in legal definitions, concerns about consumer protection, compliance requirements and the complexities of cross-border transactions. In this section, we will explore these regulatory issues and describe how they may impact the adoption and functionality of blockchain-based insurance systems.

Smart Contract as Legally Binding Agreements

There is no universally accepted definition of a smart contract, which creates difficulties in establishing their legal status across different jurisdictions. While some jurisdictions may recognize smart contracts as legally binding agreements, others may not, leading to ambiguity for businesses and individuals operating across multiple legal systems. This lack of standardization complicates the enforceability of smart contracts and may create additional legal complications for the users and providers of such systems (Mik 2017).

Consumer Protection Laws

Additionally, consumer protection laws pose challenges for the adoption of smart contracts. Automated transactions initiated by smart contracts may violate local regulations if consumers lack the ability to contest or reverse them. For example, a customer could encounter issues with a smart contract that automatically executes a payment, even in situations where the transaction is disputed or unintended. This lack of reversibility could lead to legal disputes and undermine trust in the system (Ferreira 2021).

Compliance with Data Privacy

Another critical concern is compliance with data privacy regulations, such as the General Data Protection Regulation (GDPR) in the European Union. Smart contracts often store data on an immutable blockchain, which could conflict with legal requirements, such as the ”right to be forgotten” (Mantelero 2013). This creates significant challenges for developers and operators of blockchain-based systems, as meeting the demands of immutability and data privacy simultaneously can be difficult. Ensuring that sensitive user data is not exposed or permanently stored may not be possible for certain implementations or use cases of a blockchain-based system.

Cross Border Disputes

The cross-border nature of blockchain networks and smart contracts introduces additional complexities, as transactions and data exchanges often involve components and systems located in different countries, each with its own regulatory framework. Policies such as taxation, anti-money laundering (AML) compliance and know-your-customer (KYC) requirements make it challenging for the provider of a blockchain-based system to navigate and address these legal issues effectively (Spafford et al. 2019; Li 2023).

1.4 Objectives

Even though the weather-based index insurance approach represents a significant improvement over traditional crop insurance, there are still many problems associated with it (see section 1.1.2). These limitations reduce accessibility, efficiency and the range of weather insurance solutions available to individuals and businesses, especially in developing areas. The key objective of this thesis is to develop blockchain-based weather insurance prototype that addresses the challenges and drawbacks of traditional insurance models and identify its potential applications as well as its limitations. The specific objectives are as follows:

- Identify and analyze the key challenges of current weather insurance solutions.
- Propose a blockchain-based weather insurance design that utilizes decentralized oracles and globally available weather data.
- Compare the blockchain-based solution to traditional weather insurance solutions in order to assess its potential and identify improvements in terms of efficiency, transparency and trust.
- Analyze potential real-world applications of a blockchain-based system and discuss its limitations

Chapter 2

Methodology

This chapter presents the research design, data collection methods and the selection of key technologies and tools used in the development of the blockchain-based weather insurance prototype. The research design section introduces the exploratory approach used to gather qualitative and quantitative data, ensuring a thorough understanding of blockchain technology, decentralized oracles, GCP and smart contracts. The data collection section focuses on identifying and categorizing essential data types, addressing the challenges of gathering reliable information due to the rapid development of blockchain technologies and the complexity of insurance systems.

Finally, the chapter discusses the technologies and tools chosen for the development of the prototype, which include Ethereum, Chainlink and Google Cloud Public Datasets. These components were deliberately selected to align with the thesis objective of enabling the integration of real-world weather data into a blockchain-based system while addressing key challenges such as transparency and the trustworthiness of traditional systems.

2.1 Research Design

The research design for this thesis is primarily exploratory, focusing on collecting and synthesizing information from a variety of sources in order to develop a comprehensive understanding of smart contracts, blockchain technology, Chainlink and Google Cloud Platform (GCP). This research process involved extensive review and analysis of academic papers, articles, documentation and credible online resources with the goal of identifying technical possibilities and practical implications of integrating real-world data into blockchain-based systems (see section 3.4).

2.1.1 Exploratory Research Design

The exploratory research design approach was chosen because blockchain technology, which is the basis for the proposed system, is still a new topic and not yet established in mainstream technology and society. The flexible and unstructured approach of exploratory research allows the use of various information sources. This flexibility is crucial to understand the complex connections and interactions between the different technologies and components. Additionally, the rapid development and technological advancement make it challenging to create structured, enduring documentation. As a result, several components, such as GCP datasets and Chainlink, rely on dynamic, short-lived online technical documentation, which is subject to frequent updates by its authors (Kişi 2022).

2.1.2 Scope

With the aim of developing a blockchain-based insurance system as an alternative to traditional insurance models, the research explores the advantages and opportunities of using blockchain technology compared to traditional methods. The scope encompasses the key limitations of traditional insurance methods (see section 1.1.2) and an analysis of blockchain technology, smart contracts and decentralized oracles (see chapter 4). Key areas include policy management, payout mechanisms and the technical challenges of bridging on-chain and off-chain environments. Detailed premium calculation mechanisms are out of scope for this thesis.

2.2 Data Collection

In a first step, the economic significance of weather insurance is presented by providing financial costs and losses associated with weather-related disasters (see section 1.1). This analysis is based on current reports from reputable international organizations, such as Swiss Re (Swiss Re Institute 2017), which regularly publishes data on the economic impact of such events. These reports provide the quantitative basis for emphasizing the need for innovative insurance solutions like those explored in this thesis.

Subsequently, qualitative research is conducted to establish the technical and practical foundation for the development of a blockchain-based weather insurance system as an alternative to the traditional model. This research includes an in-depth review of academic literature, industry white papers and technical documentation related to blockchain technology, smart contracts and their application in insurance systems. The qualitative analysis aims to identify potential advantages of using blockchain in weather insurance, such as increased transparency, trust and reduced administrative costs.

By combining qualitative insights with quantitative data, this thesis establishes a comprehensive foundation for designing, implementing and evaluating a blockchain-based weather insurance system compared to a traditional system.

2.2.1 Source Selection Criteria

Sources were selected based on their relevance to the topic of interest, such as blockchain technology, decentralized oracles, smart contracts and GCP datasets. Given the rapidly evolving nature of blockchain technology and its components, recent and regularly updated sources, such as developer documentation and current reports, were included in the research to ensure technical relevance. Financial aspects of blockchain technology are laid out in more scientifically solid research.

To provide a well-rounded perspective, the research selection included academic literature and scientific papers in addition to the above-mentioned industry reports and documentation. In the analysis chapter, the diverse range of selected research and the findings of the developed prototype are synthesized in order to produce a cohesive and meaningful evaluation.

2.2.2 Specific Data Types

This subsection focuses on the identification and categorization of specific data types essential for the development and evaluation of the blockchain-based weather insurance system. These data types include meteorological data, technical data, economic data and regulatory data. Each category serves a distinct purpose within the system's design and research.

Meteorological Data

The data includes real-time and historical weather information, such as temperature, wind speeds and other climate variables. This meteorological data forms the foundation for triggering insurance payouts, making its precision and availability critical to the system's success. Meteorological data is primarily sourced from governmental meteorological agencies, such as GSOD and GFS (see section 2.3.4) and made available to the smart contract via the use of decentralized oracles (see section 3.2.3).

Technical Data

Technical data refers to specific information required to design the blockchain-based weather insurance system and organize its components. This includes information about blockchain technology, smart contracts, Chainlink and GCP. The technical data ensures the system is robust, efficient and fulfills the requirements outlined in section 3.1. The primary sources for this data are developer documentation and architectural blueprints about the components used in the blockchain-based system.

Economic and Regulatory Data

This data encompasses diverse information types that support the broader objectives of the thesis, particularly in identifying limitations in traditional weather insurance systems and emphasizing the need for robust alternatives. Specifically, these include economic data about the relevance of weather insurance systems, such as financial losses from weather-related disasters. It also includes regulatory data to assess the compliance challenges faced by traditional and blockchain-based systems. Primary sources for this information are academic literature, research papers and current reports.

2.3 Key Technologies and Tools

The development of the blockchain-based weather insurance prototype (see chapter 3) required deliberate selection of technologies and tools that align with the objective of developing a blockchain-based prototype that utilizes decentralized oracles and globally available weather data (see section 1.4).

2.3.1 Etherum Blockchain Technology

Ethereum was chosen as the underlying blockchain due to its support for decentralized applications (dApps) and smart contracts (Oliva et al. 2020). It is widely adopted across both academic and industry settings (Kosmarski 2020). Its ecosystem provides flexible and extensive integration tools, libraries and frameworks, making it a suitable choice for an innovative blockchain-based system. Ethereum's public nature ensures transparency, which is critical for strengthening trust in insurance systems. While alternatives such as Hyperledger Fabric were considered, Ethereum's widespread adoption and compatibility with decentralized oracles made it the preferred option (Ferreira 2021).

2.3.2 Smart Contracts

Smart contracts form the backbone of the system by automating critical functions such as premium calculation, policy management and payout execution. The rationale for their use lies in their ability to eliminate intermediaries, reduce administrative costs and ensure rule-based execution (Zheng et al. 2019). By coding the insurance logic directly onto the blockchain, smart contracts provide a transparent and immutable way of enforcing policy terms. Their native support on the Ethereum blockchain makes this choice ideal for achieving the system's objectives of efficiency, transparency and trust.

2.3.3 Chainlink

Chainlink is widely regarded for its ability to securely connect and integrate smart contracts with off-chain data sources through a global, decentralized network of nodes (Breidenbach et al. 2021). This decentralized nature of Chainlink improves the security, reliability and validity of the data inputs (Beniiche 2020). The use of traditional centralized APIs was rejected since they represent a single point of failure, which could compromise data integrity and the reliability of the system. To achieve the transparency objectives of this thesis, a decentralized oracle service was chosen. Chainlink's compatibility with Ethereum simplifies the integration process for a functional system and ensures, through its decentralized architecture, that the weather data can securely be retrieved and used to trigger the logic embedded in the smart contract (see section 3.2.3).

2.3.4 Google Cloud Public Datasets

Google Cloud Platform (GCP) hosts a wide range of datasets, two of which will be used in this system: the Global Surface Summary of the Day (GSOD) and the Global Forecast System (GFS). These datasets provide comprehensive historical and predictive weather data, enabling the proposed blockchain-based weather insurance system to create policies based on the received weather data.

Global Surface Summary of the Day

Global Surface Summary of the Day (GSOD) will be used as the primary weather data source. Over 9'000 stations provide weather data for the dataset, with each station required to report a minimum of four observations per day of a set of measured variables, including temperature, wind speed, pressure and others. This high frequency, comprehensiveness and global coverage of the GSOD dataset makes it an ideal source for a blockchain-based weather insurance system. The entire dataset is hosted on the GCP and updated daily, ensuring consistent access to the latest weather data. (Environmental Information 2023).

Global Forecast System

In addition to GSOD, the prototype also utilizes data from the Global Forecast System (GFS), which provides global weather predictions for up to 16 days. Unlike GSOD, which focuses on historical weather data, GFS is a numerical system based on four different models (atmosphere, ocean, land and sea), which together produce highly accurate and detailed weather forecasts. Similar to GSOD, GFS is hosted on the GCP, allowing for the reutilization of GCP access methods within the system and ensuring access to a comprehensive collection of weather data (Environmental Information 2020).

Chapter 3

Development of the Prototype

This chapter outlines the development of a blockchain-based weather insurance prototype with a focus on the design, architecture and functionality. First, we present the necessary requirements for the system, which include functional, non-functional and technical aspects. Later, the architecture of the proposed system is introduced, which provide an overview of the key components of the system, including smart contracts, Chainlink oracles and Google Cloud Public Datasets.

In section 3.3 it is described how the different components of the system work together to enable purchasing policies, executing eligibility checks and paying out claims. Finally, real-world applications of the system are explored, which demonstrate how the prototype can address specific challenges across diverse sectors and industries, such as disaster relief, tourism and renewable energy.

3.1 Requirements

In order to provide the blockchain-based weather insurance, our system must fulfill several key requirements. In this section we describe each category of requirements in a dedicated subsection. These requirements are derived from the objectives outlined in section 1.4 and are designed to address the limitations of traditional models described in section 1.1.2.

3.1.1 Functional Requirements

- **User Interaction**
  - The system must provide a user interface for purchasing policies and triggering payout eligibility checks.
  - The user interface must be able to directly communicate with the smart contract.
- **Weather Data Integration**

   - The system must be able to receive and process global weather data from reliable and trusted external sources such as the Global Surface Summary of the Day (GSOD) and the Global Forecast System (GFS).
   - The weather data must be validated using a decentralized mechanism such as oracles to ensure reliability and prevent single points of failure.

- **Smart Contract**
   - The smart contract must allow end users to purchase and terminate weather-based insurance policies based on parameters provided by the end user and the external sources.
   - The smart contract must store the policy terms.
   - The smart contract must be able to perform eligibility checks on existing policies.
   - The smart contract must be able to payout funds for policies that have passed eligibility checks.

3.1.2 Non-Functional Requirements

1. **Security**
   - All the bilateral interactions between the smart contract, Chainlink oracles, GCP and the end user must be secure.
   - The system must be able to authenticate and authorize users through their associated digital wallets during operations.
2. **Scalability**
   - The system must be able to scale to handle large amounts of policies and end users.
   - The system must be able to maintain performance and low latency as the number of policies grows.
   - The system must be able to prevent high gas costs during periods of high transaction throughput.
3. **Transparency**
   - All transactions and insurance claims must be recorded on the blockchain.
   - Users must be able to access a history of all transactions with the system.
   - Policies and payouts must be verifiable by all users.

3.1.3 Technical Requirements

1. **Blockchain Platform**
    - The platform should provide high availability and redundancy to ensure uninterrupted operations.
    - The smart contract must be deployed on the Ethereum blockchain.
2. **Data Retrieval**
    - The system must be able to retrieve weather data from GCP.
    - The data must be fetched with precise location and time-specific parameters.
    - The integrity of the data must be verified to prevent the use of corrupted or incomplete weather data.
    - The data retrieval must happen in a decentralized manner.
3. **Chainlink Oracle**
    - The system must integrate with a Chainlink node to facilitate data retrieval from GCP.
    - The Chainlink nodes must validate the data before transmitting it to the smart contract.
    - The oracle network must be able to handle inconsistencies in the received data.

3.2 Architecture

In this section, we outline the architecture of our blockchain-based weather insurance system. We begin with a high-level overview of the system, followed by detailed subsections that focus on the key components and their roles within the architecture.

3.2.1 General Overview

In fig. 3.1 we present an overview of the general architecture of our proposed system. The center of the architecture is the smart contract deployed on the Ethereum blockchain. It manages all policies and handles the payout process. The end user interacts directly with the smart contract through the use of a decentralized app (see section 3.2.2), where they can request insurance policies and eligibility checks.

The weather data is provided by Global Surface Summary of the Day (GSOD) and Global Forecast System (GFS), respectively. These datasets can be accessed via GCP BigQuery and GCP Storage through the GCP API interface. To bridge the gap between the off-chain data from GCP and the on-chain smart contract, the system uses a Chainlink oracle (see section 3.2.3). This Chainlink oracle retrieves the weather data from GCP through its API interface and passes it on to the smart contract on the Ethereum blockchain.

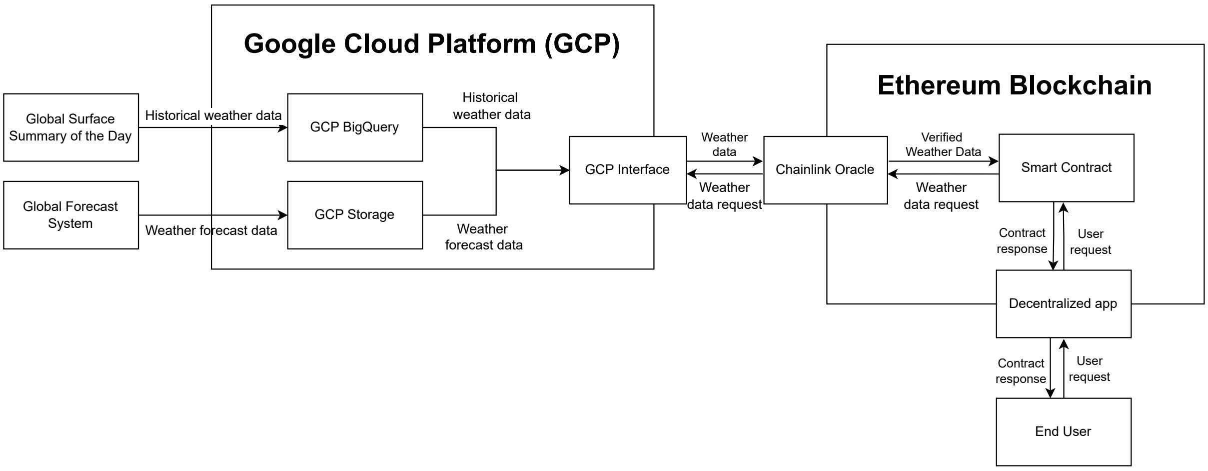

Figure 3.1 – High-level architectural diagram of the proposed blockchain-based weather insurance system, illustrating interactions between the smart contract, decentralized app, Chainlink and Google Cloud Public Datasets. *Source: Author's own representation.*

This architecture effectively addresses the technical requirements defined in section 3.1.3 and ensures compatible and reliable communications between each component.

3.2.2 Decentralized App

The decentralized application (dApp) allows a non-technical end user to directly interact with the blockchain. Through its interface, a user can request insurance policies, eligibility checks and receive payout funds. Unlike traditional applications, which interact with a centrally managed backend, decentralized applications interact directly with a decentralized blockchain network (Wu et al. 2019).

This interaction requires a digital wallet (for example, MetaMask), which enables the user to initiate and sign a transaction when making a request, such as purchasing an insurance policy. In our architecture, the dApp serves as the primary interface in order for the end-users to interact with the smart contract.

3.2.3 Backend service nodes

Since the weather data from GSOD and GFS, which is accessed through the GCP datasets, is not directly available from the on-chain environment of the smart contract, we need to leverage oracles, which retrieve and verify external data before delivering it to the blockchain.

In our proposed system, Chainlink oracles are used to securely interact with the GCP and pass the data on to the smart contract. The Chainlink oracle network consists of globally distributed nodes.

When a request is triggered, multiple nodes independently access GCP and receive the weather data specified in the request. If any nodes return results that differ from the majority, they are flagged as potentially malicious (Breidenbach et al. 2021). This decentralized approach ensures that only verified and reliable weather data is passed on to the smart contract.

3.3 Services

In this section, we examine the two primary services central to our blockchain-based weather insurance system: the process of purchasing a weather insurance policy (see section 3.3.1) and the process of triggering a policy payout (see section 3.3.2). These scenarios represent the fundamental interactions between the end user, the smart contract and the external data sources. In the subsequent chapters, we elaborate on the core functionalities utilized in the two scenarios, such as the process of retrieving weather data and calculating the policy conditions.

3.3.1 Purchase Weather Insurance Policy

The sequence diagram in fig. 3.2 outlines the steps involved in purchasing a weather insurance policy in our proposed system. The main components are the end user, the smart contract, Chainlink oracles and the Google Cloud Platform (GCP). Each of these components plays a central role in enabling the policy purchase and the associated data retrieval and validation processes. Each request between components includes a set of parameters. These parameters contain the necessary information that each component needs in order to perform its role and functions accurately. For example, in a purchase policy request, parameters such as location, coverage duration and type of coverage are sent to the smart contract. Table table 3.1 contains all requests with their respective parameters.

The end user starts the process by requesting a weather insurance policy from the smart contract. This interaction happens through the use of a decentralized app (dApp) section 3.2.2, which is not explicitly mentioned in the diagram but can be thought of as the interface enabling the end user to interact directly with the smart contract. Through the dApp, the end user can request a weather insurance policy. In table 3.1, we find the detailed description of each request. In the policy request, the user has to specify the conditions of the policy. These include the location, start and end date, the type of coverage (for example, drought coverage or storm coverage), as well as the data type (whether the request should return historical or forecast data).

The smart contract then fetches the necessary weather data needed for the calculation of the policy conditions by sending a request to the Chainlink oracle containing the necessary parameters (see ”Weather data request” in table 3.1). The Chainlink oracle propagates this request to the Google Cloud Platform (GCP). Due to the decentralized nature of Chainlink oracles, this request is sent multiple times to the GCP from different Chainlink nodes (see section 3.2.3). The responses from

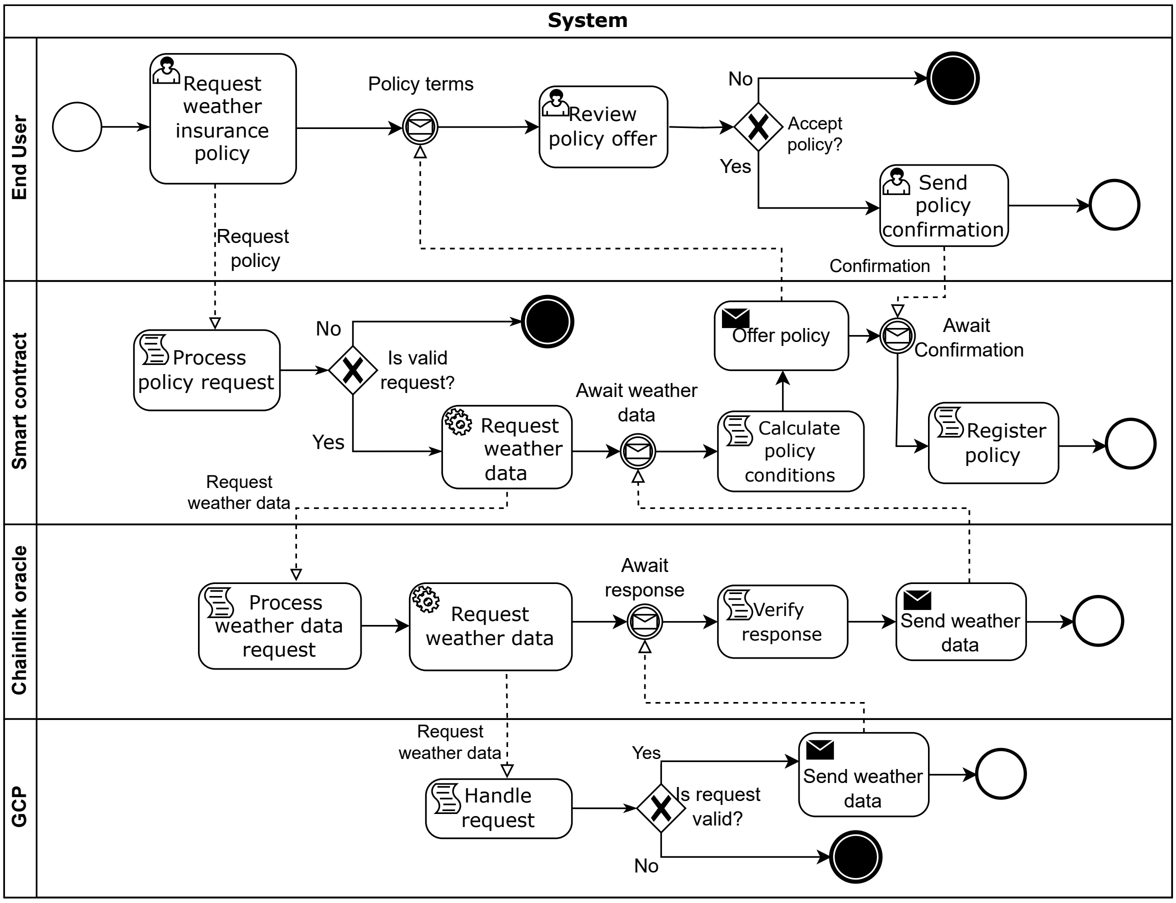

Figure 3.2 – Sequence diagram illustrating the process of purchasing an insurance policy in the proposed system. *Source: Author's own representation.*

each of these requests are then analyzed and verified by the Chainlink network before being sent back to the smart contract. The smart contract calculates the policy conditions (such as the premium amount) and sends an offer to the end user. If the end user accepts the terms offered by the smart contract, then the policy is valid and registered on the blockchain.

Note that in the diagram there are two "Request weather data" requests depicted. One is from the smart contract to the Chainlink oracle and one from the Chainlink oracle to the GCP. Even though these requests differ in their technical details (such as type of request and authorization headers), we have combined them in table 3.1 as one entry. This was chosen specifically for simplicity purposes, since the diagram is an abstraction of a policy purchase process and leaves space for flexibility in technical implementation.

Name	Parameters	Description	Response
Request policy	Location: String Coverage start date: Date Coverage end date: Date Type of coverage: Enum	Requests a policy with the given parameters as the underlying conditions.	Binding policy offer including financial conditions and a unique policy ID.
Request weather data	Location: String Weather start date: Date Weather end date: Date Type of weather data: Enum Frequency: Enum Data Type: Enum	Requests weather data in a specific date range. Examples of weather data types include rainfall, wind speed, and temperature. Frequency indicates the data granularity (e.g., hourly, daily). Data Type can be either forecast or historical.	Weather data in JSON format.
Confirmation	Policy ID: String Confirmed: Boolean	Sends a confirmation to the smart contract for a specific policy ID.	-

Table 3.1 – Requests depicted in fig. 3.2 and their respective parameters. *Source: Author's own representation.*

3.3.2 Trigger Policy Payout

The second service is shown in fig. 3.3. It presents the process of triggering a policy payout. This payout happens when the specified policy conditions from section 3.3.1 are fulfilled (assuming a policy has been agreed upon between the end user and the smart contract beforehand).

A key decision in the design of the payout process is determining what triggers an eligibility check and the following payout process. A possible solution would be to use scheduled tasks that periodically trigger an eligibility request on every policy held by the smart contract. Since the Ethereum blockchain does not support scheduled or automated tasks natively, such functionality would require an external solution. For example, Chainlink offers an automation service (Chainlink 2024) with which it would be possible to trigger a scheduled eligibility check on the smart contract (for example, once a day). This service would, however, cost gas, which has to be paid by the smart contract and would result in a lot of unnecessary transactions. In our proposed solution, the end user initiates the eligibility check instead. This decision prioritizes simplicity and cost-efficiency, avoiding unnecessary transactions that would otherwise increase the policy premium for the end user.

After the end user has initiated the eligibility check through the use of a decentralized app (dApp), the smart contract gathers the weather data for the specific location and covered duration of the policy. This process of retrieving the relevant weather data is similar to the one in section 3.3.1, with a key distinction being that the weather data contains past data and not forecast data. Once the weather data is received, the smart contract evaluates whether the conditions for a payout are met and communicates the outcome to the end user. If the end user is eligible for a payout, they can submit a request to the smart contract, which will then transfer the agreed-upon funds as specified in the policy.

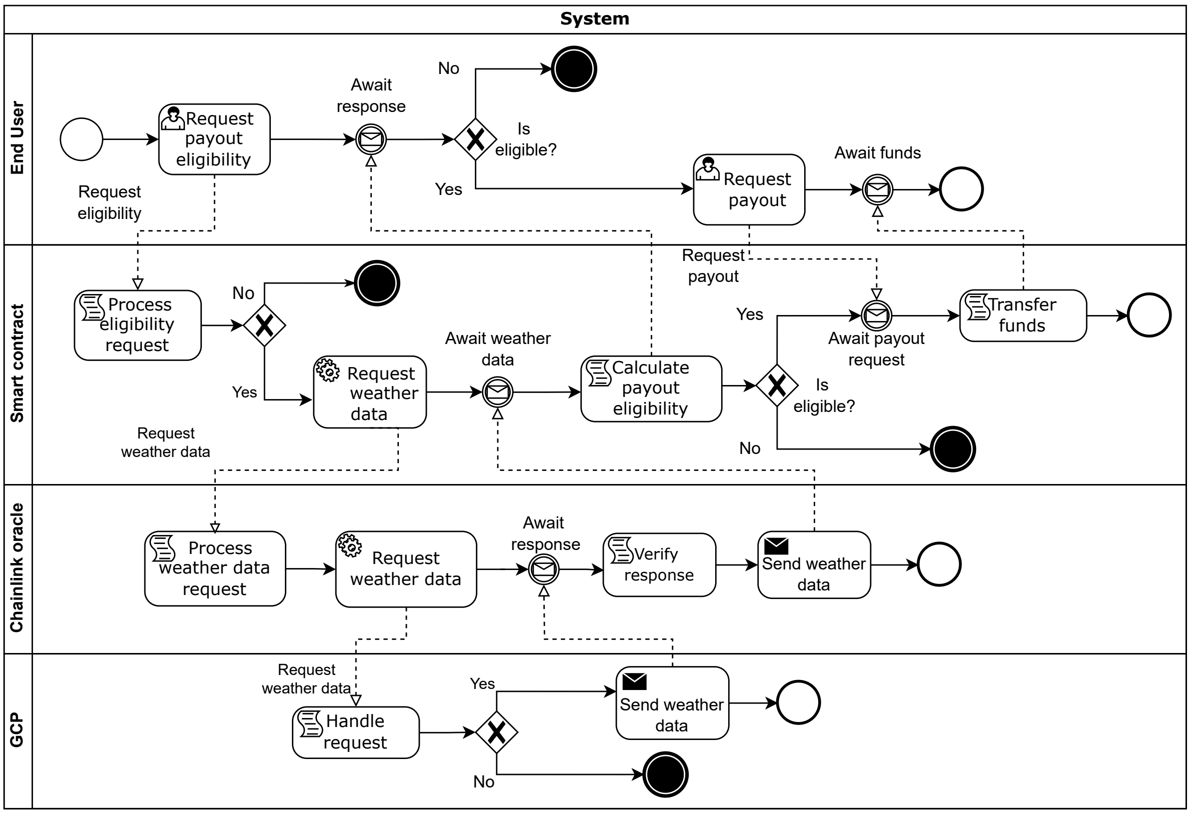

Figure 3.3 – Sequence diagram illustrating the process of triggering a policy payout. *Source: Author's own representation.*

3.3.3 Interaction with the Smart Contract

As mentioned in section 3.3.1 and section 3.3.2, the end user communicates with the smart contract through a decentralized app (see section 3.2.2). The dApp interface is indistinguishable from a regular app interface, with the difference being that it interacts directly with the blockchain instead of a traditional backend. Within the dApp, the end user can create the requests and enter the relevant parameters. Once the user submits a request, the dApp creates a transaction that is signed using the end user's digital wallet. This transaction is then broadcasted to the blockchain, where it can interact directly with the smart contract.

As the focus of this prototype is primarily on the general architecture of a blockchain-based weather insurance solution and its smart contract functionality, we will not dive further into the specifics of

Name	Parameters	Description	Response
Request eligibility	Policy ID: String	Requests an eligibility check, which is then performed by the smart contract.	Whether the policy is eligible for a payout or not in JSON format.
Request weather data	Location: String Weather start date: Date Weather end date: Date Type of weather data: Enum Frequency: Enum Data Type: Enum	Requests weather data in a specific date range. Examples of weather data types include rainfall, wind speed, and temperature. Frequency indicates the data granularity (e.g. hourly, daily). Data Type can be either forecast or historical.	Weather data in JSON format.
Request payout	Policy ID: String	Requests the payout of funds.	Amount of funds specified in the policy.

Table 3.2 – Requests depicted in fig. 3.3 and their respective parameters. *Source: Author's own representation.*

decentralized app (dApp) development.

3.3.4 Calculating Policy Conditions

One of the core functions of the smart contract is calculating the policy conditions. In fig. 3.2, it is presented as an internal process of the smart contract. This process involves assessing the parameters provided by the end user in the "Request policy" request (see table 3.1) as well as the weather data that the smart contract receives from GCP through the "Request weather data" request (see table 3.1).

In a first validation step, the smart contract ensures that all the parameters are valid, for example, that the location is within a supported region and that the coverage is within the allowed limits. The latter is defined through the furthest available forecast data, which in our solution is 16 days (Environmental Prediction 2016). Next, the smart contract calculates the policy conditions based on the following parameters:

- Premium amount (the cost of the policy that is paid by the end user)
- Trigger conditions (specific thresholds or events that must occur for a payout to be issued, for example rainfall above a certain level)
- Coverage limit (the maximum payout amount available under the policy in the case the condi-

tions for a payout are met)

Note that the coverage limit is defined by the end user in the ”Request policy” request (see table 3.1), but it must still be validated and included in the policy by the smart contract, as there may be limits on the maximum coverage amount due to the total funds held by the smart contract.

Calculating the premium amount is the most critical part of the policy conditions. It determines the balance between risk and reward for both the end user and the smart contract. The premium is determined using a formula that considers the following key factors:

- Coverage duration
- Location
- Type of coverage
- Forecast weather data
- The contract margin

This formula represents a fundamental approach to premium calculation. However, it can be further refined by including historical data and actuarial models, allowing for a more dynamic calculation based on real-world risk. Developing a fully-realized mathematical formula suitable for use in a production environment is beyond the scope of this thesis. Instead, we focus on identifying and outlining the key factors included in the formula.

3.3.5 Fetching Weather Data

Both in fig. 3.2 and in fig. 3.3, the retrieval of weather data from GCP plays a central role. The security and transparency of our blockchain-based system are only as strong as each component involved in the data retrieval chain. By using Chainlink oracles (see section 3.2.3), the smart contract can maintain its decentralized nature.

3.4 Real-World Application of the Prototype

This section explores the practical applications and broader implications of the blockchain-based weather insurance prototype in real-world scenarios. By addressing challenges specific to various industries and sectors, the system shows its ability to improve current insurance practices. Additionally, this section highlights the system’s scalability and its ability to reach global audiences, while also acknowledging potential technological and regulatory barriers that need to be addressed for a successful implementation.

3.4.1 Application Scenarios

The following subsections outline three potential real-world applications for our proposed system, presenting how our system's advantages can be effectively leveraged to address specific challenges in each use-case.

Disaster Relief Efforts

Certain regions and countries are particularly vulnerable to extreme weather events and catastrophes, such as floods, hurricanes or droughts. As described in Chapter 1 (see section 1.1), these disasters can result in significant loss of life and extensive financial damage. Relief efforts for such catastrophes are often concentrated in specific areas and rely heavily on government and aid organization support (Fitch-Fleischmann and Kresch 2021).

By offering transparent weather insurance to governments and humanitarian organizations, the financial burden of disaster relief can be better managed and distributed. As these organizations and governments are often funded through taxpayer money, the proposed application ensures that payouts are automated and verifiable to the general public through blockchain technology, enhancing transparency, trust and accountability in the use of such funds.

Tourism Industry

The tourism industry can be very sensitive to weather conditions, particularly in regions prone to extreme or unexpected weather events, such as heavy rainfall, storms or prolonged droughts. A traveler visiting a region with a high risk of heavy rainfall might want to complete short-term insurance to protect their trip costs in case of such a weather event (Wilkins et al. 2018).

In this application, the system's ability to complete quick policy insurance and automated payouts ensures that the customer can obtain weather insurance on short notice without much bureaucracy involved. This makes the system suitable for spontaneous decisions, which are very common in the tourism sector. Unlike the disaster relief application section 3.4.1, which focuses on large-scale policies for a few large policyholders, this application is tailored to a smaller-scale, high-volume model.

Renewable Energy Sector

Renewable energy projects, such as wind farms, solar parks and hydroelectric plants, are highly dependent on favorable weather conditions. Adverse weather conditions, such as long cloud cover, insufficient wind speeds or droughts can significantly reduce energy output, which can impact the financial stability and operational efficiency of such projects.

The proposed blockchain-based weather insurance system offers a practical solution to mitigate these risks. Through automated payouts when predefined conditions are met, such as insufficient wind speeds or weak sunlight, the system provides project operators with quick financial compensation.

Similar to the disaster relief efforts application section 3.4.1, large energy projects are often funded by governments. The transparent nature of our blockchain-based system allows the general public to oversee how funds are allocated, used and distributed. This enhances accountability, builds public trust and ensures the funds are managed efficiently and fairly.

Chapter 4

Analysis and Discussion

This chapter evaluates the blockchain-based weather insurance prototype proposed in section 2.3 by examining the functional and non-functional aspects of the system in a thorough analysis and provides a comparative analysis of the prototype against traditional weather insurance models.

4.1 Analysis of the Prototype

In this section, we take a closer look at the prototype itself and analyze whether and how it achieves the objective of ”Propose a blockchain-based weather insurance design that utilizes decentralized oracles and globally available weather data” from Chapter 1 (see section 1.4) and the concrete requirements specified in section 3.1. Furthermore, we discuss the limitations of the prototype and the challenges encountered during the data collection process.

4.1.1 Functional Analysis

In the first step, we evaluate how the blockchain-based weather insurance prototype fulfills the functional requirements outlined in section 3.1.1. Each function is evaluated based on the ideas proposed in chapter 3.

User Interaction

The prototype provides a decentralized application (dApp) as the user interface, enabling the end user to interact directly with the system. Through the dApp, the user can send requests for weather insurance policies as well as insurance payouts directly to the smart contract. This interaction is possible through a digital wallet (e.g. MetaMask), which allows the user to sign in and broadcast the transaction to the Ethereum blockchain. The user experience is kept to the bare minimum in order to provide an easy-to-use system, especially for non-technical users.

Weather Data Integration

In section 3.3.1 and section 3.3.2, we outline how the smart contract is able to receive the relevant weather data from GCP through Chainlink. Through two separate endpoints on the side of GCP, the platform which hosts Global Surface Summary of the Day (GSOD) and Global Forecast System (GFS), Chainlink is able to access both historical and forecast weather data, making it available to the smart contract. This integration ensures decentralized access to GCP, which enables the system to meet the functional requirement of securely retrieving external weather data.

Smart Contract

As the heart of the system, the smart contract interacts directly and indirectly with the other components, synthesizing their functions to provide a smooth and automated insurance process. In fig. 3.2 and fig. 3.3, we illustrate the different kinds of tasks the smart contract performs. These tasks, combined with its interaction capabilities described in section 3.3.3 and its storing capability through the blockchain, let the smart contract fulfill its requirements specified in section 3.1.

4.1.2 Non-Functional Analysis

In this subsection, we analyze whether the blockchain-based weather insurance prototype fulfills the specified non-functional and technical requirements. These requirements address the system's general characteristics, such as security, scalability, transparency and its technical capabilities.

Security

To ensure that the interactions and transactions of the system are secure, we look at the most vulnerable points. Transactions within the blockchain ecosystem itself are inherently secure due to the decentralized mechanisms of the blockchain, which ensure immutable records (Cheng et al. 2020). Vulnerable points exist between the end user and the smart contract, since the user needs to pass sensitive data onto the blockchain and between Chainlink and GCP, since this connection bridges the gap from external weather data to the blockchain ecosystem (see section 3.2.3).

As described in section 3.2.2, users interact with the smart contract through a digital wallet, such as MetaMask. These transactions are cryptographically secured with a digital signature before being broadcast onto the blockchain. This ensures that only authorized users can interact with the system and that sensitive data, such as policy details, is protected during broadcasting.

On the other side of the system, we have Chainlink, which interacts in a decentralized manner with GCP, making the necessary requests from all over the globe through independent nodes (see section 3.2.3). This decentralized structure mitigates the risk of a single point of failure or of tampering with the external weather data.

By leveraging these robust security measures, the system effectively fulfills the security requirement specified in section 3.1.

Scalability

Unlike traditional insurance systems, which often face bottlenecks due to their reliance on centrally managed infrastructure, the proposed blockchain-based system leverages decentralized technology to simplify policy management, claims processing and payouts. However, achieving wide-range scalability remains a significant challenge. The system's reliance on the Ethereum blockchain introduces limitations due to throughput problems and high gas fees, as mentioned in Chapter 1 (see section 1.3.1). These issues can result in delays and increased costs, particularly as the number of users and transactions grows. While decentralized networks like Chainlink and widely available datasets from GCP support global applicability, the combination of technical and economic constraints of the Ethereum blockchain limits the efficient scaling of the system to accommodate a large user base across different regions and jurisdictions. With these scalability problems, there is no efficient solution for creating a global and scalable blockchain-based system that can successfully mitigate the systemic risk of traditional models. Thus, the non-functional requirement of scalability is not fulfilled.

Transparency

Transparency is a key aspect of the proposed system, with all transactions, policies and claims immutably recorded on the Ethereum blockchain. In section 3.3.1 and section 3.3.2, it becomes evident that all the different data involved is centrally accessible through the smart contract. In a concrete implementation of the prototype, the smart contract needs to ensure that the data is stored and presented accordingly. Such an implementation could include tools like dashboards or published records to make the activity on the smart contract more accessible to non-technical users.

Technical Capabilities

The proposed system fulfills the technical requirements by leveraging Ethereum as the blockchain platform where the smart contract is running, Chainlink oracles for data retrieval in a decentralized manner and GCP for access to reliable weather datasets. The integration and combination of these components, outlined in section 3.2.1, section 3.3.2 and section 3.3.1, ensure the system can perform all its functional requirements.

4.1.3 Limitations

While the blockchain-based weather insurance system offers significant advantages over traditional models, it also comes with trade-offs and limitations. In this subsection, we focus on three key limitations, which include scalability challenges, regulatory challenges and user adoption.

Scalability Challenges

Scalability is heavily influenced by the underlying Ethereum blockchain, which has limited transaction throughput. High congestion in the network can lead to increased gas fees and slower transaction processing times. These issues pose challenges with a large user base, especially during times of high demand, such as a natural disaster, where the system could become congested, leading to significantly increased gas fees. In section 4.1.2 we mention how the requirement for a scalable system was not achieved in the proposed solution. This marks a key limitation in the blockchain-based prototype, which also reduces its applicability in real-world scenarios, since solutions for weather-related disasters like the one described in section 3.4.1 require a scalable system to mitigate centralized weather-related risks.

Regulatory Challenges

The regulatory challenges presented in Chapter 1 (see section 1.3.2) significantly affect the feasibility of implementing the blockchain-based weather insurance prototype. These challenges originate from the innovative and decentralized nature of blockchain technology, which often exists outside traditional and centralized legal frameworks.

A key part of regulatory considerations in a blockchain-based insurance system is compliance with local licensing requirements. In most parts of the world, approvals or licenses are required to operate legally as an insurance provider. Furthermore, a decentralized system may conflict with centralized oversight, as existing regulatory frameworks are designed for centralized entities, where oversight is conducted through reporting, audits and direct communication with regulatory authorities. A blockchain-based system, which by nature lacks a central authority or entity, may create conflicts with these established systems of oversight. An example is the lack of universal legal recognition for smart contracts which creates uncertainty, especially for applications such as disaster relief and renewable energy, where automated payouts rely on enforceable agreements. If smart contracts are not legally binding, their ability to reduce bureaucracy and ensure efficient operations is greatly diminished if not eliminated.

Compliance with consumer protection and data privacy regulations also poses challenges. Automated transactions may conflict with local laws if users are unable to contest or reverse them. This is particularly problematic in consumer-facing applications like tourism insurance, where disputes over denied payouts can erode trust. Furthermore, the immutable nature of blockchain data storage may conflict with privacy laws, such as the GDPR's "right to be forgotten", limiting the system's applicability in regions with strict data regulations.

Cross-border transactions further complicate the system's scalability. The decentralized architecture relies on interoperability across jurisdictions, each with diffrent requirements for taxation, anti-money laundering (AML) policies and know-your-customer (KYC) compliance. These regulatory differences can introduce inefficiencies and operational complexities, impacting the system's core advantages of transparency, efficiency and trust. Interoperability across borders is also essential for addressing systemic risk described in section 1.1.2. Without seamless operations, bureaucratic processes across different jurisdictions could reduce the system's perceived efficiency, which limits its ability to scale globally. Coupled with the technical scalability challenges discussed in section 4.1.3, these regulatory barriers further diminish the feasibility of developing a global and scalable solution.

User Adaption

The adoption of new technologies, especially in rural areas, often faces challenges based on skepticism and unfamiliarity. Many individuals have prejudices against emerging technologies like blockchain, viewing them as too complex, untrustworthy or unnecessary (Alabdali et al. 2023). This skepticism can result in slower user adoption rates than what might be expected based on the system's rational benefits and capabilities outlined in this thesis.

Additionally, the proposed system introduces unique concepts, such as digital wallets, dApps and smart contracts, which require a basic level of technical understanding. This can act as an entry barrier for individuals who have limited time or access to educational resources. The time and effort needed to understand the system's functionality and advantages may discourage users from engaging with a blockchain-based system, further slowing adoption.

4.1.4 Challenges in Data Collection

The data collection process for analyzing and designing the prototype faced several challenges, originating from the evolving nature of blockchain technology and the inherent complexity of insurance systems. These challenges span technical and organizational domains, both of which must be addressed to ensure the validity of the proposed system.

One of the primary challenges is the rapid evolution of blockchain technology. While it does offer innovative aspects like decentralization, transparency and automation, the technology is still in its early stages, with frequent updates to technical documentation and shifts in standards. Ensuring compatibility between blockchain components, decentralized oracles and real-world weather data requires continuous monitoring and adaptation, adding complexity to the data collection process.

Additionally, insurance systems are highly complex, involving numerous components that influence policy design, premium calculation, risk assessment and claim management. Collecting comprehensive research to address these variables requires synthesizing diverse sources. However, these data sources often vary significantly in their format and scope, such as structured datasets, unstructured text, historical or current information. The granularity of this data can differ as well, with some sources providing localized information while others offer only high-level insights, making it challenging to align and analyze the data consistently. Moreover, the reliability of these sources can be inconsistent, with some being prone to errors, omissions or outdated information. Consideration of these variations necessitates the use of data transformation and validation techniques to ensure a cohesive and accurate representation of the overall system.

4.2 Comparative Analysis

In this chapter, we compare the blockchain-based approach used in our prototype with the traditional weather insurance model. The analysis presents key areas where our blockchain-based system offers significant improvements, while simultaneously addressing limitations and potential trade-offs.

4.2.1 Efficiency and Bureaucracy

Traditional insurance models are often hindered by extensive bureaucracy and manual processes. Policy creation, eligibility checks and claim payouts often involve multiple intermediaries, leading to increased administrative costs. In section 3.3.1 and section 3.3.2, we present how, in a blockchain-based system, these inefficiencies can be eliminated through automated processes. A key part of that automation is the capabilities of smart contracts and blockchain technology, enabling the retrieval and validation of external data, such as weather and user data, through decentralized Oracles and decentralized apps (dApps). Such a system not only reduces bureaucratic expenses but also accelerates processing time, which greatly benefits the end user.

Furthermore, a dApp interface provides the user with a single point of access, simplifying the interaction process and eliminating the communication challenges often encountered in traditional models, such as complex paperwork or lengthy approval processes. This streamlined approach gives the blockchain-based system a significant advantage for spontaneous and short-term insurance needs, such as travel insurance (see section 3.4.1).

4.2.2 User Interaction and Trust

The proposed blockchain-based weather insurance system significantly improves user interaction while bolstering trust through its transparent and decentralized design. In traditional models, users interact only with the front-end interface of an insurance provider, without insights into the backend processes. Our proposed solution offers users a clear view of the system's backend processes through the record-keeping of the smart contract on the blockchain. This transparency not only enhances the user experience by providing greater confidence in the system's operations but also bolsters trust by ensuring that all transactions and processes are verifiable and immutable.

By combining the intuitive user interface of a dApp and its security features with the reliability and transparency of blockchain technology, the system not only simplifies user interaction but also builds a foundation of trust, addressing two key challenges faced by traditional insurance models.

4.2.3 Accessability and Transparency

Traditional insurance models often rely on centralized offices and intermediaries, which can limit their reach to users in local environments. The proposed system, in contrast, can operate through a dApp anywhere in the world where sufficient internet infrastructure exists. Combined with the digital wallet, which can hold the necessary cryptocurrency, the system enables policy creation, eligibility checks and payouts without the need for cumbersome documentation or in-person visits. This accessibility is particularly beneficial for individuals and businesses in regions vulnerable to extreme weather events and lacking insurance infrastructure. Moreover, the users of the proposed system can view the entire lifecycle of their insurance policy, from policy creation to payout. This level of transparency can enhance trust and user engagement, particularly among users in regions where confidence in traditional companies is inherently low. By combining an easily accessible interface with transparent blockchain record-keeping, the proposed system offers a reliable, trustworthy solution to weather-based insurance needs.

Chapter 5

Conclusions and Future Work

This thesis explored the potential of using a blockchain-based weather insurance system to address the limitations of traditional weather insurance models, particularly in terms of efficiency, transparency and accessibility. By identifying these limitations and leveraging the capabilities of blockchain technology, the thesis designed a prototype, which acts as a blueprint for a concrete implementation of such a system. In this chapter we present our conclusion, reflect on the contributions of this thesis and list ideas for future work.

5.1 Conclusions

The thesis demonstrated and outlined that blockchain technology, combined with smart contracts and decentralized oracles, offers significant improvements over traditional weather insurance systems. A key advantage of the blockchain-based prototype is its transparency feature, which allows users of the system to follow up with the internal processes and record-keeping. A similarly impactful advantage is the system's efficiency potential, where through automated policy creation, eligibility checks and payouts it reduces the administrative overhead associated with traditional systems. These advantages, in combination with its easy accessibility, highlight the significant potential of a blockchain-based weather insurance system.

However, the thesis also identified significant limitations and challenges (see section 4.1.3) that must be addressed to realize the full potential of such a system. One notable limitation is the scalability of the blockchain-based prototype, particularly due to Ethereum's transaction throughput and potentially high gas fees. Especially during periods of high demand, such as a natural disaster, fees for transactions with the system could skyrocket, limiting the system's ability to handle large-scale adoption. Additionally, user adoption presents a challenge, especially in regions where familiarity with blockchain technology is low. The basic knowledge needed to interact with a dApp and the setup of a digital wallet may discourage non-technical users from engaging with the system. Finally, we also have regulatory challenges, such as centralized authorities, local licensing requirements and cross-border transaction regulation.

While in theory, the advantages of using blockchain technology in weather insurance make the system a lot better than traditional systems, there still remain many challenges, especially when it comes to concrete adoption. From our analysis, we can conclude that the proposed prototype works in a smaller scale setting, where the transaction load is manageable and the regulatory framework is limited. For example, a local event organizer could use such a system to insure against bad weather during an event, since the conditions due to the efficiency advantages might be better compared to a traditional insurance provider. However, other limitations, such as systemic risk (see section 1.1.2), are not addressed since the insurance only works in a local environment. Larger real-world applications, such as a disaster relief insurance system (see section 3.4.1) are not possible with the current state of the prototype, mainly due to scalability and regulatory issues. A possible solution could be to explore other blockchain technologies, such as Polygon or Solana, which are better at handling a high volume of transactions and provide better conditions in a large-scale system. However, switching to alternative blockchain technologies may introduce new challenges, such as the interoperability with external sources like the GCP.

5.1.1 Significance and Contributions

Despite the limitations of the proposed blockchain-based weather insurance system, the findings of the thesis underscore its transformative and innovative potential. By addressing its challenges, such a system can redefine and complement traditional weather insurance models in transparent, efficient and accessible solutions for a wide range of use-cases. Through the automation of key functions, such as policy creation, eligibility checks and payouts, a blockchain-based system can outperform traditional models in different insurance areas. In this thesis we chose the weather insurance industry since the integration of weather data into a blockchain system is not very difficult due to the deterministic nature of weather data and the global availability through various institutions, in our case GSOD and GFS. But opportunities for blockchain-based systems exist in many different industries, for example healthcare, supply chain and agriculture sectors.

The thesis contributes to the growing amount of knowledge on blockchain technology by addressing its potential improvements and opportunities in areas like transparency, efficiency and automation. While the technology is still new and shows a lot of opportunities, it still has a significant number of limitations, especially in the regulatory area. These limitations also played a significant role in this research since the proposed prototype was heavily limited through these limitations. In order for the technology to reach its full potential, these limitations will need to be addressed and appropriate solutions must be found.

5.2 Future Work

While the proposed blockchain-based prototype provides a solid foundation and explores the potential of leveraging blockchain technology in insurance, there are many key areas that need further exploration in order to address its limitations. In this section we mention the key directions for future work.

5.2.1 Scalability Improvements

One of the critical challenges faced with the proposed prototype is the scalability of the Ethereum blockchain. Future work could explore alternative blockchain platforms which offer higher transaction throughput and lower fees in a large-scale system. Another promising aspect is the use of sharding, a technique where the blockchain is divided into smaller segments, where each segment is capable of processing transactions independently. This approach could dramatically improve transaction throughput while simultaneously lowering costs (Hong et al. 2022).

5.2.2 Regulatory Compliance

Ensuring compliance with local and international regulatory frameworks is essential for a real-world adoption of a blockchain-based insurance system. Future work could explore how these regulatory rules can be addressed in an efficient way. For example, introducing middleware into the system which can adapt to different legal requirements depending on the jurisdiction, abstracting the legal problems away from the smart contract as the heart of the system.

5.2.3 User Adoption

Future work could try to address challenges related to user adoption of blockchain technology. For example, by abstracting away blockchain interactions one could lessen the technical aspect of a system while still being able to use its advantages. For instance, hiding the management of private keys or gas fees could make the system more approachable for non-technical users. However, this could also shy away technical users who may want to have full control over their private keys and gas fees, thus requiring a delicate balance, which could be explored in a future thesis.

Bibliography

Ahmad, Ahmad Yahiya Ahmad Bani (2024). "Fraud Prevention in Insurance: Biometric Identity Verification and AI-Based Risk Assessment". In: *2024 International Conference on Knowledge Engineering and Communication Systems (ICKECS)* 1, pp. 1–6. DOI: 10.1109/ICKECS61492.2024.10616613.

Alabdali, Salem Ahmed, S. F. Pileggi, and D. Cetindamar (2023). "Influential Factors, Enablers, and Barriers to Adopting Smart Technology in Rural Regions: A Literature Review". In: *Sustainability*. DOI: 10.3390/su15107908.

Beniiche, Abdeljalil (2020). "A study of blockchain oracles". In: *arXiv preprint arXiv:2004.07140*.

Breidenbach, Lorenz, Christian Cachin, Benedict Chan, Alex Coventry, Steve Ellis, Ari Juels, Farinaz Koushanfar, Andrew Miller, Brendan Magauran, Daniel Moroz, et al. (2021). "Chainlink 2.0: Next steps in the evolution of decentralized oracle networks". In: *Chainlink Labs* 1, pp. 1–136.

Al-Breiki, Hamda, M. H. Rehman, K. Salah, and D. Svetinovic (2020). "Trustworthy Blockchain Oracles: Review, Comparison, and Open Research Challenges". In: *IEEE Access* 8, pp. 85675–85685. DOI: 10.1109/ACCESS.2020.2992698.

Caldarelli, Giulio (2022). "Overview of blockchain oracle research". In: *Future Internet* 14.6, p. 175.

Chainlink (2024). *Chainlink Automation*. Accessed: 2024-11-05.

Chauhan, Anamika, O. P. Malviya, Madhav Verma, and Tejinder Singh Mor (2018). "Blockchain and Scalability". In: *2018 IEEE International Conference on Software Quality, Reliability and Security Companion (QRS-C)*, pp. 122–128. DOI: 10.1109/QRS-C.2018.00034.

Chen, Jiachi, Xin Xia, David Lo, J. Grundy, Xiapu Luo, and Ting Chen (2019). "Defining Smart Contract Defects on Ethereum". In: *IEEE Transactions on Software Engineering* 48, pp. 327–345. DOI: 10.1109/TSE.2020.2989002.

Cheng, Jieren, Linfu Xie, Xiangyan Tang, N. Xiong, and Boyi Liu (2020). "A survey of security threats and defense on Blockchain". In: *Multimedia Tools and Applications* 80, pp. 30623–30652. DOI: 10.1007/s11042-020-09368-6.

Cho, R (2022). "With Climate Impacts Growing, Insurance Companies Face Big Challenges". In: *State Of The Planet: Columbia Climate School* 3.

Courbage, Christophe and Christina Nicolas (2021). "Trust in insurance: The importance of experiences". In: *Journal of risk and insurance* 88.2, pp. 263–291.

Eigelshoven, Felix, Andre Ullrich, and Douglas Parry (2021). “Cryptocurrency Market Manipulation-A Systematic Literature Review.” In: *ICIS*.

Environmental Information, NOAA National Centers for (2020). *Global Forecast System (GFS)*. Accessed: 2024-10-21.

— (2023). *Global Surface Summary of the Day - GSOD*. Accessed: 2024-10-21.

Environmental Prediction, National Centers for (2016). *Global Forecast System (GFS) - Global Spectral Model (GSM) V13.0.2*. https://vlab.noaa.gov/web/gfs/documentation. Accessed: 2024-11-06.

Ferreira, Agata (2021). “Regulating smart contracts: Legal revolution or simply evolution?” In: *Telecommunications Policy* 45.2, p. 102081.

Fitch-Fleischmann, Benjamin and Evan Plous Kresch (2021). “Story of the hurricane: Government, NGOs, and the difference in disaster relief targeting”. In: *Journal of Development Economics* 152, p. 102702. DOI: 10.1016/J.JDEVECO.2021.102702.

Gatteschi, Valentina, Fabrizio Lamberti, Claudio Demartini, Chiara Pranteda, and Víctor Santamaría (2018). “Blockchain and smart contracts for insurance: Is the technology mature enough?” In: *Future internet* 10.2, p. 20.

Gennaioli, Nicola, Rafael La Porta, Florencio Lopez-de-Silanes, and Andrei Shleifer (2022). “Trust and insurance contracts”. In: *The Review of Financial Studies* 35.12, pp. 5287–5333.

Glauber, Joseph W (2004). “Crop insurance reconsidered”. In: *American Journal of Agricultural Economics* 86.5, pp. 1179–1195.

Guiso, Luigi (2012). “Trust and insurance markets 1”. In: *Economic Notes* 41.1-2, pp. 1–26.

Hawlitschek, Florian, Benedikt Notheisen, and Timm Teubner (2018). “The limits of trust-free systems: A literature review on blockchain technology and trust in the sharing economy”. In: *Electronic commerce research and applications* 29, pp. 50–63.

Hoffmann, Christian Hugo (2021). “A double design-science perspective of entrepreneurship–the example of smart contracts in the insurance market”. In: *Journal of Work-Applied Management* 13.1, pp. 69–87.

Hong, Zicong, Song Guo, and Peng Li (2022). “Scaling Blockchain via Layered Sharding”. In: *IEEE Journal on Selected Areas in Communications* 40, pp. 3575–3588. DOI: 10.1109/JSAC.2022.3213350.

Initiatives, Development (2016). *Global Humanitarian Assistance Report 2016*. Accessed: October 1, 2024. Development Initiatives.

Jones, Roger and LO Mearns (2005). “Assessing future climate risks”. In: *Adaptation policy frameworks for climate change: Developing strategies, policies and measures*, pp. 119–143.

Kajwang, Ben (2022). “Weather based index insurance and its role in agricultural production”. In: *International Journal of Agriculture* 7.1, pp. 13–25.

Khan, Dodo, L. T. Jung, and M. Hashmani (2021). “Systematic Literature Review of Challenges in Blockchain Scalability”. In: *Applied Sciences*. DOI: 10.3390/app11209372.

Khan, Kashif Mehboob, R. Taufique, and Maryah Abdul Rauf (2022). “Investigation on a price oracle problem”. In: *Mehran University Research Journal of Engineering and Technology*. DOI: 10.22581/muet1982.2204.14.

Kişi, Nermin (2022). “Exploratory research on the use of blockchain technology in recruitment”. In: *Sustainability* 14.16, p. 10098.

Kosmarski, Artyom (2020). “Blockchain Adoption in Academia: Promises and Challenges”. In: *Journal of Open Innovation: Technology, Market, and Complexity*. DOI: 10.3390/joitmc6040117.

Kusuma, Aditya, Bethanna Jackson, and Ilan Noy (2018). “A viable and cost-effective weather index insurance for rice in Indonesia”. In: *The Geneva Risk and Insurance Review* 43, pp. 186–218.

La Barbera, Salvatore (2023). “Insurtech Revolution in the Insurance Sector: A Comprehensive Review of the Transformational Impact and the Lemonade Case Study”. In.

Li, Chengjie (2023). “Cross-Border Payment Based on Blockchain Technology and Digital Currency”. In: *Applied and Computational Engineering*. DOI: 10.54254/2755-2721/8/20230175.

Makki, Shiva (2002). *Crop insurance: inherent problems and innovative solutions*. Ames: Iowa State University Press.

Mantelero, Alessandro (2013). “The EU Proposal for a General Data Protection Regulation and the roots of the ‘right to be forgotten’”. In: *Computer Law & Security Review* 29.3, pp. 229–235.

Michler, Jeffrey D, Frederi G Viens, and Gerald E Shively (2022). “Risk, crop yields, and weather index insurance in village India”. In: *Journal of the Agricultural and Applied Economics Association* 1.1, pp. 61–81.

Mik, Eliza (2017). “Smart contracts: terminology, technical limitations and real world complexity”. In: *Law, Innovation and Technology* 9, pp. 269–300. DOI: 10.1080/17579961.2017.1378468.

Monasterolo, Irene (2020). “Climate change and the financial system”. In: *Annual Review of Resource Economics* 12.1, pp. 299–320.

Oliva, G., A. Hassan, and Z. Jiang (2020). “An exploratory study of smart contracts in the Ethereum blockchain platform”. In: *Empirical Software Engineering* 25, pp. 1864–1904. DOI: 10.1007/s10664-019-09796-5.

Omar, Ilhaam A., Raja Jayaraman, Khaled Salah, Haya R. Hasan, Jiju Antony, and Mohammed A. Omar (2023). “Blockchain-Based Approach for Crop Index Insurance in Agricultural Supply Chain”. In: *IEEE Access* 11, pp. 118660–118675. DOI: 10.1109/ACCESS.2023.3327286.

Pasdar, Amirmohammad, Young Choon Lee, and Zhongli Dong (2023). “Connect API with blockchain: A survey on blockchain oracle implementation”. In: *ACM Computing Surveys* 55.10, pp. 1–39.

Salem, Mukuan Junior, Fajar Henri Eranmus Ndolu, Diar Eka Risqi Hidayatullah, and R. F. Sari (2021). “Developing NEO Smart Contract for Weather-Based Insurance”. In: *2021 4th International Seminar on Research of Information Technology and Intelligent Systems (ISRITI)*, pp. 603–608. DOI: 10.1109/ISRITI54043.2021.9702853.

Sheldon, Mark D. (2020). “Auditing the Blockchain Oracle Problem”. In: *J. Inf. Syst.* 35, pp. 121–133. DOI: 10.2308/isys-19-049.

Spafford, M., Daren F. Stanaway, and Sabin Chung (2019). “Blockchain and cryptocurrencies: a cross-border conundrum”. In: *Journal of Investment Compliance*. DOI: 10.1108/JOIC-05-2019-0027.

Swiss Re Institute (2017). *Natural catastrophes and man-made disasters in 2016*. Sigma No. 2/2017. Accessed: October 1, 2024. Swiss Re.

Tardieu, Hubert, David Daly, José Esteban-Lauzán, John Hall, George Miller, Hubert Tardieu, David Daly, José Esteban-Lauzán, John Hall, and George Miller (2020). “Case study 4: The digital transformation of insurance”. In: *Deliberately Digital: Rewriting Enterprise DNA for Enduring Success*, pp. 255–264.

Tucker, Michael (1997). “Climate change and the insurance industry: the cost of increased risk and the impetus for action”. In: *Ecological Economics* 22.2, pp. 85–96.

Van Aalst, Maarten K (2006). “The impacts of climate change on the risk of natural disasters”. In: *Disasters* 30.1, pp. 5–18.

Wilkins, Emily J., Sandra De Urioste-Stone, A. Weiskittel, and Todd Gabe (2018). “Effects of Weather Conditions on Tourism Spending: Implications for Future Trends under Climate Change”. In: *Journal of Travel Research* 57, pp. 1042–1053. DOI: 10.1177/0047287517728591.

Wu, Kaidong, Yun Ma, Gang Huang, and Xuanzhe Liu (2019). “A first look at blockchain-based decentralized applications”. In: *Software: Practice and Experience* 51, pp. 2033–2050. DOI: 10.1002/spe.2751.

Xu, Wei, Guenther Filler, Martin Odening, and Ostap Okhrin (2010). “On the systemic nature of weather risk”. In: *Agricultural Finance Review* 70.2, pp. 267–284.

Zheng, Zibin, Shaoan Xie, Hongning Dai, Weili Chen, Xiangping Chen, J. Weng, and M. Imran (2019). “An Overview on Smart Contracts: Challenges, Advances and Platforms”. In: *Future Gener. Comput. Syst.* 105, pp. 475–491. DOI: 10.1016/j.future.2019.12.019.

Eidesstattliche Erklärung

Der/Die Verfasser/in erklärt an Eides statt, dass er/sie die vorliegende Arbeit selbständig, ohne fremde Hilfe und ohne Benutzung anderer als die angegebenen Hilfsmittel angefertigt hat. Die aus fremden Quellen (einschliesslich elektronischer Quellen) direkt oder indirekt übernommenen Gedanken sind ausnahmslos als solche kenntlich gemacht. Die Arbeit ist in gleicher oder ähnlicher Form oder auszugsweise im Rahmen einer anderen Prüfung noch nicht vorgelegt worden.

. . . .
Ort, Datum

. . . .
Unterschrift des/der Verfassers/in