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Research Report

Decentralized finance – How triple-entry accounting and distributed ledger technology is revolutionizing the world of financial services from a business perspective

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RESEARCH PAPER

MAY 2023

DECENTRALIZED FINANCE

**HOW TRIPLE-ENTRY ACCOUNTING AND
DISTRIBUTED LEDGER TECHNOLOGY IS
REVOLUTIONIZING THE WORLD OF
FINANCIAL SERVICES FROM A BUSINESS
PERSPECTIVE**

IUCF Working Paper, No. 7/2023

LENNART T. SCHULDT

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DECENTRALIZED FINANCE – HOW TRIPLE-ENTRY ACCOUNTING AND DISTRIBUTED LEDGER TECHNOLOGY IS REVOLUTIONIZING THE WORLD OF FINANCIAL SERVICES FROM A BUSINESS PERSPECTIVE

Lennart T. Schuldt, Prof. Dr. Markus Peskes*

Abstract

Decentralized finance (DeFi) is a rapidly growing science that leverages distributed ledger technology (DLT) to offer peer-to-peer financial services. The DeFi ecosystem consists of decentralized applications that range from traditional financial services like decentralized stock exchanges (DEX) and lending platforms to novel services like flash loans.

By eliminating the need for intermediaries and leveraging the public design of DLT networks, DeFi offers a more efficient, transparent, and accessible financial system. This results in lower transaction costs, higher control for users, and increased accessibility. The interoperable nature of DeFi applications enables the creation of new applications and financial services through the use of existing applications, which leads to a high degree of comparability and flexibility, allowing network participants to efficiently execute services. However, there are also barriers to the wider adoption of DeFi, such as the unsettled regulation in many countries, and the current user experience, which requires technical expertise and is less user-friendly than traditional centralized financial services. The strong adoption of DeFi by individuals and surveys indicating growing interest in DeFi by businesses will likely lead to these barriers being overcome as the user base grows.

Despite the volatility of the crypto market, the trend of increasing adoption of DeFi applications is evident and reflected in an increasing number of users, projects, market capitalization of projects, and total value locked. Thus, DeFi is creating a decentralized financial system in parallel with the traditional centralized system, depriving it of a growing amount of resources.

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III. Abbreviations

BTC	Bitcoin
DAG	Directed Acyclic Graph
DAO	Decentralized Autonomous Organization
DApps	Decentralized Applications
DeFi	Decentralized Finance
DLT	Distributed Ledger Technology
ETH	Ethereum
EVM	Ethereum Virtual Machine
NFT	Non-Fungible Token
TVL	Total Value Locked
TPS	Transaction per second
VM	Virtual Machine
Web 3	Decentralized web
USDC	US Dollar Coin
UTXO	Unspent Transaction Output

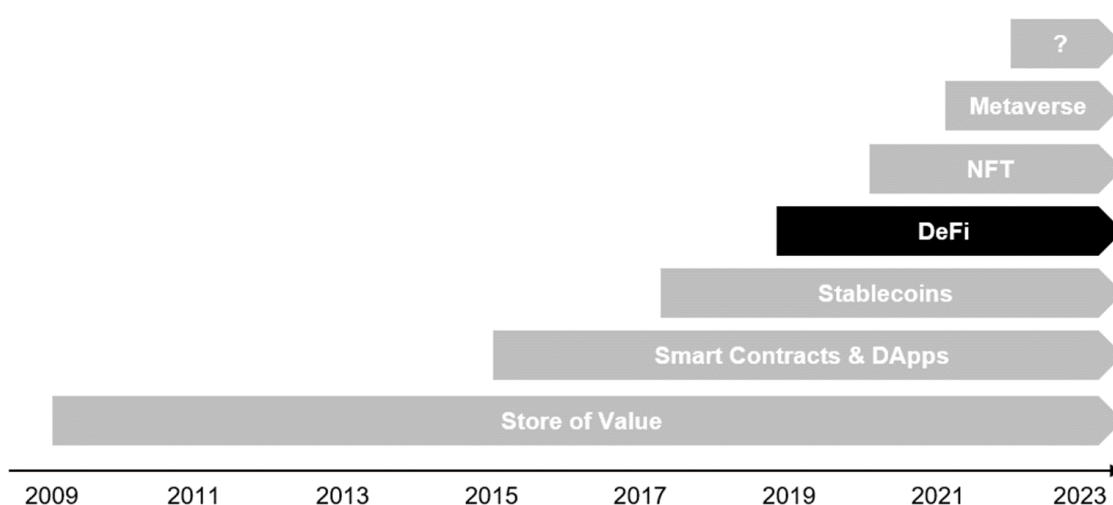
1. Introduction

1.1. Problem definition

Blockchain and crypto - The interest of the media and the population increases with the exploding prices of cryptocurrencies. The topic is clearly polarizing in this regard and while there are well-known supporters of a ban on cryptocurrencies such as Charlie Munger, there are also prominent supporters, such as Elon Musk, who regularly influences the prices of cryptocurrencies with his tweets (Bloomberg, 2022; Musk, 2021) The central subject of public reporting and attention is the function of cryptocurrencies as an object of speculation.

In addition to this use as a speculative asset, there are a number of other applications. These decentralized applications, DApps, do away with trusted third parties. Trusted third parties include intermediaries such as banks, financial service providers, insurance companies or brokers and platforms such as e-commerce platforms, social media networks or other middlemen. Obviously, these trusted third parties now account for a significant portion of value creation across diverse industries - for example, some of the world's largest companies such as Alphabet, Amazon or Visa can be classified as intermediaries or platforms. Decentralized applications are emerging as an alternative to these trusted third parties. The application fields include Web 3 applications, Decentralized Finance or DeFi applications, NFT applications, Metaverse applications, Decentralized Autonomous Organizations short DAOs, and other.

Figure 1. Development of multiple domains in the DLT ecosystem



Source: Adapted in accordance with Sandner, 2022.

Decentralized Finance is one fast growing domain in the crypto ecosystem that enables peer to peer financial services and has been gaining adoption since 2018. Here, DeFi services differ from traditional financial services in that no trusted third party is needed to transact financial services. Instead, they are processed through a DLT network that creates security between the contracting parties through its technical design. DeFi is intended to create an alternative financial infrastructure to the traditional centralized financial infrastructure operated and controlled by banks, financial service providers, insurance companies and brokers.

With slogans like "unbank the banks," a world without banks is being conjured up on Reddit and other social media platforms (Reddit, 2020). DeFi could be the solution to creating a system in which control over the financial system is distributed globally and decentral. Because it is such a young and rapidly developing industry, the need for research in DeFi is enormous. The huge importance of DeFi and its far-reaching impact will be discussed later in this paper.

1.2. Aim and structure of research paper

This paper will address the question of what impact the development of DeFi has on the world of finance, with a particular focus on the adaptation of DeFi in businesses. This goal will be met by analyzing how DeFi applications operate and what advantages and disadvantages they have over traditional centralized financial services. Furthermore, the adaptation of DeFi applications today will be evaluated, taking into account the adaptation in enterprises. The object of consideration in this work is the user and network participant, which can be an individual or a business. The implications that may arise for traditional centralized financial service providers are not part of this work, as this would go beyond the scope.

The topic of decentralized finance encompasses various disciplines, both areas of business administration such as accounting, finance, economics, as well as areas of computer science and law. This paper deals with the topic of decentralized finance mainly in a microeconomic context. Due to the high degree of topicality, the central objects of investigation will consist increasingly of primary sources and public DeFi usage data, while specialist literature will be drawn upon primarily in the first half of this paper. For the technical excerpts of this paper, this means that the processes are explained, but no mathematical proof is part of this paper. Likewise, a rough legal classification is given, but is not the focus of this paper.

In this paper, the technical and accounting functionality of DLT networks and DeFi applications is first explained from the ground up, starting with the evolution of accounting in chapter 2.1. In this and the following chapters, characteristics and technical structure of DLT network are then discussed and two different types of Layer-1 protocols, Blockchain and directed acyclic graph, DAG, are explained.

The focus of this chapter and the rest of the paper is exclusively on public DLT networks. The reason for this is that DeFi takes place exclusively on public DLT networks and private DLT networks are organizationally much more similar to centralized networks than public DLT networks. In the following chapters, voting mechanisms and consensus mechanisms are explained, which together form the technical basis for trust building in DLT networks.

While consensus mechanisms are a widely documented scientific field and usually part of scientific literature on DLT, the different types of voting mechanisms are less frequently discussed in scientific literature, compare Adam, 2022 or Hastenteufel, Broß, 2022. In the context of this thesis, voting mechanisms will be dealt with, that they have a decisive influence on the success of DLT networks, more about this in chapter 2.3.3. In the second chapter, primary sources are mainly used, such as Nakamoto, 2008 or Popov, 2018. In the crypto field, these primary sources are whitepapers, in which public DLT projects scientifically document their developed DLT networks. The second chapter ends with the success factors of DLT networks.

This is followed by the third chapter, "Financial services become decentralized," which first addresses the question of what DeFi is. In the course of this chapter, we will look at how DeFi is revolutionizing the world of financial services. As a comparison, the influence of the Internet on the media industry is considered. The main purpose of chapter 3.1. is to create understanding of DLT as the infrastructure for DeFi, which will be built upon in the remainder of the chapter.

Thereupon, DLT platforms in the DeFi area are presented, of which Ethereum, Avalanche and NEAR are discussed in more detail. In the last part of the third chapter, three decentralized financial services are presented: Decentralized Payment, Decentralized Trading, and Decentralized Lending, which are compared to their centralized alternatives.

As in the second chapter, project whitepapers are mainly used as sources. At the same time, internet-based information platforms such as Coinmarketcap and DefiLlama are used. For non-specialist readers, a service like DefiLlama may sound not serious, but it is a leading platform for the evaluation of on-chain data in the field of DeFi, which is also used by the European Commission and many more in publications on crypto (European Commission, 2022, p. 2).

The fourth chapter, "DeFi in businesses," begins with a brief analysis of DeFi services versus centralized financial services. This is not a holistic analysis, but only an examination of selected key performance indicators at a small sample of six financial service providers. In addition to published business figures from companies, internet-based information platforms such as Tokenterminal are used to provide information about the revenues of DeFi services. These data are used to determine key figures in order to gain an insight into the efficiency of DeFi Services.

Following this analysis, the advantages of DeFi over traditional financial services are considered and the regulatory environment is assessed. At the end of the fourth chapter, the adaptation of DeFi in general and specifically in businesses is considered. For the latter chapters, the sources consist in particular of studies and surveys by management consultancies since data from companies are less freely available than the totality of data for DeFi transactions.

The final chapter then succinctly summarizes the findings collected and concludes on the impact of DeFi on the world of financial services providers. This is followed by a conclusion of the findings. Finally, an outlook is given on future developments in the DeFi field.

Finally, it should be noted that the terms in the crypto field are often used several times in different functions. In particular, the term protocol is used for both the technical infrastructure design of DLT networks and DLT applications. The term application is also used differently, with Heines referring to Bitcoin as an application in the following chapter. At the same time, we use the term application in the later part of this thesis for provision of products or services. It is therefore important to classify these terms depending on the context.

2. Fundamentals of Distributed Ledger Technology

2.1. Evolution of accounting

The following chapter describes the historical development of accounting from single-entry, to double-entry, to triple-entry, which creates the foundation of distributed ledger technology.

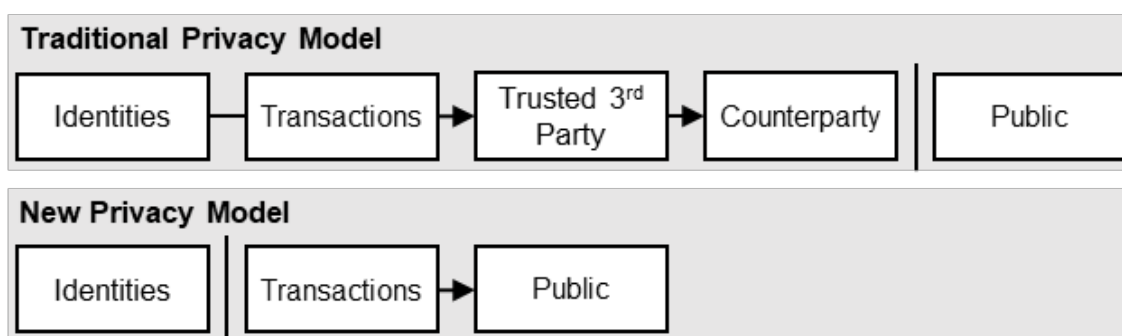
As long as people have been able to read and write, they have used simple accounting to list economic activity. It consists of a list of entries with inflows and outflows in a chronological order on an account. It is easy to understand, but offers little overview of relationships. To check a matter, e.g., the total expense for rent in a household, all entries must be viewed individually. Then, for each transaction, it must be checked whether it is a matter of "rent" and then all amounts must be added up. Nevertheless, simple accounting is still used today when little complexity is required, e.g., for the revenue surplus statement in small companies and associations (§ 4 (3) sentence 1 EStG).

Double entry bookkeeping was first mentioned by Luca Pacioli, an Italian monk, in his 1494 work "Summa de arithmetica, geometria, proportioni et proportionalità", in English: Summary of arithmetic, geometry, proportions and proportionality (Pacioli, 1494). It represents a further development of simple accounting, in which there are additional subject-related accounts instead of one account, such as cash on hand. Here, a business transaction affects two accounts. Each entry simultaneously generates an inverted entry in the same amount in another account. For example, the purchase of food in a household affects the cash balance account with a negative amount and the food inventories account with a positive amount. The more complex accounting structure makes it much clearer to check facts. For example, the food inventory in the household is the sum of all inflows and outflows to this account. The spread of double entry bookkeeping enabled companies to create and manage much larger organizations. The emergence of banking can be traced back to double-entry bookkeeping; for example, the oldest banks in existence today, such as Hamburg's Berenberg Bank, founded in 1590, were created during this period (Joh. Berenberg, Gossler & Co. KG, 2022). Double-entry bookkeeping is thus one of the decisive factors that led to the emergence of modern capitalism in the early modern period. It also allows states to better determine and tax the success of companies, since manipulating balance sheets is more difficult in double-entry accounting.

The way accounting works within the framework of distributed ledger technology, triple entry bookkeeping, is similar to double entry bookkeeping: transactions take place between accounts, with the consumption of a credit in one account, as in double entry bookkeeping, leading to the creation of a credit in the same amount in another account. All transactions are recorded in a chronological account book that contains the two accounts concerned and the amount. In contrast to double-entry bookkeeping, where each actor keeps its own books, this triple-entry book of accounts is kept by a network of pseudonym persons. Each transaction must be confirmed by the network before it is included in the public ledger. The network participants decide on this by a consensus mechanism or trust mechanism, more on this in 2.3.4. Based on the transaction history of the public account book, in which all transactions can be viewed, each network participant can determine the current state of the network (Tapscott, Tapscott, 2016, pp. 22-23.).

The decentralized design of a triple entry bookkeeping network can thus create a system in which no trust towards the other party, no set of rules and no controlling trusted third party is required, but in which no fraud is possible due to the technical infrastructure. It is therefore not an accounting system in which laws guarantee proper accounting, but a system in which proper accounting is guaranteed by the technical infrastructure design. Therefore, verification by a trusted third party, such as an auditor, is unnecessary. This triple-entry system thus enables decentralized databases operated by a network of participants according to their jointly determined rules. At the same time, this new type of accounting enables improved privacy where users themselves control what data they disclose to the public or other network participants (Nakamoto, 2008, p. 6).

Figure 2. Parties and Privacy



Source: Adapted from Nakamoto, 2008, p. 6.

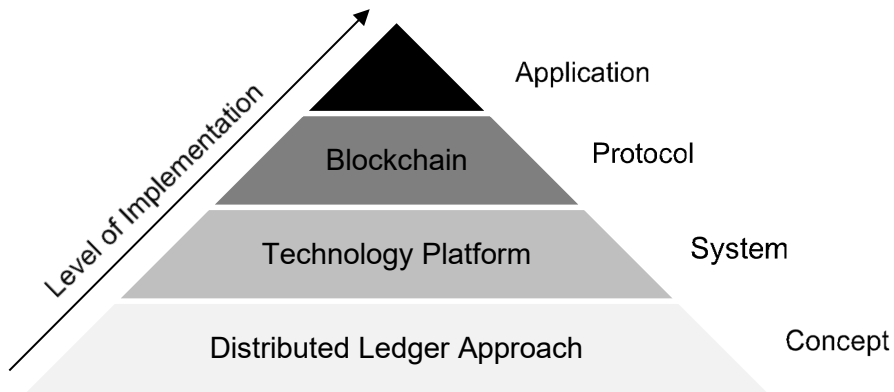
2.2. Characteristics of DLT Networks

The term Distributed Ledger Technology, abbreviated DLT, describes decentralized databases, run by multiple devices (Hellwig, Karlic, Huchzermeier, 2020, p. 4). DLT is a concept on the basis of which DLT networks operate. In these DLT networks, it is possible for network participants, also referred to as nodes, to carry out transactions without needing a trusted third party to establish trust in the network. Thus, in DLT networks, there is no need for central platform companies or intermediaries. Since these platform companies and intermediaries claim a significant part of the value creation, transactions, and processes in DLT networks can save these costs. This significantly increases the efficiency of transactions and processes. More information on this in Chapter 3 when considering decentralized financial services. Another factor that distinguishes DLT networks from today's platforms and intermediaries is their systematic openness to new players.

People can easily become participants in public DLT networks without permission. They can participate in the network regardless of country and nationality, income, and other factors. This means that they can use all the services available on the network. This may seem unimportant from a European or North American perspective, but in many emerging and developing countries, services are less developed. As described, these services are offered globally with the highest market efficiency. At the same time, new network participants can also immediately provide services on DLT networks. Example: By offering labor globally on DLT networks, it is possible for a software developer in a developing country to provide the same service as a software developer in an industrialized country - this represents a potential for people in emerging countries on the one hand, and a potential for industrialized countries on the other, which lack workers in many sectors. DLT networks are thus contributing to globalization of the service market in various industries.

Heines' Systematics of the DLT Space is a model that presents an overview of the DLT space from concept to application. The distributed ledger approach serves as the concept of this entire DLT space. Different systems can be built on this approach, such as payment systems or technology platforms. These decentralized systems in turn use protocols such as Blockchain or DAG to process transactions. Placed at the top of Heine's model are applications. These can be simple payment applications such as Bitcoin, as well as more complex decentralized applications, which will be discussed in the third chapter of this thesis. As the height of the pyramid increases, so does the level of implementation (Heines, 2020, p. 10).

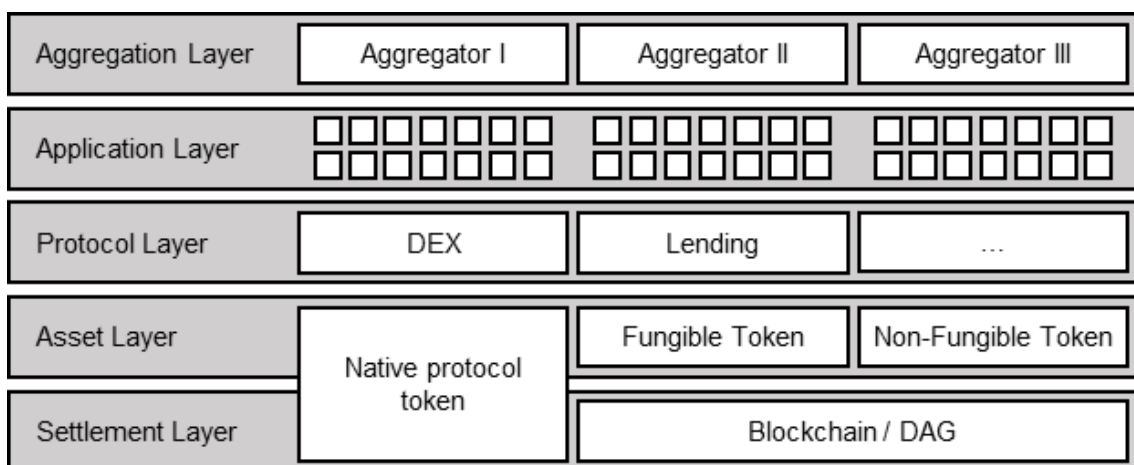
Figure 3. Systematics of the DLT Space



Source: Adapted from Heines, 2020, p. 10.

Schär's DeFi Stack represents an alternative view that is more technically oriented (Schär, 2021). In this model, the Settlement Layer represents the lowest technical layer, where protocols such as Blockchain or DAG perform transaction processing and consensus building. On the Asset Layer above, all kinds of tokens are stored, whereby the native protocol tokens are also part of the transaction process. Every Layer-1 DLT network / platform consists of these two layers. Above these is the Protocol Layer on which application-specific protocols reside. These can be e.g. decentralized exchange in the DeFi area or others. Based on these application-specific protocols, the Application Layer provides concrete applications. It should be noted, however, that applications are intertwined and complex applications often use basic applications, as described in more detail in Section 3.3. The top layer, the Aggregation Layer, enables users to access these applications via a front end (Schär, 2021, p. 4).

Figure 4. The DeFi Stack



Source: Adapted from Schär, 2021, p. 4.

The two models differ primarily in their objectives. Heine's model provides more of a conceptual overview of the DLT Space. In contrast, the DeFi Stack describes a broader technical overview and provides an overview of the relationship between the individual segments of the DLT Space. However, when comparing the two, it is also noticeable that, as described in the introduction, the wording in the DLT Space is a problem: In both models, the terms protocol and application are used differently.

2.3. Operation of DLT

In this chapter, the technical foundations of DLT protocols are presented, covering the lower two layers of the DeFi stack: Settlement Layer and Asset Layer. First, in chapter 2.3.1, Blockchain protocols are discussed and then, in chapter 2.3.2, DAG protocols. In doing so, the technical and accounting operations of Blockchain will be explained using the Bitcoin network and the operations of DAG will be explained using the IOTA network. These two networks were chosen because both have been extensively documented scientifically. Chapter 2.3.3. then discusses voting methods within DLT networks and chapter 2.3.4. deals with consensus and trust mechanisms within DLT networks.

2.3.1. Blockchain

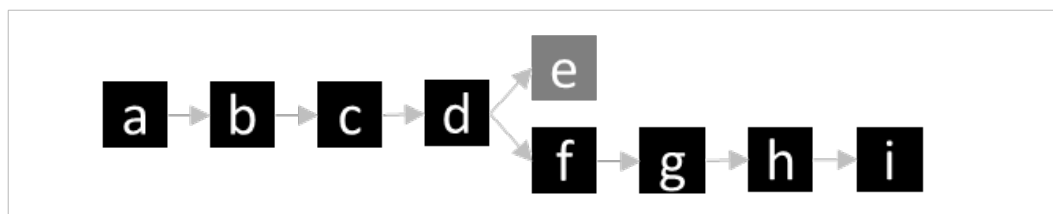
The Blockchain is the most widespread type of protocol used in DLT networks. The name Blockchain is composed of the words "block" and "chain" and describes the structure of the protocol in which transactions are stored in blocks one after the other (Nakamoto, 2008, p. 3). The largest DLT projects by market capitalization, such as Bitcoin and Ethereum, use the Blockchain as a layer-1 protocol type (Coinmarketcap, 2022). The first Blockchain-based DLT network known to the general public was the Bitcoin network, whose whitepaper was published in 2008 by Satoshi Nakamoto. This is a pseudonym whose true identity remains unclear to this day. Bitcoin is a peer-to-peer payment network that enables the transfer of money without intermediaries (Nakamoto, 2008, p. 1). In the following, we will look at how such a Blockchain-based payment system works.

A transaction is to be processed within the network. The sender enters the transaction data and releases the transaction. This is then sent to all nodes in the network. The nodes collect all transactions in a block. This time period differs from network to network. In the Bitcoin network it takes about five minutes, in the Ethereum network about twelve seconds while in the Avalanche and Fantom networks it only takes about three seconds (Txstreet, 2022; Cointool, 2022).

This is followed by the encryption of the block, which depends on the particular consensus mechanism of the Blockchain, more on this in chapters 2.3.3. and 2.3.4. From this mechanism, one node emerges as successful and appends the encrypted block to the existing blocks of the Blockchain. The block is cryptographically encrypted, this is comparable to a fingerprint for the block, and the encryption of the preceding block is included in the calculation. A subsequent change to the preceding block would therefore result in the encryption of all subsequent blocks being changed and these would have to be recalculated. The longer a transaction has been in the network, the higher the security of this transaction.

The other nodes in the network check for their part whether the block was created correctly. Bitcoin uses what is known as the unspent transaction output model, UTXO, for this, where a transaction is legitimate if no two or more transactions spend the same amount of bitcoins (Nakamoto, 2008, p. 2). In addition to the UTXO model, there are also other accounting models such as the account balance model from Ethereum, which will not be discussed here. From the transaction history of the Blockchain, which every participant can view, nodes get the information about the correctness of bookings. If all bookings in the block are correct, work is done on the next block in the sequence. However, if the block contains incorrect bookings like illustrated block “e”, a new competing block is created in parallel, this is called a fork (Gierschner, 2017, p. 2).

Figure 5. Fork in a Blockchain network

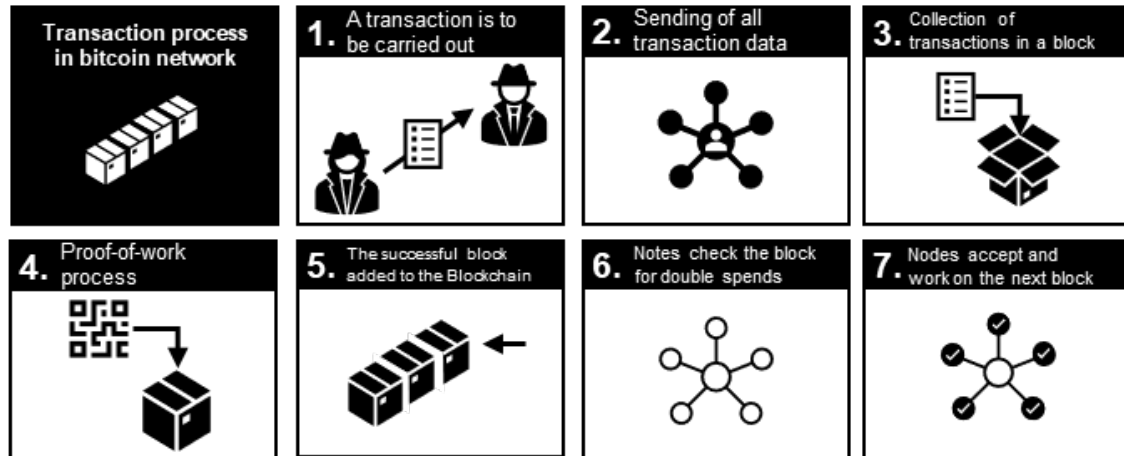


Source: Adapted in accordance with Gierschner, 2017, p. 2

A confirmed transaction is therefore not final but can be revised afterwards if necessary. As long as the honest nodes in the consensus process are more often influential than the nodes trying to legitimize false transactions, the longest chain of blocks will be correct (Nakamoto, 2008, p. 3). In addition, the nodes that provide their computing power to the network are compensated. When a node successfully emerges from the consensus mechanism and adds a new block to the Blockchain, it receives a defined amount of network tokens as a reward, plus the transaction fees incurred for each transaction. This exchange of computing power for network tokens in a Blockchain is also known as

mining (Gierschner, 2017, p. 2). The incentives are thus such that it is more attractive for miners to work for the network than to work against it.

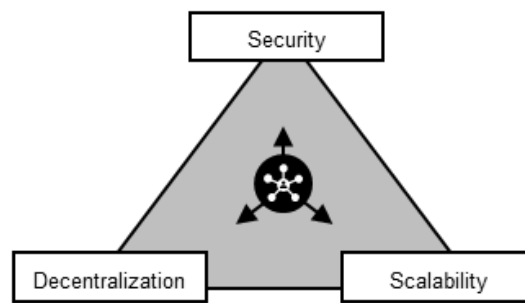
Figure 6. Transaction process in bitcoin network



Source: Own illustration.

As described earlier, Blockchain networks require a fixed general order, a uniform time perception, of transactions so that nodes have the same information when they vote. However, because nodes are many in number, geographically dispersed, have different technical specifications, and have different speed internet connections, some nodes receive transaction data significantly faster than other nodes. To keep the nodes at the same speed, there are two options: The first way is to slow down the faster nodes - in simplified terms, this is how the Bitcoin Blockchain works, and the result is high transaction times. The other option is to reduce the number of nodes in the network and increase the technical requirements. This is the case with the Solana Blockchain network, where fast transactions are possible, but the number of nodes is low, around one thousand eight hundred, which significantly reduces decentralization (Solana Foundation, 2022). Thus, with high security, a Blockchain network without sharding, sidechains, and layer-2 solutions must choose between higher decentralization and higher scalability. The Blockchain Trilemma describes the dilemma that Blockchain networks have to balance between the three factors of scalability, security, and decentralization (Im, 2018, p. 14ff). Further treatment of success factors is provided in chapter 2.5.

Figure 7. Blockchain trilemma



Source: Own illustration.

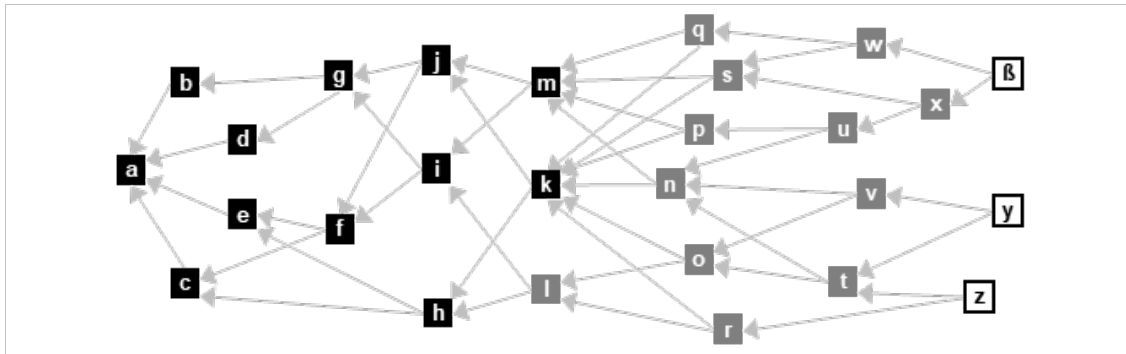
2.3.2. Directed Acyclic Graph

Directed acyclic graph, short DAG, is an alternative protocol infrastructure to Blockchain. While Blockchain protocols operate synchronously and track an overall sequence of transactions, DAG protocols can operate asynchronously and allow transactions to be processed in parallel (Popov 2018, pp. 1-3). For example, you can think of a DAG as a highway on which there are multiple lanes, while a Blockchain is just a one-lane road. DLT networks that use a DAG include Avalanche on the Exchange Chain, Fantom, and IOTA. In this chapter, we will discuss how the DAG works in the IOTA network, which is also known as the Tangle. In the current IOTA 1.5 Chrysalis network, there is a coordinator that acts as a central authority to establish trust for other nodes. Since this coordinator is a transitional solution, figuratively speaking, training wheels on which the IOTA network has been dependent until now, but which will disappear with the update to IOTA 2.0, this paper will deal with the functioning of IOTA after the abolition of the coordinator (Popov et al., 2020, p 5). In addition to the Tangle, there are other DAGs that differ from it in their technical design.

In the Tangle transactions are confirmed individually on the network, instead of collected in blocks. Each participant that releases its own transaction verifies two or more other transactions that are waiting to be verified. In return for the work done, there is no transaction cost for the own transaction in addition to the computing power expended. More precisely, a node that wants to perform its own transaction selects two or more unconfirmed foreign transactions, checks the transaction history of the tangle to see if there are any conflicts in the transactions, and cryptographically encrypts the transactions if they are identified as correct (Popov 2018, pp. 2-3). As described, there is no overall sequence of transactions in the Tangle because they do not occur in series, as in the Blockchain, but in parallel. Accordingly, there is no uniform time perception of

the nodes because the network runs asynchronously. This means that the nodes' perception of the order of transactions can differ (Popov 2018, p. 3).

Figure 8. Operation of the Tangle



Source: Adapted in accordance with Al-Rakhami, Al-Mashari, 2021, p. 3.

Consensus algorithms in Blockchain networks prevent false transactions from entering the network because an attack cannot succeed as long as malicious miners or validators are in the minority, and they also do not receive compensation for their work. The Tangle, on the other hand, is designed to allow false transactions, but to understand whether transactions are conflicting and to track these conflicting strands of the Tangle in a timely manner. For this purpose, the triple-entry bookkeeping described in chapter 2.1. is extended to a "quadruple-entry bookkeeping" by adding another dimension, a status that describes whether a transaction is conflicted.

Valid transactions are transactions that create the same amount of assets as they consume, that consume only tokens originating from other valid transactions, and that do not issue tokens that have been previously issued. IOTA uses the UTXO model for this, which is also used in the Bitcoin network (Sealey, Aijaz, Holden, 2022; Nakamoto, 2008, p. 2). As a result, some of the transactions, those that meet all the criteria when they are released, are immediately valid and become part of the master branch. The transactions with "conflicted" status and all transactions resulting from them – these inherit the "conflicted" status from their previous transaction – will continue to be tracked as an external branch but will not be considered confirmed until a decision is made. The decision is therefore shifted to a higher level, while the master branch, which contains all valid transactions, continues to exist unaffected. A consensus mechanism or trust mechanism is then used to decide which conflicting parties are legitimate and which are not. This is done by nodes confirming the correct transaction, or a transaction following the correct transaction. This way, vote weights for the two competing transactions can

be determined. After the nodes have made their decision on higher level, the successful branch is merged with the master branch and the rejected branch is removed.

Thus, the conflicts do not need to be resolved at the moment of transaction release, which will hold up the network and all subsequent transactions until the conflict is resolved. Instead, transaction speed is decoupled from consensus (Moog, 2021). As just described, conflicting transactions and their subsequent transactions are moved to a higher level to make a decision here. At this level, different types of consensus are basically possible which are also used in Blockchain networks. The IOTA network uses a Mana-based trust mechanism here, but other resource-based consensus mechanisms such as Proof-of-Work would also be possible, more on this in chapter 2.3.4.

Since not all nodes are needed to validate a transaction, but a small number of neighboring nodes validate the transactions, there is no Blockchain trilemma in the Tangle and it is possible to transact in a secure, decentralized, scalable, fast and fee-free way. This leads to another problem: spam. If it is possible to execute transactions under the circumstances described above, nothing prevents attackers from flooding the network with nearly empty transactions. In a so-called Sybil attack an attacker subverts the service's reputation system by creating a large number of pseudonymous identities and uses them to gain a disproportionately large influence (Popov et al., 2020, pp. 11-12). A Sybil protection mechanism prevents such attacks by subjecting them to a resource test. This involves linking a transaction to a scarce resource. It would be possible to test the resources in the form of computing power, Proof-of-Work, as takes place in the Bitcoin network. Simply put, this means some energy consumption per transaction. However, due to the external environmental costs, the IOTA network instead uses Mana, the internal trust value presented in chapter 2.3.4. (Popov et al., 2020, pp. 11-12). Thus, the consensus mechanism is not only used in the IOTA network to adjudicate conflicting transactions but also serves to allocate network resources. This means that trusted network participants can perform more transactions in the network than participants who are less trustworthy.

As described, the DAG is an alternative protocol infrastructure to the Blockchain. The first key advantage of the DAG is the decoupling of transaction speed. This concept significantly increases efficiency because a lot of coordination between the nodes is avoided. In addition, a system is made possible in which complex transactions such as Smart Contracts, more on this in chapter 2.4.3, do not slow down the entire network, but small transactions can be executed quickly in parallel. To stay with the example of the highway: On the DAG highway, there are lanes on which large trucks drive slowly that have Smart Contracts attached. At the same time, there are lanes on which simple

transactions can drive as sports cars without speed limits. The second key advantage lies in the fact that only a subset of the validators is involved in a transaction. The voting subset of validators does not increase the communication overhead, even if the network is extremely large. Instead, transaction speed remains high even in a growing network. The Blockchain trilemma therefore does not apply. A holistic overview of voting in DLT networks is given in the next chapter.

2.3.3. Voting

In order for nodes in a DLT network to communicate whether the corresponding block or the individual transaction is legitimate, there must be a voting mechanism in which the nodes cast their vote and thus a result is reached. In this regard, two different voting mechanisms prevailed and are used in networks today: Point-to-point communication and the Gossip Protocol, which in turn have different manifestations depending on how many nodes vote in the network. In this chapter, an overview of these characteristics and their properties is given.

Point-to-point communication describes the direct communication of network participants. Each voting network node informs the other voting network nodes how it votes (Khan, Vaidya, 2021, p. 2). You can think of point-to-point communication as writing down and delivering a message to someone in person.

Classical consensus, that mean point-to-point communication involving all network participants, is a voting mechanism that was scientifically documented even before the invention of the Internet. This is because classical consensus can be applied in groups of people as well as in networks consisting of computers (Bashir, 2022, p. 163). In classical consensus, each network participant informs every other network participant of its voting result. Subsequently, all participants dispose of the opinion of all other participants. In this voting mechanism, the network is safe as long as over $2/3$ of the network participants are honest. This is also called byzantine fault tolerance. In addition, a transaction is immediately final because all participants have been consulted. The disadvantage of the classical consensus is the low scalability: With a linearly increasing number of network participants, the number of messages in the network increases exponentially, since each network participant communicates with every other (Bashir, 2022, p. 210). For decentralized networks, therefore, classical consensus has not prevailed.

A voting mechanism similar to classical consensus is used at the “Snow”-called voting and consensus mechanism of the Avalanche network: point-to-point communication

involving a subset of the network participants. For each transaction to be confirmed in the Avalanche network, a random group of nodes is selected to vote with each other on whether the transaction is legitimate. Using a resource-based consensus mechanism that influences voting weights in the case of Avalanche Proof-of-Stake, transactions that are in conflict according to the UTXO model similar to the mechanism presented in the IOTA network are then decided (Bashir, 2022, p. 415).

Since only a subset of the network participants was polled, the transaction is revisable. However, it is crucial for the scalability of such a network that there are no nodes that do more work than others when passing information among nodes, as these would otherwise slow down the entire network. The last case of a point-to-point communication network with a validator describes a fully centralized network where an intermediary executes all transactions. An example of this would be the Visa network. This area is irrelevant for our consideration of DLT voting mechanisms.

Besides point-to-point communication, the other type of communication that networks use is the Gossip Protocol: one-to-many communication. In the Gossip protocol, a node communicates its opinion to all its neighbors, then the neighbors communicate their opinion to their neighbors, and so on. In this way, after a few messages, the whole network is informed about the opinion of a node (Apt, Grossi, Van der Hoek, 2016, p. 1). In simple terms described, one node shouts its opinion out loud and the other nodes continue to shout their opinion until all nodes have heard it.

The Nakamoto consensus, which is using the Gossip protocol involving one network participant with Proof-of-Work consensus was one of the innovations that made Bitcoin possible as the first large DLT network. In Nakamoto consensus, a network participant is identified through a Proof-of-Work consensus mechanism, which then creates the block and informs the network about it. To successfully attack the network, an attacker would need to emerge from the consensus mechanism as successful more often than the honest network participants (Nakamoto, 2008, pp. 1-3). Thus, it requires an attack with over 50% of the network resources. Transactions are not immediately final and the correct transactions end up in the longest chain of blocks. This is why the Nakamoto consensus is often called the longest chain consensus. The disadvantage of the Nakamoto consensus and similar voting mechanisms is, as described in chapter 2.3.1, the different time perception of the nodes, which leads to the fact that secure Blockchain networks are not decentralized and scalable at the same time. In addition to the Nakamoto consensus, which works with a Proof-of-Work consensus, it is also possible to use other consensus mechanisms instead, such as Ethereum does with Proof-of-Stake (Ethereum, 2022).

IOTAs network is similar to the Nakamoto consensus on a DAG basis. In its voting mechanism, the Gossip protocol is used, with a subset of all nodes voting. As in the Avalanche network, the resource-based consensus mechanism that influences voting weights is then used to decide on transactions that conflict according to the UTXO model. In case of IOTA this is a Mana-based trust mechanism (Popov et al., 2020, p. 18). Since only a subset of the network participants was consulted, the transaction is revisable. However, this voting mechanism can also be used by Blockchain networks. The Algorand network also uses the combination of Gossip protocol and a subset of the validators. The result of this is an overcoming of the Blockchain trilemma. By having only a subset of nodes voting, the Blockchain network can quickly approve transactions even with a very high number of nodes (Gilad et al., 2018, pp. 4-5).

The last form of the Gossip protocol, in which all nodes vote, is not very common, but is used by the DAG project NANO. Here, all network nodes give their opinion to all other network nodes. A resource-based consensus mechanism is also used, and since all nodes are consulted, the transaction is immediately final (NANO, 2022). Due to the high communication overhead among the nodes, an increasing number of nodes quickly leads to high transaction times.

Figure 9. Node communication of selected networks

Node communication of selected networks			
Voting mechanism	All validators	Subset of validators	One Validator
Point-to-point com.	Classical consensus	e.g., Avalanche, NEAR	Centralized payment e.g., Visa, PayPal
Gossip protocol	e.g., NANO	e.g., IOTA, Algorand	Nakamoto consensus e.g., BTC, ETH

Source: Adapted in accordance with Moog, 2021.

As can be seen from the descriptions, the inclusion of all validators in the voting process is always associated with a high communication effort, which prevents decentralization and scalability. Using one validator with the Gossip Protocol is the dominant voting mechanism in DLT networks today because the largest networks such as Bitcoin and Ethereum use this mechanism. Networks in this sector are affected by the Blockchain trilemma, which is why the scalability or decentralization of these networks lags significantly behind centralized networks like Visa. The two sectors that use a subset of the validators are used by many recent DLT networks. Well-known representatives are Avalanche, NEAR, IOTA and Algorand. The inclusion of a subset avoids the Blockchain

trilemma, therefore these two sectors enable voting solutions for both DAG and Blockchain networks. At the same time, the selection of a subset of validators does not affect decentralization and need not have a negative impact on network security. Since the transactions are not immediately final, they must be confirmed several times by subsequent transactions. The security of the executed transaction increases the more transactions follow. Which consensus and trust mechanisms are used in the validation process, will be chapter in the next chapter.

2.3.4. Consensus and trust mechanism

It has already been indicated within the last chapters that consensus mechanisms serve to support the voting process and establish security in the network. If we imagine that there are no consensus mechanisms and every node has the same voting rights, it would be easy for an attacker to control the majority of the network by adding many new nodes to the network. To prevent such attacks, consensus mechanisms use resource tests that tie the power of a node in the network to a resource.

The most well-known consensus algorithm, Proof-of-Work, was published together with the Bitcoin whitepaper. In Proof-of-Work consensus, the computing power of the nodes determines the weight of votes from them. Nakamoto himself describes that CPU time and electricity must be expended (Nakamoto, 2008, p. 4). In this process, nodes solve a complex mathematical puzzle. The nodes with more computing power have a higher probability of solving the puzzle first and consequently receiving the reward of network tokens (Nakamoto, 2008, p. 4). This system creates a high level of security, as an attacker would need to control over half of the network's computational pipeline to manipulate the network, and it would likely be less profitable for them to attack the network than to work for the network. However, it should be noted that the three largest Bitcoin mining pools provide over half of the computing power. Although these pools also consist of a large number of smaller miners, the decentralization in this field is very low (btc.com, 2022). Due to the strong growth of Proof-of-Work networks such as Bitcoin, the high energy consumption of the networks has now become a problem, which is why Ethereum switched completely to the Proof-of-Stake consensus in 2022 (Ethereum, 2022). Among the major DLT networks, Bitcoin is now the only network that uses Proof-of-Work consensus.

The Proof-of-Stake consensus distributes voting rights according to the share of deposited network tokens of the total stock. Thus, the probability of validating the next block depends on how large one's own share of tokens one provides for validation (Salimitari, Chatterjee, 2018, p. 4). That is, an attacker needs over half of the network

tokens to manipulate the network. Furthermore, it can be assumed that it would not be profitable for the attacker to harm the network, since half of a functioning network is probably worth more than a complete network that no longer works correctly. As an incentive to provide its network tokens, the deposited network tokens receive the transaction fees paid and, if applicable, the new network tokens created through inflation during staking, which is the name given to the process. The largest Blockchain network that uses Proof-of-Stake consensus is Ethereum (Ethereum, 2022).

The IOTA network uses a Mana-based consensus that shares similarities with a Proof-of-Stake consensus. This trust mechanism uses an internal trust and reputation metric called Mana. Mana is thereby generated for each transaction. In this process, the node that performs a transaction receives Mana when its transaction is confirmed by other nodes. The amount of Mana generated depends on how many IOTA tokens the trust-giver / confirming node owns (Popov et al., 2020, pp. 11-13). Thus, the amount of Mana an identity possesses tells how trustworthy it is, because only those who are trustworthy will receive confirmation of their own transactions from many identities with high wealth. This system also allows identities with low ownership of IOTA tokens to participate in the network's trust mechanism, rather than excluding this multitude of users as with Proof-of-Stake. So even participants with little wealth can contribute a great deal to trust if they act honestly. The trust mechanism therefore favors a high diversification of nodes and makes it attractive to operate even small nodes. Mana expires over time and therefore only temporarily increases the trustworthiness of an identity (Popov et al., 2020, pp. 12-13). So, when it comes to a decision on conflicting transactions or branches, the adjacent nodes vote, with their voting weight depending on their possession of Mana (Popov et al., 2020, pp. 12-13). Thus, via this trust mechanism, trust is implemented in the IOTA network without requiring high resources, as in Proof-of-Work networks, and without excluding most trusted users, as in Proof-of-Stake networks.

In addition to the consensus mechanisms described above, there are various other consensus mechanisms that pursue the same goal. In addition to the mechanisms described, there is, for example, proof of authority in the VeChain network, proof of history in the Solana network, or proof of space in the Chia network. It is beyond the scope of this paper to go into these in detail; if you are interested, it is recommended that the white papers of the networks be viewed.

2.4. Evolution of DLT

The previous chapter gave an overview of how DLT networks work, making it possible to process transactions with network tokens in a secure, decentralized and, depending on the design, scalable manner. However, this limits the scope of such systems to payment transactions. In the following chapter, we will look at how DLT networks have evolved beyond this, first discussing Smart Contracts and virtual machines, then tokens and Stablecoins, and finally scaling solutions for DLT networks.

2.4.1. Smart Contracts and Virtual Machines

The term Smart Contracts were coined in the 1990s by computer scientist Nick Szabo to describe the combination of contract law in e-commerce protocols (Szabo, 1994). In the DLT space, Smart Contracts became popular with the proliferation of Ethereum starting in 2015 by Vitalik Buterin's team. Ethereum, the second largest DLT network today, was designed as a platform capable of executing programs that any network participant could write, in addition to the functionality that Bitcoin provided (Buterin, 2014, p. 1). In addition to Ethereum, there are a number of other DLT networks available today that enable the execution of Smart Contracts.

A Smart Contract is an electronic contract or program that automatically monitors stored rules and autonomously executes defined actions in the presence of a trigger event (Schlatt, Schweizer, Urbach, Fridgen, 2016, pp. 23-24; Hellwig, Karlic, Huchzermeier, 2020, p. 75). They enable complex contracts which are not legally binding, but technically binding, which is why the term "contract" is slightly misleading, or transactions to be concluded without the need for intermediaries. The following quote is used particularly frequently in connection with Smart Contracts:

„Code is law“ (Lawrence, 1999)

This statement is from the title of the 1999 book "Code and other Laws of Cyberspace" by Lawrence Lessing, a former American constitutional lawyer (Lawrence, 1999). On DLT networks where Smart Contract are enabled, which are also referred to as DLT platforms, "code is law" prevails, as programmed Smart Contracts work as they are programmed, with no legal authority such as a court to intervene. Complete programs consisting of multiple Smart Contracts operating on a DLT platform are referred to as decentralized applications or DApps. Smart Contracts can also be used to implement digital assets or representations of real objects in a Blockchain, but more on this in the following chapter (Finck, 2019, p. 4).

When we talk about virtual machines, VMs, in the context of DLT platforms, we mean programming interfaces that translate programmed code in programming languages, such as Solidity, into Smart Contracts that can be executed by nodes. The best-known VM is the Ethereum Virtual Machine, which enables the creation of Smart Contracts and DApps in the Solidity and Vyper programming languages on the Ethereum platform (Ethereum, 2022). VMs from other DLT platforms such as IOTA, NEAR and many more today, on the other hand, work with Web Assembly Virtual Machine, which makes it possible to program Smart Contracts in all common programming languages (Webassembly, 2022).

2.4.2. Token

The term token in the context of distributed ledger technology covers both cryptocurrencies and economic goods and assets deposited on a distributed ledger platform (Adam, 2022, p. 161).

Cryptocurrencies and utility tokens

All the tokens described so far in this paper are native network tokens that are used for transactions within a network, and there are two different types: Classic cryptocurrencies are network tokens of DLT networks that are used exclusively for payment transactions, such as Bitcoin. The term currency is used in this context even though these cryptocurrencies do not perform all monetary functions. In contrast, utility tokens are native network tokens that grant the owner usage rights of a DLT application / platform (Benedetti, Caceres, Abarzua, 2022, p. 1). Network tokens such as Ether from Ethereum or IOTA entitle their holders to use network resources like storage in the form of transactions, Smart Contracts, DApps and other. Thus, the token holder owns a share in the infrastructure of such a DLT project. Utility tokens can also include governance tokens, which give their owners a voting right of a network. This is the case, for example, with decentralized autonomous organizations, DAOs. DAOs are communities owned by their members without central leadership, where management is done via governance tokens that grant their owners certain rights, such as voting rights in decisions (Buterin, 2014, p. 23).

Stablecoins

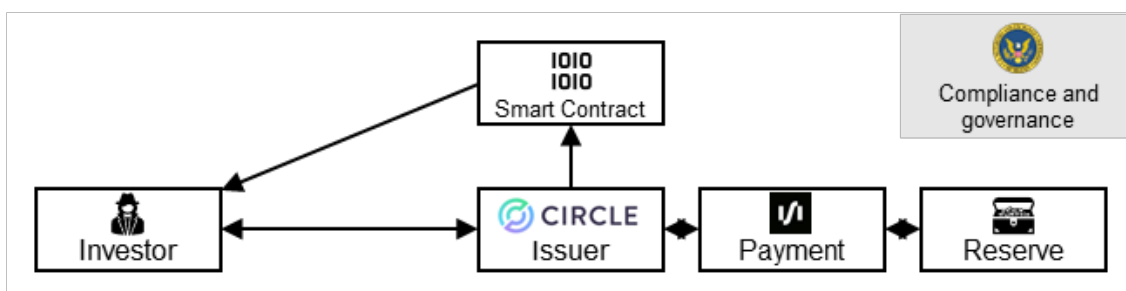
The prices of network tokens are characterized by high volatility (Coinmarketcap, 2022). Thus, two of the three money functions, the storage function and the computation function are limited, while the exchange function is fulfilled. This limited utility is creating a demand in the growing DLT universe for money that resembles the functions of central

bank money: Stablecoins. Stablecoins are tokens whose value is tied to another asset (Schmudde, Drott, 2021, p. 4). Stablecoins are not native tokens on DLT platforms but credit money. You could also consider Stablecoins as a DeFi application, but for the sake of clarity, Stablecoins are listed here with the other tokens.

The most common Stablecoins such as US Dollar Coin, USDC are tied to the USD and replicate the value of the USD on DLT platforms such as Ethereum. USDC is thereby managed by a company, Circle Internet Financial, LLC, which buys or sells USDC to keep the value at exactly one USD.

This is referred to as a centralized Stablecoin. The amount of USDC tokens is thereby backed by USD and short-term USD government bonds, and Circle earns enough from the interest on the funds to bear all the costs of keeping the value of USDC (Grant Thornton, 2022). For companies like Circle to keep their Stablecoins stable, they need to have access to their reserve and the markets at all times. Centralized financial service providers like Silvergate Bank provide this access (Circle Internet Financial, 2018). The assets under management of Circle’s USDC pool are USD 52 billion as of end of August 2022 (Grant Thornton, 2022). Besides USDC, there are other centralized Stablecoins that are also based on other currencies as EUR or other assets like gold. It should be noted that with centralized Stablecoins there is a counterparty risk if the eminent is unable to deliver on its value proposition.

Figure 10. Centralized Stablecoin (USDC)

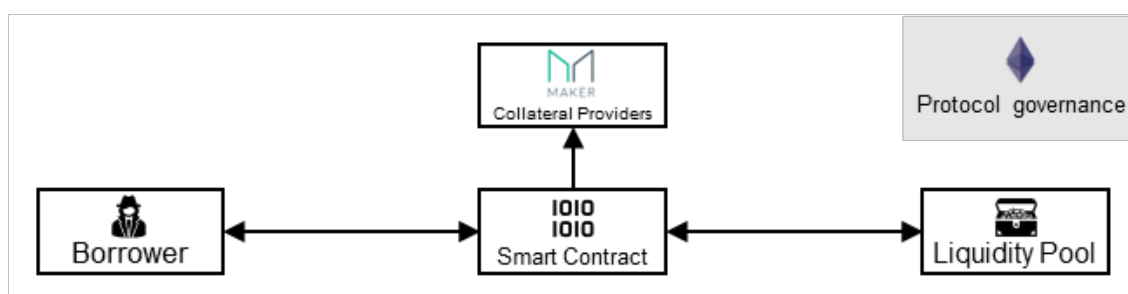


Source: Adapted in accordance with Gogel, 2021, p. 9.

In addition to centralized Stablecoins, there are also Stablecoins that are managed decentral by a DAO managed by a Smart Contract. One example is MakerDAO, which issues the Stablecoin DAI. Like USDC, DAI is a USD-linked Stablecoin. Unlike a centrally managed Stablecoin, DAI is managed by the Smart Contract protocol on Ethereum. Here, a DAI token is issued as a loan if an investor deposits appropriate collateral, e.g. Ethereum tokens. In this process, the DAI position is overcollateralized. If the value of

the collateral falls to the value of the issued DAI tokens, the position is liquidated similar to a margin call. Dai provides a decentralized alternative to centralized Stablecoins, but it is less capital efficient because it is overcollateralization. If the investor wants to liquidate his DAI position voluntarily, he has to pay back the DAI tokens and interest and gets his collateral back (MakerDAO, 2014). The total value of all DAI tokens issued is equivalent to USD 6 billion as of November 2022 (Coinmarketcap, 2022). With DAI, there is no counterparty risk, as only own assets are lent. However, there is governance risk with MakerDAO, whereby an attacker who gains control of half of the MakerDAO tokens is able to influence new lending and interest rates.

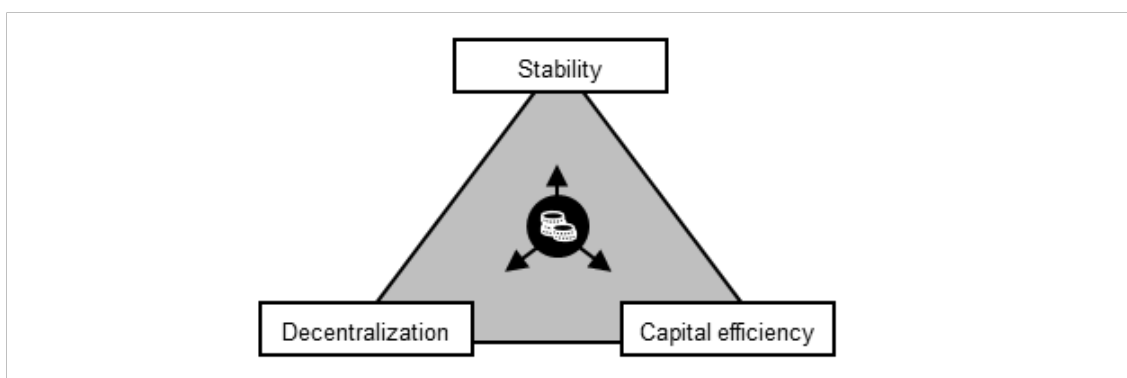
Figure 11. Decentralized asset backed Stablecoin (DAI)



Source: Adapted in accordance with Gogel, 2021, p. 9.

Besides centralized Stablecoins and decentralized asset backed Stablecoins, however, there is a third category of Stablecoins that has gained notoriety: Decentralized algorithmic Stablecoins. Algorithmic Stablecoins are Stablecoins that are not kept stable by buying or selling deposited assets. The best known algorithmic Stablecoin is the USD Terra token. This is kept stable by creating or burning Luna, Terra's native network token. This means that if TerraUSD rises above the value of one dollar, Terra USD tokens are sold and Luna tokens are burned. When TerraUSD falls below the value of one dollar, Terra USD tokens are bought and Luna tokens are minted (Kereiakes, Kwon, Di Maggio, Platias, 2019, pp. 4-5). However, in the case of Terra, this mechanism in 2022 resulted in a large withdrawal of tokens causing the TerraUSD price to fall below the value of one dollar. At the same time, so many Luna tokens were created that the price collapsed (Coinmarketcap, 2022). With USDD there is another known decentralized algorithmic Stablecoin today that is backed by more collateral than TerraUSD and has a market capitalization of USD 700 million (USDD, 2022, p. 1; Coinmarketcap, 2022). So there are different solutions for Stablecoins, however each of them has a weakness either in stability, decentralization, or capital efficiency. This phenomenon is called the Stablecoin trilemma in parallel to the Blockchain trilemma.

Figure 12. Stablecoin trilemma



Source: Own illustration.

Central bank digital currency

A central bank digital currency or abbreviated CBDC is generally defined as a digital liability of a central bank that is available to the general public (Scharfman, 2022, pp .6-7). The Fed writes: "As a liability of the Federal Reserve, however, a CBDC would be the safest digital asset available to the general public, with no associated credit or liquidity risk" (Federal Reserve System, 2022). Depending on their design, these digital central bank currencies will then be tradable directly on DLT platforms. For example, the Swedish central bank is researching the e-krona, which will operate on a private Blockchain system (Sveriges riksbank, 2022). It is possible that such a system will then work interoperable with public DLT platforms and CBDC will be tradable on DLT platforms such as Ethereum. Such CBDCs would be a safe alternative to Stablecoins. However, it remains to be seen how open and interoperable these systems are. For central banks, more openness also means a loss of control over their currency.

Security tokens

Security tokens are a digital securitization of an asset. These can be shares or bonds, for example, which can be traded on a DLT platform using a Smart Contract (Scharfman, 2022, p. 16; Adam, 2022, pp. 165-166). Since shares or bonds are regulated legal transactions, this regulation typically also applies to security tokens that contain such a value. Due to this regulation, trading shares on the Blockchain is not possible in large parts of the world, such as Germany, while in Switzerland it has been possible to use digital shares on DLT platforms since 2019 (Neue Zürcher Zeitung, 2019). Technically, however, it is possible to create any type of fungible asset as a security token and store it on a DLT network. This is often referred to as "digital assets" or the "tokenization of assets".

Non-fungible tokens

Non-fungible tokens or short NFTs are, as the name suggests, unique tokens (Adam, 2022, p. 167). NFTs are possible with hard assets such as the transfer of real estate ownership, as well as with soft assets such as intangible assets (Scharfman, 2022, p. 17). Technically, a smart contract is used to create a unique digital asset containing, for example, an MP3 or a JPEG. However, the application areas for NFTs go beyond art. It is technically possible to trade any unique asset as an NFT on a DLT network. For example, it is conceivable to trade rights to unique assets such as real estate or cars via NFTs or to securitize event tickets as NFTs.

2.4.3. Sharding, Sidechains and Layer-2 solutions

Sharding is a mechanism that increases the scalability of DLT networks and is used by some DLT networks, such as NEAR (Skidanov, Polosukhin, 2019, p. 1). Sharding divides the tasks that need to be performed by the nodes into smaller subtasks. The entirety of the nodes is also divided into smaller groups. These smaller groups then do the validation of their subtasks (Gao, Nobuhara, 2017, pp. 1-2). In centralized databases, sharding has been used for a long time, for example, when a database of personal data is split between two servers and one server stores the names A-O and the other around the names O-Z, it is sharding in a simple form. In DLT networks, sharding is used to distribute the Blockchain / DAG across a number of higher-performing smaller shards, significantly increasing scalability. At the same time, this reduces the technical requirements for the operators of nodes in the network. The smaller groups of nodes validating transactions in the individual shards increase the vulnerability to attacks. If many nodes working together want to manipulate a shard, they need significantly less than half of the total amount of network tokens. It is sufficient if the attacker provides the majority of votes in this particular group associated with a shard. So, the risk to the network increases. However, DLT networks that use sharding or plan to use it in the future, such as Ethereum, reduce this risk by randomly assigning nodes to shards, making collaboration much more difficult to the detriment of the network (Ethereum, 2021).

A sidechain is a fork from the original Blockchain that allows the owner to exchange tokens between it and the mainchain. Sidechains may exhibit different rules from their mainchain, e.g., a different consensus algorithm (Back et al., 2014, pp. 5-6). As a result, the sidechain is not necessarily visible by all nodes of the mainchain. These different sets of rules and the fact that a mainchain can have multiple sidechains at the same time create flexibility for users between the specifications of the individual chains.

Building on the basic protocols, Blockchain or DAG, further solutions exist on Layer-2, technically one level above, which are not directly linked to the Layer-1 protocols. As a result, these solutions can exist apart from potential scalability limits of Layer-1. However, they also do not provide the security that exists at Layer-1 (Jourenko, Kurazumi, Larangeira, Tanaka, 2019, p. 2). By incorporating Layer-2 applications into the more secure Layer-1 protocols, use cases arise that combine the benefits of Layer-1 and Layer-2 solutions. One of the most popular Layer-2 solutions is Arbitrum , a Smart Contract scaling solution on Ethereum (Kalodner, Goldfeder, Chen, Weinberg, Felten, 2018, p. 1).

2.5. Success factors of DLT Networks

The key success factors for decentralized DLT networks are security, decentralization, and scalability, as already indicated in section 2.3.1. The successful implementation of these factors is necessary to achieve the adaptation of a DLT network (Im, 2018, pp. 14-15). Security in DLT networks is essential to ensure that assets and data on a DLT network are protected from misuse. In this context, security is measured by how much resources a potential attacker needs to attack the network and how much incentive there is to attack a network. Decentralization represents the evolution from traditional networks to DLT networks. Higher decentralization means that individual actors have less influence on the network. Decentralization is therefore also a security factor to protect the rights of small network participants from the large network participants. Decentralization is measured by the distribution of nodes and the distribution of miners or validators. A high number of miners or validators does not necessarily mean a decentralized network, since it must be considered by whom the miners are controlled. Scalability means that DLT networks are just as capable with a high number of nodes, validators, and transactions as with a low number of them. One scalability metric is transactions per second / TPS, but there are others.

In addition to the classic three success factors in DLT networks, there are other factors that contribute to the spread of DLT networks. For one thing, regulation and legislation is a decisive factor. States cannot directly influence DLT networks, but they can regulate citizens in their country. The sustainability of DLT networks plays a crucial role here. For example, in 2021, the Swedish Financial Supervisory Authority advocated for an EU-wide ban on Proof-of-Work mining, which would affect Bitcoin among others (Finansinspektionen, 2021). The reason for this is the high energy consumption of the

Bitcoin network, which, at about 110 TWh, is equivalent to Netherlands total energy consumption (Digiconomist, 2022).

In addition, the application area is a factor that determines the spread of DLT networks. The programmability and which programming languages are supported has an influence on whether or how many applications are created on a platform.

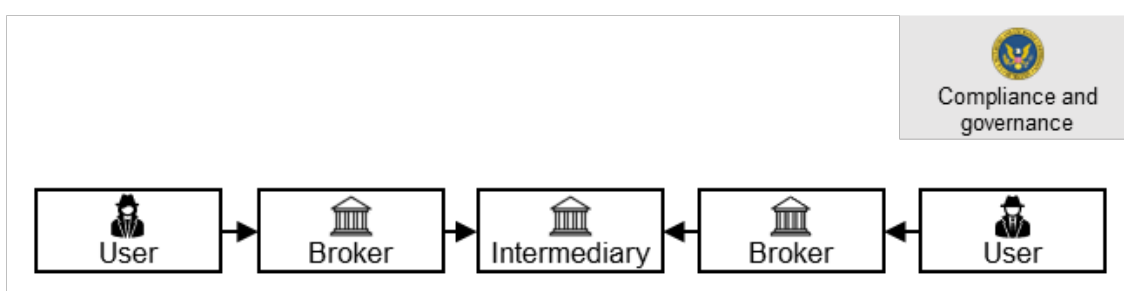
3. Financial services become decentralized

3.1. What is Decentralized Finance?

The third chapter of this thesis deals with the topic of decentralized finance. It first describes what DeFi is, then looks at DLT networks in the DeFi space, and finally compares key DeFi applications with traditional financial services.

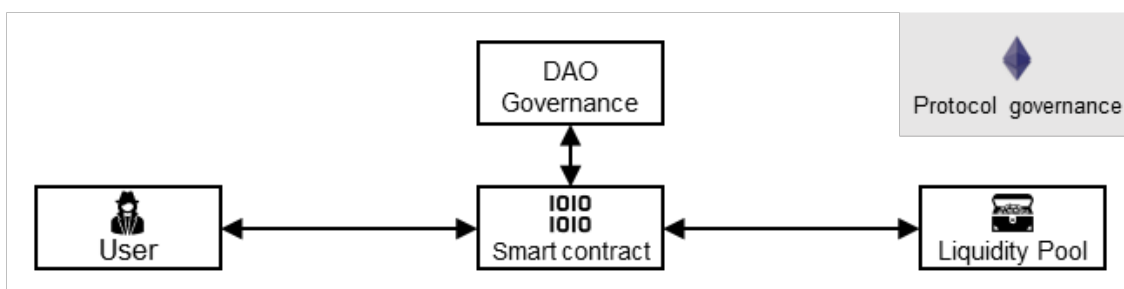
The DeFi space describes peer-to-peer financial services that take place on DLT platforms (Coinbase, 2022). In the DeFi ecosystem, financial services are executed by Smart Contracts or DApps instead of brokers, exchanges, or banks. By excluding these intermediaries, financial services can thus be performed more efficiently from DLT platforms, more on this in Section 3.3. (Scharfman, 2022, p. 171). In most cases, decentralized autonomous organizations, DAOs, are responsible for the further development of Defi applications in the interest of users and governance token holders.

Figure 13. Typical traditional financial service



Source: Own illustration.

Figure 14. Typical DeFi service

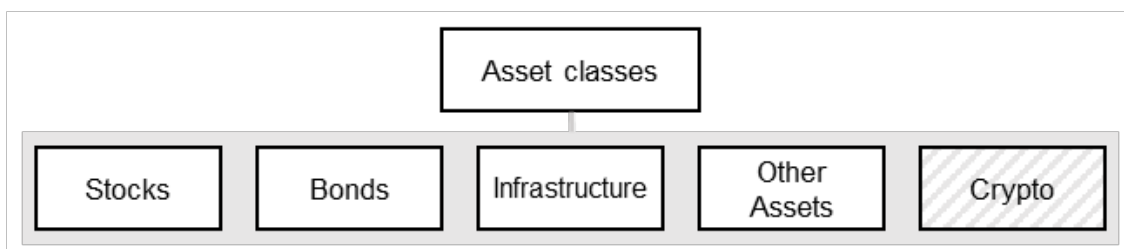


Source: Own illustration.

The following pages will provide an overview of the impact DeFi has had on the world of financial services, comparing this development with that of the Internet on the media industry.

In public reporting, the terms crypto, Blockchain and bitcoin are mostly used when reporting on DLT topics. The focus of this coverage is on the use of cryptocurrencies as an object of speculation. In this context, even well-known business journals such as the Wall Street Journal with headlines such as "Bitcoin Trades Above \$20,000, Crypto Stocks Surge" (Wall Street Journal, 2022) and leading management consultancies such as Bain & Company with articles on the topic "Cryptocurrencies: A new asset class is emerging" (Bain & Company, 2022) focus on the use as a speculation object. This conveys an image to non-specialist readers, as shown in the following illustration: Cryptocurrencies are thereby a new asset class alongside the classic asset classes such as shares, bonds, and other assets. The fact that crypto tokens can be very different assets has already been described in chapter 2.4.2. Tokens can also include the other asset classes described and digitally securitize them on a DLT platform.

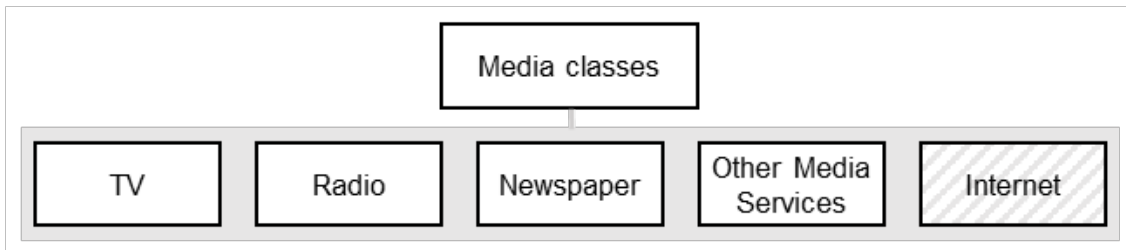
Figure 15. Misconception of Crypto as an asset class



Source: Own illustration.

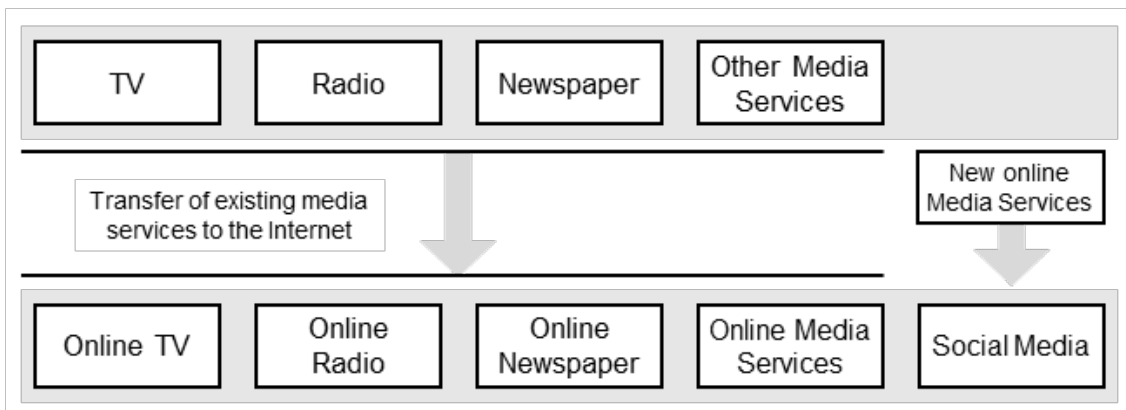
American technology investor Cathy Woods looks at this misconception in her "Big Ideas 2022" annual research report from her investment firm Ark Invest. She draws a comparison with the early stages of the internet, when it was thought to be a new class of media alongside existing classes such as TV, radio, and newspaper (Ark Invest, 2022, p. 41).

Figure 16. Misconception of the internet as a media class



Source: Adapted in accordance with Ark Invest, 2022, p. 41.

Figure 17. Media revolution through the rise of the internet



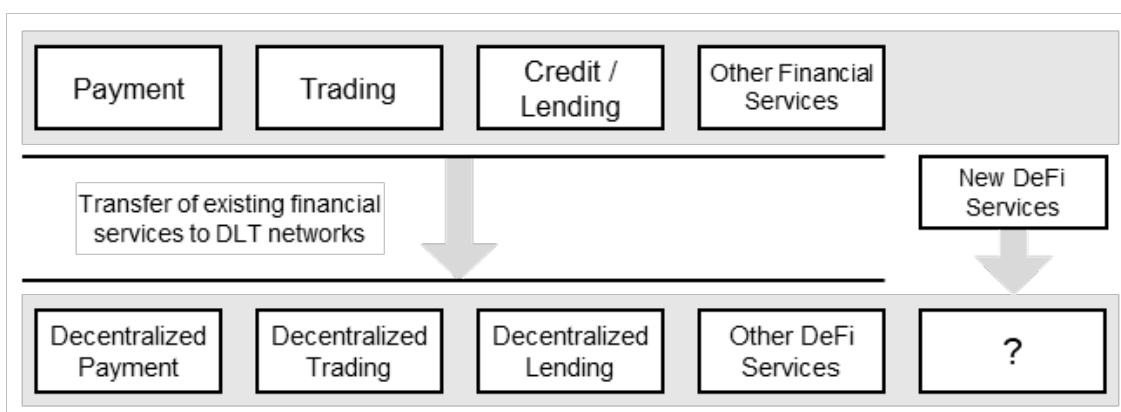
Source: Adapted in accordance with Ark Invest, 2022, p. 41.

As it turned out later, this assessment was wrong, since the internet is an infrastructure on which most of our media takes place today (Interactive Advertising Bureau, PricewaterhouseCoopers, 2022, p. 12). There are two pillars to consider: On the one hand, existing media services were brought into the new internet infrastructure. This development enabled media companies to operate more globally and offer improved services thanks to the new technical environment. As a result, media services such as Netflix emerged as an alternative to TV, Spotify as an alternative to radio, and Twitter as an alternative to newspapers. On the other hand, the new infrastructure enabled completely new solutions. With social media, a new media class developed. The special

feature of social media compared to the other media classes is that users here are not only readers but have more opportunities for interaction. Within the last two decades, social media has developed into one of the largest media classes (Interactive Advertising Bureau, PricewaterhouseCoopers, 2022, p. 22). Of course, the spread of the Internet had consequences that went beyond the development of the media industry, but the example illustrates how a new infrastructure can affect an existing industry.

Today's financial industry is a completely different industry at a different point in time than the media industry of that time, but here, too, a possible transition to a new infrastructure is imminent. This transition is not seen today in large parts of the financial world, as the media coverage at the beginning of this chapter shows. It remains to be seen whether an adaptation of DLT infrastructure will take place in the traditional financial industry. This chapter will look at the extent to which financial services can already be provided on DLT networks today.

Figure 18. Financial revolution through the rise of DLT platforms



Source: Own illustration.

In the figure above, it can be seen that existing financial services such as payment, trading, lending, and others are being transferred to DLT networks. On the other hand, new financial services are created, which are enabled by the decentralized environment of a DLT network.

The first step, the transfer of existing financial services, will be discussed in the following three chapters of this thesis. Thereby, the three central financial services Payment, Trading and Lending on DLT networks will be presented. These three were chosen because they form the basis of many other financial services. Financial products such as futures, swaps, options, and other derivatives are legal contracts or, in DLT networks, Smart Contracts that use these basic financial services. These derivatives in turn form

the basis for decentralized insurance to hedge assets on DLT networks. Likewise, these financial services allow asset management to be carried out, as income can be generated by providing liquidity or trading assets. Second, new financial services are emerging that are only made possible by DLT platforms, such as flash loans, more on this in 3.3.2.

The DeFi applications build on each other in this way. This means that complex DeFi applications are based on basic DeFi applications. You can imagine this decentralized system of applications simplified like a building made of Lego bricks. Applications that are used can be flexibly exchanged if there is an application that fulfills the purpose better or cheaper. This system makes it easier for every user to provide new applications, because he can fall back on all existing applications. At the same time, there is an incentive to be most efficient because users can switch to an alternative application.

3.2. Distributed Ledger Networks in DeFi

3.2.1. Overview

Since DeFi applications consist of Smart Contracts, DeFi applications can only run on DLT networks that allow Smart Contracts to be created. DLT networks such as Bitcoin are thus excluded. DLT networks that are used for DeFi applications include, for example, the networks included in the following overview. “The total value locked [or TVL], meaning in DeFi is a reference point that represents the number of assets that are currently being staked in a specific protocol. These assets can include rewards, interest, new coins and tokens, fixed income and more” (Berg, 2022).

Figure 19. Overview selected DLT networks in DeFi

Overview selected DLT networks in DeFi				
on November 24, 2022	#	Total Value Locked (in million USD)	Number of DeFi Protocols	Market capitalization (in million USD)
Ethereum	1	23,640 ²	603 ²	146,127 ¹
Binance Smart Chain	2	5,820 ²	502 ²	47,574 ¹
Tron	3	4,280 ²	11 ²	4,841 ¹
Polygon (L2 ETH)	4	1,050 ²	337 ²	7,435 ¹
Arbitrum (L2 ETH)	5	959 ²	141 ²	-
Avalanche	6	791 ²	273 ²	3,866 ¹
Fantom	9	430 ²	268 ²	465 ¹
Solana	11	283 ²	90 ²	5,164 ¹
Algorand	17	128 ²	18 ²	1,708 ¹
MultiverseX	19	101 ²	1 ²	1,006 ¹
Celo	21	88 ²	34 ²	239 ¹
Near	22	86 ²	13 ²	1,381 ¹

Source 1: Coinmarketcap, 2022

Source 2: DefiLlama, 2022

In this chapter, we will take a closer look at the Ethereum, Avalanche, and NEAR networks. Ethereum is the largest DLT network that enables DeFi with a market share of roughly 60% of the Crypto TVL. Avalanche and NEAR are also DLT networks that enable DeFi solutions but differ significantly from Ethereum in technical terms. Colloquially, these and other alternative Layer 1 networks are also referred to as "Ethereum killers" in media because they are high scalable and compete with Ethereum network (Genç, 2022).

3.2.2. Ethereum

Ethereum, abbreviated ETH, is a Layer-1 DLT network and was the first DLT network to implement Smart Contracts. Currently, it is the second largest network behind Bitcoin (Coinmarketcap, 2022). In 2015, Vitalik Buterin and his team released Ethereum (Buterin, 2014, p. 1). Today, Ethereum is backed by the Ethereum Foundation, which is based in Switzerland and continues to develop Ethereum (Ethereum, 2022). The Ethereum network uses a Blockchain protocol that uses an account model instead of the UTXO model (Buterin, 2014, p. 12). A Proof-of-Work consensus was used as the

consensus mechanism, which was replaced by a Proof-of-Stake consensus in 2022. Ethereum enables its network participants to run DApps on the network via Smart Contracts. These programs can be executed through the Ethereum Virtual Machine, EVM (Buterin, 2014, p. 17). This innovation that Ethereum spurred in the DLT universe enables Ethereum to deliver a value proposition that goes well beyond Bitcoin. The Ethereum Foundation describes this as follows:

“Ethereum is a technology for building apps and organizations, holding assets, transacting and communicating without being controlled by a central authority. There is no need to hand over all your personal details to use Ethereum - you keep control of your own data and what is being shared. Ethereum has its own cryptocurrency, Ether, which is used to pay for certain activities on the Ethereum network.” (Ethereum, 2022)

This description reflects Ethereum's dominant role as the most important DLT platform. Ethereum's TVL accounts for 57% of the total TVL of all DLT platforms at approximately USD 24 billion (DefiLlama, 2022). A key advantage of Ethereum is its long track record, as the network has been operating continuously since July 30, 2015. This higher trust on the Ethereum platform is also reflected in the fact that availability on Ethereum is higher than on alternative Layer-1 platforms.

One challenge in the Ethereum network is scalability. As described in chapter 2.4.3., this problem is to be solved in the long term via sharding. Today, however, there are a number of layer-2 solutions such as Polygon or Arbitrum. These make it possible to use complex DApps or Smart Contracts in particular without long waiting times or high transaction fees. For example, an analysis by Delphi Digital puts the share of Arbitrum at 62% of all Ethereum transactions (Delphi Digital, 2022). This strong adoption of Layer-2 scaling solutions compromises Ethereum's decentralization but increases scalability very significantly.

3.2.3. Avalanche

Avalanche is an alternative Layer-1 Proof-of-Stake DLT platform released in 2020. Avalanche is backed by Ava Labs, a company founded by Cornell professor Emin Gün Sirer. The latter, along with a research community called Team Rocket, published the so-called Snow consensus and the Avalanche network (Team Rocket, Yin, Sekniqi, Van Renesse, Sirer, 2020, p. 1).

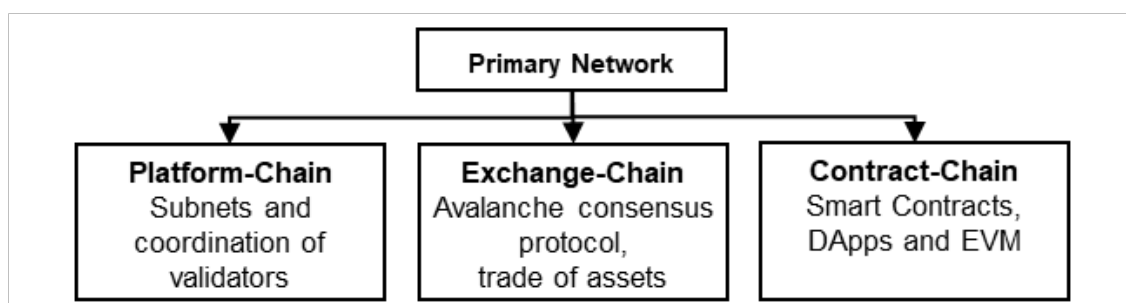
The three stated goals of the Avalanche platform are:

- “Building application-specific Blockchains, spanning permissioned private and permissionless public deployments

- Building and launching highly scalable and decentralized applications, Dapps
- Building arbitrarily complex digital assets with custom rules, covenants, and riders, smart assets” (Sekniqi, Laine, Buttolph, Siner, 2020, p. 1)

Unlike Ethereum, Avalanche uses not just one protocol, but three protocols, including two Blockchain networks, the Platform Chain and the Contract Chain, and one DAG, the Exchange Chain. The Exchange-Chain acts as a decentralized platform for creating and trading digital smart assets, a representation of a real-world resource. “The Platform-Chain is the metadata Blockchain on Avalanche and coordinates validators, keeps track of active Subnets, and enables the creation of new Subnets. The Contract-Chain allows for the creation Smart Contracts using the EVM” (Avalanche, 2022).

Figure 20. Avalanche network structure



Source: Avalanche, 2022

This DLT infrastructure enables Avalanche to provide infinite scalability, while decentralization is very high with thousands of nodes and the network can even operate securely with only 20% honest nodes (Avalanche, 2022). This is made possible by the Snow Consensus which combines the advantages of the classical consensus and the Nakamoto Consensus (Sekniqi, Laine, Buttolph, Siner, 2020, p. 5).

3.2.4. NEAR

NEAR is an alternative Layer-1 Proof-of-Stake DLT platform released in 2020. Behind the NEAR platform is the company Near Inc., which consists of the development team around Illia Polosukhin and Alexander Skidanov. In addition, the Near Foundation was founded in 2019 to support the NEAR ecosystem in development (NEAR, 2022).

NEAR defines its goals as follows:

- “Usability: Applications deployed to the platform should be seamless to use for end users and seamless to create for developers. [...] Basic applications should

be intuitive and simple to create while more robust applications should still be secure.

- **Scalability:** The platform should scale with no upper limit as long as there is economic justification for doing so in order to support enterprise-grade, globally used applications.
- **Simplicity:** The design of each of the system's components should be as simple as possible in order to achieve their primary purpose. Optimize for simplicity, pragmatism and ease of understanding above theoretical perfection.
- **Sustainable Decentralization:** The platform should encourage significant decentralization both in the short term and the long term in order to properly secure the value it hosts. [...]” (NEAR, 2022)

Regarding the usability, NEAR allows Smart Contracts to be written in common programming languages like JavaScript instead of using specialized programming languages like Solidity, which Ethereum uses. This makes it possible for significantly higher numbers of programmers to contribute to the network. In addition, NEAR provides its developers with tools like those used for traditional web applications in order to program them more simply (NEAR, 2022).

In terms of scalability and decentralization, NEAR uses a sharding mechanism known as Nightshade. Nightshade uses a point-to-point voting mechanism where a subset of validators are polled so that transactions are immediately final - the same quadrant as Avalanche's Snow Consensus (Skidanov, Polosukhin, 2019, p. 22). This instant finality also allows transactions between different shards to be executed expeditiously, which contributes to scalability. At the same time, sharding affects the hardware requirements of nodes that significantly decrease, making mobile devices such as smartphones suitable and thus enabling higher decentralization (NEAR, 2022).

3.3. Applications from DeFi

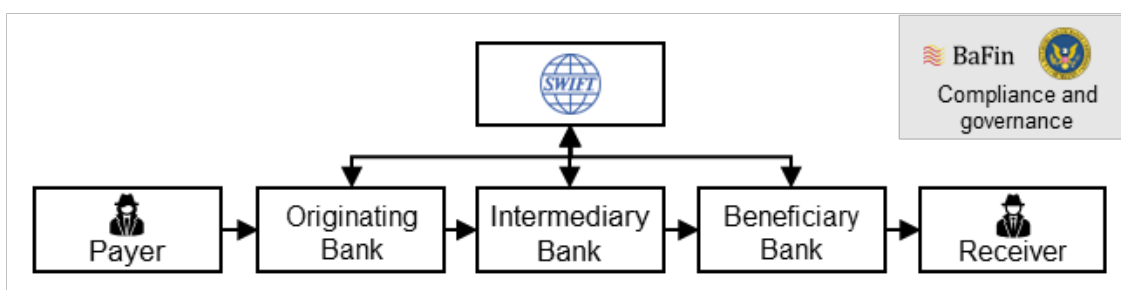
A variety of DeFi applications exist, most of which are decentralized alternatives to centralized financial services that exist today. One example is decentralized exchanges, which operate differently but perform the same function as traditional centralized exchanges. However, new financial services are also emerging, such as flash loans, which are discussed in Section 3.3.3. Since DeFi applications are structurally based on each other, according to the Lego principle, complex DeFi applications such as decentralized insurance fall back on basic DeFi applications such as payment, trading and credit. The following chapters deal with these three basic functions, which systematically affect the entire DeFi ecosystem.

3.3.1. Payment

Payment is the foundation of all other financial services and central to the success of DLT networks. In this chapter, we look at how payment processing works in the traditional financial world compared to payment processing via DLT networks. Concrete an international bank transaction is considered, as DLT networks are establishing themselves increasingly in this area as a low-cost and fast alternative to traditional bank transaction.

Today, international bank transactions are processed via the SWIFT payment network. SWIFT does not process payments itself but acts as a communication platform for banks to coordinate the transaction. The paying bank customer releases an international bank transaction at his bank. This is processed by the originating bank and passed on to the intermediary bank, which passes the transaction on to the beneficiary bank. The payee is then informed that the payment has been received (Bank of International Settlement, 2022, p. 3). As can be seen, the process is complex and each of the banks involved deserves a share of the whole process.

Figure 21. Traditional international payment



Source: Adapted in accordance with Bank of International Settlement, 2022 p.3.

How long this process takes depends largely on the location of the beneficiary bank. For example, an average international bank transaction with the USA as the destination takes about 12 minutes and with Germany as the destination about 39 minutes. In contrast, an international bank transaction with India as the destination takes an average of 23 hours (Bank of International Settlement, 2022, p. 2). In many developing countries large sections of the population have no access to bank accounts at all. In Africa, it is less than half of the adult population, which has access to financial services through a bank account (Statista, 2022).

In decentralized networks, it does not matter whether a payment is made national or across national borders. The transaction takes place as described in sections 2.3.1 or 2.3.2 and is executed within minutes or seconds depending on the DLT network. Since no service providers are involved, the user only incurs the transaction fees charged by the network. If the transaction takes place via a Smart Contract, additional fees for the execution of the Smart Contract may also be incurred.

Figure 22. Decentralized payment



Source: Own illustration.

For the sake of correctness, it should be mentioned that payment is not a DeFi application, as DLT networks support payment and settlement natively. Since payment is a financial service in the traditional financial world, the comparison still makes sense.

In the area of international payments, DLT networks thus represent an alternative to classic foreign transfers. Transaction times and transaction costs are many times lower. The greatest increase in efficiency benefits emerging and developing countries, because transaction times and transaction costs are particularly high here.

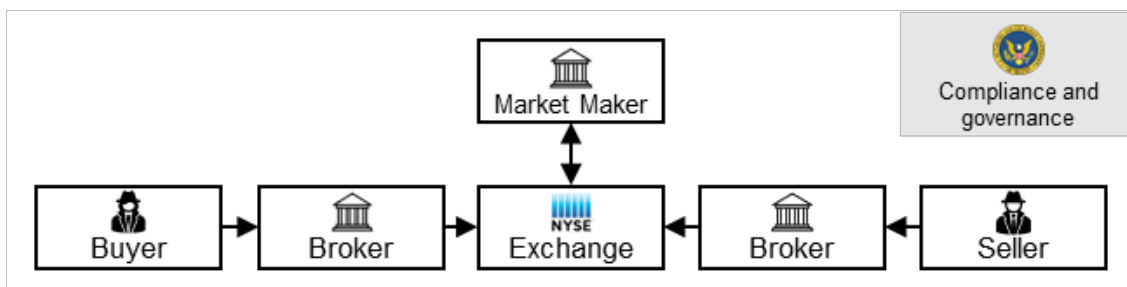
Especially for the large populations of developing countries which does not have a bank account people, DLT networks represent an alternative to banks in the area of payments and also enable other financial services. The permissionless and open environment is an advantage, which allows everyone to participate who has internet access.

3.3.2. Trading

In addition to payments, trading is another key financial service. Today, trading in fungible assets usually takes place on exchanges. "Exchanges regulate and monitor multilateral systems that bring together buy and sell orders for assets and rights admitted to trading there in accordance with defined rules, thus generating a contract" (Translated from German via DeppL). There are different types of exchanges, such as securities exchanges, commodity exchanges, futures exchanges, and many others, which differ in the assets that are traded. In this chapter, centralized exchanges and decentralized exchanges are compared.

Consider a central securities exchange such as the New York Stock Exchange, NYSE. A buyer and a seller transmit their buy and sell orders respectively via their brokers. The brokers transmit the orders to the exchange and a transaction takes place. The exchange and both brokers charge fees that are paid by the buyer and seller. In addition, market makers act on the exchange, whose task is to constantly guarantee liquidity on the exchange by providing bid and ask prices at which market participants can trade. However, they are not paid directly by traders, but earn money indirectly when they sell positions more expensively than they buy them. Thus, they trade at their own risk. The provision of liquidity is therefore also a cost factor borne by the buyer and seller. From the moment the transaction is made, it takes a few seconds for transaction to be completed legally. However, it should be noted that at this moment the securities have not yet changed hands. It is only in the so-called post-trading that the securities are transferred by the Central Securities Depository (Deutsche Börse Group, 2022). As can be seen, there are at least four parties involved in this process, who earn their fees through the transaction costs of the traders.

Figure 23. Centralized Exchange

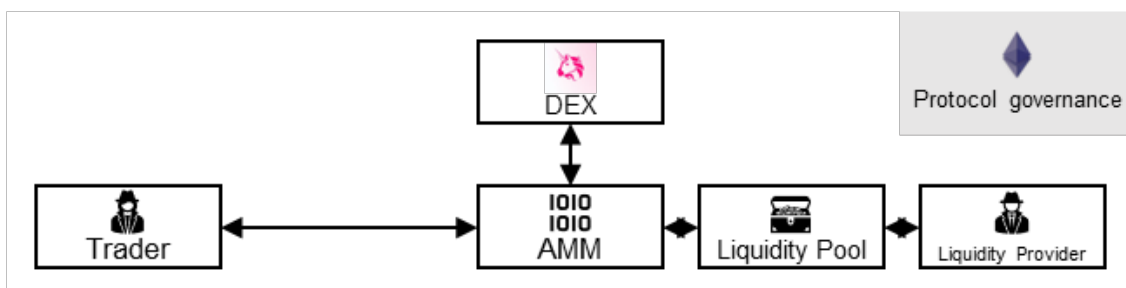


Source: Own illustration.

Decentralized exchanges, DEX, are decentralized financial service providers that enable trading of fungible tokens on DLT networks. In the following, we look at DEX using the example of Uniswap, the largest DEX with an annual trading volume of USD 679 billion (Token Terminal, 2022). Uniswap, as the largest DEX, has a 44% market share in this as of Nov. 14, 2022. Besides Uniswap, there are a variety of other DEX such as SushiSwap, PancakeSwap, Curve or dydx (DefiLlama, 2022).

Uniswap is a DAO that is constantly developing DEX Uniswap (Uniswap, 2021). Uniswap do not use a traditional order book as used by centralized exchanges, as liquidity on DLT networks is significantly lower than on traditional markets and therefore no immediate trading would be possible. Instead, Uniswap uses a system called an Automated Market Maker, AMM (Adams et al., 2021, p. 1f). However, there are DEX that use an order book like dydx. An AMM is a decentralized automated application that acts as a trading partner. No distinction is made between buyers and sellers as both parties are traders: A trader who wants to trade DAI against ETH is to be considered in the same way as a trader who wants to trade inverted ETH against DAI. There is no central currency used as a universal unit of exchange, such as the USD on US securities exchanges, instead assets are exchanged directly against each other. The AMM uses a liquidity pool of the exchange pair, which contains equal amounts of ETH tokens and DAI tokens for the example case (Adams et al., 2021, p. 2).

Figure 24. Decentralized AMM-based Exchange



Source: Own illustration.

If the liquidity pools of an AMM are too small, a so-called slippage problem occurs. If you imagine that you want to buy all available tokens, the purchase price increases exponentially from token to token. This phenomenon, in which temporarily no market price can be provided, is called slack. If the AMM price moves away from the price on other exchanges, this gives traders the opportunity to arbitrage and the prices equalize again. AMMs thus rely on sufficiently large liquidity pools to provide market-based prices on a continuous basis.

The funds for the liquidity pools are provided by investors, so-called liquidity providers, who receive interest. On Uniswap, the trading fees today are paid to the liquidity providers (Adams et al., 2021, pp. 3-4).

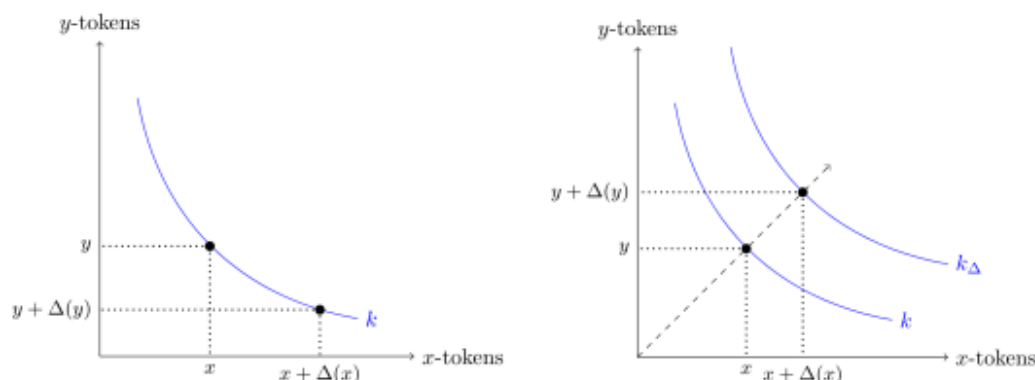
The trading price is calculated by the following mathematical algorithm:

$$\text{tokenA_balance}(p) * \text{tokenB_balance}(p) = k \text{ or}$$

$$x * y = k \text{ (Adams et al., 2021, p. 2)}$$

The constant, represented by "k", means that there is a constant asset value that determines the price of tokens in a liquidity pool. So, in the example case, if x tokens are bought with y tokens, the price of x increases, and conversely, if y tokens are bought with x tokens, the price of x decreases. The pool remains in constant equilibrium, with the total value of x tokens in the pool always equal to the total value of y tokens in the pool (Adams et al., 2021, p. 2). The figure below left shows the availability of x token in relation to y token. The right figure shows how the curve changes when liquidity increases.

Figure 25. Visualization of liquidity pool token reserves of an AMM-based DEX



Source: Adapted from Adams et al., 2021, p. 2.

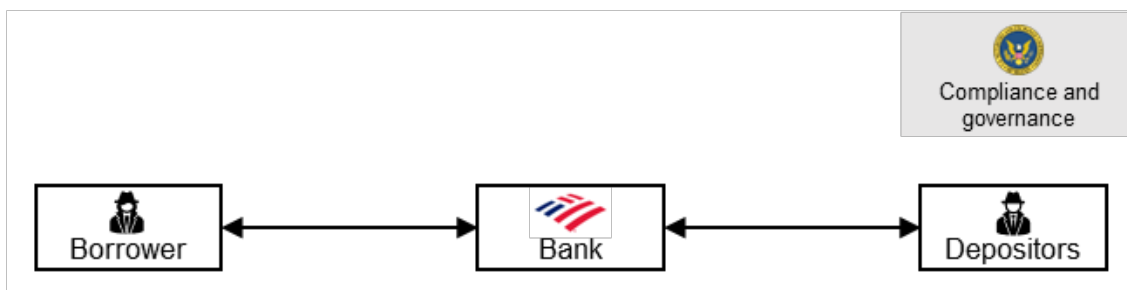
As can be seen, with decentralized exchanges there is only one fee through one party, the AMMs. The costs for the fees arise from transaction fees of the DLT network used and from capital costs earned by the liquidity providers. There are no operational costs for running an AMM and no profits need to be made. There is therefore a systematic advantage of DEXs over traditional centralized exchanges. However, it should be noted that most DAOs incentivize their users to hold the governance tokens of the DAO. However, this also contributes to the security of the DEX, as the governance token holders control the DEX.

3.3.4. Credit

In addition to payment and trade, the third pillar of financial services will now be discussed: Credit. Credit describes the transfer of capital or purchasing power for a certain period of time, the granting of credit and the confidence in the ability and willingness to fulfill debt obligations [...], creditworthiness. In addition, the capital itself that is surrendered in debt financing is also referred to as credit. Lending thus enables borrowers to invest more financial resources than they have. Lenders can generate income with the capital that is not needed. Lending thus has a central function in the economy to allocate resources efficiently. In this chapter, we consider lending through a traditional bank, such as Bank of America, and lending through a DeFi application. Two different types of decentralized lending are presented: Overcollateralized lending using the example of Aave and uncollateralized lending using the example of Maple Finance.

Traditional banks, such as Bank of America, act as intermediaries between lenders/savers and borrowers. A loan is granted after an examination of the borrower's financial situation. If the borrower has sufficient collateral and income to repay the loan amount including interest, the bank offers a loan at an interest rate depending on the risk. If the borrower agrees, a loan agreement is concluded. The borrower usually has to collateralize the loan with his assets. In the event of default, the bank has the option of accessing and selling the assets in order to repay the borrower's debts. The funds that the bank issues to the borrower usually consist of deposits and savings of lenders/savers, but it can also be partly bonds of the bank. Since the bank pays less interest on these funds than it receives from its borrowers, it earns on the difference. In addition, banks earn money by investing part of the short-term customer funds in the long term, generating higher returns.

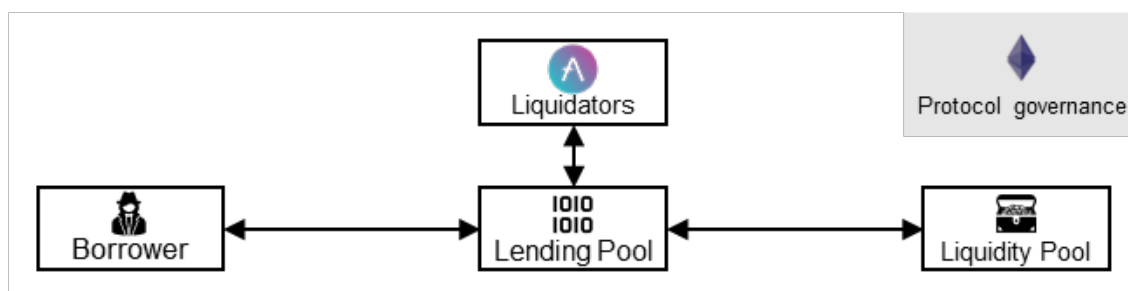
Figure 26. Centralized lending



Source: Own illustration.

Decentralized lending allows peer-to-peer loans to be taken or money to be invested in a decentralized manner based on DLT networks. With a Total Value Locked, TVL, of USD 5.5 billion, Aave is the largest decentralized lending platform (DefiLlama, 2022). Aave is a DAO that is constantly developing the Aave lending platform (Aave, 2022). In this, Aave works similar to the system how MakerDAO issues DAI tokens. A loan is issued by depositing collateral. This collateral must exceed the credit limit, i.e., the credit is overcollateralized. If the deposited collateral falls to the value of the loan, it is sold to repay the loan in full (Aave, 2020, p. 1). However, Aave allows its borrowers to take their loans for specific terms and variable or fixed interest rates. The interest rate on these loans depends on the market rate, the asset borrowed, the financing term, and the type of interest rate, variable or fixed. In return, market participants receive interest on their deposited collateral. These are subject to the same factors as the borrowing acute (Aave, 2020, pp. 4-5).

Figure 27. Decentralized overcollateralized lending



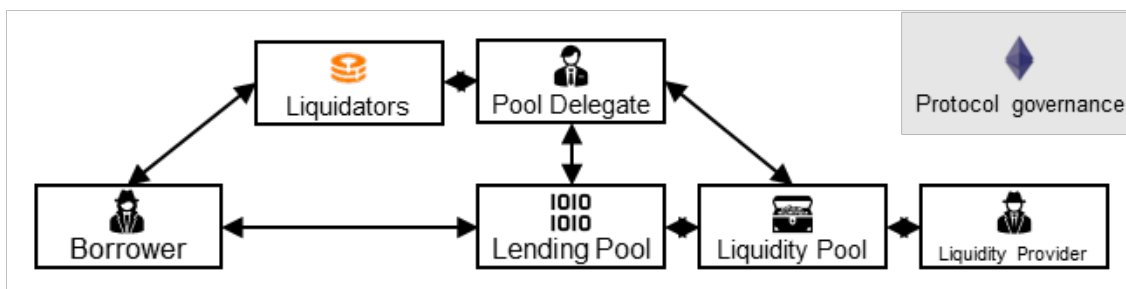
Source: Own illustration.

In addition to these collateralized loans, Aave also makes it possible to take so-called flash loans. These are loans for a few seconds within the time it takes to create the next Ethereum block and do not need to be fully collateralized. These flash loans are linked to other transactions and only take place if the associated transaction also takes place. Flash loans can be useful, for example, to enable the exchange of cryptocurrencies, especially in the case of arbitrage between exchanges. A credit risk does not exist because the contract only takes place if the associated transaction succeeds (Aave, 2020, p. 1). Accordingly, a flash loan can be seen as a kind of short-term credit option, which Aave will only fulfill if the associated transaction takes place. Interest is paid in arrears when the flash loan condition occurs. The success of flash loan has also made them a popular target for hackers. Because loans are given unsecured, attackers can give themselves huge loans when they hack DeFi protocols that offer flash loans. (Coinmarketcap, 2021).

In addition to automated decentralized lending platforms such as Aave and Compound, non-automated decentralized financing platforms such as Maple Finance are increasingly establishing themselves. Maple Finance is a DAO that enables a decentralized marketplace for unsecured loans. The offering is primarily aimed at institutional borrowers and can best be described as a decentralized marketplace for debt funds (Maple Finance, 2022).

Borrowers submit a loan application to Maple Finance and bear the costs of due diligence. Pool delegators, who act as asset managers or lead investors for the DAO, can then invest in the requested loans. These pool delegators are designated as trusted experts by the DAO and must contribute a minimum of USD 100,000 to their liquidity pool. Liquidity providers provide the remaining funds in the pools and receive interest on their invested capital. However, they have no influence on how their funds are invested, but invest as co-investors of the pool delegators, similar to the role of limited partners in private equity. Part of the liquidity pools is also a cover pool, whose investments are subject to higher interest rates and are the first to be liquidated should a loan default occur, similar to a subordinated loan. With this decentralized financial platform, Maple Finance makes it possible to issue more capital-efficient loans than over-collateralized platforms. In return, liquidity providers bear higher risks (Maple Finance, 2022).

Figure 28. Decentralized uncollateralized lending



Source: Adapted in accordance with Maple Finance, 2022.

Decentralized lending is now an alternative to centralized lending in some areas. The solutions differ significantly and enable automated / manual and overcollateralized / unsecured lending. The amount of interest depends on the asset borrowed, the collateral, the financing term, and the market interest rate.

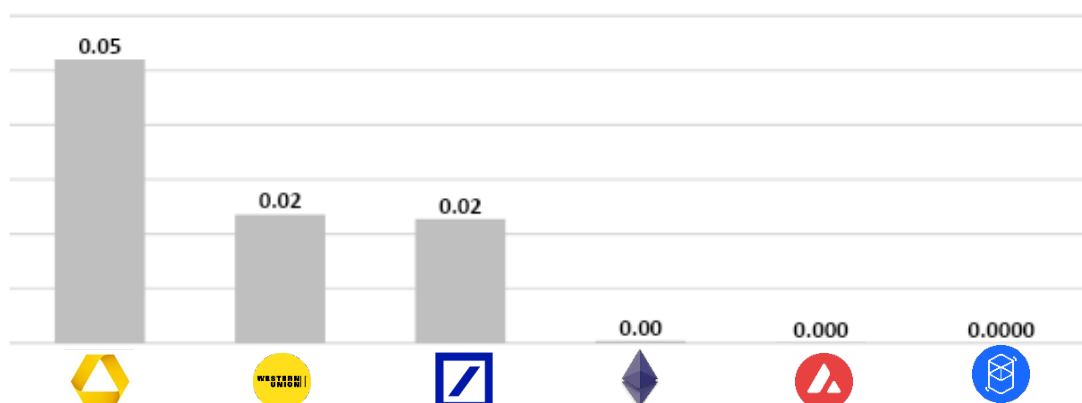
4. DeFi in businesses

4.1. Evaluation of DeFi according to success factors

This chapter assesses the extent to which DeFi applications today conclude in terms of success factors. A comparison is made between DeFi applications and traditional financial services for the three financial services described. In principle, DeFi Apps are only limited at the technical level. That means any application that adds value for network participants can be used. The marginal cost of creating a DeFi App is 0 because there are no ongoing costs for the creator and it is open to every network participant to provide new applications. So, there are incentives for DeFi Apps to become better and more efficient. Since these DeFi Apps are not controlled by any intermediary that monetizes its performance to generate revenue but are owned by the network so they can be used by any participant, DeFi Apps have a structural efficiency advantage over centralized intermediaries and platforms.

Now let's look at the first financial service: payment. International transfers at traditional banks and financial service providers are associated with high fees. A 2019 study by Wise, a fintech that processes international payments, found an average fee of 27.5 EUR for a 1,000 EUR international transfers in Germany (Wise, 2019). In countries where banking infrastructure is less available than in Germany, these costs are significantly higher than 2.8%. For comparison, the transaction costs as of October 22, 2022, on the Ethereum network are approximately 0.42 USD. In the Avalanche network, the transaction costs at the same point in time are 0.009 USD and in the Fantom network, the transaction costs are 0.00008 USD (Cointool, 2022). The costs of a transaction in decentralized networks are thus significantly lower than those of centralized cross-border transfers by a factor of 100 or more.

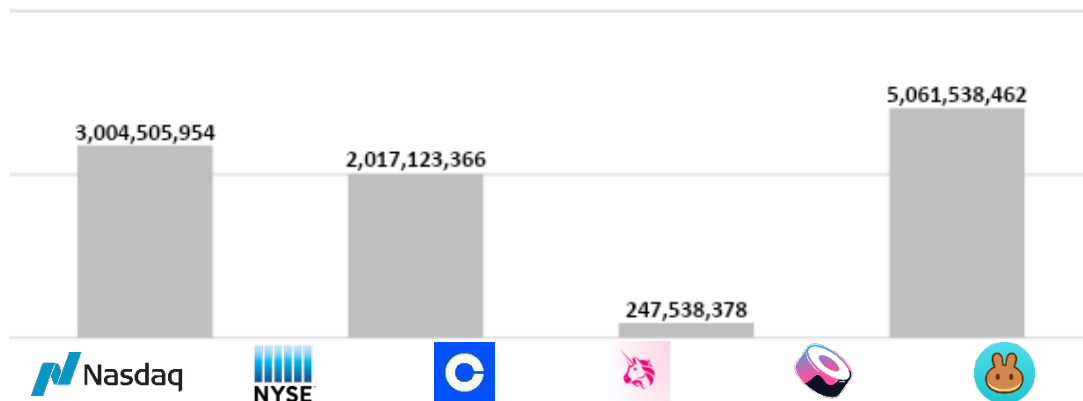
Figure 29. Centralized & decentralized payment: Fees for a 1,000 EUR cross-border transaction in Germany and a 1,000 USD crypto transaction in %



Source: Wise, 2019; Cointool, 2022

Second, a comparison is made between central exchanges and DEXs. This is done by looking at the trading volumes and revenue per employee generated by central exchanges and DEXs over the last twelve months. The ratio is one way to compare the efficiency of exchanges, as more efficient exchanges should achieve higher volumes and revenues with the same number of employees or require fewer employees to achieve the same volumes and revenues. It is worth noting here that there are many other factors that are not considered here. Thus, this is not a holistic analysis, but only an examination of selected key performance indicators. Part of the consideration are the two largest U.S. exchanges Nasdaq, NYSE, the second largest centralized crypto exchange Coinbase and three of the largest DEXs Uniswap, SushiSwap and PancakeSwap.

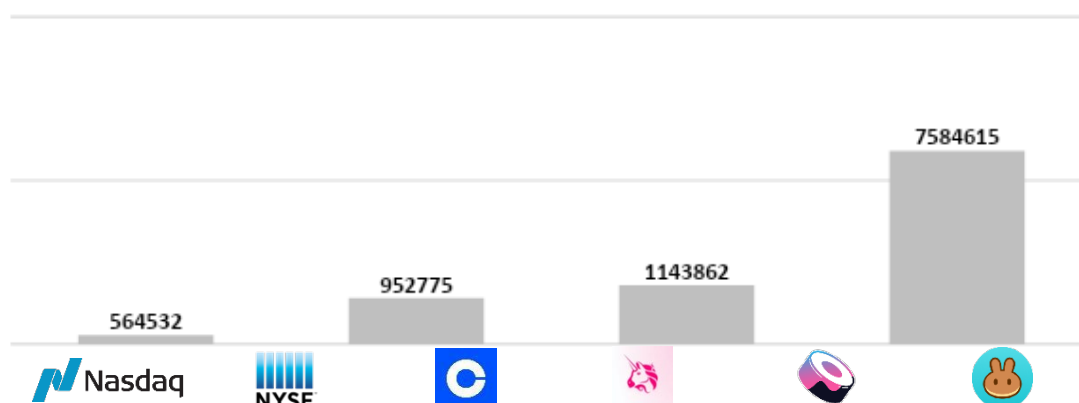
**Figure 30. | Ref. Appendix 1. Centralized exchanges & DEX:
Trading volume per employee in USD (TTM; Nasdaq & NYSE as of FY 2021)**



Sources: Nasdaq, 2021-2022; Intercontinental Exchange, 2021-2022; World Federation of Exchanges, 2022; Coinbase, 2022; Apollo.io, 2022; Tokenterminal, 2022

Figure 31. | Ref. Appendix 1. Centralized exchanges & DEX:

Revenue per employee in USD (TTM)



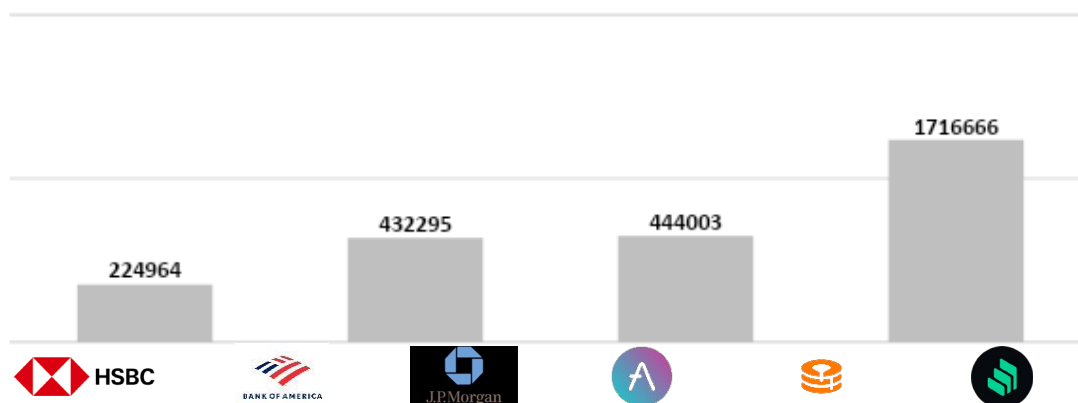
Sources: Nasdaq, 2021-2022; Intercontinental Exchange, 2021-2022; Coinbase, 2022; Apollo.io, 2022; Tokenterminal, 2022

As can be seen from the comparison of key figures, decentralized exchanges handle higher trading volumes than centralized exchanges. The comparison is particularly strong with the centralized crypto exchange Coinbase, which handles less than one tenth of the trading volume per employee. When looking at revenue per employee, DEX's lead over centralized exchanges is very large, about a factor of 10 higher. This results from the combination of higher trading volume per employee and higher fees when trading tokens compared to traditional securities. DEX are thus already more efficient than central exchanges according to the two selected metrics.

Since DEXs use AMMs to run the operational business in a fully automated way, there are no operational costs after the release of the decentralized finance application. Costs for running a business, providing central infrastructure, compliance and other operating costs are not incurred by DEX. The costs of goods sold of a DEX transaction consist of capital costs paid to the liquidity providers. Since decentralized exchanges compete with each other and there is constant transparency between prices on exchanges, it can be assumed that transaction costs will converge to the cost of capital for liquidity providers in the long run. Thus, as capital and liquidity on DLT platforms increases, the cost of capital for decentralized exchanges decreases resulting in lower fees on decentralized exchanges for users. Since revenues roughly correspond to the cost of capital, it can be assumed that this will decrease while the trading volume increases. In conclusion, the structural efficiency of DEX is higher than central exchanges, but the availability of liquidity on DLT platforms today is lower than in the traditional financial industry - as liquidity increases, the efficiency of DEX will further increase.

Last, a comparison is made between central and decentral lending. This is done by looking at the revenue per employee generated by central and decentralized lending platforms over the last twelve months. The ratio is one way to compare the efficiency of lenders, as more efficient lenders should achieve higher revenues with the same number of employees or require fewer employees to achieve the same revenues. It is worth noting here that there are many other factors that are not considered here. Thus, this is not a holistic analysis, but only an examination of selected key performance indicators. Alternative metrics such as borrowing volume or total value locked are very difficult to compare, as structural differences of lending platforms such as overcollateralized unsecured have a strong impact on these metrics. Part of the consideration are the two largest U.S. banks JP Morgan Chase, Bank of America, the largest European bank HSBC and three of the largest lending platforms Aave, Compound and Maple Finance.

**Figure 32. | Ref. Appendix 2. Centralized & decentralized lending:
Revenue per employee in USD (TTM)**

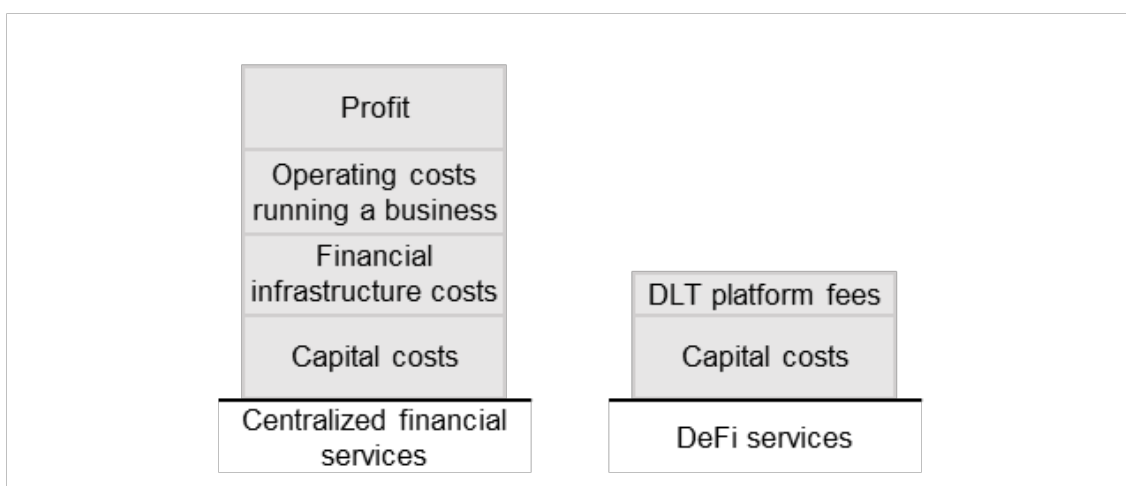


Source: JP Morgan Chase, 2021-2022; Bank of America, 2021-2022; HSBC, 2021-2022; Apollo.io, 2022; Maple Finance, 2022; Tokenterminal, 2022

The comparison shows that the decentralized lending platforms generate revenues per employee that are significantly higher than those of the banks. Similar to the analysis of the centralized and decentralized exchanges, the revenue per employee of the decentralized lending platforms is about ten times higher than that of the central banks. In this context, the costs of lending from platforms such as Aave and Compound are comparable to those of centralized exchanges. There are no operating costs due to automation. The costs of goods sold consist of the capital costs of the liquidity providers. So there is also a structurally higher efficiency, while the lower liquidity on DLT platforms has a negative impact on the efficiency of lending, but also leads to higher revenues of lending platforms due to high interest rates.

DeFi applications are emerging as a challenger to traditional centralized financial services providers in key areas of financial services such as payments, trading, and lending. Their decentralized and open design that eliminates the need for trusted third party files makes them structurally more efficient than traditional financial service providers that are less automated, more regulated and profit driven. Two factors in particular influence the efficiency of DeFi applications: Efficiency of the underlying DLT platform and available liquidity. DLT platforms on which DeFi applications are successfully operated should fulfill the three key success factors of a DLT network: Security, decentralization, and scalability. In terms of scalability, it is important that very high transaction throughputs, including complex transactions, can be processed quickly at very low fees. High liquidity is important for DeFi applications as they compete with traditional centralized financial service providers that have very good access to liquidity. As described in this chapter, increasing liquidity leads to increasing efficiency in DeFi applications, since cost of capital is the central cost item in DeFi applications.

Figure 33. Centralized finance & DeFi: Composition of transaction costs



Source: Own illustration.

4.2. Benefit of DeFi for using businesses

Efficiency

By replacing trusted third parties with DLT networks, financial services are performed with increased efficiency. As described in the previous chapter, this saves operational costs and profits to be generated by traditional centralized financial service providers. Instead, costs for decentralized financial services are driven by the cost of operating the

DLT infrastructure, as transaction fees, and the cost of capital or available liquidity. The costs saved are seen as efficiency gain. This increase in efficiency for financial services in turn affects the costs of businesses and thus leads to an overall increase in productivity in the economy. The fact that this is also perceived by businesses is shown by an international survey by Deloitte in which 44% of senior executives stated that they considered more efficient processes to be the greatest impact of digital assets (Deloitte, 2021, p. 11).

Accessibility

DLT platforms are a permissionless environment in which anyone can participate. DeFi applications can also be deployed and used by all network participants. Since DLT networks are globally available via Internet access, the majority of people and companies worldwide can access DeFi services. While traditional centralized financial services often exclude many users because they are only accessible in individual countries or to certain groups of people, DeFi services are aimed at the entirety of network participants. DeFi applications thus enable a globalized financial system in which everyone can participate and all network participants have access to the same applications at the same conditions.

This alternative financial infrastructure is particularly lucrative today in places where traditional centralized financial services are scarce or non-existent. This applies in particular to emerging markets and developing countries, where traditional centralized financial services are not available to large segments of the population and the proportion of young people in the population is high. This is also confirmed by looking at the countries where the percentage of crypto owners is the highest: Nigeria with 45% in 2022 vs 28% in 2019, Thailand with 44% in 2022 vs 23% in 2019, Turkey with 40% in 2022 vs 20% in 2019, Argentina with 35% in 2022 vs 16% in 2019 and United Arab Emirates with 34% in 2022 vs 20% in 2019. For comparison, the USA is at 16% and Germany at 12% (Statista, 2022). This confirms that the acceptance of DLT services is particularly high in young developing and emerging countries, whereby the geographical distribution does not seem to play a role here, but rather it is a global development.

Transparency and trust

The control of DLT wallets lies with the user according to the principle "Your keys your coins". The counterparty risk of the financial service provider is thereby avoided and the control lies completely with the owning person or business. It is therefore the inclusion of control over the assets of individuals and businesses as the trusted third party that previously held this control is no longer needed. In businesses, external services from

financial service providers thus become unnecessary and the depth of value creation of the companies increases, while the compliance and transparency is rising. For example, 44% of senior executives see higher compliance and transparency as a key impact of digital assets, and 41% see this in enhanced trust (Deloitte, 2021, p. 11). At the same time, individuals or companies need to build up their own expertise to ensure the secure custody of their assets. Today, in-house expertise in this segment is costly, but it is likely that with a growing importance of self-custody, software applications for this area will also be offered.

Composability

As described, DeFi applications can be interoperable combined and work together. You can think of the individual applications as individual Lego bricks that can be built on top of each other. This not only creates greater efficiency by allowing DeFi apps to be flexibly swapped to get the best deal, but also makes it easy to create new apps because a creator can draw on the existing universe of DeFi apps. In addition, DeFi aggregators act as a search engine for DeFi platforms, acting as a one-stop-shop to access the best DeFi applications at any given time (Coinmarketcap, 2022).

4.3. Regulatory framework

The basic design of DLT platforms is that protocols and applications are regulated by their code and not by a legal authority. This means it is possible to create DeFi services roughly independent of national legislation. This technological freedom brings benefits to many individuals and businesses. However, for highly regulated organizations and businesses, it means a lot of uncertainty and risk. In a survey by KPMG Germany, 58% of banks and asset managers state that unclear regulation is one of the biggest risk factors (KPMG, 2022, p. 19). Regulation is not intended to take a central place in this work, but since it is an influencing factor for adaptation, especially in businesses, it is dealt with briefly at this point.

Since very different types of transactions take place on DLT networks and different types of tokens are used, there are different institutions within a country that each regulate their area of responsibility. For example, in the United States, the SEC, CFTC, FINRA, and several other agencies govern the crypto market. Which of these authorities is responsible for regulation depends on the type of transaction or token involved. The classification of tokens on DLT networks marks the beginning of regulation by these authorities. This is because existing law is also applied to corresponding tokens. A debt

security token that is tradable on a DLT network must therefore fulfill the same regulatory requirements that a classic debt security must fulfill. In the EU area, many crypto tokens therefore fall under the regulation of the EU Markets in Financial Instruments Directive II / MiFID II (European Parliament, 2021). However, this regulatory influence ends at the border of a country. For example, trading equity on the Blockchain is not possible in Germany. However, in Liechtenstein it is possible to tokenize any kind of assets and rights without legal detours. The basis for this is the Liechtenstein Blockchain Act, which allows assets and rights to be represented by tokens (Weber, 2020, pp. 3-4). These tokens under Liechtenstein law can be accessed by DLT users worldwide.

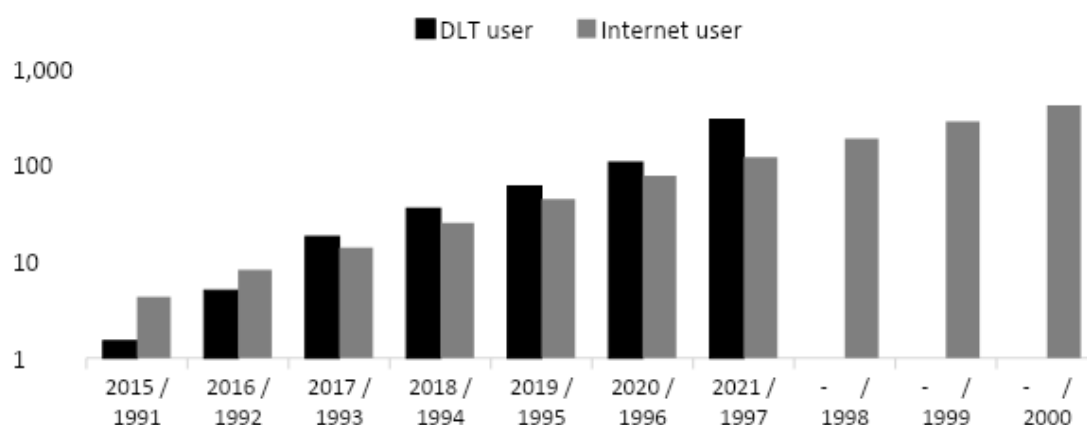
In addition to the regulation of tokens, there is also regulation of centralized financial service providers operating in the crypto sector. This regulation is ensured by the Markets in Crypto Assets, MiCA, regulation at EU level, which will come into force in 2024. This regulation is intended in particular to prevent money laundering and terrorist financing via DLT networks. However, it does not affect DeFi services, but the institutions that exchange money in cryptocurrencies, i.e. European crypto exchanges (European Parliament, 2020). However, it should be noted that only European financial institutions are regulated and it is still possible for EU citizens to use unregulated offshore exchanges such as Binance or by recently insolvent FTX.

4.4. Adaptation of DeFi in business

This chapter deals with the adaptation of DeFi in businesses. On the one hand, we will look at metrics for the general adaptation of DLT and DeFi, which includes private and institutional use. On the other hand, we look at surveys of businesses, with the data available here in banks and asset Managers.

The number of total DLT users is regularly published by the crypto exchange Crypto.com in the Crypto Market Sizing Report. It can be seen that the user base of DLT increased more in recent years than that of the internet in the 1990s. According to the forecast of the 2022 report, the global number of DLT users will reach one billion in 2022 or 2023 (Crypto.com, 2020, 2021, 2022). It is useful to mention here that a large part of these users does not use complex applications, but only perform simple transactions. On the other hand, this also applies to the Internet users of the 1990s.

Figure 34. Number of DLT user 2015-2021 and internet user 1991-2000 in millions

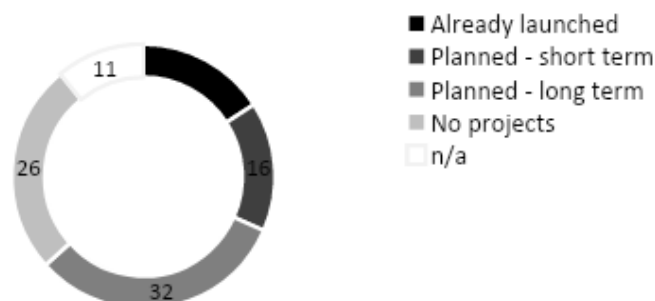


Source: Crypto.com, 2022; World Bank, 2022.

The number of DeFi applications is 1924 in October 2022, according to the internet platform DefiLlama, with TVL increasing from under 50 thousand USD in November 2018 to over 180 billion USD in November 2021. The assets locked on DeFi applications in October 2022 is 53 billion USD (DefiLlama, 2022). The total market capitalization of DLT tokens is 790 billion USD. For comparison, the global equity market is at a total value of 111 trillion USD as of Q3 2022 (SIFMA, 2022, p. 4). The user base of DLT is therefore already high and growing dynamically. The same applies to the TVL and market capitalization of the DLT ecosystem, although these two indicators are much more volatile as they are subject to economic cycles. Another driver for the adaptation of DeFi in businesses is the strong funding from leading global venture capital firms such as Andreessen Horowitz (Andreessen Horowitz, 2022).

As indicated in the introduction to this chapter, the data situation in the corporate adaptation of DeFi services is poor. Since there are pseudonyms behind transactions on DLT networks, it is difficult to separate private use from institutional use. Data only for enterprises is mainly obtained from surveys: However, KPMG's Blockchain survey shows that a share of 64% of the surveyed banks and asset managers are already active with products or services in the DLT area or plan to do so (KPMG, 2022, p. 19). In percent, values deviating from 100 result from rounding differences.

Figure 35. Share of banks and asset managers which already offer or plan to offer services and products considering security tokens or cryptocurrencies in Germany, 2021 in %



Source: Adapted from KPMG, 2022, p. 19.

While this increasing adoption by banks and asset managers contributes to the adoption of DeFi services by creating access to capital and increasing liquidity on DLT platforms with investments, it is not a DeFi service, as they are centralized financial services on DLT networks. It is therefore not an optimal metric for measuring DeFi in companies, but rather an indicator that institutional demand for DeFi continues to grow and that banks and asset managers are enabling their customers to access it or are planning to do so.

A quantification of DeFi use in businesses is therefore difficult due to a lack of data. However, it can be qualitatively registered that institutional interest is increasing significantly, as banks and asset managers are increasingly offering products to participate in the development. At the same time, it should be noted that the number of total users, the total TVL, which includes both private and institutional users, is rising sharply. Especially with a secure regulatory framework, the lack of which is currently the biggest obstacle for institutional use, it is expected that the adoption of DeFi applications in businesses will increase massively.

5. Concluding remarks

5.1. Summary

The crypto ecosystem gets a lot of attention for its use as speculative assets, yet the benefits go far beyond that. Public DLT networks enable participants to collaborate in a trustworthy manner through technical design. Trusted third parties such as intermediaries and platform companies, whose task it is to guarantee security in transactions between two parties, are not needed in these networks. Simultaneously, the network is open to anyone who wishes to become a participant, with only Internet access required as a condition of entry. The fields of application in which DLT networks can be used are versatile: In addition to Web 3, Metaverse, NFT applications and others, there are also applications in the field of DeFi.

In finance, the use of DLT networks enables peer-to-peer financial services, DeFi. On the one hand, these DeFi applications consist of applications to which existing centralized financial services exist, such as decentralized stock exchanges and decentralized lending platforms. On the other hand, new types of financial services are developing, such as flash loans, which are only made possible by the efficient technical design of DLT networks. DeFi applications work as open technical building blocks that any network participant can create and use. This not only creates a high degree of comparability, but also enables existing applications to be used to create new applications. In this way, DeFi applications interlock in an automated manner and aggregators flexibly enable the most efficient execution of a decentralized financial service.

DeFi applications are an alternative to traditional centralized financial services. Due to their highly automated and decentralized design, the transaction costs of a DeFi transaction consist of the capital costs and fees for the DLT infrastructure. Operational costs and profits to be earned, on the other hand, are not incurred in DeFi transactions, and furthermore, there is no need to build a dedicated financial infrastructure as the existing DLT network is used. In addition to this higher efficiency of DeFi applications, the factors of transparency, trust and accessibility represent decisive advantages. Due to the public design of DLT networks, there is complete transparency over all transaction data of DeFi applications. Besides, managing financial services themselves without intermediaries creates a higher level of control for the owner and the risk of failure of the intermediary no longer exists. Finally, the increased accessibility of DeFi applications is an advantage that enables anyone to become a DeFi user and developer, which adds value especially for people and companies from emerging and developing countries.

In addition to the advantages described, there are also factors that stand in the way of the increasing adaptation of DeFi applications. Regulatory length is one such factor in many countries around the world. DeFi applications are mostly not directly regulated, as there is no execution point of a DeFi transaction, but they are settled by all transactions in the network. Instead, tokenized assets are regulated and centralized crypto exchanges if those are in the restriction of regulators. On one hand, this unsettled regulation allows individuals and companies to use DeFi applications. On the other hand, this uncertainty is a barrier to adoption for highly regulated companies such as banks and financial services providers.

In addition to regulation, the current user experience of DeFi applications is a barrier to adoption. Today's DeFi applications, similar to the use of the early Internet, require above-average technical expertise and are less user-friendly than mobile and web applications of today's banks and financial service providers. However, it is likely that the user experience of DeFi applications will improve as the user base grows, so that this hurdle will remove itself over time.

The adaptation of DLT and DeFi can be seen in the sharp rise in the number of users and projects. The adaptation is even faster than the adaptation of the Internet in the 1990s, which may be due to the low access barriers of DLT networks. Market capitalization and TVL on DLT and DeFi platforms are also increasing, although these volumes are affected by strong volatility and cycles. The overall trend of increasing adoption of DeFi applications is evident.

While the overall adaptation of DeFi applications is traceable due to the high transparency on DLT networks, the adaptation of businesses is more difficult to evaluate, as this cannot be separated from private use on on-chain data. Surveys by management consultancies show that the interest of companies in the field of DLT is increasing, and banks and financial service providers are starting to develop products and services on a large scale. Since these are centralized financial services, a conclusion can only be drawn indirectly to increasing interest in the DeFi area.

The strong adaptation of DLT and DeFi by private individuals opens up an opportunity for businesses to address the rapidly growing number of potential customers and also become a player on DLT and DeFi platforms. Another indication for a growing use of DeFi in companies is also the strong interest of global leading venture capital firms like Andreessen Horowitz, who have Crypto as one of their focus areas.

The current impact of DeFi applications on the global financial services industry can be classified as small - this is shown by the relatively tiny volumes DeFi has in contrast to

the traditional financial industry. However, the speed of development of users, projects and capital is rapid, considering that DeFi has only existed for less than four years. The number and variety of traditional financial services is still higher than that of DeFi applications, but it is evident that DeFi applications are already significantly more efficient than traditional financial services in selected areas. Businesses and financial service providers are also recognizing this development and are increasingly engaging on DLT networks.

DeFi is thus establishing a new decentralized financial system alongside the traditional and centralized financial system that is attracting an ever-increasing amount of capital and people, both users and programmers. Whether DeFi will be so successful that it becomes bigger than the traditional financial system cannot be scientifically assessed today, as there is still a lot of uncertainty, especially on the topic of regulation.

Critical appraisal

It can be stated that with DeFi there is now an alternative financial system that enables basic financial services and is growing rapidly. Companies are also participating in this development. However, it had to be determined during the preparation of this paper that the data situation, as far as the DeFi adaptation in business is concerned, is significantly worse than the overall very good data situation in the DeFi area. Specific statements to the adaptation of DeFi applications in enterprises could not be derived, therefore.

In addition, the analysis of key figures for centralized and decentralized financial services conducted in section 4.1 should be treated with caution. In addition to the relatively small group of 6 providers examined, there are also a large number of other key figures that can be taken into account, but these have not been considered due to poor comparability and in favor of the scope of this work.

In a more comprehensive paper, these two points could be addressed in more detail in order to make more precise statements about the adaptation in businesses and the higher efficiency of DeFi applications.

5.2. Outlook

As described at the outset, this paper looked at DeFi applications from the perspective of users and network participants. Traditional centralized financial service providers were not considered. How the increasing adaptation of DeFi affects banks, insurance companies and other financial service providers, which areas are particularly affected

and how the profitability of these companies is influenced could be the subject of a further paper. There is a need for further research here.

In the future legislators are expected to include the field more in their regulation. It remains to be seen whether this will have a positive impact, because uncertainty will sink, or a negative impact, because legislation will restrict users. However, it is to be expected that DeFi will develop largely independently of this regulation, as it mainly regulates access to the crypto universe.

The DeFi sector is developing rapidly. It can be assumed that the range of DeFi applications will grow significantly in the coming years and more assets and liquidity are expected to be transferred to DLT platforms. So expectations are high for DeFi, and it is likely that the media hype that started this work will continue to accompany its coverage.

Finally, following the title of this paper and paying homage to Marc Andreessen's "Software is eating the world", a commentary is presented:

DeFi is absorbing the world of finance. Instead of eating a large part of the value chain like the software industry, DeFi absorbs the traditional financial industry and releases the contained value creation as an efficiency gain to network participants.

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Appendix 1. Centralized exchanges & DEX calculation

Centralized and Decentralized Exchanges – Revenues per employee			
Exchange	Number of employees	TTM Revenue (in USD millions)	Revenue per employee (in USD)
Intercontinental Exchange Inc.	8,936 ¹	8,514 ¹	952,775
Nasdaq Inc.	6,214 ¹	3,508 ¹	564,532
Coinbase Inc.	4,977 ¹	5,693 ¹	1,143,862
Uniswap (DAO)	130 ²	986 ²	7,584,615
SushiSwap (DAO)	17 ²	175 ²	10,294,118
PancakeSwap (DAO)	19 ²	448 ²	23,578,947

1) As of June 30, 2022; Sources: Intercontinental Exchange Inc., 2021-2022; Nasdaq Inc., 2021-2022; Coinbase Inc., 2021-2022

2) As of November 24, 2022; Sources: Apollo.io, 2022; Tokenterminal, 2022

Centralized and Decentralized Exchanges – Trading Volumes per employee			
Exchange	Number of employees	TTM Trading Volume (in USD billions)	Trading Volume per employee (in USD)
Intercontinental Exchange Inc.	8,936 ¹	18,026 ³	2,017,123,366
Nasdaq Inc.	6,214 ¹	18,670 ³	3,004,505,954
Coinbase Inc.	4,977 ¹	1,232 ¹	247,538,378
Uniswap (DAO)	130 ²	658 ²	5,061,538,462
SushiSwap (DAO)	17 ²	236 ²	13,882,352,941
PancakeSwap (DAO)	19 ²	178 ²	9,368,421,052

1) As of September 30, 2022; Sources: Intercontinental Exchange Inc., 2022; Nasdaq Inc., 2022; Coinbase Inc., 2021-2022

2) As of November 24, 2022; Sources: Apollo.io, 2022; Tokenterminal, 2022

3) As of December 31, 2021; Sources: World Federation of Exchanges, 2022

Appendix 2. Centralized & decentralized lending calculation

Centralized and Decentralized Lending – Revenues per employee			
Exchange	Number of employees	TTM Revenue (in USD millions)	Revenue per employee (in USD)
JP Morgan Chase	271,025 ¹	120,336 ¹	444,003
Bank of America	210,000 ¹	90,782 ¹	432,295
HSBC	218,866 ¹	49,237 ¹	224,964
Aave (DAO)	120 ²	206 ²	1,716,666
Compound (DAO)	19 ²	99 ²	5,210,526
Maple Finance (DAO)	11 ²	52 ²	4,727,272

1) As of June 30, 2022; Sources: JP Morgan Chase, 2021-2022; Bank of America, 2021-2022; HSBC, 2021-2022

2) As of October 26, 2022; Sources: Apollo.io, 2022; Maple Finance, 2022; Tokenterminal, 2022