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Implementing a Wine Traceability System as an Ethereum Distributed Application

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Abstract

Undoubtedly, supply chain operations management is becoming more demanding for product tracing due to regulatory frameworks and fraudulent incidents. Therefore, rapidly increasing challenges arise in transparency, tracking, and data storage in many product supply chains. Especially in the case of wine supply chains, timely and accurate traceability is vital, as this industry is plagued by frequent counterfeiting activities that pose significant risks to both consumer health and business viability and prosperity. Blockchain technology can serve as a crucial aid for constructing modern wine supply chains by offering increased security and trust between all supply chain stakeholders. This paper presents a framework for developing Ethereum-based Blockchain distributed applications and demonstrates a use case for creating such an application for a wine traceability system. The developed distributed application enables the participants of the wine supply chain to track wines by adding and monitoring data about each individual wine bottle's production, fermentation, aging, bottling, and distribution, providing full supervision of its production and distribution. The demonstrated use case shows the different types of users and their interactions with the system to fully comprehend the advantages it can offer to all supply chain stakeholders as well as consumers and controlling authorities.

Keywords
Traceability, Blockchain, Ethereum, Distributed Application, Wine Supply Chain

1. Introduction

In recent years, blockchain technology has drastically advanced and begun to be implemented in decentralized applications (Dapps) (Wu et al. 2021). This technology enables developers and businesses to create Dapps that solve challenges in trust and security (Udokwu and Norta 2021). This is also why Blockchain is gradually penetrating more and more parts of daily life (Wang et al. 2019). One of Blockchain's more recent and valuable solutions is supporting product supply chain operations (Dutta et al. 2020). In particular, this technology can aid the traceability of severely counterfeited products such as alcoholic drinks and wines. Traceability refers to the ability to both track and trace a product's origin throughout its manufacturing and distribution (Hastig and Sodhi 2020; Song et al. 2019). Alcoholic drinks and wines are a peculiar set of products severely afflicted by persistent counterfeiting activities that jeopardize companies' reputations and put customers' health at great risk (Kamiloglu 2019).

In order to survive and grow in a globally networked economy, companies have understood that the performance of their operations and their profitability greatly depend on effective, ordered, and efficient supply chain operations. However, in this global market, it is becoming increasingly difficult to effectively trace the whole journey of products due to the increasing complexity of their supply networks (Patidar et al. 2021). Therefore, robust supply chain traceability is required for improved oversight and the creation of competitive advantages. Integrating blockchain technology into the traceability of the wine supply chain can offer multiple benefits, as its characteristics enable it to strengthen the immutability of the entire process. Blockchain can also guarantee authenticity, provide timely responses to potential problems, and, in a broader context, enable the secure and trusty transactions between all supply chain stakeholders (Shou et al. 2021; Hastig and Sodhi 2020).

Numerous advantages are realized from effective supply chain traceability. Initially, it helps the prompt and effective recall of products in the event of faulty batches. This helps to identify the errors that contributed to the failure, boosting the overall supply chain's efficiency and preventing similar mistakes in future occurrences (Razak et al. 2021).

Additionally, it enhances inventory management and facilitates safe transport. It preserves the reputation of businesses by providing consumers with the necessary knowledge and improving their trust in the organization, so increasing their willingness to pay more for a safer product (Wamba and Queiroz 2020). All of these factors contribute to a decrease in expenses, a rise in earnings, and an improvement in the product's quality.

Today's wine supply chains are convoluted and complicated, causing them to have several distinct nodes. Therefore, each node needs to maintain its own database, resulting in partially overlapping and inconsistent entries. This lack of trust and creditworthiness makes this supply chain model susceptible to data manipulation, counterfeiters' interventions, and final product falsifications. All these problems can severely affect the consumers' health and the stakeholders' reputation and viability (Stranieri et al. 2018). Concurrently, the rapid detection, treatment, and elimination of faulty or counterfeit products is a significant challenge for today's wine supply chains. This is because the data is encountered individually at each member node of the supply chain. It is also very time-consuming to create a macroscopic picture that will solve the resulting traceability problems (Arvanitoyannis 2022).

Blockchain technology, particularly the Ethereum platform, allows the development of decentralized applications so stakeholders can overcome the problems encountered in traditional wine supply chains, such as data volatility, untimely product traceability, and lack of trust between all members. Therefore, such implementations can offer tangible solutions, reducing production costs, increasing efficiency, and providing the maximum possible information (Tokkozhina et al. 2022). Decentralized applications have already been successfully developed for the traceability of beer (Irlandscraftbeers 2007), whiskey (Adelphidistillery 2022; Scotchwhisky 2019) as well as wine (Genuineway 2022). This research belongs to the last-mentioned category and is part of a research project aiming to deal with counterfeiting in the wine supply chain. This research aims to briefly present a framework for developing Dapps and deploying them in the Ethereum Mainnet and also demonstrate a use case for a wine traceability Dapp that is developed as part of our research project. Therefore, the objectives of the research concern presenting a clear framework for developing Dapps, explaining the necessary technologies, and, through a case study, demonstrating how the users of such a system can interact with it.

The difference between this research and similar existing ones is that it tries to holistically tackle the problem of wine counterfeiting by addressing all the related critical points. As related research shows (Adamashvili et al. 2021; Arvanitoyannis 2022; Cuel & Cangelosi 2020; Danese et al. 2021; Luzzani et al. 2021; Tokkozhina et al. 2022), blockchain systems have a great potential to prevent counterfeiting in the wine supply chain as they offer a secure and transparent way for supply chain traceability. In particular, the developed Dapp offers:

- Secure data sharing in the Ethereum MainNet, the most popular blockchain network
- Collection of real-time data from Internet of Things (IoT) sensors and enterprise systems that are streamed directly to the blockchain network, and
- Reliable and secure data access through non-replicable product labels

In the remainder of the paper, the framework for developing Dapps is first presented, including the required technologies for successfully deploying Dapps in the Ethereum Mainnet. Next, a use case is presented, focusing on the wine traceability Dapp, demonstrating the interaction of users with it, and an example of an indicative user interface for the end-consumers. Finally, the conclusions of the research are outlined, and future research objectives are presented.

2. Framework for Developing Ethereum-based Dapps

Through Ethereum and the smart contracts it provides, decentralized applications can be created, which offer complete transparency and trust thanks to their decentralized nature while keeping data inviolable and immutable. A Dapp is an application based on a decentralized network that combines a smart contract and a frontend user interface (UI). This section presents a general framework that does not focus on individual tools and provides the basic structure for each developer to build an Ethereum-based Dapp. This is possible because Ethereum itself does not limit its functionality and the development of its various applications to specific sequences and tool uses so that the bigger picture can be provided.

Before analyzing, step by step, how a developer can create the Dapp, it is crucial to understand that in Blockchains, the entered data remain unchanged. The immutability of Blockchain's data is one of its main comparative advantages over centralized systems since it ensures its integrity and trust among all involved stakeholders. However, this can

simultaneously become a brake for a developer since what is uploaded to the Blockchain cannot be modified. Therefore, it is essential that any smart contract, and by extension any Dapp, is developed and extensively tested on a Testnet. For Testnet, developers can select either a simulation of the Ethereum Blockchain locally or some public network in which no real Ethereum coins (Ethers) need to be used for transactions. This can significantly reduce the cost of an entire Dapp and help the developer build the app properly so that all stakeholders related to it are satisfied.

The first step in designing the application is to design it at a cognitive level and identify the weaknesses/needs it should aim to cover. This is a primary step in developing any application, whether in the blockchain environment or in any centralized system. As in any other application, it is important to create a specific business model for the Dapp, in which the main activities of the application, its resources, its value proposition, cost structure, revenue streams as well as all other elements, with which it can be determined whether the application will be functional and financially viable. At this level, it is also imperative to understand the advantages that Blockchain presents so that they can be contrasted with the challenges that the application intends to overcome. It is essential to investigate whether the absence of a central authority, the existence of a shared database, and the presence of untrusted nodes can enhance the efficiency of the operations. If there is no such need, then there is no reason to develop a Dapp.

The next step is the pilot development of the application on a Testnet. Having a Testnet and developing the application on it is an integral part of implementing a Dapp. As is known, a decentralized application consists of a frontend UI, which can be written in any programming language, and a backend code that works in a peer-to-peer (P2P) network, which is known as the "smart contract". Therefore, for the successful development of a decentralized application, both its backend and front end need to be developed. To connect to the Ethereum Mainnet or any other blockchain network it is essential to own a web3 wallet (e.g., Metamask). The wallet allows users to run Ethereum DApps directly in the browser without running a full Ethereum node. The wallet includes a secure identity vault, providing a user interface for managing the user's identity across different websites and signing blockchain transactions. The Smart Contract is written using a toolset (e.g., Truffle) in the Solidity programming language. The toolset enables the development and testing of smart contracts, their penetration into web applications and the front end configuration for applications.

After the smart contract code is tested in a Testnet, the next step is creating the Dapp's UI. The UI is significant for the developer, as they can shape how the application works. The user interface, if possible, needs to be developed considering the needs and opinions of the users, as it necessary to create an interface that can effectively enable their interactions without causing much confusion and only needing a slight learning curve. This feature can be implemented with any programming language, although it is common to use HTML-CSS and JavaScript with the help of the React library. Then two key elements must be integrated into the operation of the application since communication with the Ethereum Blockchain is achieved through them. The first is the web3.js JavaScript library, which is the middle ground, the "bridge", between the web application and the blockchain network. The second element is the Ethereum Application Binary Interface (ABI) of the code reported during the deployment process, which enables the application to interact with the deployed smart Contract. It is a JSON file containing all the smart Contract's features and functions.

After the developer develops the decentralized application, the remaining step necessary to make it work is to migrate it to the main network of Ethereum, i.e., the Mainnet. Therefore, after completing the actions related to writing the code in Solidity, developing the UI of the decentralized application, and testing on a Testnet or a local Ethereum simulator, the developer does not need to change much. Essentially the developer needs to renew his personal Ethereum account and add real Ethers so that they can deploy the smart contract Bytecode to the Ethereum Mainnet. To complete this process, he must confirm the transaction using his private key.

While the Dapp runs at the Ethereum Mainnet, the users can gain access to transaction info, wallet addresses, and other Smart Contracts through Etherscan.io. This blockchain explorer is used to give the user access to data from the Ethereum Mainnet and is a self-contained tracking service. It is essentially a search engine through which the user can monitor the Dapp in real-time by receiving information about the transactions carried out, the smart contracts as well as the cost of each transaction (gas fee).

Having briefly analyzed the method for developing blockchain-based Dapps, it is essential to present these steps as part of a connected framework related to the aforementioned info in order to gain comprehensive knowledge and understand how a developer can implement an Ethereum-based Dapp. Therefore, Figure 1 was created, showing a framework in which the specific tools used for developing the Wine Traceability Dapp and its deployment on the

Ethereum Mainnet are mentioned. More information about Dapp is presented in the next section. It was decided to use the Truffle suite as a development environment for the Dapp as it is a one-stop solution that can comply with and deploy smart contracts, insert them into web apps, create Frontend UI and provide a Testing Network. The first step is to install the truffle suite and create a truffle project. Next, the Metamask wallet must be installed on the web browser of choice to connect to a network, make transactions and create our account. The Smart Contract is developed using the Solidity programming language and the Solidity compiler as part of the Truffle Suite. In the next step, we need to run Ganache Local Network to start testing the Smart Contract. The smart Contract is then thoroughly tested, and appropriate improvements are performed before deployment to the main network. Afterward, using Drizzle collection of libraries, the React-based Frontend is developed, and the app can interact with the Blockchain through the web3.js library. Finally, the Dapp is deployed on Ethereum Mainnet, and its transactions can be monitored in real-time via the Etherscan.io browser.

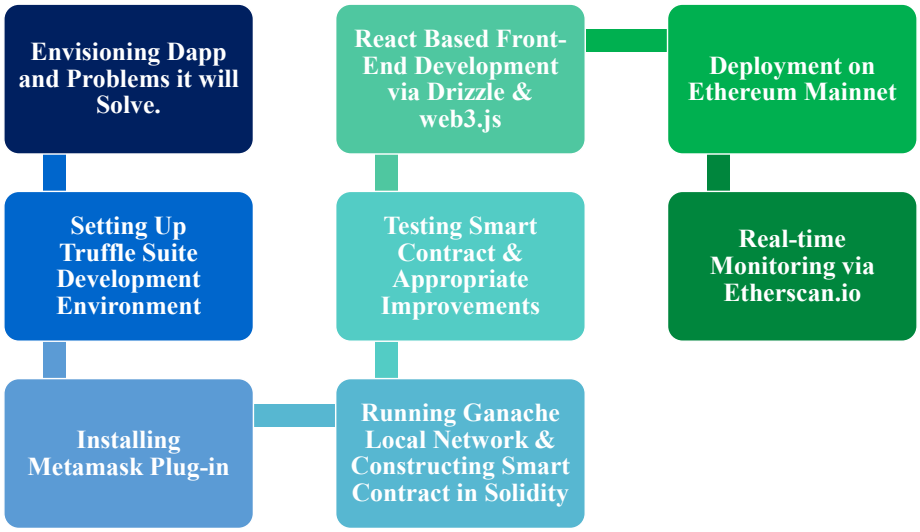

Figure 1. Framework for the Development of Ethereum Dapps

3. Use Case: Wine Traceability Dapp

The framework presented previously was followed in the research project of which the current research is part and concerns the traceability of the wine supply chain. The perspective of blockchain technology's integration in the wine supply chain is particularly exciting as it can ensure the quality of the entire production and distribution processes. That is why it was considered essential to develop a decentralized application that has specific entities and represents the real wine supply chain to a reasonable extent. The transition of all transactions in a supply chain is carried out through the particular application as it ensures numerous advantages, including security, trust, transparency, and decentralization.

The decentralized wine traceability application is implemented in order to fight counterfeit wine activities. In the first instance, it aims to integrate and digitize all stages of the supply chain by providing all involved stakeholders with the ability to enter data and maintain only one decentralized ledger. It thus offers the maximum possible trust between the stakeholders, creating an environment in which product traceability is immediate and accurate. In addition, the Dapp aims to address the significant problem of label falsifications. More specifically, the decentralized application gives the option to the end consumer to scan the label on the bottle, then certify that he has consumed it and thus "burn" it. If, using the application, the customer is convinced to participate in the specific process actively, the use of the Dapp will effectively enhance the quality of the wines and eliminate counterfeit activities.

In order to understand the way the Dapp functions, it is essential to present Figure 2, which depicts each user's interactions with the Dapp, depending on their role. Specifically, three main role categories were defined based on users' interactions with the Dapp.

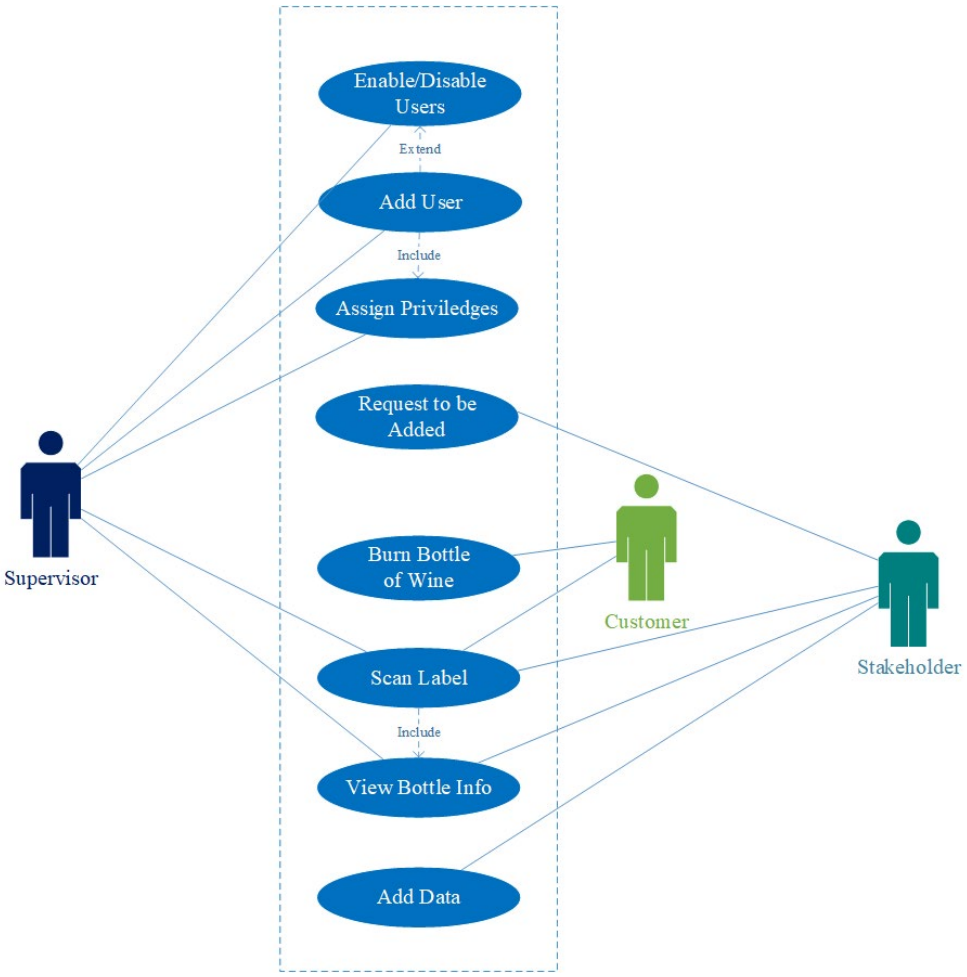

Figure 2. Users' Interaction with the Dapp

Based on these specific role categories, seven accounts were decided to be defined, representing, to a reasonable extent, the wine supply chain and will be used for its operation in the Ethereum Mainnet. These accounts are seen in Table 1.

Table 1. Dapp's User Accounts

Account Number	Account Name	Role Category
1	Main Supervisor	Supervisor
2	Secondary Supervisor	Supervisor
3	Winemaker (Producer)	Stakeholder
4	Transporter	Stakeholder
5	Bottler	Stakeholder
6	Merchant - Point of Sale (Trader)	Stakeholder
7	Consumer	Customer

The only account whose function is not so directly understandable is that of the main supervisor and, by extension, also the secondary supervisor, i.e., accounts 1 and 2. Essentially, the supervisor is nothing more than an authority that will be responsible for integrating the other members in the supply chain and its smooth operation. This authority is the system supervisor, who will run the application and will not directly participate in the supply chain of any product. An association of winemakers or any other responsible organization with the necessary knowledge background can perform this role. Furthermore, with the addition of the secondary supervisor, it becomes clear that there can be more

than one supervisor, thus giving more flexibility and more transparency, since power will not accumulate in a single authority.

Examining the accounts that have been created, we realize that the roles of the Smart Contract recognize the first 6, allowing them to perform specific related functions. These accounts include stakeholders who actively participate in the wine supply chain (Winemaker, Transporter, Bottler, Trader). Between them, six different types of movement can be identified. These are production, fermentation, aging (which can be optional depending on the type of wine), bottling, transport, and sale.

As would be expected, a complex wine supply chain involves more stages-stakeholders. These can either be directly integrated into the decentralized application as they do not add traffic types, or they go so deep that they go beyond this research's purpose. For example, a Logistics Center can be added between the bottler and the Point of Sale in the first case. Still, it is the same type of transport, so for the sake of the simplicity of the application, it is not considered necessary to activate such an account. As for the 7th account, i.e., that of the consumer, the Smart Contract does not know anything about it, simply understanding it just as a user of Ethereum Mainnet and only provides access to the consumer in order for him to check the wine traceability info and burn a wine bottle when they buy it.

An indicative example of an under-development consumer UI is shown in Figure 3. The figure shows the interface that the consumer sees with the information entered by the winemaker about fermentation, aging, and bottling. The specific interface appears specifically for the consumer, who, as already mentioned, is a separate category of users who can only view the data of the wine he is aiming to buy. The consumer connects to the application through his wallet and, after scanning the wine label, goes to the specific interface.

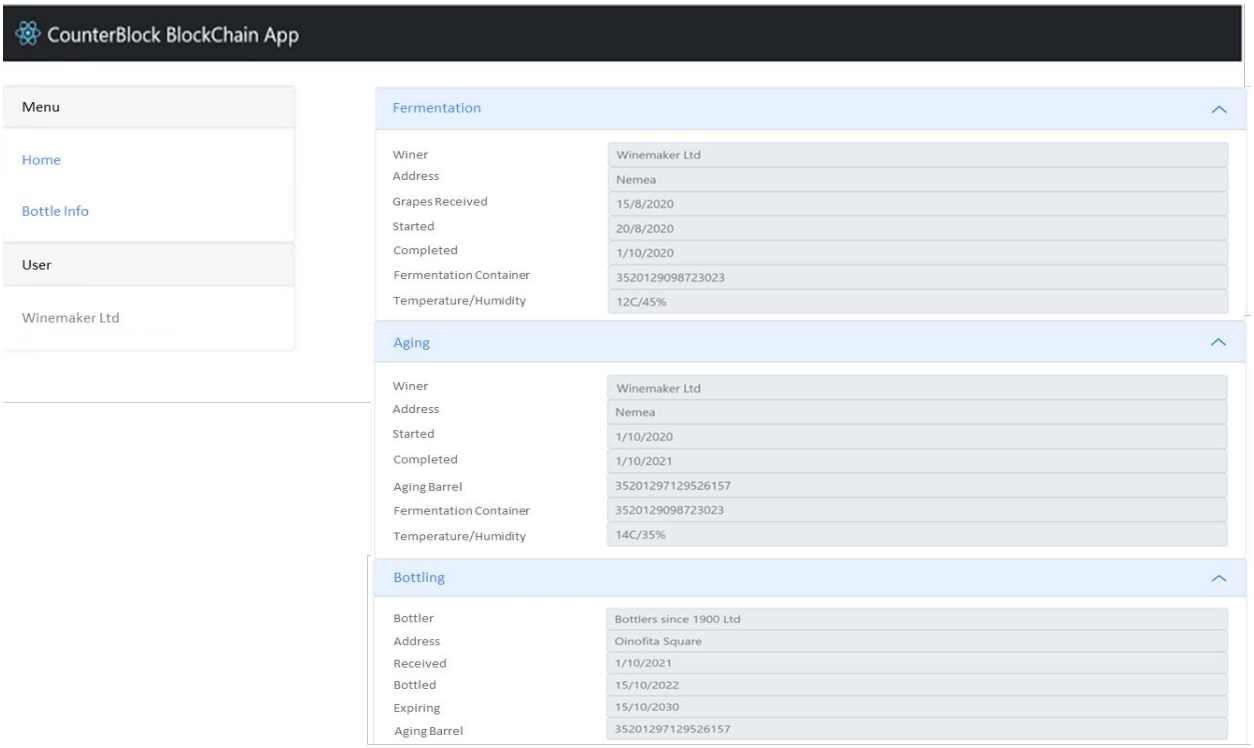

Figure 3. Indicative Interface for Consumers

More specifically, in the fermentation section, the user learns information about the winemaker, the duration of the process and prevailing conditions, the fermentation container, and when the grapes were received. In this example, the winemaker who undertakes the fermentation also carries out the aging. This sub-case in the supply chain obviously does not correspond to every wine production. Nevertheless, nothing changes, in terms of the decentralized application, the differentiation of these two winemakers, and just one more transfer between them is added. In the aging section, the winemaker who carried it out, his address, when the process started and ended, the barrel code, the

aging conditions, and the fermentation container are disclosed. Finally, in the bottling section, information is provided regarding who does the bottling, its location, when the bottling company receives the wine and when it bottles it, and the aging barrel that proves that aging has taken place. It is worth noting that for reasons of GDPR compliance, real names and data are not presented in the figure but only sample data.

4. Conclusions.

The utilization of Blockchain technology in the wine supply chain, through Dapps, can provide a solution to the counterfeiting problem through the digitization of the supply chain. The possibility of effective tracking of the respective product, throughout its production and distribution range, in minimal time and at low cost, can be effectively provided. Blockchain significantly reduces the processes required to identify counterfeit or contaminated products since only one record is kept, and traceability is much easier and more immediate. There are of course, some drawbacks, which concern the speed of transactions, the environmental burden, the scalability of the applications themselves, the training of the entities involved as well as the general regulation for data protection, that need to be addressed in the future in order for such a blockchain system to become mainstream.

Despite the obstacles in implementing Dapps, it is undeniable that this technology creates a new perspective for supply chain operations. The results of this research include the creation of a framework that is a guide for developing a Dapp and deploying it on the Ethereum Mainnet. The Ethereum platform itself does not limit its functionality to specific toolchains, so the developer can choose from a multitude of options in order to implement their own decentralized application. Thus, the provided framework can be significantly diversified according to the development needs, but its main principles will remain unchanged.

In the following stages of our research, the Dapp will be tested in depth in real-world operations on various stakeholders of the wine supply chain, and appropriate improvements will be made to the smart contracts. At the same time, the final Frontend UI will also be designed. Our future goals include adding the NFT concept to the Dapp. More specifically, as the production of wine bottles is finite, each bottle could be assigned an NFT, which the consumer can add to a digital collection after burning each bottle. This creates a more accessible app that may appeal to both collectors and non-collectors, offering an additional motive to participate in this effort to combat counterfeit wine activities. Thus, the role of the end consumer in the decentralized application will gain more value and, at the same time, create a greater incentive to burn the bottle and help maintain the wine's authenticity and traceability.

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Biographies

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