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BACHELOR'S THESIS

Fisheye on Blockchain

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TITLE PAGE FOR MAIN PROJECT

Report title: Blockchain technologies standardize readiness and integrity in the fish production supply chain	*Date:* *07.03.2022*
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Summary: The report is intended to conduct research on how blockchain technologies may be implemented in the fish farm industry in Norway to achieve the best data integrity and transparency. The current challenges include cheating during production and the potential presence of a black market in the countries where the fish products are exported. These problems lead to an uncertain customer attitude.

The utilization of blockchain is considered. The solution must guarantee data integrity, transparency, and availability.

Various alternatives to the implementation are considered and analyzed, and prospective blockchains are mentioned and compared to select the proper solution.

Key words:

Blockchain	Supply chain	Fish farm

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Preface

In the accomplishment of the Information Technology bachelor's degree, we, Arsenii Dmitriev, Karl Kristen Gjølsjø, and Adrian Phillips, are submitting a project report, "FishEye on Blockchain."

The present report is the outcome of the bachelor's project of The Western Norway University of Applied Sciences hosted by Ørn Software. The project's objective was to investigate how blockchain technologies may be implemented in the fish farm industry in Norway to achieve the best data integrity and transparency.

In this report, we have tried to involve constructive analysis regarding the topic and the problem. Nevertheless, subject to time limitations, every possible attempt has been made to study the topic deeply.

We would like to express our deep gratitude to our supervisor, Lars-Petter Helland. He would keep us focused throughout the project, bringing important points and valuable critics.

We also want to acknowledge the efforts of the Ørn Software supervisor Tom Henrik Aadland for sharing his knowledge, motivating, and supporting us.

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1 Introduction

Fisheye on Blockchain is a project proposed by Ørn Software that involves implementing blockchain technologies in the Norwegian fish production industry. The essence is to change the routing of data handling and processing used nowadays.

1.1 Project owner

Ørn Software[1] is the business that owns this project. The company is a field leader in industrial maintenance and management and facility and property management. Now, Ørn Software is about to secure an equally strong position within Norway's second-biggest export: aquaculture. The firm also offers solutions for businesses wishing to track their energy consumption and environmental footprint. Their user-friendly systems give all its users a complete overview of business-critical tasks, thus facilitating better cooperation and streamlining operations. All the above-mentioned ensures efficient management of the real estate and industrial assets, as well as the ability to document sustainable operations.

Today, 1100 companies with over 140 000 employees use Ørn Software's SaaS (Software as a Service) services. In February 2021, Ørn had 90 employees, a 400 % increase in subscription income in 3 years, and the biggest shareholder is Viking Venture, with 61% of the shares. Ørn has a growing income as their income from subscriptions increases by 400%.

The fish farms have already collected the data required to ensure the quality of the fish. What if Ørn Software could prove this quality by making all this information accessible to consumers and distributors. Ørn Software wants to explore how blockchain can help make this information accessible and trustworthy. Its desire can also help eliminate some of the concerns regarding faking vaccination.

1.2 Motivation

Ørn Software is a software company that delivers many services to the fish industry. The company has developed a platform called InControl distributed to fish farms. InControl is complete web-based control and monitoring system. The system gives a complete overview of fish feeding and handles one of the most challenging tasks for fish farms, lice. InControl is a fantastic tool for fish farms, and many of Ørn's customers are satisfied. Nils Tore Karstens from E.Karstens Fiskeoppdrett says “For å kunne levere verdens beste laks er vi helt avhengig av at fisken vår har det bra, og da er InControl et godt og viktig verktøy for oss» (To deliver the best salmon we fully rely on the fish life quality, and for this InControl is an important tools for us) [2].

The fish farms already collect data to ensure the quality of fish. What if Ørn could increase the trustworthiness of that data, thus providing a better way of ensuring the quality of the fish to their consumers and distributors? If the trustworthiness of data increases, the products are considered more premium. The information about how the fish is handled and transported accessible to consumers and distributors could help prove their quality. Ørn

Software, therefore, wants to explore how the use of blockchain can help make this information accessible and trustworthy. Such change can also help eliminate some of the concerns regarding faking vaccination.

Ørn Software invests heavily in aquaculture, and this project could potentially be a massive product for the fish industry in the coming years [3].

1.3 Context

Ørn Software wants to explore the potential of blockchain technology and do something about the lack of transparency in fish production and the supply chain. Today fish producers store any data that is just used internally and not accessible to distributors and consumers. This issue is something Ørn Software wants to change. As of today, there is little to no transparency in the fish production industry. It is hard to assure that the bought fish has been handled the way it should. Vaccines, poison, and tampering numbers are just some of the ways industry players use to cheat. Such deceit is not only an issue for consumers. Distributors will experience problems when fish is faulty. They do not have the required information to identify where this could have happened in the process. Was there a temperature change during transit, or was the fish stored too long at the wrong temperature?

Issues like this will mean they have to throw out large amounts of fish they suspect may be affected. To acquire reliable data on the fish means they must only discard the fish affected by the issue. Having a full display of the supply chain is a great marketing move as this assures complete trust between the consumer and distributor.

Switching to a blockchain solution for the data handling routine is motivated by multiple challenges in the farm fish production industry.

- Cheating during the production phase.
- Customer relationships.
- Economy factors.

Cheating during the production – that aspect covers fraud and thieving. The fish production companies that follow the law suffer economically from such deceit. Thieving in this context means modifying fish production statistics, a breach of the Norwegian laws related to fish farming, corruption, and others. For example, the data on the volume of farm fish may be corrupted. Today, data flow has a distinct structure: the source of information (e.g., client software at a fish farm or a fishing vessel) submits the data securely to a data center. The facts are analyzed, processed, secured, and allocated to servers[4] which keep information and reveal it on a demand basis. Nevertheless, only a few people have access to the servers and, thus, to the data. Storing data on regular servers means that the data can be modified manually. If corruption occurs, the information may be easily updated, and figures get lowered, resulting in the newly formed excess of fish being reallocated, benefiting individuals.

Furthermore, the figures on the volume of fish caught might be downplayed to fit into law-defined quotas. Nevertheless, such machinations rarely occur in Norway due to strict regulations and complete internal control. Fraud and thieving instead affect Norwegian fish export [5]. Not honest foreign producers may supply low-quality products locally, pretending to be Norwegian brands. This machination contributes to the black market and degrades the relationship with the end customers. Therefore, there is a need to secure domestic fish farm products abroad. All the listed factors breach the Norwegian regulations and disrupt marine ecosystems [6].

Next, customer attitude towards fish farms varies. The end customers that consume fish products tend to think that fish quality perception is often characterized by the fish origin[7]. Wild-caught product is regularly considered higher quality and healthier than farm-raised fish due to vagueness related to what farm fish was fed and the conditions in which it was preserved. Therefore, there is a need to make the fish farm production data transparent and trustworthy to affect the end customers' opinions and erase the uncertainty.

Overall, there is an opportunity for the fish production companies to use a new solution that establishes trustful relationships with the end customers, potentially boosts revenue and sales due to marketing, reduces cheating during the production and export, and is a great advertisement tool. Therefore, the report's outcome will help the target audience outline all the advantages and disadvantages of the innovative approach and decide.

1.4 Problem description and goal

Problem description

When it comes to real-life issues, the fish industry in Norway requires an automated supply chain solution that prevents fraud and thieving, ensuring easy operation and robustness. Not only data integrity and product authentication are crucial, but a track of supply chain problems and a trustful relationship with end customers with better data transparency.

From the consumer's perspective, they rely primarily on a company's reputation when selecting products. The knowledge of the fish's origin and temperature during transportation are crucial to ensure the quality of fish. A combination of high technology sensors and blockchain will make the data accessible and trustworthy. Such an approach limits manual input and makes the data unchangeable. That allows customers to know essential information on how a product has been manipulated.

Problem statement

The problem of the report is to develop and describe a solution that will mitigate the challenges mentioned earlier, including fraud and unclear customer relationships, in the farm fish production industry in Norway.

Our team has formulated a research question that will help us achieve a quality report and navigate us throughout the project: *To what extent can the challenges in the current fish farm supply chain be mitigated by using blockchain?*

That question covers the most critical aspects of the investigation: challenges the project is intended to mitigate and how the utilization of blockchain may solve them.

Goal

The project goal is to research the way blockchain solutions may be integrated into the Norwegian farm fish production market and how such solutions may mitigate the current issues in the industry. Furthermore, the project will outline the investigation if it is reasonable to utilize blockchain in terms of revenue or not.

Financial estimation based on additional blockchain-related expenditures and research on alternative blockchains will be performed. Expenditure evaluation is another sub-goal that would help understand whether the solution is realistic. Learning blockchain mechanics and presenting them in the project, selecting the most suitable alternative with the requirements.

Moreover, a proper analysis requires mentioning both pros and cons of the solution. The project will summarize the advantages and disadvantages of the economy, technology, and environment-wise. This summary assures that the report is not biased and is thorough.

The project aims to develop an API that handles data accessing and forwarding between the underlying blockchain and a higher-level system that communicates to the API. In other words, there will be an agent responsible for accessing the blockchain by unique credentials and uploading or retrieving data from the blockchain-based on the task received from the higher-level system.

1.5 Abstract

1.5.1.1.1 Introduction

The introduction discusses the company hosting the project and its motivation. Next, the reader gets to know the context of the project and the related problems.

1.5.1.1.2 Project description

The project description introduces historical notes and technical aspects required to understand the solution. This part is essential because it allows the reader to understand the terms used in the report and outlines the essential properties of the solution relevant to the stated problem.

Furthermore, the reader will learn about companies with an alternative or similar solution to a similar problem.

The mindset and the way the problem was approached by those who worked on the report are expressed in the "*initial solution*" part.

1.5.1.1.3 Design of the project

The design of the project part gets the reader familiar with some alternative solutions to the specified problem. In this chapter, the pros and cons of each variant are discussed, and the preferred solution is selected.

The project also discusses the working method.

1.5.1.1.4 Solution details

After the required information is obtained and analyzed to the best possible solution, the project discusses how the problem is to be mitigated in practice.

1.5.1.1.5 Results

Here, the effects of the proposed solution concerning the specified research question are discussed. The research question is answered and discussed. An evaluation of how the proposed solution meets the requirements is presented.

1.5.1.1.6 Discussion

This part is intended to discuss why the results are the way they are. Moreover, the pros and cons of the proposed solution are discussed.

1.5.1.1.7 Conclusion and further work

This chapter concludes the project goals and suggests further elaborations.

1.5.1.1.8 References

The reference list represents a collection of referenced sources.

2 Blockchain and supply chain

2.1 Theoretical background

The project is mainly based on the knowledge of blockchain, tools required for its implementation, and economic analysis of the implementation. First, the reader must get familiar with the terms used in the report. Thus, the following part will describe the respective definitions.

The term blockchain was first used in 1991[8]. The scientists Stuart Haber and W. Scott Stornetta described a solution for time-stamping digital documents. The system was based on a cryptographically secured chain of blocks to store the time-stamped documents. The goal was to prevent documents from backdating or tampering. Further elaboration of this concept led in 2004 to an allowance of several documents into one block.

However, in 2009 the first decentralized blockchain that introduced its currency was released. Satoshi Nakamoto released Bitcoin – a decentralized blockchain. That elaboration made blockchain look the way it is nowadays. Bitcoin is famous for its currency, which allows for trading without any centralized entity like a bank. In 2016, Satoshi Nakamoto's paper was popularized.

Bitcoin – a cryptocurrency that jumpstarted the entire industry

It is essential to mention the technology that popularized the concept of blockchain and thus allowed its further evolvement. As mentioned earlier, Bitcoin[9] was launched in 2009 by Satoshi Nakamoto and is the first decentralized peer-to-peer cryptocurrency based on a proof-of-work mechanism with a limited supply that would hinder inflation and provide a digital economy.

Initially, the project consisted of a dozen mining nodes and users. However, it has evolved into a trillion-dollar financial system that revolutionized finances, providing an alternative away from banks and governments.

Nowadays, Bitcoin is the most expensive[10][11] [transaction-wise blockchain. Being a pioneer in the new industry, investors often consider Bitcoin as the reserve currency of the cryptocurrency market, as the USD in the global stock market.

Overall, Bitcoin is the currency that started the entire industry and allowed further blockchain development. Many altcoins (e.g., Litecoin, Bitcoin Gold) got inspired by Bitcoin's success and attempted to provide a better version of it by copying the Bitcoin code. A multi-billion userbase made it the most secure network in the ecosystem. Thus, the influence of Bitcoin on the blockchain industry is enormous.

Blockchain technology is a database of records of transactions distributed, verified, and maintained by a network of computers worldwide. The crucial distinction between the centralized and regular system, e.g., banks, is that a large community supervises the records. No person has control over it or the privilege to modify a transaction history. In other words, the crucial difference is that blockchain reaches total decentralization.

The principle of blockchain functions involves the network of computers to determine the authenticity of a transaction via computer algorithms. Although the network of computers calculates the consensus algorithm, the nodes that vote do not belong to a blockchain. Once the transaction is signed, it is linked with the previous transactions forming a chain of transactions. This chain is called the blockchain.

Blockchain[8] works on the concept of a decentralized database where the copies of the database exist on multiple computers and are identical. These features ensure consistency, aliveness, and fault-tolerance.

A transaction in a blockchain consists of metadata on the transaction, inputs, and outputs[12].

Metadata

Metadata includes housekeeping information such as the size of a transaction, the number of inputs, lock time, and the number of outputs. The transaction's hash is present, serving as a unique identifier. That allows us to use hash pointers to reference a particular transaction. The lock time tells miners not to publish the transaction before the specified time is up. So, that acts as a safety valve to reassure the sender will be able to refund tokens if something goes wrong.

Inputs

First, all input fields have the same form. An input specifies the hash of a previous transaction and the index of the previous transaction's outputs that are being claimed.

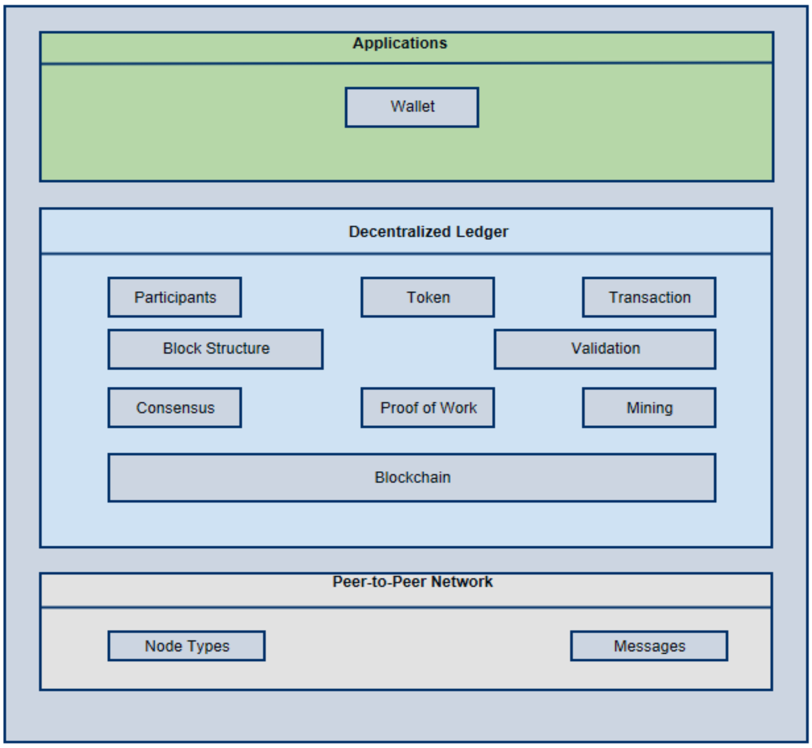
Outputs

Each output has only two fields: value which the sum of all the output values must be less than or equal to the sum of all the input values. If there is a difference between these two sums, a transaction fee goes to the miner who publishes the transaction. Plus, a script represents a hash encoded by the recipient's public key and the sender's public key.

Blockchain's architecture is split into three layers: application, decentralized ledger, and Peer-to-Peer Network (See Figure 1).

The application layer consists of a user interface and other application software, such as a wallet. The wallet software creates and stores both public and private keys enabling users to access their tokens.

A decentralized ledger represents a middle layer that confirms a consistent and tamper-proof global ledger. Here, transactions are grouped into blocks that are



cryptographically linked. To group blocks, each transaction must be signed by miners. The process of mining cryptocurrency corresponds to grouping transactions into a block added to the end of the current blockchain.

Peer-to-Peer network layer includes information on the node type, which plays different roles. Also, various massages are exchanged with the Decentralized Ledger.

Figure 1, Three layers in Blockchain

Figure 2 demonstrates the inside of a block[12]. Each transaction has its identifier and a reference to a previous transaction. Hash chain of blocks allows linking different blocks to one another. The hash tree is internal to each block and is a tree of transactions in the block.

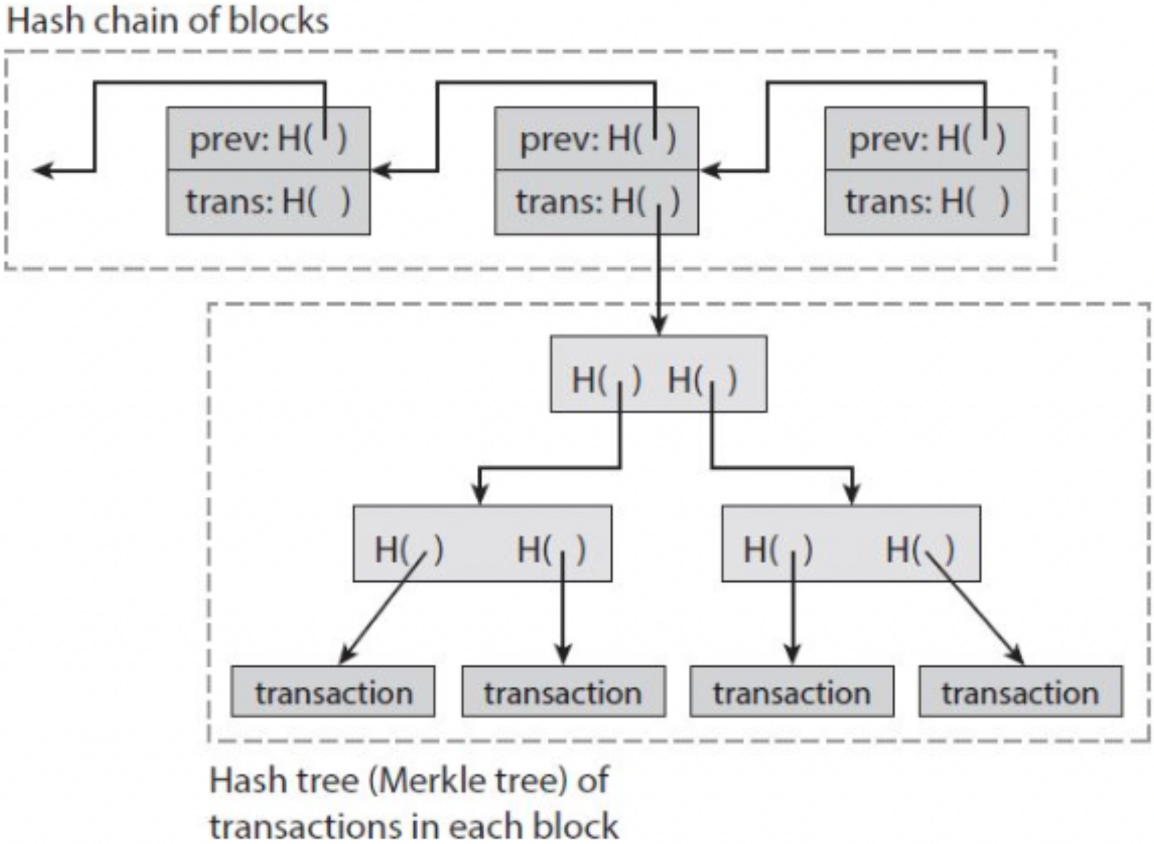


Figure 2, Blockchain, structure of blocks

We need to keep the transaction description in mind to understand the transaction verification process. So, the script mentioned in the *output* section is to be executed by miners. The script contains a public key of the referenced output transaction appended to the transaction's signature. The scripting language is stack-based. Thus, every instruction is executed only once, in a linear manner.

Furthermore, there are no loops. That makes it possible to define the upper bound for each transaction and how long it might take to run. Miners run these scripts, which arbitrary participants in the network submit. After the script is run, it might be successfully executed if there are no errors, or the whole transaction is invalid if there is an error.

However, blockchain is not an ideal solution. It is expensive to maintain and resource-sensitive since every node repeats a task to reach a consensus. The verification process heavily relies on the mining nodes; therefore, it might be a slow process because the inserted block requires all the nodes' responses.

Next, there are critics related to the environmental effect of the use of blockchain. Recent studies[13] estimated Bitcoin's electricity consumption, which correlates to the verification of transactions by the mining pool, to be between 20 and 80 TWh (terawatt/hour) annually. This was claimed to be 20 000 times more energy-intensive than the Visa's system. On the other hand, blockchain contributes to sustainability by offering opportunities to make existing consumption and production processes more transparent. For example, all paperwork might get digitalized through blockchain, or the risk of fraud and errors could reduce. Nevertheless, Bitcoin is only one of many applications of blockchain. Thus, the green footstep might be mitigated by swapping the original consensus algorithm to a less resource-intensive mechanism r switching to clean energy.

Furthermore, blockchain is prone to several attacks[14] that are less likely to happen if a blockchain has a vast number of pools of mining nodes that are not representing a considerable proportion of the entire mining pool (total hash rate).

In summarizing, blockchain mechanisms achieve decentralized security and trust. Avoiding the human factor in the transaction verification process improves data accuracy and integrity. The information that gets in a decent blockchain cannot be modified or updated but is available to everyone – transparent technology. On the other hand, maintaining a blockchain is costly for the environment.

2.2 Project roots

2.2.1 Related projects

There are several blockchain-based systems for storing production and supply chain data.

Norway in a Box [15] – is a company that exports Norwegian marine products abroad. The essential philosophy of the company is to make sure that its customers know what they are purchasing. Thus, Norway in a Box utilized blockchain to keep track of each step in the supply chain and make this data transparent and available for the customers. The facts find their way onto NiBchain[16] – a blockchain technology based on VeChain and developed by Norway in a Box. In other words, it is an elaborated blockchain for commercial purposes specifically.

The team contacted Norway in a Box to get hold of some insights on the pros and cons of operating a blockchain (Project Handbook, meeting 14). It turned out that the customers were interested in the authentic production information. Thus, the customer attitude towards the products improves. The utilization and development of such a system are costly and require quality human resources. Moreover, it is expensive to maintain a blockchain.

Next, Det Norske Veritas [17] offers the My Story product. My Story is a BaaS providing a product for data management of packaged goods. My Story Veritas uses VeChain as their Blockchain.

Amazon Managed Blockchain [18] is a service used to set up and manage scalable blockchain networks. Scalable blockchain networks allow the creation of private blockchains that are easily managed and highly scalable. Companies can use this service to build supply chain solutions. However, using a private blockchain results in a more centralized solution than a public blockchain.

2.2.2 Initial requirements

Ørn Software's perspective consists of the clue that this project will be a foundation for their continuing developments within the blockchain industry and a master project in the future. The company counts on us to bring a thorough analysis of possible alternatives to tracking production and logistic data, ensuring security and integrity. Ørn Software wants the entire fish production cycle to be quickly and securely shared between agencies that need the information. The idea is to develop a web service that runs independently where the data can be uploaded or retrieved via an API.

The project includes the estimation of approximate expenditures the implementation mentioned above may cost based on the data samples we receive from the firm, ensuring the average data flow frequency is known.

2.2.3 Initial solution - idea

The initial idea is based on the properties of a blockchain. A client can insert and read data via higher-level software. The software will include an underlying API, which is the essence of the project and responsible for the system to blockchain communication. Nevertheless, unlike a typical database, it is impossible to delete or modify data on the ledger. Thus, the solution mainly covers the pros and cons of utilizing the blockchain technologies brought further by Ørn Software into a complete system distributed to fish farms.

2.3 Limitations

The project is scaled down to focus on the research. The research will help the company decide whether such a system is worth implementing in real life. The blockchain sphere consists of several variants and technologies corresponding to different needs and standards. The potential time used for research is vast. The research in our project will be scaled down to blockchains that are widely used today and how we may mitigate fraud in the fish production process and enable end-to-end transparency.

The formulated research question "*To what extent can the challenges in the current fish farm supply chain be mitigated by using blockchain?*" allows keeping the scope on the main aspects of the investigation: problems in the current farm fish supply chain and to what extent the utilization of blockchain may mitigate them.

Although, there are limiting factors that affect us. Most importantly, time that we do not have. Thus, a decent version of a functional API may not be accomplished. Moreover, we cannot trust every source of information. Thus, we used to check the article's origin and alternative or contrast opinions to form a complete overview.

2.4 Resources

The project primarily relies on sources of information. Therefore, the leading resource we can use is reliable data. Nevertheless, the group members invest their efforts in forming the report and investigating the clause.

Communication with the Ørn Software's representative and University supervisor is persistent. They help us stay motivated and focused throughout the project. Weekly meetings keep us updated and let us perceive insider knowledge. Actual data samples and statistics we receive and discuss with the company's coordinator assist in writing a relevant and constructive report.

For the project's final phase, when a beta version of functional code is developed, capital is required for the testing period. Each transaction in a blockchain requires some tokens that have value in the fiat money.

Overall, we depend on all the resources mentioned above to help us get the report done.

2.5 Literature associated with a similar problem

Designing supply chain models with blockchain technology in the fishing industry in Indonesia[19] is an open-access article published in 2021 by the Department of Industrial Engineering, University of Surabaya, Raya Kalirungkut, Indonesia. Designing supply chain models with blockchain technology in the fishing industry in Indonesia[19] is an open-access article published in 2021 by the Department of Industrial Engineering, University of Surabaya, Raya Kalirungkut, Indonesia. The article's problem is highly relevant to our case: "*There are several challenges in the fishery supply chain, including non-transparent file recording, limited production infrastructure, and supporting facilities, high logistics costs, and long shipping time that leads to low product quality. The lack of an open supply chain allows many fishery business players to access and manipulate data; this is undoubtedly a violation of recognized legal and ethical standards. Illegal, unreported, and unregulated (IUU) activities, such as overfishing, human rights violations, and fraud, often occur in the fishing industry*" (first page, 1st-2nd paragraphs). Moreover, the article brings up an analysis of how can blockchain mitigates the current problems. Relevant diagrams and references to figures plus other documents make the article legitimate and give us an insight into how other researchers approach a similar problem.

Using blockchain to implement traceability in Fishery Value Chain[20] is an article that covers the theoretical part of the supply chain model implemented in real-life using blockchain technologies and the technical aspect of applying a blockchain solution. Using blockchain to implement traceability in Fishery Value Chain[20] is an article that covers the theoretical part of the supply chain model implemented in real-life using blockchain technologies and the technical aspect of applying a blockchain solution. This document is valuable because it reveals the legal side of the problem and mentions ISO (International Standards Organization), responsible for setting up rules for the food traceability system. Yet, a class diagram and code fragments are present, which, combined with the description, may give us a hint during the development of a beta version of the project idea.

BlockDiploma – Decentralizing the Norwegian Diploma Registry using Blockchain Technology [21] is a bachelor's thesis written by Thomas Reite. The stated problem covers current problems with falsified diplomas and how blockchain may mitigate them. This thesis is relevant because it is a bachelor's project based on an investigation of how blockchain technologies may ensure data integrity. Thus, it suggests the narration style and initial thoughts.

3 Introduction to prospective solutions

3.1 Alternative solutions

There are quite a lot of prospective solutions on the market. The solutions differ based on the approach, philosophy, governance, and mechanisms. First, it is desired to outline the requirements to select a relevant solution. Referencing the research question, the defined challenges in the farm fish production industry are fraud and uncertain customer attitudes. Therefore, the chosen mitigation strategy must provide a large extent of data integrity, data trustworthiness, and transparency.

Next, the regular data handling routines should be commented on before diving into blockchain solutions.

Centralized database

A centralized database is a type of database that is stored, located, and maintained at a single location only.

The database management system provides various optimization, integration, and security tools. On the other hand, it is costly to maintain and is a centralized system. No matter how secure the database is, there is a possibility that a single individual that knows how to avoid the hindrances may retrieve or update database content. Thus, such information cannot be considered trustworthy and be used for transparency purposes.

Such an approach does not provide absolute data integrity and cannot be used as a comprehensive solution.

Distributed (Decentralized) database management system

Distributed database [22] is also a type of database that consists of multiple databases spread across different physical locations and connected via a computer network. This type of database is more expensive than the centralized one but helps increase availability and concurrency.

Databases share the same concepts – the human factor may breach the data integrity needed to be achieved. Therefore, a regular data handling routine cannot be used to mitigate to a large extent the challenges in the supply chain of the farm fish production industry.

The following discussion will switch the focus to alternative blockchain solutions.

A massive industry of blockchain solutions mitigates many potential issues for various production spheres. First, the more general types of prospective solutions will be discussed.

Private VS Public blockchain

There are two alternatives: Public blockchain and Private blockchain. The overall result is the same: data we parse gets saved in a blockchain, ensuring data integrity and authenticity. On the other hand, the way the data find its way to a blockchain is different.

A private blockchain (permissioned blockchain) allows entry only for verified participants. The undergoing processes are pretty much the same as in a public blockchain. However, with one requirement: verification is also necessary either by the network (nodes that verify a transaction) or by a clearly defined set protocol implemented by the network. Overall, the significant distinction is that private blockchains control who can participate and who is allowed to execute the consensus and maintain the shared ledger[23]. Private blockchains are prone to some attacks too.

In the case of a farm fish production company, the data frequency needed to be stored in a blockchain is relatively small, and the speed of data processing/uploading is not crucial. Thus, data integrity and server stability take the first place. The essential property of a private blockchain is that all the nodes in a network are selected. Therefore, there is a confidentiality issue: blockchain might be attacked from the inside by the predefined players so that data can be corrupted. Furthermore, due to synthetical centralization (only one organization can write or read on a ledger), blocks can be deleted in some cases. Although it is expected to be secure and fast, there are no hidden costs, and it turns out cheaper. However, public blockchains are nearly immutable since their mining pools account for more nodes compared to private blockchains.

After selecting a blockchain type, two public blockchain alternatives that satisfy the given requirements and provide production-relevant features, such as smart contract, test net, and others, are considered.

3.1.1.1 Ethereum

Ethereum [24] is a general-purpose public blockchain. Today, it is the second biggest blockchain, measured by the market cap of its associated coin, Ether (ETH). Such a high ranking shows a good amount of trust in the blockchain. A general-purpose blockchain is intended to fulfill any kind of service that can take advantage of smart contracts. As of now, its consensus mechanism is Proof-of-Work.

Smart Contract

A smart contract is a self-executing contract with the terms of the agreement between buyer and seller being directly written into lines of code[25]. The contract exists across a blockchain network. The code controls the execution, and transactions remain trackable and unreversible. The prominent feature is that a smart contract allows trusted transactions and agreements to be processed among anonymous parties without needing a central authority, legal system, or external enforcement mechanism.

Proof of Work (PoW)

PoW is a cryptographic proof where one miner proves to others that a cryptographical problem is solved by computational effort. The miners compete to append new blocks to the blockchain to earn cryptocurrency as a reward. The other miners would reject an altered version of the blockchain, making the altered version worthless. Experts criticize PoW for being very energy consuming and causing a lot of electricity waste[26].

Proof of Stake (PoS)

The Ethereum team plans to switch from PoW to the PoS consensus mechanism. This update goes under the name Ethereum 2.0. Yet, the transformation has been postponed several times, and it is unknown when the switch will happen.

A PoS-based blockchain does not rely on miners. On the contrary, the validators, called VeChain stakers, are selected in proportion to their staked holdings. A minimum of 32 ETH is needed to become a staker. The validators are also responsible for checking and confirming blocks they do not create themselves. A staker can lose a proportion of their stake according to the seriousness of unwanted behavior to promote good behavior.

Ethereum 2.0 is believed to reduce Ethereum's energy consumption significantly. Coin market cap estimates a reduction of 99.95% [27].

Transactions

The average time for a new block appended to the blockchain is roughly 13 seconds. This has been stable for years. In theory, this means that a new transaction and data can be inserted every 13 seconds. However, the most who pay are chosen to decide which transaction to put on the block. This results in competition among transaction senders, and those who pay the highest transaction fees win. On May 04, the average transaction fee was 1.67 USD [28].

Overall, the Ethereum blockchain is a decent alternative that provides complete data integrity and service availability due to the substantial entire mining pool. A smart contract may be implemented the way that data is uploaded or retrieved easily, securely, and fast enough. The only throwback is the economy factor – each transaction is costly.

3.1.1.2 VeChain

VeChain [29] is a project that manages the VeChainThor blockchain. This blockchain platform is designed to enhance supply chain management and business processes. The goal is to streamline these processes using distributed ledger technology. Furthermore, VeChain uses the Proof of Authority consensus mechanism and two tokens: VeChain token (VET) and VeChain Thor Energy (VTHO), as a smart contract layer. The blockchain plans to become a leading platform for conducting transactions between the internet of things (IoT), which is essential when eliminating the human factor and creating a trustworthy infrastructure around a farm fish production company.

Proof of Authority (PoA)

VeChain's consensus mechanism is called Proof-of-Authority. PoA allows authorized nodes, called Authority Master nodes (AM), to participate in the consensus algorithm. The authorization process includes the Know Your Customer approach [30] - a set of standards used to verify customers, their risk profiles, and their financial profile. All the AMs are registered in a whitelist, and a smart contract handles operations on the whitelist. A new AM is added to the whitelist after the VeChain Steering Committee [31] members approve the new AM through multi-signature authorization. Nowadays, the blockchain has 101 AMs providing the consensus mechanism[32]. All mining nodes have an equal chance of publishing a new block in a blockchain. In comparison to Proof of Stake and Proof of Work, all AMs have an equal chance of being rewarded. However, the algorithm lacks an effective approach to manipulating newly added blocks to handle potential nodes.

Currently, VeChain Steering Committee is in control of developing a new version of PoA, called Proof of Authority 2.0. The new mechanism addresses the issues mentioned above and further improvements.

The consequences of high prices and the strict practice of the Know-Your-Customer approach limit the number of nodes. A total of 101 authority nodes is a relatively low number compared to other public blockchains.

Two-token design

A proper economic model is one of the fundamental elements of a blockchain. One of the significant blockchain downsides is the cost of using blockchain due to the volatility of cryptocurrencies. To encounter the problem, VeChain designed a bi-token system[33] that consists of two tokens, namely, VET and VTHO. The former is to enable rapid value circulation within the VeThor ecosystem. The latter represents the underlying cost of using VeThor (Gas) and will be consumed once the blockchain operations are performed. The design also allows VTHO to be generated with a constant speed from just holding VET. Overall, the bi-token principle makes it possible to adjust the per-transaction price by reducing the minimum amount of VTHO needed and increasing the generation rate of VTHO per VET. This way, the transaction fees stay predictable and stable.

VeChain happens to be cheaper to operate compared to Ethereum. The average transaction fee in Ethereum is estimated to be about 1.67 USD. The real-life tests show that uploading an actual JSON file from Ørn Software to VeThor costs 2.99 VTHO, equivalent to 0.006 USD (as of May 04, 2022). See figure 3 for the transaction details.

The bi-token design of VeChain is similar to Ethereum's concept. A crucial distinction is that VeChain's token system was devised for effective governance and a predictable economic model. Ethereum lacks such a model because the price of ether, its native token, is volatile – the developers must estimate the amount of ether required for a transaction. If the estimate is incorrect, the transaction fails.

Status	Success ≥ 12 Confirmations
ID	0x52443b87e1f0e5e5e241c6a8df0e4740fee90e2cf8653731a0679fb71cd11575
Timestamp	06.05.2022, 13:37:00
Clauses	1
Total Transfer	0,00 VET
Gas Used	298 751/313 751 price coef 0
Origin	0x240edd80b222AA55cCfEC327526B7F41e40b5dD0
Fee	2,99 VTHO paid by **Origin**
Size	1475 B
Reward	0,90 VTHO
BlockRef	12 180 567 (0x00b9dc57a527c548)
Expiration	32 blocks
Nonce	0x3b8af5b20836e5c9

Figure 3, successful transaction in the VeThor blockchain. Link to the transaction: *https://explore-testnet.vechain.org/transactions/0x52443b87e1f0e5e5e241c6a8df0e4740fee90e2cf8653731a0679fb71cd11575#info*

In summarizing, VeChain provides a full spectrum of required features – good data integrity, availability of service, and predictable and reliable transaction fees, thanks to the bi-token design. Furthermore, it helps achieve full automatization and autonomy of the program Ørn Software is planning to develop. VeChain makes it possible to use IoT, thus integrating RFID tags and sensors in the system. The tags and sensors broadcast vital information onto the blockchain that authorized stakeholders can access in real-time. Implementing the internet of things eliminates the human factor, ensures product authenticity, makes the production data trustworthy and transparent, and facilitates data handling.

In the end, the business-oriented VeChain platform delivers a greater variety of tools and features relevant to the farm fish production industry. Stable fee rates and IoT possibilities make VeChain an appropriate option that has the potential to mitigate the challenges in the fish production industry.

3.1.2 Implementation approach 1 – without a smart contract

The first alternative solution will utilize the VeChainThor blockchain and a centralized database (See Figure 4). The database will store the necessary information to find and retrieve data, for example, IDs.

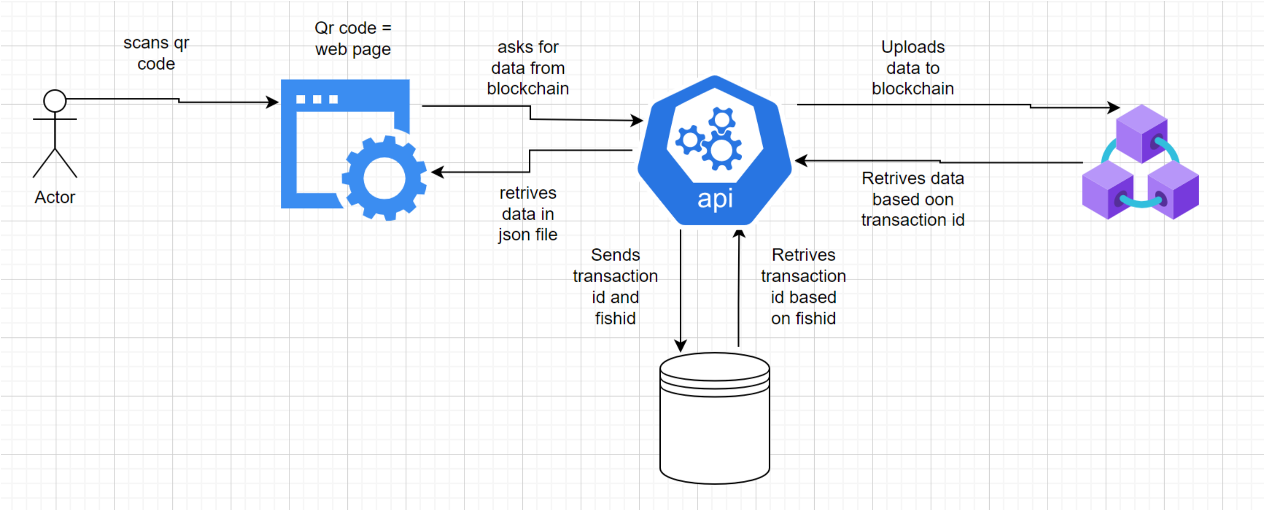


Figure 4, Solution with database architecture

The database used here provides a single central point of failure. The security of this solution heavily depends on the implementation of the database — the database stores critical information to retrieve the correct data from the blockchain. Therefore, the database provides a single point of failure, increases the cost of a human factor, and might break the purpose of having a blockchain-backed API.

3.1.3 Implementation approach 2 – with a smart contract

It is feasible for the API to rely only on the blockchain for data storage and retrieval with smart contracts. The idea is to let the API interact with the smart contract. The smart contract will store and provide the functions necessary to store data and retrieve data corresponding to specific IDs.

3.1.4 Implementation approach 3 – with a smart contract and hashed data

Similar to Alternative 2. This approach also uses a smart contract to store IDs and data on the blockchain. However, to reduce the amount of data inserted in the blockchain, this solution will just store the hash value of that data with a fixed number of bits. The pre-hashed data will be stored in a database. The hash value will be compared to the one stored with the smart contract to prove the data integrity.

3.2 Proposed approach

Approach two and three provide solutions where all necessary data is stored in the blockchain. Alternative one depends on the security of the database. Therefore alternatives

2 and 3 provide better safety. Since VeChain is relatively cheap, approach 2 is a good solution combined with the VeChainThor blockchain. It provides the best data integrity and service availability but relies only on the blockchain.

Moreover, VeChain features allow efficient use of this approach because of a smart contract. The alternative does not require storage solutions other than the blockchain, while alternatives one and three do. This reduces costs and the amount of the overall complexity. Implementing the Ethereum blockchain would make more sense to reduce the fees by uploading less data (the hash). However, since operating a database also has its expenses, the small savings of such an approach will not be worth it.

3.3 Research method

For proper analysis and research, the project requires a massive array of data relevant to a complex and new topic - blockchain technologies. Since the essence of the project is to perform research, data is the most valuable source for the investigation.

There are several bases of valuable information for us: online articles on blockchain technology, web pages of the solutions we consider relevant, textbooks, journal articles, documentation, and source code of similar projects.

First, the sources of information must be checked for bias. Thus, we would always inspect the references and make sure whether an article/web page is worth being trusted or not. We select articles that correspond to our area of interest. The essence of relevant information reaches into our documents and is applied in the analysis. Nevertheless, one source of data is not enough. The information must be compared, weighed, and understood. Therefore, we never stop at the first link and keep browsing further, acquiring more knowledge. Additionally, we want to read about blockchain principles, how the technology works, what it persuades, and its purpose. Next, we go into detail on the blockchain's mechanisms and problems.

Web pages of the solutions we stick to (e.g., Vechain) are relevant because they represent the primary source of documentation we can trust. Although, there is always an exaggeration because it is intended to attract customers. Respectively, we check other sources for a detailed comparison of the rivalry alternatives and a list of cons and pros.

Source code of existing blockchain projects helps us get an insight into how the actual implementation may be accomplished. Moreover, the code gives us an idea of what technologies we should use.

3.4 Development method

The development of a blockchain-based API mainly relies on the knowledge of programming languages, tools for compiling the code, and a testing environment.

For example, the programming languages Solidity and Python have been used.

Solidity [34] is a high-level programming language responsible for implementing smart contracts – the way the API may talk to a blockchain.

Python [35] is also a high-level, interpreted, general-purpose programming language. It plays a communicator's role in processing requests and responding to them in the API.

Next, Remix – Ethereum IDE [36] is used to compile and test the Solidity code. Remix IDE is an open-source web/desktop application with modules for testing, debugging, and deploying smart contracts.

The testing tool also has significant importance because this way, we identify flaws in our program and get a chance to fix them. The program to test whether the API proceeds requests the intended way is Postman [37]. Postman is an API platform for building and testing APIs.

Moreover, the development phase involves team members' collaboration. The correct version control tool would help keep each team member informed on what is done and what must be done. Furthermore, it is a way to store code on the cloud for better availability. The version control tool the development relies on is GitHub [38]. It is a cloud-based service that helps store and manage code, as well as track and control changes to the code.

4 Proof of Concept

A Proof-of-Concept solution is provided and explained here to show that the chosen solution from chapter 3.2 is feasible. This solution only implements the minimum requirements found in the appendix titled "requirements_document." The solution is not meant to be used for production. Additional functionality may need to be added, such as more detailed logging and identification management.

The API has been tested on a test net provided by VeChain Foundation. The test net only simulates the blockchain, VechainThor. It is offered to be used for testing and experimenting. The transaction fees on the test net are paid by coins that do not have a value and are provided for free.

4.1 Architecture

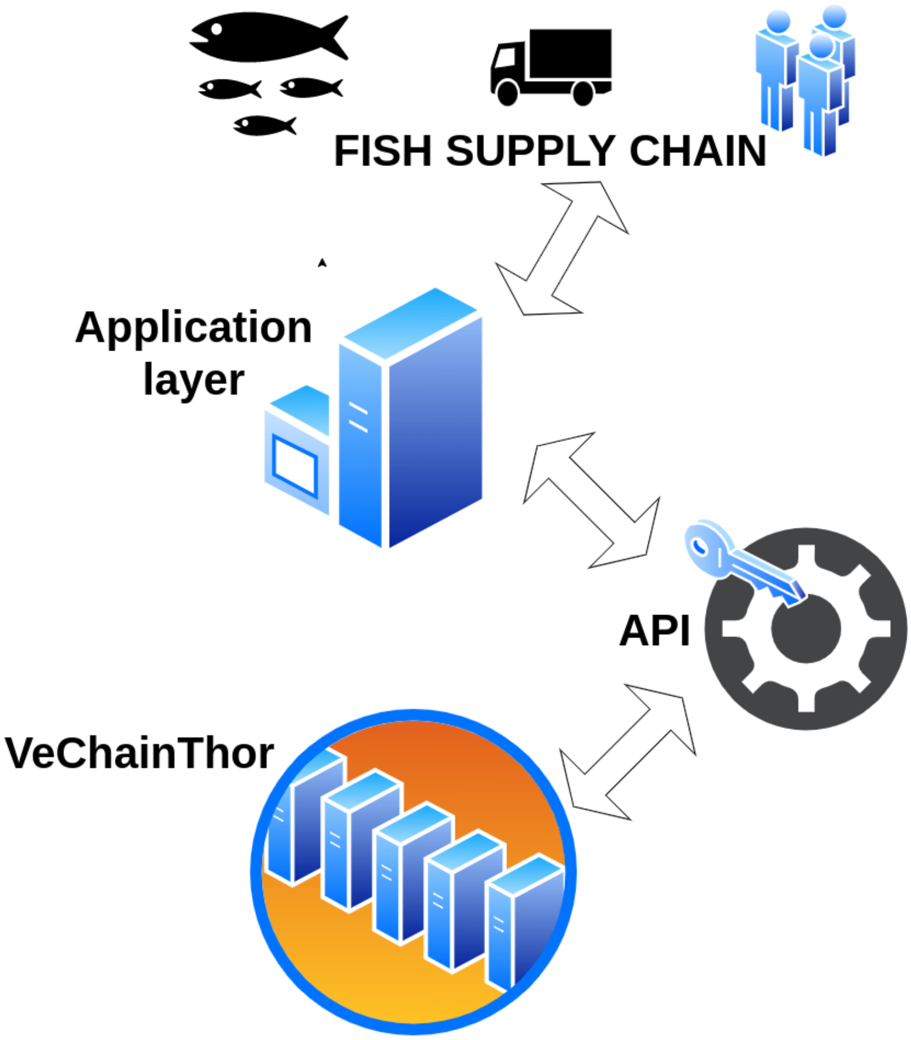


Figure 5, architecture prototype

The architecture displayed in Figure 5 shows the relationships between the blockchain, the API, and the application layer that provides the services to the customers.

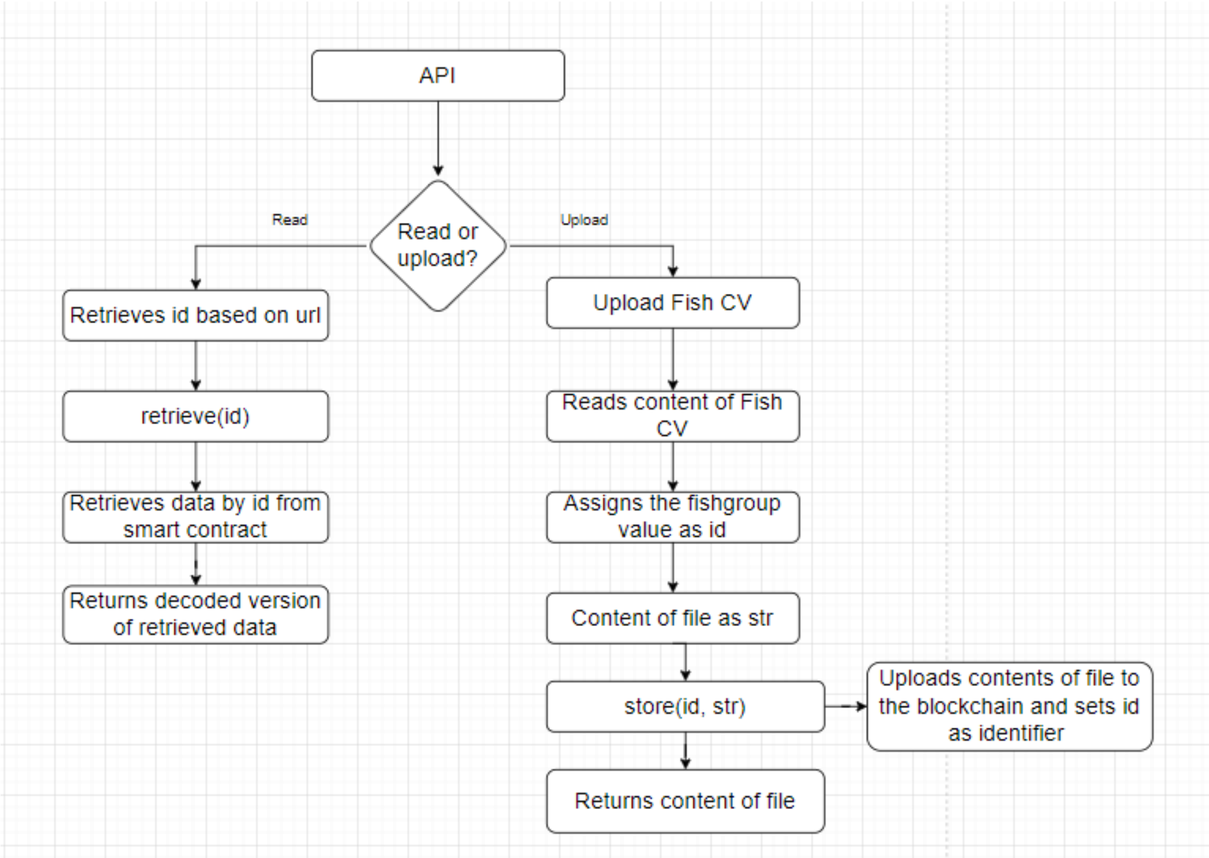


Figure 6, API flow diagram

Figure 6 illustrates the flow diagram for the developed API. The flow diagram represents an algorithm the API follows to solve tasks. The flowchart is helpful for understanding dynamic relationships in the system.

4.2 Private key management

In order to interact with the blockchain and pay transaction fees, the API needs to have access to the private key which deploys the smart contract. The private key needs to be stored safely and read securely. The private key management reduces unauthorized access to the smart contract and keeps the coins associated with the private key safe.

In this case, the private key will be stored in the filesystem on the server. It means that if the source code of the API is available, the key will remain unknown. The security of the host server determines the security of the private key.

4.3 API

The creation of the API stateless was accomplished by following the Represential state transfer (REST). REST is a set of guidelines and an architectural style that is widely accepted.

HTTP METHOD	Endpoint	Description
Get	/fish/<fish_id>	Get information about the fish
Post	/fish	Create a fish cv

Table 1, API HTTP methods

The Post method is responsible for uploading new data to the blockchain. The API will retrieve the ID from the JSON file (See Table 1).

The Get method helps retrieve data based on the specified ID as a parameter in the URL (See Table 1).

Notice that the API will not provide the HTTP method. The reason for this is explained in the upcoming chapter.

Smart contract

In order to save the ID to data relation effectively, the smart contract uses mapping, also called key-value storage. Mappings are an effective way to store data mapped by a key. They do not require much computational effort. Thus usage requires as little gas as possible. Code fragment 1 demonstrates the store function. Only the deployer of the smart contract is eligible for storing new data.

```
function store (string memory _id, string memory _jsonElement) external {
      require(msg.sender == owner);
      data[_id] =_jsonElement;
}
```

Code fragment 1, the Store function of the smart contract

The other significant part of the smart contract is the retrieve function (See Code fragment 2). The function reads data corresponding to a given key.

```
function retrieve(string memory _id) external view returns (string memory) {
return data[_id];
```

```
}
```

Code fragment 2, the Retrieve function of the smart contract

API

The following segment of code (See Code fragment 2) is responsible for processing requests and responding to the requests. The code is written in Python. The Flask framework is used for the essential API functions.

```
"""
/upload
Read the content of the uploaded file
Stores the content of the file on VeChain with id/fish group as the identifier
Returns the content of the file
"""
@app.route('/upload', methods=['POST'])
def upload():
    if request.method == 'POST':
        f = request.files['file']
        f.save(f.filename)
        file = open(f.filename, "r")
        contents = file.read()
        dictionary = ast.literal_eval(contents)
        file.close()
        id = dictionary["Fish group"]
        s = str(dictionary)
        store(id, s)
        return dictionary

"""
Retrieves information based on ID specified as an argument in the URL
"""
@app.route('/fish', methods=['GET'])
def api_id():
    #get json data on fish based on ID
    if 'id' in request.args:
        id = request.args['id']
    else:
        return "Error: No ID field provided. Please specify an id."

```

```
    s = retrieve(id)
    res = ast.literal_eval(s)
    return res
"""
Defining the retrieve function from the smart contract
Takes one parameter (id)
Returns the decoded version of the retrieved data
"""
def retrieve(id):
    res = connector.call(
        caller='0x240edd80b222AA55cCfEC327526B7F41e40b5dD0',
        contract=_contract,
        func_name="retrieve",
        func_params=[id],
        to=_contract_addr,
    )
    return res['decoded']['0']

"""
Defining the store function from the smart contract
Takes two parameters (id) and (str)
Uploads given (str) to the blockchain
"""
def store(id, str):
    send = connector.transact(_wallet, _contract, "store", [id, str], to=_contract_addr)
    print(send)
```

Code fragment 3, the API code

A smart contract is presented with the **retrieve** function and the **store** functions in the final solution. The retrieve function is intended to contact the blockchain and request data with the respective ID. The store function stores the given data on the VeThor blockchain.

For the API solution, the framework Flask is used, which is a microframework used to build web applications and REST APIs[39]. The solution accounts for two post and two get methods. The post request in /upload allows submitting JSON files and uploads them to the VeThor blockchain. Get request in /fish takes a given ID and retrieves data based on the ID.

5 Results

After defining requirements for the project and developing an API, it is possible to conduct an evaluation of the created technology and whether it meets the requirements or not.

However, an economic estimation for the solution will be presented before that. Each FishGroup object is transmitted as a string representing a JSON file. One transaction would cost 2.99 VTHO (see Figure 3 for details). The average transaction frequency is unknown; therefore, the estimations refer to the number 4000. This number of queries should be sufficient to capture all the events around a fish farm, including internal activities and various supply chain milestones. By a simple mathematical equation, we may produce the cost analysis:

$$2.99 * 4000 = 11960\ (VTHO)$$

The estimated price, which is relevant on May 06, 2022, is 35.21 USD. The result represents a relatively minor figure and might not reflect reality. Nevertheless, the real-life expenditures are not expected to vary too much from the presented calculations. The estimation is based on an actual data sample from a fish farm. VeChain offers a thorough test net that imitates genuine transactions and provides accurate figures. Furthermore, the VeChainThor blockchain transaction fees remain stable over time due to the efficient two-token design.

5.1 Evaluation method

The project is evaluated by linking the stated problems to the accomplished research outcomes and the proposed solution. First, a brief throwback to the problems in the farm fish production industry and the suggested solution may be necessary.

The current problems include a lack of security and thus an uncertain customer attitude. These problems mainly refer to the exported farm fish products as a black market may exist in the countries where the export goes. The black market may involve fraud like faking Norwegian fish products – selling low-quality fish by Norwegian brands or other machinations that affect the Norwegian producers. Nevertheless, such a scheme harms the reputation of Norwegian brands and affects the end customers' attitude towards Norwegian marine products.

The goal is to create an API that would utilize technology for increased data integrity and allow data flow both ways.

The proposed solution suggests using the public blockchain VeChainThor from VeChain, which offers decent security and plenty of production-relevant features.

Furthermore, the evaluation of the API is processed via the integrated debugging/testing tools provided by Remix – Ethereum IDE and Postman. These tools help to ensure the quality of the product and define whether it satisfies the product-related requirements or not.

5.2 Results of evaluation

The utilization of the VeChainThor blockchain conforms with the requirements to a large extent. The research outcomes tell that the blockchain is an excellent opportunity to fulfill Ørn Software's desires. The blockchain mechanisms guarantee data integrity, transparency, and accessible data traceability. All the mentioned aspects contribute to dealing with the known problems regarding Norwegian farm fish production and export.

The VeChain blockchain mechanism allows securing and verifying the production data and the producer (KYC approach). A not honest producer cannot replicate this process. Thus, end customers will be able to acquire information on the entire life and transportation cycle of a particular fish product. Only authentic products can have a QR code to present trustworthy, blockchain-supported information. The end customer will be sure that the presented information is not modified and comes from a legitimate source.

As a result, not honest producers will no longer be able to replicate Norwegian products entirely. Authentic products will be easily distinguishable. Moreover, the solution involves the utilization of blockchain and its combination with sensors and RFID tags. IoT allows eliminating the human factor and any local cheating during production. No individual involvement is needed as the data from sensors or tags get onto the blockchain autonomously.

Furthermore, the developed API and smart contract function as expected. Thorough testing through Remix IDE shows that the methods coded in the smart contract work, and the smart contract is deployable.

5.3 Project results

The evaluation allows answering the head research question: *To what extent can the challenges in the current fish farm supply chain be mitigated by using blockchain?* The answer is – to a large extent. Implementing the VeChain blockchain to the data handling routine minimizes the human factor, which is a source of all evil and fraud, and allows a relatively cheap and secure data storage and further development of the system into a robust autonomous solution for fish farms. Supply chain issues can be defined precisely and fast. Increased transparency of reliable data may potentially attract new customers and improve customer relationships both inside the country and abroad.

Moreover, blockchain may stimulate sales due to marketing. Marketing includes advertisement, selling, and delivering products to consumers. It refers to all activities a company does to sell products. It is strongly tied to customer relationships. In this sense, blockchain is a comprehensive source for marketing as well as transparency and trust. Furthermore, that is why it has recently become one of the most rapidly growing technologies across various industries [40].

On the other hand, the solution harms the environment and is costly to develop. Nevertheless, the blockchain industry persuades to reduce its environmental footprint and contribute to sustainability by offering opportunities to make existing consumption and production processes more transparent.

5.4 Project implementation

The project is intended to present thorough research on the best possible way to implement blockchain technology in a farm fish production company. Data integrity and transparency are the crucial elements of the solution.

The functional API is only a proof of concept and a minor part of a potential blockchain-based system. The API is responsible for two ways data flow between a client - a higher-level system and a blockchain. The API and the coded smart contract might be enhanced in the future and use other methods, such as retrieving ranges of data or retrieving information selectively.

The higher-level system will implement features of the API responsible for blockchain communication. The application layer will prepare and send requests processed by the API. The selected solution makes it possible to integrate the internet of things (IoT) to achieve the finest autonomy and security.

The implementation of the higher-level system is expected to be expensive. Therefore, the financial result might be noticed only in the long run. Instead, security and data transparency are enforced right after deploying the product in production.

6 Discussion

The chosen approach made it possible to focus mainly on the research. That conforms to the project requirements. Nevertheless, the alternative blockchains discussion is based on a relatively small subset of the available blockchains. However, other blockchains have been tested publicly for a shorter period, have a lower market cap, and thus offer lower security and robustness. Further investigation would be preferable. The additional research may discuss other blockchains or the possibility of developing a new blockchain that is built upon an existing one. This solution is flexible and customizable to the given requirements. However, it increases development expenditures dramatically, for example, following the example of Norway in a Box, which developed NibChain upon the VeChainThor blockchain.

In order to prove that the research is feasible, the project method included the development of a Proof of Concept. The time it took to develop the API could have been used for broader research of technology backbones instead.

The project result represents a summary of the accomplished research. The problem and requirements are mentioned throughout the report. The result includes answering the research question and proposing a solution that provides excellent integration, scalability, and features fulfilling the requirements and the farm fish production industry needs.

The end product accounts for the research and the API. The report discusses alternative technologies that would fulfill the requirements. Namely, Ørn Software expected thorough research to be produced that lists prospective blockchain-based solutions to get the entire overview of logistics and production data, ensuring data integrity, transparency, and security. The solution that does it to the greatest extent is selected. The negative aspects of the solution also contribute to the soberness of the investigation and provide an alternative perspective. For example, the strengths of the proposed solution entail the fulfilled requirements, an economy estimation with a real-life data sample, and a comparison of various alternatives from the perspective of confronting the requirements. On the other hand, the implementation of the API lacks functionality and is meant only to prove the concept.

Next, the chosen working method facilitated the learning process. It allowed optimizing and distributing workload, sharing, and discussing the acquired knowledge.

When it comes to the development, a lack of time caused omitting Agile methodologies to help manage the development phase more optimally, achieving a finer API and increased collaboration.

The project has shown that the developed API can rely only on blockchains for storing data from the fish supply chain without involving databases. It handles data forwarding and access between the underlying blockchain and a higher-level application system. Additionally, a mechanism for handling authentication and authorization needs to be applied to fit in with Ørn Software's business model and provide better security.

The application layer will handle the relations between different IDs on uploaded data and the correlations with existing data in the given Proof of Concept. Appropriate changes need to be made in the code if adding this to the API.

The costs associated with a blockchain solution have been outlined. Choosing a blockchain storing approach like involving databases or relying on a smart contract (See chapters 3.1.2, 3.1.3, and 3.1.4) results in various maintenance costs. Another aspect was to specify the environmental effects. For the most part, the investigation results show the advantages of switching the Proof of Work consensus mechanism, thus showing one of the significant benefits of using another algorithm.

7 Conclusion and further work

The authors of this report share the opinion that the research goals have been met entirely. A few blockchain-based approaches have been considered and discussed concerning the stated research question. Furthermore, alternative blockchains have been examined and compared, outlining the best suitable choice for Norway's farm fish production industry. The tests on financial estimation suggest whether the utilization of some blockchains is reasonable or not.

The developed API proved the concept of utilizing the VeChainThor blockchain and sticking to the approach where a smart contract is a central element of storing/retrieving data.

Next, further research should be centered on developing a blockchain upon another blockchain to deliver the best possible service. An analysis should be applied to define the complexity of such an approach, the efforts it might require, and whether it is worth the sweats or not. The design of the application layer can be studied to present a decent and complete product. It may involve the implementation of IoT.

However, the functionality of both the smart contract and the API may be enhanced and populated with various methods. Such functionality helps distribute the workload between the higher-level system and the API.

A security policy and security requirements should be defined for the entire system. Protected communication between the application layer and the API is one of the most important factors ensuring service availability and robustness.

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9 Attachments

All of the following documents can be found in the submission attachments.

9.1 Vision document

9.2 Requirements specification document

9.3 System documentation document

9.4 Project handbook

9.5 Source code