Empowering small farmers in developing markets with a blockchain-based index insurance solution against droughts

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SMART CONTRACTS LAB

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Glossary (in order of appearance)

Smart Contract	A smart contract is a self-executing digital agreement with its terms written directly into code, automatically enforcing, and executing conditions when predetermined criteria are met (Buterin, 2014).
Insurance Gap	An insurance gap refers to insufficient or no insurance coverage for a specific risk or event, leaving the individual or entity vulnerable to financial losses. The insurance gap is the quantifiable equivalent of underinsurance (European Insurance and Occupational Pensions Authority, 2022).
Underinsurance	Underinsurance refers to the state of an individual or group where they may only partly or not at all be insured against their risk as a whole (Sandroff, 2022).
GDP	GDP is the acronym for "Gross Domestic Product". This macroeconomic performance indicator measures the monetary value of all final goods sold within a country's borders and over a certain period (Bureau of Economic Analysis, 2022).
Information Asymmetry	Information Asymmetry describes the situation where one party has more or better information than the other during a transaction. Asymmetric information refers to a specific instance of Information Asymmetry (Bloomenthal, 2021).
Moral Hazard	Moral Hazard describes the incentive for an economic actor to increase their exposure to risk because he/she will not have to bear a part of the costs resulting from a risky event (Kenton, 2020).
Adverse Selection	Adverse Selection results from a lack of information in a trade. A party with essential information might participate selectively in trades at the expense of others (Hayes, 2022a).
Systemic risk	Systemic risk is the risk of a financial crisis caused by factors inherent to the financial system, leading to widespread instability (CFI Team, 2023).
BPMN	The "Business Process Model and Notation" graphically depicts an organization's internal and external procedures (Object Management Group, 2023).
Oracle	An oracle is a specific kind of smart contract. It is a data feed that adds real-world data to the blockchain to deliver data to other smart contracts. (Macellaro, 2023).
IDE	An "Integrated Development Environment" is a programming application that facilitates efficient software coding (Olawanle, 2022).

Abstract

This research paper explores the challenges of providing affordable and accessible agricultural insurance for small farmers in developing markets, focusing on sub-Saharan Africa. The paper examines the potential benefits of a blockchain-based index agriculture insurance program. It investigates the efficiency and accessibility of a blockchain-based insurance program compared to off-chain insurance systems. The research evaluates three hypotheses (mentioned in the introduction) regarding the conventional agriculture insurance system, the effectiveness of current index-based agriculture insurance, and the potential of blockchain-based index agriculture insurance to close the insurance gap for small farmers in developing markets.

Moreover, the paper conducts a SWOT analysis on a real-life use case in Kenya and one on our self-designed blockchain-based index insurance solution. The research additionally explores ways to improve agriculture insurance products for small farmers in developing countries. The findings highlight the need for innovative solutions to overcome the sector's challenges in developing countries, particularly the issue of underinsurance in traditional agriculture insurance.

1. Introduction

Many climate specialists consider drought the most complex yet the least understood of natural hazards (Hagman, 1984). They occur across all climate zones and continents, mainly related to reduced rainfall throughout a season or year. Multiple other climatological and hydrological parameters, such as temperature, and rain characteristics, influence droughts (Wilhite, 1992). Due to increased water demands and geographical changes in climate patterns, drought frequency is expected to increase (Mishra & Singh, 2010).

Droughts and other extreme climate events are disproportionally common in the sub-Saharan region, where one-third of the world's droughts occur. As proof, Ethiopia and Kenya endured one of the worst drought periods in at least four decades in 2022 (Kemoe et al., 2022). The situation is similar in many African countries, where many natives still depend heavily on agriculture. For example, in 2021, the agriculture sector in Kenya constituted 22% of the GDP. Alternatively, Ethiopia ranked third compared to all African countries (Saleh, 2022), with agriculture making up 38% of the country's GDP (O'Neil, 2022).

According to the Food and Agricultural Organization of the United Nations (FAO, 2023), the agriculture sector employs 40% of the total population in Kenya and 70% in rural areas. Due to high population growth and the resulting demand for land, farmers are being pushed into arid regions, becoming more vulnerable to unpredictable weather patterns such as droughts. The FAO (2023) stresses that "strengthening and improving the performance of the agricultural sector and enabling the engagement of the poorest and most vulnerable in this process is, therefore, a prerequisite and a necessary condition for achieving recovery and growth in Kenya after recent years of drought and slow development."

According to Dumba et al. (2021), countless strategies exist to mitigate agricultural risk. These include investments in infrastructure (e.g., irrigation facilities), technological innovations (e.g., drought-tolerant cultivars), agriculture management practices (e.g., changes to the timing of production activities), and financial instruments (e.g., credit or insurance). Unfortunately, many of these strategies are not viable for smallholder farmers as their resources are limited (Hill et al., 2019). Out of the proposed systems, agricultural insurance is one of the most helpful tools for farmers to lessen the negative financial impact of bad natural events (Kwadzo et al., 2013).

Kwadzo et al. (2013) determined and analyzed how food crop farmers in Ghana traditionally manage their risk. 42% of the subjects mitigate and cope with risk by selling or liquidating productive assets, negatively impacting future productivity. 39% of farmers shift to or add another business to diversify their income. 8% vary their cropping practices, 5% cope with risk by borrowing money from family and friends, and another 5% return to family labor – often resulting in child labor. Since many agricultural risks, including droughts, are systemic and supra-regional, many coping mechanisms mentioned above are ineffective. Support from relatives is absent, borrowing gets costly, and assets can only be liquidated at a low price because many farmers sell simultaneously (Barrett et al., 2001).

The introduction of agricultural insurance happened recently in Sub-Saharan Africa. For many farmers, conventional agriculture insurance has always been too expensive. Traditional agriculture insurance products include so-called indemnity insurance, where insurance companies provide coverage of losses in exchange for premiums. To calculate the losses, the insurer must observe the harvest yield. The whole process is very enduring and costly. Furthermore, this insurance product is subject to moral hazard (Vargas Hill, 2015).

In the past few years, index insurance based on geological triggers was promoted as a solution for farmers in developing countries. With index-based insurance, the pre-defined meteorological value, e.g., days without precipitation, triggers a payout when reaching a certain threshold (Herbold, 2010). As a result, the World Bank put together a program called Global Index Insurance Facility, which facilitates access to finance for smallholder farmers in developing countries. In addition, the Global Insurance Facility partnered up with implementing partners focused on specific regions. This partnership enables affordable and accessible index-based agriculture solutions for smallholder farmers to address the negative financial consequences of natural disasters such as drought. For Sub-Saharan Africa, this partner is ACRE Africa (Herbold, 2010).

ACRE has developed weather, area yield, and livestock index insurance products that cover a wide range of cattle and crops. With those products, they have already gained 800,000 farmers in Kenya, Rwanda, and Tanzania as customers (IFC, 2023). In addition, to reduce costs and improve small farmers' attractiveness, profitability, and reach, ACRE partnered with Etherisc, Chainlink, Climate Ledger Initiative, and other blockchain partners to implement index insurance with smart contracts that use blockchain technology (Eyase, 2021).

All these progresses lead us to wonder: What are the effects of implementing blockchain-based index insurance in the agricultural industry against droughts, and how can severely underinsured farmers in Africa benefit from it?

Abbreviated from the research question, we critically discuss three hypotheses:

Type	*Description*
H_1:	The conventional agriculture insurance system in developing markets is inefficient.
H_2:	The existing index-based agriculture insurance system is the most efficient insurance system.
H_3:	Blockchain-based index agriculture insurance narrows the insurance gap in developing markets for farmers.

Figure 1: Hypotheses

Structurally, we will proceed as follows. After this introduction, we will explain the methodology and our approach to answering the hypotheses. After that, we will analyze developing countries' current agricultural insurance systems and answer hypothesis H_1. Then, a real-life use case of index-based agriculture insurance for drought from Kenya is compared to our self-designed blockchain-based agriculture insurance. With that comparison analysis, we can answer hypotheses H_2 and H_3, listed in Figure 1. Finally, we discuss and conclude our results in section 6.

The insurance companies and NGOs are our primary target audience, and the secondary ones are farmers. There are parts in this paper that might seem too technical for farmers. However, this is inevitable since smart contracts are highly technical. They are not comparable to conventional legal contracts.

2. Methodology

In recent years, blockchain's potential applications in the insurance industry have been explored superficially. However, while some progress has been made, such as the development of index Insurance for developing markets and the work of the index insurance forum, existing literature on the agriculture insurance of developing markets is scarce. Furthermore, specific smart contract solutions are hard to find. Therefore, this thesis aims to use a paper and article review approach (also known as secondary data analysis and archival study) and their analysis to subsequently self-design a blockchain-based insurance smart contract for the agricultural industry against droughts that can provide benefits to severely underinsured farmers in Africa. Additionally, we explore an existing index insurance solution that has been implemented by the International Livestock Research Institute and assess its potential using the SWOT Analysis.

The literature research was conducted using academic databases like google scholar and internet searches, with keywords such as "blockchain insurance", "insurance in Africa", "underinsurance", and "agriculture insurance". Each source was evaluated using the CRAAP test, which stands for "Currency, Relevance, Authority, Accuracy, and Purpose". "Currency" refers to the timeliness of the source, "Relevance" to the specific overlap with our topic, "Authority" to the author's background, "Accuracy" to the reliability of the content, and "Purpose" to the reason for the information's existence (Kurpiel, 2023).

SWOT analysis is a strategic planning tool to identify and analyze an organization's internal and external factors. SWOT stands for strengths, weaknesses, opportunities, and threats. The analysis can help evaluate a company's current situation and to develop strategies for future growth (Chermack, 2012; Houben, Lenie, & Vanhoof, 1999). The strengths and weaknesses are internal factors that relate to an organization. Opportunities and threats are external factors that relate to the industry or market in which an organization operates. The goal is to identify areas where the organization can improve or has a competitive advantage (Lussier & Achua, 2015). In our case, we will analyze institutions (not just organizations), and the framework will be applied identically.

The first and third hypotheses will be answered via theoretical research, e.g., using past papers, books, and the internet. Furthermore, to analyze hypothesis H_2, we will examine the current index insurance provided to farmers in Kenya by ACRE Africa, a beneficiary of the World Bank's One Million Farmers Platform. Based on this analysis, a blockchain-based index insurance smart contract will be designed.

3. Analysis of the current agricultural insurance sector in developing countries

In this section, we conduct theoretical research and analysis on the current state of agriculture insurance in developing countries to answer hypothesis H_1.

Indemnity-based agriculture insurance contracts consist of a farmer and an insurance company. Based on the scope of risks, agriculture insurance can be divided into single-peril or multi-peril. The single-peril policy provides damage coverage for losses caused by a specified risk. If the specified risk occurs, the farmer will receive a payment according to the terms in the contract after the amount of damage has been evaluated by the insurance firm. On the contrary, multi-peril indemnity insurance covers a variety of risks (Ali et al., 2020). In general, insurance firms demand a premium that must cover the costs of indemnity paid to a subset of the insured and administrative costs (Smith & Glauber, 2012).

Farmers living in deplorable conditions in developing countries are often affected by extreme weather events, such as droughts or floods, destroying their harvest. In addition, a large percentage of the total population living in those countries worsens the initial situation because more people are affected by natural disasters. Given that most individuals residing in those regions are farmers, who face challenges in protecting themselves against income losses, many challenges arise from the current farming system (Hazell & Hess, 2010). Despite having the above-mentioned agricultural insurance, the conventional insurance model has demonstrated limited effectiveness in developing economies and, therefore, must be improved. The underperformance in traditional insurance is closely linked to the problem of systematic risk, dependence on governmental support, asymmetric information, moral hazard, and adverse selection.

Moral hazard also called "the hidden action" occurs when insured parties increase their risk-taking behavior in pursuit of their interests because they will not have to bear the entire costs while receiving an indemnity. Nevertheless, to mitigate the moral hazard, insurance coverage for farmers was capped, leading to inefficiencies as farmers were required to bear a portion of potential losses (Miranda & Farrin, 2012). In addition, according to Ghosh et al. (2021), conventional insurance faces high administrative costs, which can result in expensive premiums or high risks of insolvency for the insurance company.

Another problem conventional insurance faces is adverse selection, also known as "hidden information". This problem arises when farmers with expected crop failures sign an insurance contract to prevent massive losses. In this case, the indemnity would be higher than their premiums because the farmers have more information regarding their yields than the insurance companies (Miranda & Farrin, 2012).

One more challenge of conventional agriculture insurance is the systemic risk which refers to losses across geographical regions due to extreme weather events. Hence there is a positive correlation between these events and farm-level yields because it is most likely for all the crop yields to be lower in all regions affected by the disaster. For example, suppose a severe drought in a specific

African region destroys the farmers' crops. In that case, all the insurance companies in that area are impacted by the disaster because they are responsible for covering the costs of the damage. As a result, insurers need to take a higher risk per unit of premium into account, leading to financial instability. Moreover, insurance companies face massive costs if they cannot cover the losses (Miranda & Glauber, 1997).

In addition, natural disasters have limited diversification options because they often affect a large geographical region, which makes it hard to spread the risk across different areas. Besides obtaining international reinsurance, an insurance of an insurance is expensive and challenging. These challenges contribute to the problem of systemic risk. These limitations lead to an increase in premium rates which reduces the attractiveness of the insurance for farmers. Furthermore, the traditional insurance system in developing countries is highly dependent on governmental support because their subsidies cover a significant portion of insurance premiums for farmers. These subsidies can also cover other expenses, such as administrative costs or reinsurance agreements. (Miranda & Farrin, 2012).

After analyzing the current agriculture insurance system in developing countries, our analysis confirms hypothesis H_1 that conventional agriculture insurance is inefficient due to asymmetric information, systemic risk, limited diversification options, expensive international reinsurance premium rates, and high dependence on government support for subsidies.

4. Real-Life Use Case: ACRE's Livestock Insurance in Kenya

In section 3, we looked at the conventional agriculture insurance systems. We address a newer agriculture insurance concept, the so-called index-insurance system. This insurance type is presented using a real-life use case in Kenya. The concept of index insurance is introduced in subsection A, followed by a description of the use case in subsection B. Subsection C provides a detailed analysis of the use case, including a SWOT analysis comparing the strengths and opportunities of index-based insurance with its weaknesses and threats.

A. Concepts of index-based insurance

To address the limitations of conventional agriculture insurance, index-based insurance was introduced. This index-based insurance system is designed to link the payouts to a predetermined index, such as a specific weather variable like rainfall or temperature. For a weather variable to be a suitable index, it must adhere to objectivity, verifiability, and quantifiability. Furthermore, weather events such as droughts or intense heat are the foundation and trigger for numerous index insurance contracts (Carter et al., 2017).

The idea behind index-based insurance is to separate the payout from the assessment of individual claims, whereby the index is strongly linked to actual losses. As a result, farmers are protected against losses resulting from natural disasters (Carter et al., 2017). Suppose the value of the index exceeds the predefined threshold. In that case, the insured receives a payment based on the insurance contract agreement. However, a capping mechanism ensures that the indemnity cannot go beyond a specific limit. No further payment is made if the value is higher than the limit (Barnett & Mahul, 2007).

Index-based insurance reduces asymmetric information such as moral hazard and adverse selection (Carter et al., 2017). In addition, index insurance is advantageous because its premium rate is subject to public information. Furthermore, these contracts are standardized, resulting in cheaper implementation and more transparency. As a result, more poor farmers in developing countries can afford to obtain insurance coverage (Miranda & Farrin, 2012).

B. Case Description

Now that we have introduced the concept of index-based insurance above, we continue with a concrete example in Kenya. A significant part of the Kenyan economy is supported by livestock production, accounting for 12% of the country's GDP and making it a crucial source of employment. The importance of livestock production becomes more apparent when looking at some numbers: 70% of the country is made up of dry and semi-arid territory, home to an astonishing 60% of the livestock herd (Artful Eyes Productions, 2022). One of the major obstacles for farmers in Africa is the danger and uncertainty of droughts, which account for 75% of livestock deaths in Africa (Swiss Re, 2022). These droughts are putting their only source of livelihood at high risk, especially since the frequency and severity have risen over the past ten years, and future forecasts predict a continued increase. Between 2008 and 2011, the estimated loss to the Kenyan economy was 12.1 billion dollars, of which 72% was attributed to the livestock sector.

To tackle this problem of weak sustainability and drought management, the Kenya livestock insurance program (KLIP) was successfully launched in 2014/2015 by the International Livestock Research Institute and the World Bank Association across four different countries in East Africa. Its roots extend back to 2009, when the first index-based insurance model emerged as an international success. It is based on a public-private partnership, in which the government purchases insurance coverage ("macro coverage") on behalf of the most vulnerable households, which covers up to five animals per household (Swiss Re, 2022). The key feature of this index-based insurance consists of using satellite data to identify a decline in the vegetation index below a predetermined critical level, which then triggers a lump sum payment to the insured beneficiaries allowing them to support their livelihoods and recover from the drought. In addition, the grazing conditions from the satellite data are analyzed for vegetation color, which varies from yellow (extremely dry) to green (abundantly wet) (Swiss Re, 2022).

There are some criteria farmers must fulfill to access this kind of insurance:

"(i) be active in pastoralism and own a minimum of five [Tropical Livestock Units (TLUs)]
(ii) not benefiting from any of the programs under the Kenya National Safety Net Program
(iii) not owning more livestock above a certain threshold (currently set at 20 TLUs)
(v) should have either a formal money transfer system (e.g., bank account, mobile money service) or commit to acquire one after being considered a beneficiary"
(World Bank Group [WBG], 2017).

The main goal of this program was to increase the awareness of insurance in remote areas by reaching 65'000 affected pastoralists by 2020 (WBG, 2017) while also being a long-term solution to increasing the farmers' resilience to drought. Overall, this can drastically improve the lives and incomes of vulnerable pastoralists by sustaining their livestock and preventing them from falling back into poverty.

C. SWOT Analysis

In this part of the paper, we analyze the real-life use case introduced in the above-described use case using a SWOT analysis. We conduct the SWOT analysis as follows. First, we start with the strengths, then move on to the opportunities. Next, we continue with the weaknesses and then address the threats. When explaining the points, we always follow chronological order.

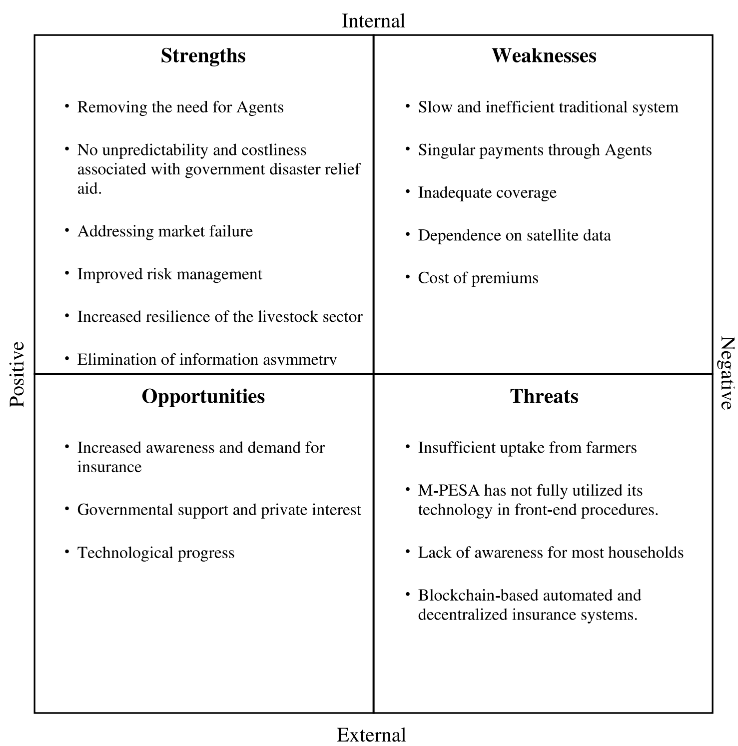

Figure 2: SWOT-Analysis Kenya

Strengths

The Kenya Livestock Insurance Program (KLIP) has a list of strengths, including that the insurance program has eliminated the need for insurance agents to monitor fodder and animals in remote fields, leading to lower costs and premiums. Due to this lower premium, farmers can purchase additional livestock, including cows, camels, and goats, as well as animal feeds, medicine, and water (Citizen TV Kenya, 2019).

Secondly, the program increased the efficiency of the insurance system by eliminating asymmetric information by introducing new suitable insurance products that increase demand and affordability (WBG, 2017).

Secondly, KLIP has solved the unpredictability, costliness, and high premiums of traditional insurance systems with government disaster relief aid. Before the introduction of this program, farmers had to rely on assistance from the government and development partners through disaster relief aid - ex-post - rather than protecting themselves with insurance products (WBG, 2017).

KLIP also supports farmers in managing risks associated with drought and other natural disasters, providing a safety net for livestock owners, and reducing the financial burden of farmers during times of crisis (Disaster Risk Financing & Insurance Program, 2017).

Finally, KLIP has increased the resilience of the livestock sector. By helping farmers cope with the risks associated with livestock farming, KLIP can contribute to the sector's long-term sustainability. This can improve farmers' livelihoods and contribute to the country's economy by preserving livestock assets (WBG, 2017).

Opportunities

Information at everyone's disposal nowadays is an essential foundation for improving financial literacy. Regarding our case, insurance awareness has increased in remote areas and among vulnerable farmers. This fact increases insurance product demand (WBG, 2017).

Governmental support and private interest are a compelling combination that could bring in more funds and expertise in the future. KLIP has already leveraged this opportunity to its advantage through its public-private partnership model (Swiss Re, 2022). However, it could be utilized even further.

Future technological advancements will inevitably lead to improved satellite data quality, leading to faster and more accurate payouts, which is essential in times of crisis (WBG, 2017).

Weaknesses

The KLIP solution has its flaws. Since payments are made through a network of agents formed by banks or by issuing checks, the existing system in northern Kenya is ineffective and slow.

Moreover, the current program may not be adequate for larger households or those with a bigger herd, leaving them vulnerable to drought impacts.

The solution of KLIP is highly dependent on satellite data for triggering indemnity payments which pose a risk of technical failures or delays in data collection, resulting in delayed payments and reduced trust in the program.

Finally, the premium costs may be too high for some farmers, limiting the uptake of the program and leaving them vulnerable to drought impacts. Therefore, addressing these challenges is essential to ensure the program's success and achieve its goal of protecting farmers' livelihoods from drought.

Threats

Lastly, we come to the threats. One of the threats is that farmers are averse to this new agricultural insurance solution. For index-based insurance to be effective, enough farmers must participate. While the KLIP can transform the lives of farmers by protecting their livelihoods from drought, there is a risk that uptake by those may be lower than anticipated (WBG, 2017). This could be due to a lack of awareness about the program, mistrust of insurance products, or difficulties meeting eligibility criteria. Therefore, an insufficient uptake would lead to a failing Insurance program.

As the WBG (2017) mentioned, most affected households in Africa must be aware of insurance's relevance. Although only a few farmers have internet access, most have mobile network access.

M-PESA, a mobile money transfer system, can solve this problem. Because M-PESA already has insurance technology incorporated into its backend operations, it can easily be implemented for small farmers. However, it has yet to completely utilize its potential in its front-end operations (Markovich & Snyder, 2018). Thus, farmers and stakeholders need to be educated about the program's relevance to fully reach its effectiveness for insurance coverage. Without proper education, the program lacks awareness.

Furthermore, our blockchain-based index insurance presented in the Self-designed Solution section threatens existing index-based insurance because blockchain technology allows for a more efficient and automated process.

Since conventional index-based insurance still has many shortcomings for farmers and could be replaced by a more efficient solution, for instance, blockchain-based index insurance, we reject hypothesis H_2. More details on the hypotheses are given in the discussion.

5. Self-designed Solution

Although the index-based insurance system presented in section 4 is already a much better alternative than the indemnity-based agriculture insurance system presented in section 3, we want to go one step further and optimize the index-based insurance system using blockchain technology in this section. Referring to the SWOT analysis in section 4, we want to address the weaknesses of the "slow and inefficient system" and "singular payment through agents". Additionally, we want to address the threats of "insufficient uptake from farmers" and "cost of the premium".

First, an introduction to blockchain technology is given. Then, in the General Overview, we will explain the concept of blockchain to offer a better readability of the Smart Contract - Technical Overview section, which explains our Smart Contract functionality with the help of a BPMN model. Finally, the solution design is analyzed with a SWOT analysis. With that analysis, we will be able to answer hypothesis H_3.

A. Blockchain 101

Before we describe blockchain-based insurance products, we want to introduce Blockchain. Hayes (2022b) defines Blockchain as follows: "A blockchain is a distributed database or ledger shared among the nodes of a computer network. As a database, a blockchain stores information electronically in digital format". Blockchain stores data, respectively, transactions in blocks linked together via cryptography. Once a block is filled, it chronologically attaches to the previous block and cannot be changed (Nofer et al., 2017).

A transaction is added to the block after a participant (miner) checks the transaction. Then everyone participating in this network (nodes) verifies it and updates their shared ledger. The first miner who correctly checks the transaction and solves the mathematical puzzle is rewarded (Bradley, 2018).

Blockchain has many use cases. Smart contracts are one of them. Automated contracts trigger the transaction if a pre-defined condition is met. (IBM, 2023) Using an oracle, off-chain data like "days without rain" can be included as triggering conditions (Macellaro, 2023).

Agricultural insurance provides security but faces challenges in developing countries due to expensive costs and complex development processes. However, there is a potential solution in the form of blockchain-based insurance that can overcome many of the limitations of traditional agriculture insurance. Furthermore, blockchain technology enables the implementation of smart contracts in the agriculture industry, which can be programmed with oracles to provide real-time external data (Kshetri & Kshetri, 2021). The following subsection General Overview and the other subsections in this section show how a blockchain-based solution can be implemented.

B. General Overview

The General Overview section provides an understanding of how our Self-designed solution works using Figure 3.

In Figure 3, starting at the top, three farmers are pictured first. Each farmer lives in a different region in Kenya. Farmer 1 lives in Region A, Farmer 2 lives in Region B, and Farmer 3 lives in Region C. As described in the real-life use case, Kenya experiences recurrent droughts. To protect themselves against this risk, farmers buy drought insurance.

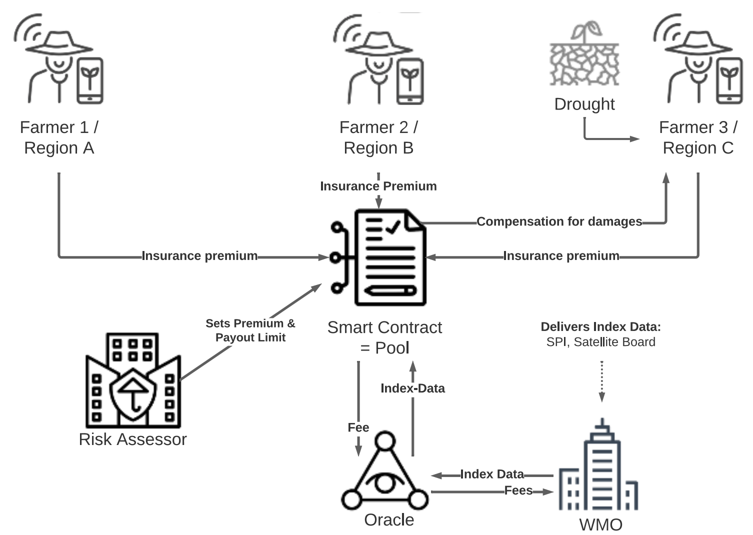

Figure 3: Blockchain-based index insurance

Therefore, the three farmers in Figure 3 each pay an insurance premium. Instead of paying it to an insurance company in a conventional manner, they transfer the premium amount directly to the smart contract, which functions as an insurance pool. The smart contract's creator acts as the risk assessor and establishes the premium amount, the indemnity limit, and the triggering conditions that lead to indemnity payment. The question arises whether a farmer is eligible for a payout based on his region. To address this issue, an oracle inputs the Standardized Precipitation Index (SPI) data to the smart contract's database. In exchange for the delivered data, a small portion of the smart contract's balance flows back to the oracle as a fee. The oracle then pays a fraction of this fee to the World Meteorological Organization (WMO), which supplies the index data in our example. If the SPI index provided by the WMO indicates a drought in region C, farmer 3 automatically receives the right to compensation for the damage. This index-insurance system is unique because it requires no administrative effort once set up.

C. Smart Contract – Technical Overview

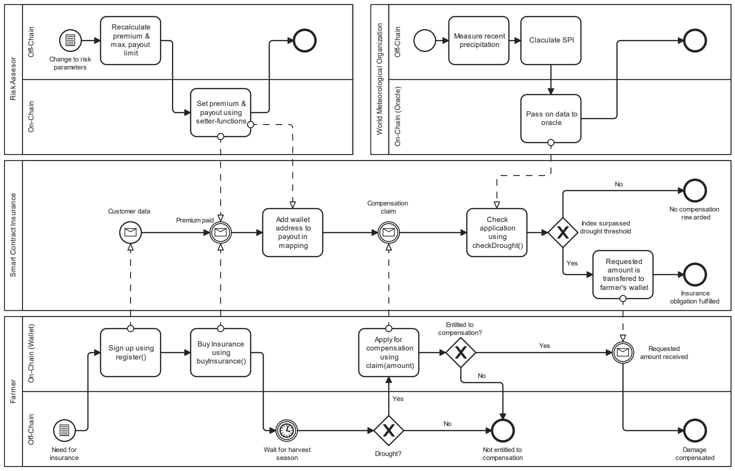

Figure 4: Process of self-designed solution (BPMN)

This section will explain how our blockchain-based insurance solution would work in real life, referencing the Smart Contract, whose code is available in the appendix. Figure 4 illustrates the whole process comprehensively.

Firstly, every actor in this scenario must set up a wallet which is the blockchain equivalent of a bank account. Next, a farmer needs to register and purchase an insurance policy. The registration process involves providing personal information such as first name, last name, the region where the crops and livestock are to be insured, and the wallet address. It is important to note that if the farmer wants to buy insurance for another region, he/she would need to open an additional account.

The claim process will be initiated if a drought affects the farmer's crops and livestock. First, the "claim" function is called, which checks if a drought occurred in the region ("checkDrought") using an index provided by an oracle. If a drought is confirmed, the requested amount will be paid out, but no more than the payout limit.

Regarding the index oracle, various ways and index types are being used. However, it is crucial to define the correct index threshold. Therefore, we opted for the SPI (Standardized Precipitation Index), measured by the World Meteorological Organization. The SPI defines drought on a spectrum ranging from extremely wet (+2.0) to extremely dry (-2.0) and considers the severity and recurrence of a drought incident in a certain period. Standardizing the index on the normal distribution is beneficial due to the increasing occurrence of extreme weather conditions resulting from climate change (World Meteorological Organization [WMO], 2012). It also facilitates risk assessment.

As the scope of this paper does not allow us to explore risk analysis for insurance, we have left it to the smart contract owner to change the premium. Payout amounts freely using the setter functions ("setPremium" and "setPayout"). Thus, calculating risk and determining premium and payout is done outside the smart contract (Kaye & Casualty Actuarial Society, 2005). Furthermore, we would like to stress that we are not addressing the issue of misuse of insurance, such as double coverage or missing insured objects in our code.

The smart contract is a pool to distribute risk across different regions and periods. In the future, the risk should be spread across various dimensions to manage it effectively.

D. SWOT Analysis

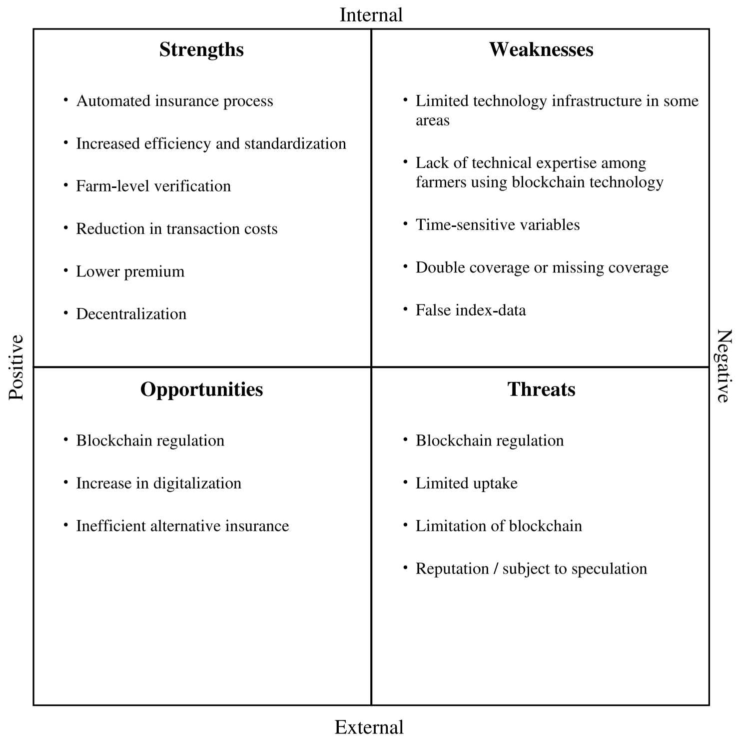

Figure 5: SWOT-Analysis of Blockchain

The SWOT analysis will be conducted in the same way as in the analysis of the real-life use case. The order is the following: strengths, opportunities, weaknesses, and threats.

Strengths

Starting with the strengths of our solution, the use of blockchain technology can enable the automation of the insurance process, leading to faster payouts and reduced fraud (Micale & Van Caenegem, 2019). Standardization and automation of insurance processes can increase efficiency while reducing transaction costs and intermediaries (Gatteschi et al., 2018). Index insurance products that use objective proxies to pay claims without farm-level verification can speed up the claims process (Index Insurance Forum, 2021). According to the Index Insurance Forum (2021), blockchain-based index insurance can reduce the cost of issuing contracts by 41%. This reduction leads to a reduction in the premium by up to 30%. This reduction of the premium leads to higher demand for insurance products. Another advantage of our blockchain-based solution is directly linked to blockchain technology. Since blockchain technology is decentralized, it also means that the farmer does not have to go to any insurance company. He/She can manage all insurance activities from the comfort of his/her home. Additionally, our developed solution replaces the current inefficient alternative insurance.

Opportunities

Coming to the opportunities, blockchain regulation can be both an advantage and a disadvantage for our blockchain-based index insurance. According to Werbach (2018), regulation can address several concerns associated with blockchain, including security, privacy, and fraud prevention, and accordingly increases confidence in our solution. Furthermore, the rate of digitalization is increasing in Africa and accelerating due to the COVID-Pandemic (Katjomuise, 2022). This development could set the foundation for further blockchain applications.

Weaknesses

Coming to the weaknesses, the limited technology infrastructure in some areas can lead to poor connectivity and slow adoption (Index Insurance Forum, 2021). Additionally, using blockchain technology may require the technical expertise that some farmers and stakeholders lack. For example, do farmers know how to set up a wallet? Do they know how to buy cryptocurrencies (Gatteschi et al., 2018)? Thirdly, since our smart contract uses a time-sensitive variable, it is vulnerable to exploitation. More specifically, the use of the timestamp of a block is not entirely secure because the block's miner can manipulate said timestamp (Gondek, 2023). Since our solution is partly decentralized, there will be no verification of each insured. This could lead to double coverage by malicious actors or coverage without an underlying asset. Moreover, using a single index and entity as our data feed poses an apparent vulnerability since the misuse or accidental falsification of data would reduce the reliability of our product.

Threats

Regarding the threats, regulation could be just as much one, contradicting the abovementioned point. The regulatory landscape constantly changes, and we may be forced to adapt our smart contracts (Wang et al., 2019). Another threat could be farmers' insufficient uptake of the blockchain-based index insurance due to a lack of trust or understanding of the technology among farmers, and other stakeholders may limit adoption (Gatteschi et al., 2018). Moreover, we come to the limitations of blockchain technology. The irreversibility of errors, because of the immutability feature of a blockchain, can become a problem, meaning that a bug cannot be fixed.

Furthermore, updating the contract requires manual data transfer, which is cumbersome (Wang et al., 2019). Wang et al. (2019) also mention that lacking trusted data feeds could be problematic. The WMO could unintentionally deliver incorrect data feeds into the blockchain in our solution design. Consequently, the blockchain-based index insurance process would fail. In addition, the blockchain on which the smart contract runs must also be secure. Blockchain systems can be hacked or attacked (Santhana & Biswas, 2017). Because the crypto scene is associated with scandals, such as fraud and scams, and the prices of crypto assets are very volatile, the reputation of blockchain technologies suffers and thus hinders mainstream appeal.

Finally, we confidently confirm hypothesis H_3 that the blockchain-based index solution will narrow the insurance gap in developed countries because of the automation of our solution, eliminating the intermediary, which in turn lower the premium amount. As a result, more farmers could afford insurance against drought. In addition, farmers can participate in a decentralized manner without having to visit a geographically distant agency.

6. Discussion

A. Summary

The research paper shows how vital agriculture insurance is for small African farmers. Our analysis finds that many current solutions are unavailable or inappropriate for small farmers. To increase the availability and affordability for farmers in developing nations, we created a self-designed blockchain-based index insurance solution. The advantages of a blockchain-based index insurance product are the main conclusions of this paper. The results of our research paper emphasize the need for innovative methods to resolve the issues with traditional agriculture insurance.

B. Interpretation and Implications of Results

We have stated three Hypotheses which will be discussed in the following part. The discussion should show what results we gathered and is here to discuss whether our hypotheses can be confirmed or denied critically.

Hypothesis H_1: The conventional agriculture insurance system in developing markets is inefficient.

Our results support hypothesis H_1. The conventional agriculture insurance system in developing markets is inefficient. There are many issues with the existing agriculture insurance system, such as insufficient and, therefore, asymmetric information, limited diversification options, high administrative costs, systemic risk leading to expensive international reinsurance premium rates, high dependence on government support for subsidies, and financial illiteracy of the farmers. These problems make it very difficult for small farmers to get insurance policies that are affordable and suitable for their individual needs. As a result, farmers stay financially vulnerable to drought-related crop loss. Moreover, since most farmers are impoverished and dependent on a stable and predictable income, such disasters can quickly ruin their lives. In summary, we confirm hypothesis H_1 that the conventional agriculture insurance system in developing markets is inefficient because of all the reasons mentioned above.

Hypothesis H_2: The existing index-based agriculture insurance system is the most efficient insurance system.

Based on our results, existing index-based crop insurance products are a solution for some of the current problems of conventional crop insurance. In addition, existing index-based insurance products have many benefits, such as low costs, simple-to-use processes, and minimized crop risk. This makes agricultural insurance more accessible for small farmers, helping them to manage risks associated with drought and enhancing their overall quality of life.

However, the disadvantages outweigh the advantages of existing index-based crop insurance. The use of standardized indices may not reflect the actual risks of individual farmers. The missing transparency of the index calculations lowers trust in the insurance system, which would even worsen the current insurance situation of small farmers. Even though index-based insurance can benefit some farmers, there are more efficient solutions for small farmers. Hence, we reject hypothesis H_2.

Consequently, there needs to be an improved system that solves the existing problems of index-based insurance. To address these problems, we have developed a blockchain-based insurance solution that presents an innovative approach to improve the current index-based insurance systems.

Hypothesis H_3: Blockchain-based index agriculture insurance narrows the insurance gap in developing markets for farmers.

The analysis of hypothesis H_3 shows that blockchain-based insurance products have significant potential to close the insurance gap in emerging markets for farmers. Blockchain-based technology products have many advantages, including increased transparency, reduced fraud, and improved data collection and analysis. These advantages help to overcome trust issues and inadequate data in connection with conventional and index-based crop insurance systems. Blockchain-based insurance products can also reduce transaction costs and improve the speed and efficiency of processes, making a farmer's insurance process much faster and simpler. The claims settlement process can become automated by using smart contracts in the insurance system, such as the one we have designed. This would lead to faster and more accurate payouts and reduced administrative costs for farmers. Blockchain-based insurance products can also improve the accessibility to insurance for small farmers who may have been excluded from traditional insurance markets because of the high costs. This would then lead to a growing number of farmers with insurance products, resulting in increased agricultural productivity and improved living standards for small farmers. According to a report by The Geneva Association (2018), insurance purchases have significantly increased due to the launches of such new insurance programs. With these advantages and positive consequences, we can confidently confirm hypothesis H_3, on-chain index insurance products can narrow the insurance gap in developing African countries.

Using the answers to the hypothesis in this section, we can address the research question:

"What are the effects of implementing blockchain-based index insurance in the agricultural industry against droughts, and how can severely underinsured farmers in Africa benefit from it?"

Blockchain-based index insurance has great potential to narrow the insurance gap in the agricultural industry. Besides, damages caused by increasing and more extreme droughts will no longer set back economies so drastically and leave the population with economic and social consequences. The individual farmer will have similar benefits to society at large. Farmers can compensate for their losses and secure a more moderate lifestyle in the long term.

C. Limitations and Further Research

Insurance solutions built on blockchain are still in the early stages of development. Therefore, there are still some problems that need to be solved. The high cost of implementing such blockchain-based technologies is one of the main problems, which also restricts the usability of small farmers for those insurances. In addition, new regulatory frameworks are also needed to prevent misuse and fraud, which might lead to uncertainty and act as an entry barrier for farmers. Another significant limitation is that according to World Bank data, only 29% of the region's population has access to the internet. This lack of widespread connectivity can challenge the effective implementation and scaling of blockchain-based index insurance solutions (World Bank Group, 2023).

Technical aspects and infrastructure of the blockchain need to be improved. However, oracles and reliable smart contracts will lay the foundation for secure applications in the future. Therefore, organizations and governments should embrace the technology and do their research to identify more use cases. Moreover, oracles will be the most integral connection between the real world and the blockchain. For instance, the WMO could set up its SPI oracle to encourage and support the development of sound risk-minimizing tools against droughts.

In our case, the solution design we provided only serves as a script for the application. Only if a farmer knew how to use an IDE such as Remix would he/she be able to use the smart contract. Therefore, building a user interface that supports the farmer during the insurance process is essential.

We want to stress that the depth of our research was limited due to time constraints. Additionally, the scarcity of index-based insurance and the novelty of blockchain technology provides little information on their respective subject.

D. Conclusion

In this research paper, we address the weaknesses of the current agricultural insurance system in developing countries, which are often unaffordable and inaccessible for smallholders due to the high premiums. Due to the various limitations of conventional insurance and even the current index-based agricultural insurance, we showed the full potential of the blockchain-based index solution for agricultural insurance in developing countries using a solution design. As a result, blockchain technology can massively reduce costs and thus premiums for farmers. At the same time, it increases farmers' trust in agricultural insurance because our Blockchain-based insurance smart contract is immutable and thus has clearly defined payout structures from the outset. Furthermore, as the Blockchain processes are fully visible, i.e., public access, full transparency of the processes is given to the farmers.

The results and findings of our study are highly relevant to agricultural policy in developing countries. They can help these third-world countries to achieve higher productivity and growth in the agricultural sector and beyond due to higher predictability and security in agriculture. Furthermore, as mentioned in answer to hypothesis H_3, this paper fills a scientific gap by using a SWOT analysis to compare existing agricultural insurance products with the blockchain-based index insurance we propose and implement and concludes that with this novel insurance via a smart contract, the underinsurance problem could be reduced or even eliminated.

With this study, we would like to educate farmers about the novel insurance options on the one hand and motivate insurance companies, governments, and regulators to promote it on the other hand so that more farmers in developing countries can benefit from it.

Given all our research, blockchain-based insurance solutions show much potential to solve most of the issues of the current agriculture insurance industry. While implementing these ideas may take some time, we are confident they will eventually be necessary for small farmers and improve the agriculture insurance industry.

7. References

Ali, W., Abdulai, A., & Mishra, A. K. (2020). Recent Advances in the Analyses of Demand for Agricultural Insurance in Developing and Emerging Countries. *Annual Review of Resource Economics*, *12*(1), 411–430. https://doi.org/10.1146/annurev-resource-110119-025306

Artful Eyes Productions. (2022, March 4). *Kenya Livestock Insurance Programme - KLIP (HD)* [Video]. *YouTube*. https://www.youtube.com/watch?v=0bAxrO4x9L0

Barnett, B. J., & Mahul, O. (2007). Weather Index Insurance for Agriculture and Rural Areas in Lower-Income Countries. *American Journal of Agricultural Economics*, *89*(5), 1241–1247. https://doi.org/10.1111/j.1467-8276.2007.01091.x

Barrett, C. B., Reardon, T., & Webb, P. (2001). Nonfarm income diversification and household livelihood strategies in rural Africa: concepts, dynamics, and policy implications. *Food Policy*, *26*(4), 315–331. https://doi.org/10.1016/s0306-9192(01)00014-8

Bloomenthal, A. (2021, January 19). *Asymmetric Information in Economics Explained*. Investopedia. Retrieved March 13, 2023, from https://www.investopedia.com/terms/a/asymmetricinformation.asp

Bradley, R. (2018). *Blockchain . . . erklärt in weniger als 100 Wörtern*. Deloitte. Retrieved March 15, 2023, from https://www2.deloitte.com/ch/de/pages/strategy-operations/articles/blockchain-explained.html

Bureau of Economic Analysis. (2022, April 26). *Gross Domestic Product*. BEA. Retrieved March 13, 2023, from https://www.bea.gov/resources/learning-center/what-to-know-gdp

Buterin, V. (2014). *A next-generation smart contract and decentralized application platform*. Finpedia. Retrieved March 15, 2023, from https://finpedia.vn/wp-content/uploads/2022/02/Ethereum_white_paper-a_next_generation_smart_contract_and_decentralized_application_platform-vitalik-buterin.pdf

Carter, M. R., De Janvry, A., Sadoulet, E. & Sarris, A. (2017). Index Insurance for Developing Country Agriculture: A Reassessment. *Annual Review of Resource Economics*, *9*(1), 421–438. https://doi.org/10.1146/annurev-resource-100516-053352

CFI Team. (2023, January 15). *Systemic Risk*. Corporate Finance Institute. Retrieved March 13, 2023, from https://corporatefinanceinstitute.com/resources/risk-management/what-is-systemic-risk/

Chermack, T. (2012). *Scenario Planning in Organizations: How to Create, Use, and Assess Scenarios* (16th ed.). ReadHowYouWant.

Citizen TV Kenya. (2019, April 3). *Livestock insurance in Samburu* [Video]. YouTube. https://www.youtube.com/watch?v=c6lU8ALYkUU

Disaster Risk Financing & Insurance Program. (2017, June). *Kenya Livestock Insurance Program (KLIP)*. Financial Protection Forum. Retrieved February 27, 2023, from https://www.financialprotectionforum.org/publication/kenya-livestock-insurance-program-klip

Dumba, H., Danquah, J. A., & Pappinen, A. (2021). Rural Farmers' Approach to Drought Adaptation: Lessons from Crop Farmers in Ghana. Springer EBooks, 1033–1051. https://doi.org/10.1007/978-3-030-45106-6_29

European Insurance and Occupational Pensions Authority. (2022, September 7). *Addressing the protection gap: challenges and opportunities for (re)insurers*. EIOPA. Retrieved March 13, 2023, from https://www.eiopa.europa.eu/publications/addressing-protection-gap-challenges-and-opportunities-reinsurers_en

Eyase, J. (2021, March 11). *Reimagining Agriculture Insurance using Blockchain Technology.* Acre Africa. https://acreafrica.com/reimagining-agriculture-insurance-using-blockchain-technology

Food and Agriculture Organization of the United Nations. (2023). *Kenya at glance.* FAO. Retrieved February 26, 2023, from https://www.fao.org/kenya/fao-in-kenya/kenya-at-a-glance/en/

Gatteschi, V., Lamberti, F., Demartini, C., Pranteda, C., & Santamaría, V. (2018). Blockchain and Smart Contracts for Insurance: Is the Technology Mature Enough? *Future Internet*, *10*(2), 20. https://doi.org/10.3390/fi10020020

Gondek, C. (2023). *How Accurate and Reliable Is the Block Timestamp in Ethereum?* OriginStamp. Retrieved March 2, 2023, from https://originstamp.com/blog/how-accurate-and-reliable-is-the-block-timestamp-in-ethereum/

Ghosh, R., Gupta, S., Singh, V., & Ward, P. S. (2021). Demand for Crop Insurance in Developing Countries: New Evidence from India. *Journal of Agricultural Economics*, *72*(1), 293–320. https://doi.org/10.1111/1477-9552.12403

Hayes, A. (2022a, September 15). *Adverse Selection: Definition, How It Works, and The Lemons Problem*. Investopedia. Retrieved March 13, 2023, from https://www.investopedia.com/terms/a/adverseselection.asp

Hayes, A. (2022b, September 27). *Blockchain Facts: What Is It, How It Works, and How It Can Be Used*. Investopedia. Retrieved February 21, 2023, from https://www.investopedia.com/terms/b/blockchain.asp

Hazell, P. B., & Hess, U. (2010). Drought insurance for agricultural development and food security in dryland areas. *Food Security*, *2*(4), 395–405. https://doi.org/10.1007/s12571-010-0087-y

Herbold, J. (2010, April). *Crop insurance in developing economies – the insurers' and reinsurers' perspective*. Rural21. Retrieved February 21, 2023, from https://www.rural21.com/fileadmin/_migrated/content_uploads/R21_Crop_insurance_developing_economies_01.pdf

Hill, R. V., Kumar, N., Magnan, N., Makhija, S., De Nicola, F., Spielman, D. J. & Ward, P. S. (2019). Ex ante and ex post effects of hybrid index insurance in Bangladesh. *Journal of Development Economics*, *136*, 1–17. https://doi.org/10.1016/j.jdeveco.2018.09.003

Houben, G., Lenie, K., & Vanhoof, K. (1999). A knowledge-based SWOT-analysis system as an instrument for strategic planning in small and medium sized enterprises. *Decision Support Systems*, *26*(2), 125–135. https://doi.org/10.1016/s0167-9236(99)00024-x

IBM. (2023). *Was sind Smart Contracts in einer Blockchain?* IBM. Retrieved February 23, 2023, from https://www.ibm.com/de-de/topics/smart-contracts

Index Insurance Forum. (2021, October 23). *Blockchain Application in Agriculture Insurance*. IIF. Retrieved February 24, 2023, from https://www.indexinsuranceforum.org/blog/blockchain-application-agriculture-insurance

Katjomuise, K. (2022, November 29). *Digitizing Africa, the key to stronger institutions*. United Nations. Retrieved March 2, 2023, from https://www.un.org/africarenewal/magazine/november-2022/digitizing-africa-key-stronger-institutions

Kaye, P. (2005). *Risk Measurement in Insurance: A Guide To Risk Measurement, Capital Allocation And Related Decision Support Issues*. Casualty Actuarial Society. Retrieved February 27, 2023, from https://www.casact.org/abstract/risk-measurement-insurance-guide-risk-measurement-capital-allocation-and-related-decision

Kemoe, L., Mitra, P., Okou, C., & Filiz Unsal, D. (2022, September 14). *How Africa Can Escape Chronic Food Insecurity Amid Climate Change*. IMF. Retrieved February 21, 2023, from https://www.imf.org/en/Blogs/Articles/2022/09/14/how-africa-can-escape-chronic-food-insecurity-amid-climate-change

Kenton, W. (2020, July 23). *Moral Hazard: Definition, Meaning, Examples, and How to Manage*. Investopedia. Retrieved March 13, 2023, from https://www.investopedia.com/terms/m/moralhazard.asp

Kshetri, N. & Kshetri, N. (2021). Blockchain-Based Smart Contracts to Provide Crop Insurance for Smallholder Farmers in Developing Countries. *IT Professional*, *23*(6), 58–61. https://doi.org/10.1109/mitp.2021.3123416

Kurpiel, S. (2023, February 17). *Research Guides: Evaluating Sources: The CRAAP Test*. Benedictine University Library. Retrieved March 13, 2023, from https://researchguides.ben.edu/source-evaluation

Kwadzo, G. T.-M., Kuwornu, J. K. M., & Amadu, I. S. B. (2013). Food Crop Farmers' Willingness to Participate in Market-Based Crop Insurance Scheme: Evidence from Ghana. *Research in Applied Economics*, *5*(1). https://doi.org/10.5296/rae.v5i1.2617

Lussier, R. N., & Achua, C. F. (2015). *Leadership: Theory, Application, & Skill Development* (6th ed.). Cengage Learning.

Macellaro, D. (2023, February 20). *Oracles*. Ethereum. Retrieved February 25, 2023, from https://ethereum.org/en/developers/docs/oracles/

Micale, V., & Van Caenegem, H. (2019, September). *Blockchain Climate Risk Crop Insurance*. Climate Policy Initiative. Retrieved February 27, 2023, from https://www.climatepolicyinitiative.org/wp-content/uploads/2020/08/Blockchain-Climate-Risk-Crop-Insurance_instrument-analysis.pdf

Miranda, M. J. & Farrin, K. (2012). Index Insurance for Developing Countries. *Applied economic perspectives and policy*, *34*(3), 391–427. https://doi.org/10.1093/aepp/pps031

Miranda, M. J. & Glauber, J. W. (1997). Systemic Risk, Reinsurance, and the Failure of Crop Insurance Markets. *American Journal of Agricultural Economics*, *79*(1), 206–215. https://doi.org/10.2307/1243954

Mishra, A. K. & Singh, V. P. (2010). A review of drought concepts. *Journal of Hydrology*, *391*(1–2), 202–216. https://doi.org/10.1016/j.jhydrol.2010.07.012

Nofer, M., Gomber, P., Hinz, O., & Schiereck, D. (2017). Blockchain. *Business &Amp; Information Systems Engineering*, *59*(3), 183–187. https://doi.org/10.1007/s12599-017-0467-3

Object Management Group. (2023). *BPMN Specification - Business Process Model and Notation*. BPMN. Retrieved March 13, 2023, from https://www.bpmn.org/

Olawanle, J. (2022, September 1). *What is an IDE? IDE Meaning in Coding*. freeCodeCamp. Retrieved March 13, 2023, from https://www.freecodecamp.org/news/what-is-an-ide-for-beginners/

Saleh, M. (2022, August 16) *Contribution of agriculture, forestry, and fishing sector to the Gross Domestic Product (GDP) in Africa as of 2021, by country,* 2021 [Data set]. Statista. https://www.statista.com/statistics/1265139/agriculture-as-a-share-of-gdp-in-africa-by-country/

Smith, V. H. & Glauber, J. W. (2012). Agricultural Insurance in Developed Countries: Where Have We Been and Where Are We Going? *Applied economic perspectives and policy*, *34*(3), 363–390. https://doi.org/10.1093/aepp/pps029

Sandroff, R. (2022, August 31). *Underinsurance Definition*. Investopedia. https://www.investopedia.com/terms/u/underinsurance.asp

Santhana, P., & Biswas, A. (2017). *Blockchain risk management*. Deloitte. Retrieved February 26, 2023, from https://www2.deloitte.com/us/en/pages/risk/articles/blockchain-security-risks.html#

Swiss Re. *Successful Kenya Livestock Insurance Program scheme scales up.* Swiss Re. Retrieved February 22, 2023, from https://www.swissre.com/our-business/public-sector-solutions/thought-leadership/successful-kenya-livestock-insurance-program-scheme.html

The Geneva Association. (2018, April). *Understanding and addressing global insurance protection gaps.* Retrieved March 13, 2023, from https://www.genevaassociation.org/sites/default/files/research-topics-document-type/pdf_public/understanding_and_addressing_global_insurance_protection_gaps.pdf

Vargas Hill, R. (2015, January 6). *Agricultural insurance in Sub-Saharan Africa: can it work?* IIF. Retrieved February 26, 2023, from https://www.indexinsuranceforum.org/publication/agricultural-insurance-sub-saharan-africa-can-it-work

Hagman, & Beer, H. (1984). Prevention better than cure: report on human and environmental disasters in the Third World (3rd ed., [repr.]). The Swedish Red Cross.

Wang, S., Ouyang, L., Yuan, Y., Ni, X., Han, X., & Wang, F. (2019). Blockchain-Enabled Smart Contracts: Architecture, Applications, and Future Trends. IEEE Transactions on Systems, Man, and Cybernetics, 49(11), 2266–2277. https://doi.org/10.1109/tsmc.2019.2895123

Werbach, K. (2018). The Blockchain and the New Architecture of Trust. The MIT Press EBooks. https://doi.org/10.7551/mitpress/11449.001.0001

Wilhite, D.A. (1992). Preparing for Drought: A Guidebook for Developing Countries, Climate Unit, United Nations Environment Program, Nairobi, Kenya. Retrieved February 23, 2023, from https://wedocs.unep.org/20.500.11822/30153

World Bank Group. (2017, June). *Kenya Livestock Insurance Program.* Retrieved February 22, 2023, from https://www.financialprotectionforum.org/publication/kenya-livestock-insurance-program-klip

World Bank Group. (2023). *Sub-Saharan Africa*. worldbank.org. Retrieved March 15, 2023, from https://data.worldbank.org/region/sub-saharan-africa

World Meteorological Organization. (2012). *Standardized Precipitation Index User Guide*. Retrieved February 27, 2023, from https://library.wmo.int/doc_num.php?explnum_id=7768

8. Appendix

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.0;

// Creating the DroughtInsurance contract
contract DroughtInsurance {

  // Farmer struct to store farmer's information
  struct Farmer {
    string firstName;
    string lastName;
    uint region; // The region code of the farmer
    }

  // Defining the variables
  uint public premium; // Premium amount in wei (1 ether = 10^18 wei)
  uint public payout; // Payout amount in wei
  int public indexThreshold; // The threshold index value for drought
  int private index;
  address public creator; // smart contract deployer
  Farmer private newFarmer; // A new Farmer struct instance
  uint private timeOfYearBeginning;
  uint private secondsPerYear;
  uint private secondsSinceYearBeginning;
  address[] private currentInsured; // array of current Insured for iteration
over mapping
  address[] private futureInsured;  // array of future Insured for iteration
over mapping

  // Mapping: map Farmer to available, claimable amount (aka obligation)
  mapping (address => uint) private farmerToObligation;
  // Mapping for future obligations
  mapping (address => uint) private farmerToFutureObligation;
  // Mapping: Farmer to registration
  mapping (address => Farmer) private farmerToRegistration;
  // Mapping: see if a farmer has already registered (much more efficient than
iteration over an array)
  mapping (address => bool) private farmerRegistered;

  // Initializing the contract and setting the variables
  constructor(uint _premium, uint _payout, int _indexThreshold) {
    premium = 1000000000000000000 * _premium; // 1000000000000000000 Wei = 1
Ether
    payout = 1000000000000000000 * _payout;
    indexThreshold = _indexThreshold;
    creator = msg.sender;
    secondsPerYear = 31536000;
    timeOfYearBeginning = block.timestamp - (block.timestamp %
secondsPerYear);
  }

    // Setting Premium in case of risk increase/decrease (only SC owner should
be able to do it)
  function setPremium(uint newPremium) public {
    require(msg.sender == creator, "Only risk assessor owner can set
premium.");
```

```
    premium = newPremium;
  }

  // Setting Payout in case of risk increase/decrease (only SC owner should be
able to do it)
  function setPayout(uint newPayout) public {
    require(msg.sender == creator, "Only risk assessor can set payout.");
    payout = newPayout;
  }

  // farmer registration, adds farmer structure to mapping with a claimable
amount (aka obligation)
  function register(string memory _firstName, string memory _lastName, uint
_region) public {
    require(farmerRegistered[msg.sender] == false, "You have already
registered.");
    newFarmer = Farmer(_firstName, _lastName, _region);
    farmerToRegistration[msg.sender] = newFarmer;
    farmerToObligation[msg.sender] = 0;
    farmerRegistered[msg.sender] = true;
  }

  // this function checks and enforces the time constraints and will be called
anytime another function is called
  function resetYear() private {
    secondsSinceYearBeginning = block.timestamp - timeOfYearBeginning;
    if (secondsSinceYearBeginning > secondsPerYear) {
      secondsSinceYearBeginning += secondsPerYear;
      for (uint i=0; i < currentInsured.length ; i++){
        farmerToObligation[currentInsured[i]] = 0;
      }
      delete currentInsured;
      for (uint i=0; i < futureInsured.length ; i++) {
        farmerToObligation[futureInsured[i]] =
farmerToFutureObligation[futureInsured[i]];
        farmerToFutureObligation[futureInsured[i]] = 0;
        currentInsured.push(futureInsured[i]);
      }
      delete futureInsured;
    }
  }

  // Creating the function to buy insurance the year before
  function buyInsurance() public payable {
    // resetYear(); // checks time constraint transits obligations
    require(farmerRegistered[msg.sender] == true, "You need to register
first.");
    require(farmerToFutureObligation[msg.sender] == 0, "You have already
bought insurance.");
    require(msg.value == premium, "Incorrect premium amount."); // amount in
wei
    farmerToFutureObligation[msg.sender] = payout; // payout == claimable
amount (aka obligation)
    farmerToObligation[msg.sender] = payout; // THIS ONE IS USED FOR
PRESENTATION PURPOSE ONLY
    futureInsured.push(msg.sender);
  }
```

```
  // Creating the function to check if a drought has occurred
  // serves as a pseudo-oracle and for presentation purposes
  function checkDrought(uint region) private returns(bool) {
    if (region == 2) {
        index = -2;
    } else {
        index = 1;
    }
    if (index < indexThreshold) {
      return true;
    } else {
      return false;
    }
  }

  // Claim
  // I believe the claimer should pay the oracle fees to avoid excessive
claiming and subsequent
  function claim(uint amount) public {
    // resetYear(); // check time constraint
    require(farmerToObligation[msg.sender] >= amount, "Your open balance is
too low.");

    // Checking if a drought has occurred
    bool isDrought = checkDrought(farmerToRegistration[msg.sender].region);

    // Paying out the insurance if a drought has occurred
    require(isDrought == true, "Your region was not affected by a drought.");
    payable(msg.sender).transfer(1000000000000000000 * amount); // send
claimed amount in ether
    farmerToObligation[msg.sender] -= amount; // reduce obligation by amount
claimed
  }
}
```

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