POLITECNICO MILANO 1863

School of Industrial and Information Engineering

Master of Science in Management Engineering

Decentralized Applications: an Empirical Analysis of their Revenue Models and Governance Systems

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Academic year 2020/2021

Acknowledgments

First, I would like to thank my family and beloved ones for the constant support provided throughout these years and the sacrifices made to make this goal a reality.

I would also like to thank Professors Giacomo Vella and Jacopo Fracassi for the helpful insights and the assistance provided throughout this thesis. Finally, I would like to express my gratitude to all my friends that have helped me during this enriching journey.

Without your help, this milestone would have not been reachable.

Thank you.

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Abstract – English version

The blockchain was introduced for the first time by Satoshi Nakamoto in 2008 as the technology behind Bitcoin, a virtual currency exchanged within a peer-to-peer network.

Following the footsteps of Bitcoin, new applications have been developed through the blockchain in many other fields and with the same goal: filling the gap of trust between parties willing to exchange value.

The potential applications and advantages brought by this technology are unlimited, but its adoption is a slow and laborious process in constant evolution, as it was for the Internet in the 90s. In this regard, the academic literature mainly covers technical elements of the blockchain, while there is still little research on its business issues.

The purpose of this thesis is to contribute to the limited existing literature on the topic through a framework that shows the potential directions of development of this technology, outlining the trends that are emerging and the business opportunities. In order to obtain this result, the methodology involves a comprehensive analysis of blockchain-based applications – or Decentralised Applications – that focuses on business elements and governance systems.

Abstract – Italian version

La blockchain è stata introdotta per la prima volta da Satoshi Nakamoto nel 2008 come tecnologia alla base del Bitcoin, una valuta virtuale scambiata all'interno di una rete peer-to-peer.

Sulle orme di Bitcoin sono state sviluppate diverse applicazioni per mezzo di questa tecnologia anche in molti altri campi e con lo stesso obiettivo: colmare la mancanza di fiducia reciproca tra individui che instaurano un'attività di scambio.

Le potenziali applicazioni ed i vantaggi introdotti sono illimitati, ma la diffusione e l'adozione della blockchain avvengono tramite un processo laborioso in continua evoluzione, come è stato per Internet negli anni '90. A questo proposito, la letteratura accademica copre principalmente gli elementi tecnici della blockchain, mentre la ricerca sugli aspetti legati al business è ancora scarsa.

Lo scopo di questa tesi è quello di contribuire alla limitata letteratura esistente sull'argomento attraverso un framework che mostra le potenziali direzioni di sviluppo di questa tecnologia, delineando le tendenze che stanno emergendo e le opportunità di business. Per ottenere questo risultato, la metodologia prevede un'analisi completa delle applicazioni basate sulla blockchain – o applicazioni decentralizzate – che si concentra sugli elementi di business e sui sistemi di governance.

Executive summary

Introduction

Since the birth of Bitcoin in 2008, the blockchain has had a serious impact in the way of conceiving the exchange of value between individuals. Following the footsteps of Bitcoin, new applications have been developed through the blockchain in many other fields and with the same goal: filling the gap of trust between parties willing to exchange value. Historically, this need was satisfied by the presence of third parties who mediated in the commercial exchange activities. Today, the blockchain definitively replaces this need and, even more with the birth of Ethereum in 2014, the introduction of Smart contracts applied to the blockchain cancels the need for third-party intervention even in the execution of a contract. The potential applications and advantages brought by this technology are unlimited, but its adoption is a slow and laborious process in constant evolution, as it was for the Internet in the 90s.

In this regard, two elements emerged as the main source of innovation in this area: public blockchains and smart contracts. Decentralized applications (Dapps), or blockchain-based applications, are the union of these two elements. They represent completely novel applications that could change the nature of economic, social, and political systems.

This point can be proved by the growing interest of multiple actors: in April 2021, the blockchain industry grew 158% year-on-year, reaching 1 million in daily unique active users across all chains. Furthermore, the total value locked (TVL), a metric that expresses the amount of capital invested in decentralized finance activities, increased from $520 million in April 2020 to $78 billion in April 2021. The interest of companies and investors in decentralized applications is also proven by the raise of Initial Coin Offerings (ICOs), an innovative mean of fundraising. The biggest 50 ICOs to date have raised an average of $160 million.

The objective of this thesis is to contribute to the limited literature on the subject, by offering a complete analysis of how this technology affects business and governance innovation. For this purpose, a comprehensive analysis on the key features of existing

Decentralized Applications has been outlined in a framework, which is the main output of the research.

The thesis is divided in five chapter. This first section is useful in introducing the topic and its relevance as well as summarizing the overall content of the paper.

Literature review

In the second chapter the blockchain technology and its underlying mechanisms are briefly analysed to explain its functioning from a technical point of view. At this stage the different types of consensus mechanisms and mining processes are treated with particular care since they are relevant for the business model discussion in the next chapter. Later, the evolution of the protocol form from a public to a private dimension is illustrated and shows the analogy with the Internet / Intranet of the 1990s. The chapter includes the blockchain classification of Buterin (2014) and highlights several technological limitations that characterise the main public platforms. In this regard, the problem of scalability is treated extensively and the main solutions that aim to address it are presented.

Then a short literature on the history and definition of Smart contracts is presented, moving to several critical applications that stems from them. First, the literature has highlighted the importance of tokens, powerful tools that provide many of the structural features of the blockchain. With the advent of Ethereum, tokens have moved up the technology stack and can now be issued on the application layer. These application tokens have been covered starting with the underlying technology and moving towards the main use cases. In particular, their potential and implications have been further examined by introducing another revolutionary element of the blockchain: Decentralized Applications (Dapps).

In the analysis of the principal sources of innovation in this area, Dapps have emerged as completely novel applications that could change the nature of economic, social, and political systems. For these reasons, they have been treated with a holistic approach, starting with a technical analysis of the layers they are composed of, covering their formation and development, and moving on to their high-level implications. In this regard, study of the academic and grey literature has shown the different sectors that decentralized applications have the potential to disrupt.

Particular attention has been given to the sector of decentralized finance (DeFi). As the most widely adopted industry, DeFi was deeply explored highlighting its main services and the most innovative aspects, such as its composability. Research papers concerning other sectors (e.g. decentralized social networks, decentralized marketplaces) is missing and for this reason the grey literature has been relied upon.

The chapter ends with a detailed analysis of the business-level impacts of blockchain and a thorough literature on governance, both at the platform level (Blockchain protocol) and at the application level (Dapp).

Gaps found in literature

As a result of the literature review, the main gaps found in the scientific literature regarding blockchain and decentralized applications have been outlined. In particular, the literature lacks empirical analysis concerning the sectors from which new Dapps are emerging. Some scholars are beginning to explore the main use cases of some sectors, but there is still no research that paints a picture of the Dapp ecosystem and its distribution across sectors.

In addition, the literature review has highlighted many documents that address the technical aspects of blockchain, even in high detail, but fewer papers have empirically observed which are the main impact of this technology on current business models. As Schneider et al. (2020) point out, there is still a lack of a solid theoretical basis for exploring the expected implications of blockchain technology on business models and ecosystems. In this regard, there is a complete lack of studies concerning public blockchains and decentralized applications. Only Tapscott (2016) devised new business models supported by public blockchains, but even this perspective suffers from gaps and should be updated considering the current state of Dapps. In fact, this classification attempt has been made with a theoretical approach, lacking an empirical analysis that verifies which of these models are actually exploited by blockchain-based applications.

Studies on decentralized applications that have emerged in the literature have not collected information on the revenue streams used, nor has any investigation emerged that clearly highlights how they are able to create value for their stakeholders.

Finally, another element of fundamental importance for blockchain and Dapps was analysed: governance. However, similarly to other technical aspects, although there are comprehensive theoretical descriptions of governance systems, the literature lacks a vision of how governance is used by Dapps in reality. There are no empirical analyses that show, starting from the observation of a real-world set of Dapps, which Dapps use governance mechanisms, at what level they are decentralizing their operations, how they ensure a fair distribution of power and above all how they implement decentralized governance.

Research questions

The second chapter ends with the definition of the research objectives along with the phases and methodology that lead to the creation of the framework used for the research. First, the research objective is defined, and research questions formulated from the gaps that have emerged in the literature review. For the sake of clarity, the research objective is stated here: *Describe the current ecosystem of blockchain-based decentralized applications (Dapps).*

Starting from the research objective and the main gaps identified in the literature, the following research question were defined:

RQ1: In which sectors are blockchain-based decentralized applications (Dapps) developing and which ones attracting the most users?

Then, to better describe the innovations brought by Dapps, two further research questions were included in the analysis:

RQ2: What are the revenue models adopted by Dapps?

RQ3: What are the governance models adopted by Dapps?

Methodology

The research methodology comprises three different phases which consist in the construction of the framework, the selection of the Dapps to analyze and the data collection through the chosen sources. For the first phase, 32 variables were designed in order to thoroughly address the research objectives. Given the embryonic level of development and the complexity of the topic, the framework was built taking into account the impossibility of censusing certain fields, but also in a way that formalize each application in its variety.

Subsequently, the sample of Dapps serving as input for the analysis was built. At this stage, the level of adoption was considered as a decisive parameter to make assumption about the development directions of the ecosystem. A total of 112 application were selected, providing an appropriate sample for the research.

Finally, the information were gathered according to a primary research approach. As many of the fields designed investigate aspects that have not been explored in the literature or indexed by databases, a first-hand collection of data and knowledge was needed. In this regard, coding libraries (e.g. GitHub) and Dapps' whitepapers have been extensively examined, along with other sources such as analytics websites, research reports, journal articles, academic and scientific papers.

Main findings & Discussions

This section deals with the analysis of the data collected and the presentation of its most significant results, extending the analysis with qualitative considerations. The empirical research is divided into three main sections: the first one aims at describing the Dapp ecosystem, in particular showing which are the main sectors in which they operate, and which are having more success, trying to investigate the reasons why. This introduction is essential to contextualise the subsequent research questions and understand their implications. The next section focuses on business aspects, providing a comprehensive overview of the main revenue models. Finally, in the last section the investigation has addressed how blockchain-based applications are managed, focusing on governance systems, and assessing to what level they are actually decentralised.

Overview

The sample analysed consists of 112 decentralised applications representing approximately 64% of the market in terms of active monthly users (AMU). Most of the Dapp analysed are concentrated in the DeFi sector (66%), which is not surprising since cryptocurrencies and peer-to-peer monetary exchanges were the first case of use of blockchain technology.

The sector has seen remarkable growth in the recent months[1], driven by decentralised exchanges (DEXs), protocols that facilitate the non-custodial exchange of on-chain digital assets. These applications account for 72% of DeFi users and they have grown the most with an increase of 41% of their users. Binance Smart Chain (BSC) is the blockchain platform that has benefited most from DeFi's recent growth, leading both in terms of users (31% of the overall users) and number of Dapp (42% of the sample). Its low transaction costs and high processing speed make it particularly suitable for

[1] DeFi Dapps' users increased by 64% over the time period covered by the analysis.

the industry, despite not providing the same level of decentralisation as the other platforms. For this reason, a large part of the DeFi ecosystem has moved to this protocol, on which most DeFi Dapps are based[2]. Furthermore, the category represents 91% of all BSC Dapps.

This is partly due to the scalability issues faced by Ethereum, the second most adopted blockchain, whose use is currently prohibitively – for most users – given the high gas fees.

However, a significant share of Ethereum Dapps is starting to adopt or have already adopted layer 2 solutions to address these problems without giving up its inherent decentralisation and security. Looking at ETH Dapps only, 26% of ETH protocols have already launched a layer 2 solution, 19% plan to launch their solution in the upcoming months, while 4% are testing a beta version.

Generally speaking, the interest of the actors involved is high enough to guarantee full-time dedicated developers to tackle the main problems – like scalability issues – and nurture the ecosystem. To this end, the interest of external investors, was measured. In this regard, blockchain is reshaping the fundraising landscape through ICOs, IEOs, airdrops and token sales. Dapps founded through these systems were able to attract an above-average number of users[3].

Considering the time distribution of application launches, the most successful protocols at the time of writing are the ones that are comparably more recent. Among the most successful Dapps in terms of users at the beginning of 2021, only 5% were founded between 2016 and 2017. This is because recent applications are able to increase their competitive advantage by offering better services – such as asset management applications that guarantee increasingly high returns – or by broadening the range of services offered. This is the case of DEXs, which are implementing NFTs in their protocols, allowing the exchange and sale of collectibles, thus paving the way for a diverse set of use cases.

The value of tokens was also measured to assess their relevance and popularity, as well as the goodness of the underlying protocols and their ability to create value for

[2] 58% of DeFi Dapps analysed run on Binance Smart Chain.

[3] Although the protocols that exploited the sale of a token to finance themselves are rather limited – 10% of the sample – they were able to attract 58% of the overall users.

their stakeholders. The average market capitalization has more than doubled in the two months covered by the analysis (+139%). This growth was partially mirrored by the user base, which for these applications only increased by half.

One of the most plausible hypotheses explaining this disparity takes into account the possibility of trading tokens within AMMs. Similar to what happens in traditional finance, trading causes the price of tokens to soar without being directly affected by the performance or use of the corresponding applications. This would confirm an issue mentioned by Voshmgir (2020), which describe a common conflict in many Dapp designs: token holders are often more interested in seeing the price of their tokens rise, whereas users would rather see a decrease in price so as to reduce the costs of using the Dapp.

Revenue models

In an attempt to formalize and better structure the framework, the revenue streams were divided according to the stakeholders involved. In particular, they were split according to which stakeholders benefit from them. The literature review identified two main cluster of stakeholders, divided according to the value they are able to capture. The first category refers to the builders, the actors who create, implement, and support the protocol.

Only a small fraction (11%) of the Dapps examined do not provide a revenue model for their developers. The remaining applications use Tokenomics extensively (65%), a revenue stream in which application token holders gain from the appreciation of token value or from receiving inflationary rewards. This proves to be one of the easiest strategies to implement, with no cost passed on to users. Developers simply hold on to a portion of the application tokens[4] – which are priceless at the time of issue – and wait for it to appreciate through trading or use of the protocol.

However, this type of revenue stream is closely associated with the choice of implementing a token in the functionality of the protocol. Consequently, the type of service offered and the organisational form of a Dapp, which are both decisive for the presence of a token, influence the use of Tokenomics. DeFi applications are the ones

[4] Builders developing applications that exploit Tokenomics retain on average 10% of the total Dapp application tokens. Protocols that do not take advantage of Tokenomics distribute an average of only 4% of their tokens to builders.

that use application tokens the most (89% of them use tokens) while the other categories of services are all below 50% in terms of relative usage. Given the complexity of the ecosystem, a focus has been made on the different decentralised finance services and their use of application tokens, supporting data with qualitative considerations that investigate the underlying factors.

The organisational form that makes least use of Tokenomics is the private company[5]. The reason behind this choice lies in the volatility and uncertainty of the token's value. There is no guarantee that the value of application tokens will increase steadily over time. The price is often subject to strong fluctuations due to market developments and trading in AMMs. Moreover, if the application does not achieve widespread adoption, the price of the application token may be limited.

For these reasons, Tokenomics is often combined with other means of creating value. Many protocols (38% of the sample) not only rely on the appreciation of their tokens, but also charge fees to their users, while other leverage in-app sales, which refers to the selling of goods and services from inside an application.

The second cluster of stakeholders includes all users involved in using the protocol, supplying capital or core services to the protocol functionality, or making decisions on its development.

Dapps remunerating these actors are fewer in number than those remunerating their own builders. These Dapps represent 78% of the sample, 11% less than those rewarding their builders. It can be supposed that not all developers are interested in remunerating their users as they see Dapps as an opportunity to capture value, without fully embracing the values of decentralisation and peer-to-peer that characterise the ecosystem. In particular, private companies are the most inclined not to redistribute profits, implementing a revenue stream in only 65% of cases.

Among the revenue streams dedicated to these stakeholders, Tokenomics still stands out. Developers allocate most of the application tokens to their users (87% on average), in order to promote the use and adoption of the protocol. Other revenue streams include user fees, which are redistributed to users (such as trading fees distributed to

[5] Only 54% of Dapps run by private companies leverage Tokenomics as a revenue stream.

liquidity providers), and yield, a new value creation mechanism dedicated to a particular type of traders[6].

In addition to these streams, 36% of protocols provide user incentives, designed to promote the use of a smart contract or protocol token.

These can be either economic, as rewards awarded for proposing a change to the protocol, vote on proposals, or having "staked" protocol tokens, and non-economic. Among these, the most common is the showcase, which involves showing one's NFTs to the community. In this regard, blockchain technology creates real-world economies for games and marketplaces and opens a completely new way for ownership of assets to be treated and assigned.

The analysis of revenue models was integrated with a breakdown of the different actors involved and their respective roles, including a description of the revenue streams involving them as well as an outline of how they are remunerated. The data collected at this stage of the analysis are characterised by a high degree of granularity and complexity. For this reason, this section has been treated with a qualitative approach, providing a high-level description, and contextually including some insights from the analysis.

Governance

The last section aims to investigate one of the most revolutionary elements of blockchain and decentralised applications: decentralisation.

Most applications are either managed by private companies or teams of developers, while Decentralized Autonomous Organisations (DAOs) are still uncommon[7]. This is partly due to the lifecycle of a Dapp, which starts with a development team that has control over the governance parameters and later decentralises its governance processes by issuing a governance token. This is the most common design pattern for governance schemes at the time of writing.

[6] This is mainly applied by asset management applications, which offer value maximisation strategies, generating – in some cases – yields for its users.

[7] 46% of Dapps are managed by a private company, 43% are managed by teams of developers while 8% are run by DAOs.

The most common way to do that involves a particular type of Tokenomics that reduces the share of application tokens dedicated to builders over time. Others include in their roadmap the implementation of decentralised governance through technical changes to smart contracts, in order to automate those processes that in the early stage of the Dapp life cycle are managed by builders.

The analysis moves on to examine how decentralised applications use governance tokens and thus decentralise their decision-making processes.

A low level of decentralisation can be observed, as 52% of Dapps are *Completely centralised*, since their builders have full control over every aspect of the system and have not yet announced any changes in their intentions in the future.

Moreover, even considering the remaining Dapps, which on paper are *Completely (or partially) decentralised*[8], cases are emerging where builders develop a new smart contract to replace the previous one, without first consulting their stakeholders[9]. This leads to striking contradictions: despite all the progress made in the direction of decentralisation, such as immutability of blockchain-based applications and subsequent automation, fully decentralised governance processes and incentive systems to support the protocols and improve them, further efforts are still needed.

Conclusions

The research presents limitations that can, however, offer insights to future studies, as illustrated in the last chapter. Due to the low number of existing Dapps by category, the framework represents the ecosystem regardless of the service provided. As the extent of the sample is mainly due to the DeFi applications collected, the advice for future research would be twofold: first, to expand the set of applications in order to integrate and/or change the current framework over time; second, to analyse the protocols by taking into consideration the category they belong to. In particular, some individual sectors of specific interest could be the subject of specific analysis in the future, when a larger number of use cases are available.

[8] Partially decentralized: only some aspects can be altered by governance token holders. The application has a governance token, but the token holders cannot make proposals for change.

[9] Due to smart contracts' immutability, it is not possible to make radical changes to the protocol if these have not been foreseen beforehand.

In addition, the choice to focus the analysis specifically on applications that run on public blockchains has been addressed following the evidence found in the literature review, but it certainly represents a limitation. In fact, although blockchain-based applications have been analysed as the ones that hold the highest potential to disrupt existing economic models, other applications that don't run on public blockchains are emerging. These types of software exploit other kinds of technologies to run their code (e.g. IPFS), in some cases also using tokens, thus ensuring a fair degree of decentralisation and giving rise to a wide set of use cases. It would be interesting to perform a similar analysis on a database of "off-chain" applications (i.e. technically outside the blockchain) and compare the results with the solutions offered by the blockchain-based applications.

Lastly, it is important to highlight how this research reflects the early-stage nature of the implementations under discussion and the resulting small sample of active use cases. Many projects are early pilots and have not yet achieved full rollout. As more projects move from pilot stage to rollout, it will be interesting to explore which industries will create architectural innovations or generate radical innovations and to confirm whether these will be supported by public blockchains.

Chapter 1

Introduction

The blockchain was introduced for the first time by Satoshi Nakamoto in 2008 as the technology behind Bitcoin, a virtual currency exchanged within a peer-to-peer network. In the footsteps of Bitcoin, various applications have been developed by using this technology in many other fields and with the same objective: to bridge the lack of mutual trust between individuals willing to exchange value.

The potential applications and the advantages introduced are unlimited, but the diffusion and adoption of the blockchain takes place through a laborious process in continuous evolution. In this regard, two elements emerged as the main source of innovation in this area: public blockchains and smart contracts. Decentralized applications (Dapps), or blockchain-based applications, are the union of these two elements. They represent completely novel applications that could change the nature of economic, social, and political systems.

This point can be proved by the growing interest of multiple actors: in April 2021, the blockchain industry grew 158% year-on-year, reaching 1 million in daily unique active users across all chains. Furthermore, the total value locked (TVL), a metric that expresses the amount of capital invested in decentralized finance activities, increased from $520 million in April 2020 to $78 billion in April 2021. The interest of companies and investors in decentralized applications is also proven by the raise of Initial Coin Offerings (ICOs), an innovative mean of fundraising. The biggest 50 ICOs to date have raised an average of $160 million.

The objective of this thesis is to contribute to the limited literature on the subject, by offering a complete analysis of how this technology affects business and governance innovation. To this purpose, a comprehensive analysis with the key features of existing Decentralized Applications is outlined in a framework, which is the main output of this research.

Chapter 2

Literature review

The majority of articles in the scientific literature focuses on technical aspects of blockchain technology while articles on their effects on value networks are predominantly found in the grey literature (Zhao, Fan, & Yan, 2016; Risius & Spohrer, 2017; Yli-Huumo, Ko, Choi, Park, & Smolander, 2016). However, a solid theoretical basis is needed to explore the expected implications of blockchain technology on business models and ecosystems (Schneider, Leyer, & Tate, 2020).

Analysing the scientific literature surrounding the blockchain, academic articles dealing with this topic are still limited. The number of papers reported on Scopus – the largest abstract and citation database of peer-reviewed literature – barely reaches 20,000 at the time of writing (May 2021). This is mainly due to the high degree of novelty of blockchain technologies and applications. Figure 2.1 shows the number of documents dealing with blockchain over the years.

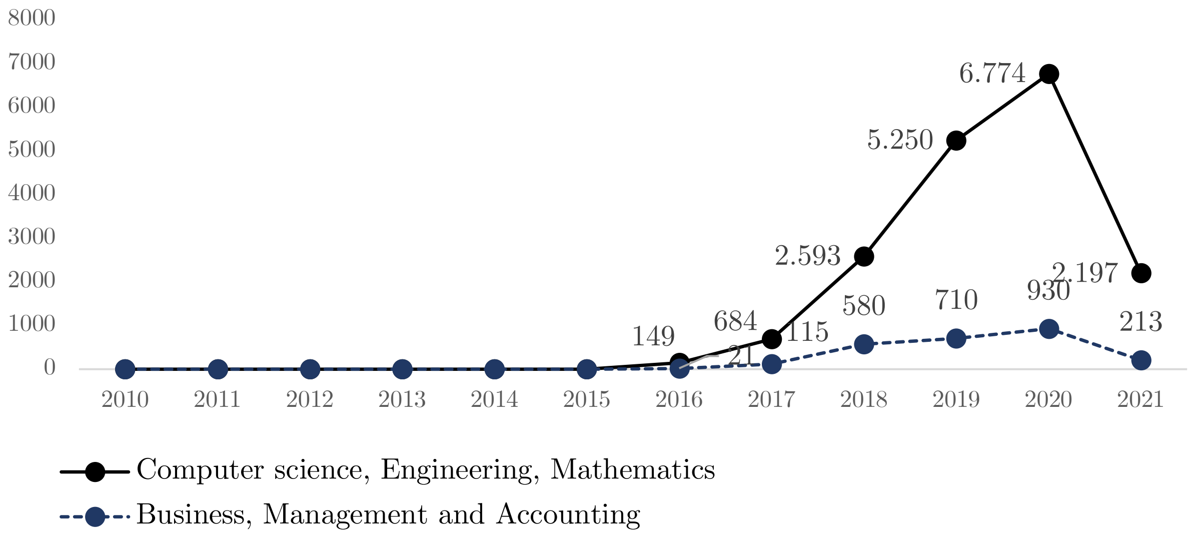

Figure 2.1: Number of documents about blockchain | Source: Scopus, May 2021

The end of 2016 saw an increase in literature, with papers beginning to explore the promises and implications of this technology such as reduced transaction costs (Schmidt & Wagner, 2019), decentralized business models (Morkunas, Paschen, & Boon, 2019; Nowiński & Kozma, 2017) and distributed autonomous organisations (Diallo, et al., 2018).

However, blockchain technology is quite recent and its commercial applications even more recent. Therefore, not only research papers, but also reports prepared by professional consulting firms, blog articles and trade journals were used. All these sources were used to introduce the blockchain technology through its components and key characteristics and explain the underlying mechanisms. This is followed by a study on the programmability of the blockchain and smart contracts, tools that allow the implementation of the blockchain in more complex applications such as decentralized applications (Dapps). Then, a comprehensive overview of the main application is presented, followed by a deeper investigation into the business implications of this technology and its impact on governance systems.

In this regard, the academic literature focused on the impacts of blockchain on business is quite scarce compared to the overall body of papers. Most articles focus on the technical elements of the technology and there is still little research on blockchain business issues (see Figure 1.1).

As the intention of this thesis is to explore the consequences of blockchain for business and governance models, it has not delved into the technical details of blockchain technology – a topic of interest in cryptography and computer science – nor has it focused on industry-specific details, for example those involving the financial and legal aspects of cryptocurrencies. However, in order to gain a deep understanding of the technology and be able to summarise it in this first part of the literature review, computer science-related research articles were also examined.

Finally, the actual number of sources examined in the desk research was substantially higher than the number of the cited ones. Many of these sources, however, present similar perspectives and for this reason only the most relevant for the purpose of this thesis have been cited.

2.1 Blockchain

Several definitions of blockchain have been written, but they are often confusing and difficult to be fully understood. The purpose of this section is to introduce the blockchain technology, explain the underlying mechanisms and provide some historical background. The key components of the blockchain are briefly analysed, highlighting the main characteristics and peculiarities, and exploring the powerful implications of each one of them.

2.1.1 History

After thirty years into mass adoption of the Internet it is still not possible to reliably establish each other's identities online or trust each other for transactions and money exchanges without the validation of a third party such as a bank or government. These intermediaries collect data and invade the privacy of customers for commercial gain and national security (Tapscott & Tapscott, 2016). Moreover, their cost structure excludes around 2.5 billion people from the global financial system (Larios-Hernandez, 2017).

Despite the promise of a world empowered by peer-to-peer, the economic and political benefits have proven to be asymmetrical – with power and prosperity channelled to those who already have it.

For most critics, the solution to some of these structural problems has been to propose strong regulation: make the tech giants subject to the same controls as other industries vital to the public interest, such as railways or telephone networks. However, it seems unlikely that these interventions will solve the fundamental problems facing the online world. Looking back, it was not only the Justice Department's antitrust division that challenged Microsoft's monopoly power in the 1990s, but also the emergence of new software and hardware – the web, open-source software, and Apple products – that helped undermine Microsoft's dominant position (Johnson, 2018).

As early as 1981, researchers were attempting to solve the Internet's problems of privacy, security, and inclusion with cryptography (Tapscott & Tapscott, 2016). In the same year David Chaum, an American computer scientist invented eCash, a digital payment system that was "a technically perfect product which made it possible to safely and anonymously pay over the Internet" (Chaum, 1983). The innovation was so remarkable that Microsoft and other tech giants were interested in adding it as a feature in its software (Frankenfield, 2021). The problem was that the issue of privacy and security was not perceived to be relevant at the time. Thus, the company went bankrupt in 1998, despite flourishing electronic commerce, but with credit cards as the "currency of choice" (Pitta, 1999).

In 1997 Nick Szabo, one of Chaum's associates, wrote a short paper entitled "The God Protocol", citing the phrase "the God particle" coined by Leon Lederman to highlight the importance of the Higgs boson in modern physics. In his work, Szabo imagined the creation of an ideal protocol that would have God as a trusted third party in the middle of all transactions.

> "All the parties would send their inputs to God. God would reliably determine the results and return the outputs. God being the ultimate in confessional discretion, no party would learn anything more about the other parties' inputs than they could learn from their own inputs and the output. (Szabo, 1997)"

Szabo points out that using the internet requires a leap of faith: since the infrastructure lacks security, there is often no choice but to regard intermediaries as gods.

In 2008, at the height of the Great Recession, Bitcoin's anonymous creator Satoshi Nakamoto proposed a new protocol for a peer-to-peer electronic cash system using a cryptocurrency called Bitcoin. This protocol established a set of rules – in the form of distributed computations – that ensured the integrity of the data exchanged among billions of devices without going through a trusted third party (Nakamoto, 2008). Nakamoto's identity is unknown even today, but we do know that he is very committed to his original vision, in fact, he never touched a single Bitcoin from the public key connected with the genesis block. According to him, the system still suffers from the trust-based model:

> "What is needed is an electronic payment system based on cryptographic proof instead of trust, allowing any two willing parties to transact directly with each other without the need for a trusted third party. Transactions that are computationally impractical to reverse would protect sellers from fraud, and routine escrow mechanisms could easily be implemented to protect buyers. (Nakamoto, 2008)"

Bitcoin remained known by only a small group of miners and early adopters for a while. During this period, due to its pseudo-anonymous nature, it was used mainly in the dark web through the anonymous software Tor, making transactions in exchange for goods, especially drugs. The most famous black-market platform, active until the FBI closing in 2013 was the Silk Road.

However, Bitcoin gained a lot of public attention after its exponential price increase in late 2017, also popularising the technology behind it, the Blockchain.

2.1.2 Blockchain as a foundational technology

The concept of disruptive innovation is limited to defining a short-term impact of an innovation in the market, disrupting existing assumptions and rendering previous knowledge obsolete (Norman & Verganti, 2014). This definition is not suitable for several technologies because it does not include the effects of long-term innovation.

In the article "The Truth About Blockchain" Marco Iansiti and Karim Lakhani define the “foundational” innovation describing a correlation between two technologies: Blockchain and Internet. According to the authors, the substantial characteristic of a foundational innovation is that it has a strong impact in the long run, such as to transform the economy and society. Unlike a disruptive innovation, whose impact is relatively rapid over time, the advent, for example, of electricity and the internet have changed the foundations of the economic system over decades.

As previously stated, blockchain was introduced as the technology underlying Bitcoin, the first virtual currency system that rejected a central authority for issuing currency, transferring its ownership, and confirming transactions among participant of the network. Contracts, transactions, and records are among the building blocks of our economic, legal, and political system. Through these elements, society is able to establish and verify identities, protect assets and set organisational boundaries. They can govern interaction among entities and guide managerial and social actions. However, these tools have not been able to keep pace with the digital transformation of the economy (Iansiti & Lakhani, 2017).

With the blockchain, it could be imagined a world in which all information is embedded in digital code and stored in transparent, shared databases, where it is protected from deletion and tampering. In this scenario, every agreement, process, and payment would be recorded together with a digital signature that could be identified, validated, and shared. Intermediaries such as lawyers, brokers and bankers might no longer be needed. But while the impact will be enormous, it will take decades for blockchain to seep into our economic and social infrastructure. The reason is that blockchain is not a "disruptive technology" that significantly alter the way businesses or entire industries operate and that incumbent can stem quickly if prepared. The process of adoption will be gradual and steady, not sudden, as waves of technological and institutional change gain momentum (Iansiti & Lakhani, 2017).

Internet comparison

As previously stated, the evolution and adoption of foundational technologies evolution can require a considerable amount of time. One of the leading examples of foundational technology is the distributed computer networking, seen in the adoption of TCP/IP (transmission control protocol/internet protocol) protocol, which laid the foundations for the development of the Internet.

Introduced in 1972, among the researchers on ARPAnet, the U.S. Department of Defence ancestor of the commercial internet. Before TCP/IP, telecommunications were based on "circuit switching", in which connections between two parties had to be passed and sustained throughout an exchange. In order to be sure that the nodes were able to communicate, telco operators invested billions of dollars in building the dedicated infrastructure.

TCP/IP blew off this model. The new protocol transmitted decomposing information data in small pieces, called packets, each with address information included. Once released into the network, the packets were able to take any routes and receiving nodes could reassemble the packets, interpreting and encoding the data. TCP/IP created an open, shared public network without any central authority or party responsible for its control, maintenance, and improvement. It took more than thirty years for TCP/IP to move through all the phases, from single use cases [i.e. e-mail] to the replacement of existing technology and the reshaping of the economy (Iansiti & Lakhani, 2017).

Analogies between blockchain and TCP/IP are self-evident. The first empowers bilateral financial transaction between peers as well e-mail enables bilateral messaging. A team of volunteers all around the world maintains the core software updated and running. For example, a standard stock transaction can be executed within microseconds, often without human intervention. However, the settlement, clearing and transfer of ownership of the stock can take as long as a week.

Intermediaries act as guarantors of assets property as the record of the transaction through organisations, and the ledgers are individually updated. With blockchain all the process, thanks to smart contracts, can be done in minutes (for further details please refer to *Smart Contracts*). While this analogy also implies that it may still take many years for the technology to exercise its full impact on business, we can already observe this technology being implemented in diverse industries from finance to supply chains (Nowiński & Kozma, 2017). These topics will be discussed in *Business Model Implications.*

2.2 Consensus mechanisms

The methods which answer the question of "how a new block is added to the blockchain?" are called consensus mechanisms. There are several consensus mechanisms potentially implementable in a blockchain, and they are generally divided between two groups: proof-based and voting-based consensus algorithm. In general, the proof-based consensus algorithm is appropriated for a network having many nodes. On the other hand, voted-based algorithms are more suitable in situations with a limited number of nodes.

2.2.1 Proof based algorithm

The grounding concept of proof-based consensus algorithm is that every node can join the network, they can immediately become part of the ecosystem and get a reward, without any check regarding their honesty and background. In the recent years several consensus algorithms have been developed (such as Proof of Activity, Proof of Burn, Proof of Space, Proof of Luck and Proof of elapsed time). However, the two mains used remain PoW and PoS.

Proof of Work

Proof-of-Work (in short, PoW) is a technique that uses computational resources to certify the work done by a user, it is the mechanism used in Bitcoin blockchain. It was introduced by Adam Back in 1997 and was initially designed to avoid Denial of

Service (DoS) attacks. A Proof-Of-Work is an algorithm that requires solving a computationally complex problem to demonstrate that it has used resources.

In Bitcoin, the algorithm requires each miner to solve a challenging puzzle with adjusted difficulty, and once the puzzle is solved, the right to add a new block to the current chain is gained. The first miner who solves the puzzle will have this right. As explained by Nguyen and Kim in 2018, before solving the puzzle, the miners would have to insert into a candidate block a list of transaction, as well as other information like the hash function of the previous block and the timestamp. After the block candidate is set up, they start solving this puzzle. The puzzle consists in guessing per random attempts a variable integer number (the nonce), such that when provided as an input with the block header for the hash-256 function, the output would coincide with a hash under a defined target. In fact, all the information inside the block header will be combined and entered into a SHA-256 hash function – the nonce included. If the hash output of this function is below a given threshold T[10], designated by the difficulty of the process, the value is accepted; otherwise, the miner has to make another guess of the nonce, until he gets an acceptable hash.

To make it clear, suppose the generated hash does not match the difficulty criteria (the target), the only way to get a different and compliant hash is to use at least slightly different data set as input for the hash 256 function. Thus, instead of changing the list of transactions put into the block, a miner can change the nonce of the block, which is just a meaningless integer that can be changed as many times as necessary to check a bunch of different hashes and see if they pass the network difficulty check.

Summarizing, proof of work is a brute forcing operation in which the aim is to find a number – nonce – to insert in a data set – the block header – such that the double SHA-256 hash of such data is a number lower than a certain target. The target is calculated on the basis of the difficulty coefficient: the greater the difficulty, the lower the target and the greater the attempts necessary to find the nonce. In practice, the computer that is running the mining program receives the header of the block that is trying to mine from an appropriately configured client or via the internet from a dedicated server. A number is added to this header, the nonce, and the double hash is calculated entirely. If this hash is numerically smaller than the target, the header is

[10] It is a 256-bit number. The difficulty coefficient defines with how many "0" the target must start.

sent to the server for approval, otherwise the nonce is incremented by one and the check is repeated.

Due to the use of SHA-256, guessing the hash value is extremely difficult and for this reason the system provides a reward for predicting the right value. A node that decides to join the network and tries to solve the puzzle is called a miner and the action of finding a fitting nonce is called mining.

When a node finds a correct nonce, it broadcasts its proposed block to the other nodes to notify them that the answer has been found. Immediately afterwards, all miners start receiving this message and stop guessing the puzzle. Instead, they check the transmitted block to see if all transactions are valid, if the block contains the previous hash of the last block in their chain, the validity of the nonce field, and so on. Clearly, it is easy to verify that the declared nonce is the one that allows the desired result to be found as it is sufficient to take the block header, concatenate the declared nonce and calculate the hash. If all the verifications are correct, then these nodes will add the proposed block to their current chain and restart the process by repeating the steps outlined above (Nguyen & Kim, 2018).

There is a rare possibility that a miner will find the answers to the puzzle before being notified that another miner has found another suitable answer. In this case, all miners with an acceptable solution will still transmit their block with the nonce they found. Then, other miners who receive the first coming block will ignore the others coming later. This leads to the forking problem, for which two branches apparently valid are mined at the same time. Nakamoto (2008) solved this problem by introducing the “longest chain” rule, for which the network considers valid only the longest chain, while the shorter chain is designed to die.

Proof of Stake

The previously explained PoW is supposed to be unfair: in fact, some miners can own very powerful types of equipment and join together, finding suitable nonce much easier. This is very different from the original view of Satoshi Nakamoto, that wanted to everyone to be competitive in solving the puzzle and get rewarded. Proof of Stake is supposed to deal with this inequality. PoS changes the requirements regarding computational power and energy typical of PoW and replaces them with stake. Stake is the amount of a specific currency that an actor is willing to lock in for a certain amount of time. In return for that, they get a probability of success proportional to their stake in selecting the next block. Specifically, if there are total “b” coins available to all the miners, and miner “M” owns “a"” coins [a < b], the chance for miner “M” to get the right to mine a new block is a basic probability a/b. Once a miner gets the chance to mine a new block, he will verify the transactions, collect them into a block, then broadcast it to the other miners, and receive the rewarding fee (Binance Academy, 2018; Nguyen & Kim, 2018).

Furthermore, using PoS would require any attackers to own at least 51% of all stakes in the network in order to perform a double spending attack, which is very unlikely due to the resources the attacker would have to buy. This would cause a dramatic increase in the value of the coin and become very expensive attack. There are various existing coins which use pure PoS, such as Binance Smart Chain and Cardano and even Ethereum is working to evolve its consensus algorithm to PoS.

2.2.2 Voting based algorithm

The main difference between voting based and proof-based consensus algorithm is that in the former case the nodes within the network must be known, as this facilitates the exchange of messages. In such algorithm, nodes cannot join freely the verifying network, contrary to the proof-based algorithms. Moreover, in voting-based consensus algorithm, apart from maintaining the ledger, all the nodes in the network would have to verify together transactions and blocks. After having communicated with others, they decide to add their proposed block to the chain or not (Nguyen & Kim, 2018).

Carry out voting-based consensus algorithms is very similar to traditional methods for tolerating faults used in the distributed system. Therefore, voting based consensus must be designed in order to resist some severe cases:

- Some nodes are crashed: in this case, nodes will wait for the messages from other nodes. However, if some nodes do not run properly, common nodes are not able to receive enough pieces of evidence in order to make the decisions. In order to operate correctly, and avoid the crash with f nodes, there should be at least f+1 nodes that are operating normally.
- Some nodes are subverted: in this case, some nodes could act, and the results can be in this way inaccurate

The problem here is the classical Byzantine general problem:

> "A group of Byzantine generals attacked an enemy's camp. They decided to divide their army into N groups led by N generals, which would attack the enemy from different sites. If they attacked at the same time, they would win; otherwise, they would lose. Consequently, they had to make an agreement with each other about the attacking time by exchanging messages and following the decision of the majority. Unfortunately, there were some traitors inside the general group, and they wanted to cheat other generals by telling different decisions to the others. Therefore, the results could be made inaccurate, which made some generals attack, while others did not, leading to failure"

This problem could be avoided if there are at least another 2f+1 standard general with them (Lamport, Shostak, & Pease, 1982).

Regarding the blockchain the worst case is if the network is not able to resist subverted nodes, causing a non-equivalent ledger in different nodes. Based on these unfortunate situations, it is possible to classify the voting-based consensus algorithm in two kinds:

- Byzantine fault tolerance-based consensus: a kind of consensus that can prevent crashing and subverted nodes
- Crash fault tolerance-based consensus: a kind of consensus that can only prevent crashing nodes

2.2.3 Protocol forks and network splits

In software engineering, "software forks" refer to the fact that any free and open-source software can be copied and modified without prior permission from the original development team and without violating copyright law. The term sometimes also refers to a split in the developer community of an existing project, rather than just the code (Robles & Gonzalez-Barahona, 2017). In this way, it is possible to create a new network from scratch by simply copying the existing code base and modifying it to build a new network or fork an existing network, including the existing ledger and community, into a different continuation for a protocol upgrade (Antonopoulos, 2017).

These protocol updates can cause a split of the network as a result of protocol upgrade disputes (as was the case with "Bitcoin Cash" and "Ethereum Classic") or deliberate secession for economic reasons, which are often designed to extract economic value above any philosophical protocol discussions (as was the case with "Bitcoin Gold"). The types and rules of software forks depend on the formal and informal protocols of each network (Voshmgir, 2020). The bitcoin network and similar networks distinguish between "hard forks" and "soft forks":

- **Hard fork**: type of protocol change that is not backward compatible. Nodes that do not upgrade to the new protocol version will not be able to process transactions as all nodes validating transactions under the old protocol will treat blocks produced under the new protocol as invalid. Nodes that want to adopt the new protocol will therefore have to update their software.
- **Soft fork**: protocol change that is backward compatible. Nodes that have not updated their protocol are still able to process transactions if they do not break the new protocol rules, while blocks produced by miners running the updated protocol are accepted by all nodes in the network. However, blocks produced by miners running the old version are rejected by nodes running the new version of the protocol. Soft forks are more gradual in their voting process than hard forks and require several weeks to be implemented.

TheDAO Incident

An interesting example of hard fork is provided by the events surrounding TheDAO, a decentralized application that functioned as a form of investor-directed venture capital fund (Waterss, 2016). A vulnerability was exploited and used to drain 3.6 million ETH – around 50 million USD at the time – from the application (Siegel, 2016). After much heated debate and several attempts at gauging the community consensus, leading Ethereum developers converged on a proposed solution: a hard fork that would transfer the funds of the attacker's child DAO into a new withdrawal smart contract that would only allow token holders to withdraw their funds (Siegel, 2016).

The proposal was implemented into code; members of the community then had to decide which network to support. While the hope was that everyone would switch to the new protocol and leave the old to die out, dissent within the Ethereum community led to the emergence of two blockchains that subsist today: Ethereum, which implemented the proposed change, and Ethereum Classic, which rejected it.

Beyond the issues internal to the Ethereum community, TheDAO attack also brought considerable attention from litigators and regulators. There was a great deal of speculation over who might be liable for any wrongdoing caused by TheDAO and who should respond to the investors who lost their funds in the attack. Meanwhile, the US Securities and Exchange Commission launched an investigation into the legal status of TheDAO tokens, and eventually issued a report concluding that the DAO had engaged in the unlicensed issuance of securities (Securities and Exchange Commission, 2017).

2.3 Blockchain classification

The most common – and one of the earliest – classifications of blockchain was offered by Ethereum founder Vitalik Buterin in 2015. According to Buterin (2015), there are three types of blockchain database-like applications: public, private and consortium (or federated) blockchain. The blockchain started out purely public – with Bitcoin – offering open access to anyone in the world. Then new blockchain protocols developed towards a non-decentralized form – the private one – where participation and write/read permissions are centralized to a lesser (consortium) or greater extent (entirely private).

2.3.1 Public blockchain

The public blockchain is a blockchain with the highest degree of openness, anyone in the world can start managing a public node, sending transactions through the network, and seeing them included once validated. In addition, anyone can participate in the consensus process, through which a new block is added to the blockchain, and finally, anyone can monitor validated transactions on the public block explorer even without taking part in the network. In practice, the network is held together by outsiders in a trustless state of aligned economic incentives. The fundamental characteristic intrinsic to public blockchain is the disintermediation, potentially able to disrupt many businesses and increasing efficiency by cutting third party costs.

2.3.2 Private blockchain

In the private blockchain, only selected members can have access to the network since a private organisation centrally administers the participation permissions. The participant can only join the network through a verified invitation, and a validation is required either by an operator or by a set of protocol implemented by the network (Seth, 2021). In simple terms, private blockchains control who is allowed to participate in the network. In particular, write permissions are centralized in a single organisation, allowing only pre-approved parties to write to the blockchain.

A private blockchain is not decentralized; it is a distributed ledger that operates as a closed and secure database based on cryptographic concepts. The benefits of using blockchains within private organisations are to increase efficiency and reduce costs, because of faster and more secure data verification between internal parties.

2.3.3 Consortium blockchain

Consortium (or federated) blockchains are a third hybrid type of blockchain that is governed by a group of participants across organisations. A pre-selected set of nodes controls the consensus process; one could imagine a consortium of financial institutions (e.g. R3), each of which manages a node and of which only a few nodes need to sign each block for the block to be valid (Buterin, 2015).

In general, the distinction between the consortium and entirely private blockchains is that the former provides a hybrid model between the “low-trust” provided by public blockchains and the “single trusted entity” model of private blockchains, while the latter can be more accurately described as a traditional centralized system with a degree of cryptographic auditing attached. Banking sectors are commonly using a network of consortia that maintains the privacy of a user's data, without merging power with a single organisation. Examples include R3 (banks), EWF (energy), B3i (insurance), Rope and Ripple.

2.3.4 Permissioned and permissionless blockchain

In addition to the notion of public/private blockchain the previous definitions point out another dimension: the notion of the permissioned/-less blockchain. Permissioning is the action of officially allowing someone to do a particular thing; it can be intended both for private and public blockchain. It is essential to keep a distinction between the two dimensions because public/private dimension refers to user authentication, "who" can access the network; the permission/permission-less dimension refers to user authorisation, "what" users can do (e.g. write and/or read).

Summarising, as Natarajan et al. (2017) states:

> "Distributed ledgers are categorised as public or private depending on whether anyone can access the ledgers or only by the participating nodes in the network. DLTs are categorised as permissioned or permissionless, depending on whether network participants (nodes) need permission from any entity to make changes to the ledger"

Figure 2.2 represents a taxonomy of the blockchain according to the public/private and permission/-less dimensions. This taxonomy offers a systematic classification of blockchain without an explicit predictive capacity. In other terms, it offers a systematic view of blockchain types without giving suggestions of how and which blockchain to choose.

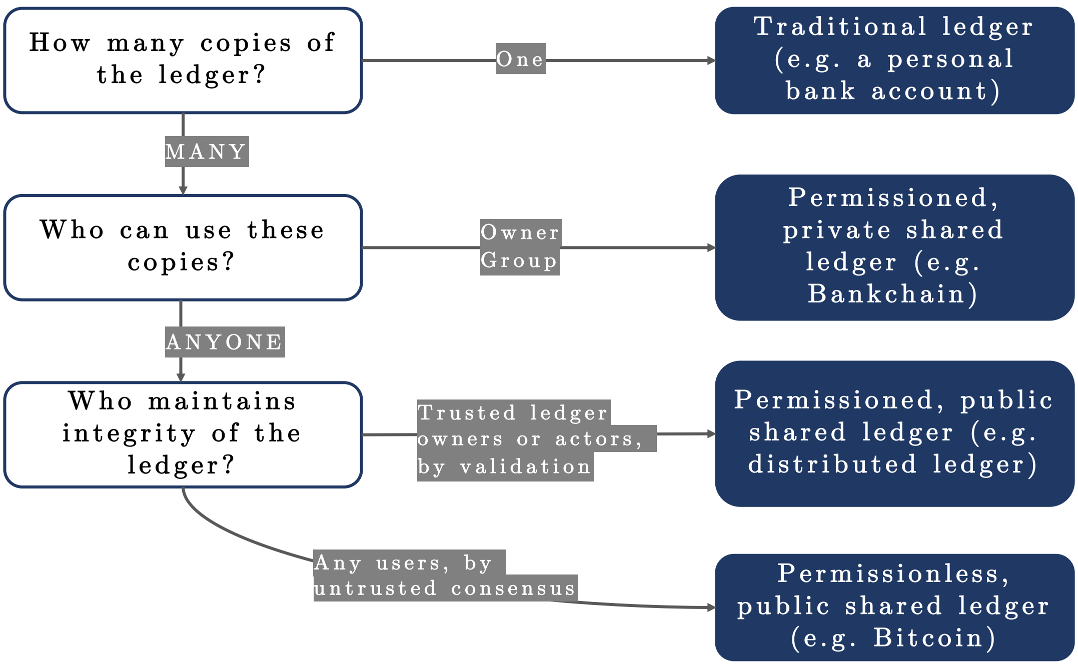

Figure 2.2: Distributed Ledger Taxonomy | Source: UK Government Chief Scientific Adviser, 2016

2.4 Scalability and Layer 2 solutions

Since its inception blockchain technologies have grown tremendously. However, the increasing size of blockchains like Bitcoin or Ethereum has led to issues of scalability. One of the greatest challenges of a distributed consensus like Proof-of-Work is indeed how to address the trade-off between decentralisation, security, and scalability (Voshmgir, 2020). The Ethereum protocol, for example, is capable of handling around 15-20 transactions per second [TPS], a negligible number compared to Visa's 24,000 transactions per second (Visa, n.d.).

The achievement of blockchain scalability at a global level is an issue that extends to many of the existing protocols, and it represent one of the main issues for the blockchain community (Paszke, 2020). The slowness of blockchain transactions is a major concern also for enterprises that depend on high-performance legacy transaction processing systems (Deloitte, 2018).

The need to achieve a higher throughput is linked to another problem related to scalability and stemming from transaction fees. Transaction fees are paid for the computational effort required to execute transactions on the network. Due to network congestion, at the time of writing (May 2021) these transaction fees are so high – especially on protocols such as Ethereum – that they are preventing utilisation by common users (Etherscan, s.d.).

Transaction fees

Transaction fees arise from a structural problem of computational theory, called the “halting problem”. The halting problem is the problem of determining, from a description of an arbitrary computer program and an input, whether the program will end or continue to run forever. In the event that an infinite loop is created in a programme, it will continue to run indefinitely (Sipser, 2006). However, if the program is on a Turing machine, it is impossible to construct an algorithm that always leads to a correct yes or no answer, making the problem *undecidable*. It can be proven that there is no algorithm that correctly determines whether arbitrary programs eventually stop when they are executed (Martin, 1965).

As described above, the Ethereum platform is Turing-complete and is therefore exposed to the risk of network clogging. The developers then introduced a transaction tax called “gas” which allows programs to be run only as long as sufficient payments are made. If the gas runs out, the program stops working. This addresses the halting paradox, making it impossible to run infinite cycles without incurring infinite fees. This keeps the network running and avoids blockages and slowdowns, which allows the Ethereum blockchain to run computer programs without being overwhelmed (Ethereum.org, 2021).

2.4.1 Layer 2

The scalability issue was predicted from the early days of the technology and experts have been trying to solve it ever since (Chen D. , 2021). However, this problem mainly affects systems that rely on the PoW consensus mechanism. PoS-based projects have tackled many of the scaling issues of PoW by achieving better latency with less computation, bandwidth, and storage.

One of the first solution was to increase the amount of information that the blockchain can store. This was achieved by increasing the block size limit and thus doubling the number of transactions that can be performed. This method, although simple, does not represent a viable long-term solution. In fact, once the block size is no longer sufficient, it has to be increased again. This leads to a path where the amount of memory needed to host the blockchain becomes too large to be handled and makes it impossible for miners, except for large companies, to run the software.

The second early solution was to reduce the time needed to create a new block. However, as seen in *Consensus Mechanisms*, a confirmation period is necessary to confirm the validity of new blocks. A shorter time would therefore allow new blocks to be created before realising that a problem had occurred (Chen D. , 2021).

Although these solutions acting directly on the blockchain have not been successful, other more promising approaches are emerging. These solutions rely on building on top of a certain blockchain protocol, creating a secondary framework where blockchain transactions and processes can take place independently of the Layer 1 (main chain). For these reasons, these techniques are also referred to as Layer 2 or “off-chain” scaling solutions. The main goal of these protocols is to solve the transaction speed and scaling difficulties that are being faced by the major cryptocurrency networks (Paszke, 2020).

One of the main advantages of using off-chain solutions is that the main chain doesn’t need to go through any structural change because the second layer is added as an extra layer. As such, layer 2 solutions have the potential to achieve high throughput without sacrificing network security (Paszke, 2020).

Sidechains

Side chains run separately from the main blockchain and operate independently using their own consensus algorithm. They connect to the main chain via a bidirectional bridge, and unlike other Layer 2 solutions they have their own security properties and do not have to rely on the security of the main chain. However, they are less decentralized than the main chain and validators may coordinate to act maliciously.

Channels

Channels offer users a way to make multiple transactions off the chain, while sending only two transactions to the settlement level, i.e. Ethereum, thus allowing high throughput at a low cost. However, there are limitations: participants must be known in advance, and they are also required to deposit funds in a multi-sig contract. This means that the network must be regularly monitored to ensure that funds are safe. It also takes time to set up channels between users, so it does not allow for true open participation. Channels come in two forms: state channels and payment channels.

Plasma

Plasma solutions use Merkle trees to create an additional chain to the main blockchain. This facilitates fast transactions at a lower cost, as blocks are not placed on the main chain, and there is no need to store data on the ledger.

However, this solution also has limitations. The framework only supports some transactions, so a more complex DeFi activity, for example, is not possible. Withdrawals are subject to potential problems and longer waiting times, and it also requires someone to monitor the network to check that the funds are secure, as well as operators to store the data.

Rollups

Rollups work by executing transactions on Layer 2, while sending data to the base chain. This means that they benefit from the security of the main chain but can perform transactions outside of Layer 1.

There are two types of rollups: ZK (zero knowledge) rollups, which bundle many transfers into a single transaction, and optimistic rollups, which operate on a sidechain parallel to Ethereum. ZK rollups group transactions together by creating what's known as a SNARK – a succinct non-interactive argument of knowledge. This is a cryptographic proof that gets submitted to the base layer, so only one transaction is sent to Ethereum. ZK rollups allow for fast transactions, but the scope of these transactions is limited (Ethereum.org, 2021).

Optimistic rollups, meanwhile, run alongside the base chain, with transactions sent to Ethereum as call data. Optimistic rollups provide composability[11], a fundamental requirement of DeFi, though they are subject to longer wait times and potential attacks.

2.5 Smart contracts

The blockchain, introduced by the Bitcoin, has bring a new way of transfer, store, and exchange value. An evolution of this protocol is represented by smart contracts, which are a powerful instrument to manage contractual relationship when applied to the blockchain environment.

Smart contracts are computer programs that secure, enforce, and execute settlement of recorded agreements between people and organizations. As such, they assist in negotiating and defining these agreements. When smart contracts are used in a blockchain environment they can express their full potential. The blockchain allows to store these special contracts in a permanent, immutable, and transparent way, such that the parties establishing a contractual relationship do not need to trust each other. Computer code allows for the self-execution, while blockchain guarantees immutability and transparency of the negotiation.

2.5.1 History

In 1994, the same year that Netscape – the first Web browser – hit the market, Nick Szabo, a computer scientist and legal scholar, created the term "smart contract" and defined it as: "a computerized transaction protocol that executes the terms of a

[11] For further details please refer to *Decentralized Finance*

contract (Szabo, 1994)." He envisioned a way of bringing efficiency to written agreements in a way that enforces them automatically.

Three years later, Szabo theorized the first essential Smart Contract model in his papers "Formalizing and Securing Relationships on Public Networks" and "The Idea of Smart Contracts". The following year he released the third document – "Secure Property Titles with Owner Authority" where he formalized the concepts outlined in previous works. In these works, the author imagined a model analogous to the one of a vending machine, in which the vending machine software and hardware manage the sale of a certain asset, verifying that when the buyer provides a certain amount, the desired product is delivered. It is a conceptually simple procedure dated back in time, at the first automatic vending machine developed by Hero of Alexandria in the first-century Roman Egypt (Jaffe, 2006).

Also in 1998, Wei Dai showed in his paper "B-Money" – mentioned in the Bitcoin whitepaper by Satoshi Nakamoto – the idea of an independent contract protocol to be implemented in an untraceable network between subjects identified by a public cryptographic key. The system provided an exchange of digital and encrypted messages and the execution of enforcement rules (Dai, 1998).

However, at that time there was no technology available that could deploy smart contracts as Szabo described. There were computer systems such as Electronic Data Interchange (EDI) that provided standards for communicating standardized business transactions between organisations, but no technology that could actually offer the possibility to formalize the will of one or more parties in an unforgeable and immutable way (Tapscott & Tapscott, 2016).

Only in 2009, Bitcoin introduced the first blockchain technology, which few years later opened the door to the advent of the Smart Contract era (Swan, 2015). It took place in 2014, when the 19-year-old Vitalik Buterin – Ethereum funder – published the Ethereum White Paper, outlining the characteristics of what would later become the reference platform for the development and execution of Smart Contracts on the blockchain. Ethereum is a protocol derived from Bitcoin, designed for the realization of smart contracts. The purpose of this platform is to provide a blockchain with a built-in Turing-complete programming language, which can be used to construct smart contracts by in a few lines of computer code (Buterin, Ethereum Whitepaper, 2014).

This means that it can host any language that is Turing complete. This enables developers to build virtually any digital application imaginable on Ethereum. These kinds of programs can perform very different tasks, from smart contracts and computational resource marketplaces to complex financial instruments and distributed governance models.

2.5.2 Definition

A contract can be defined as a set of premises agreed to in a "meeting of the minds" and represents the traditional way to formalise a relationship (Szabo, 1997). The contract is the basic element of a market economy. Over the centuries of cultural evolution, both the concept of the contract and related principles, codified in common law, have emerged. However, structures and institutions are often challenged by the digital revolution. According to Szabo, if we could abstract from our current laws, procedures, and theories the principles that remain applicable in the digital space, we could maintain much of this tradition and at the same time develop useful digital institutions. Szabo's vision is fulfilled by a new tool whose potential is made exponential by the blockchain, the smart contract.

The literature doesn't provide a universally accepted definition due to its recent appearance on the scene and its technological complexity. The basic idea behind smart contracts is that many kinds of contractual clauses (such as collateral, bonding, delineation of property rights, etc.) can be embedded in hardware and software, in such a way as to make breach of contract expensive – if desired, sometimes prohibitively so – for the breacher. As its author define it:

> "A smart contract is a computerized transaction protocol that executes the terms of a contract. The general objectives of smart contract design are to satisfy common contractual conditions (such as payment terms, liens, confidentiality, and even enforcement), minimize exceptions both malicious and accidental, and minimize the need for trusted intermediaries. Related economic goals include lowering fraud loss, arbitration and enforcement costs, and other transaction costs. (Szabo, 1994)"

Thus, technically, smart contracts are contracts written in computer code that aims at making some contractual clauses self-executing, solving the problems related to their non-fulfilment. They find application in every field involving the execution of legal clauses among parties (e.g. transfer of ownership) or in the execution of actions at the occurrence of some condition (e.g. self-driving). Specifically, the code beyond these contracts replaces the third party in executing the contractual clauses.

The fact that there are contracts that are automatically implemented is not new, the novelty lies in the fact that these Smart Contracts are a piece of code stored in a Blockchain (Greenspan, 2016). When the code of a smart contract is inserted into the blockchain, the operations and the agreements between the nodes of the network can be traced and their execution can be automatically performed by the Blockchain itself without the intervention of intermediaries. Once the Smart Contract is set up and launched in the Blockchain, when the condition occurs, the consequence will be automatically executed.

The verification of the condition has fundamental importance and it may be immediate or complicated. The event/condition that trigger the execution of the contract can result from a source external to the blockchain. However, smart contracts alone cannot get information about "real-world" events because they can't send HTTP requests. This is by design, since relying on external information could jeopardise consensus, which is essential for security and decentralization (Ethereum.org, 2021). This issue is commonly referred to as "Oracle problem" and will be addressed in the next section.

2.5.3 Oracle

As described in *Consensus Mechanisms*, the blockchain is a consensus-based mechanism: it can be simplified by saying that it only works if all nodes reach an identical state after processing each transaction and block. Everything that happens on a blockchain must be completely deterministic, with no possible way for differences to emerge. Since smart contracts are executed independently by each node on a blockchain, if one of them retrieves information from an external source, this retrieval is performed separately by each node. However, being this source outside of the blockchain, there is no guarantee that every node will receive the same answer. If the source were to change response between requests from different nodes, or if it were to become temporarily unavailable, the consensus mechanism would be compromised.

The solution lies in one or more trusted parties, called "oracles" that create transactions which embeds external data in the blockchain. In this way every node will have an identical copy of this data, so it can be safely used in a smart contract computation (Greenspan, 2016). Therefore, an oracle can be seen as a bridge between the blockchain and the real world. It acts as an on-chain[12] API that can be queried to get information into a smart contract (Ethereum.org, Oracles, 2021). This information stems either from software (Big-data application) or hardware (Internet-of-Things) and could be any data: weather temperature, successful payment, or price fluctuations. Oracles can also be bi-directional, used to “send” data out to the real world.

Technically an oracle is composed of a smart contract and some off-chain (i.e. outside the blockchain) components that can query APIs, then periodically send transactions to update the smart contract’s data.

The main challenge with oracles is that people need to trust these outside sources of information, whether they come from a website or a sensor. Since oracles are third-party services that are not part of the blockchain consensus mechanism, they are not subject to its underlying security mechanisms. one could replicate “man-in-the-middle attacks” standing between contracts and oracle. The robustness assurance of this “second layer” is of utmost importance. Different trusted cryptographic tools and computing techniques can be used as a way of solving these issues. One example is using multiple oracles to provide data in a decentralized manner, including incentives for telling the truth and disincentives for cheating. If oracle security is not adequately provided, it will undermine the widespread of smart contract implementation (Voshmgir, 2020).

2.6 Tokens

While the existence of digital tokens is not new, the speed with which these cryptographic tokens are distributed and issued is an indicator of the impact they will have on the blockchain and its development (Voshmgir, 2020). As of June 2021, there are more than 10.000 publicly traded cryptographic tokens listed on CoinMarketCap. These tokens are often issued with just a few lines of code in the form of a smart contract that is collectively managed by a blockchain network or similar distributed ledger.

[12] Refers to all components that are built on the blockchain and remain dependent on the state of the blockchain for their validity

2.6.1 History

As mentioned above, tokens have existed long before the emergence of blockchain networks. Traditionally, tokens can represent any form of economic value or access right. Tokens range from casino chips, vouchers, gift cards, bonds, stock certificates or even train tickets. Most tokens have some inbuilt anti-counterfeiting measures to prevent people from cheating the system (e.g. paper money and coins).

Tokens are furthermore used in computing, where they can represent a right to perform an operation or manage access rights. A web browser, for example, sends tokens to website when accessing the web.

Tokens always need a substrate that ensure their validity, including some inbuilt anti-counterfeiting measure. Historically, tokens have been issued and managed by centralized entities, to ensure validity, and have had security mechanisms built into the substrate. Central banks issuing coins and banknotes must ensure that their tokens, coins, and banknotes, are difficult to copy (Kazdin, 1977).

2.6.2 Cryptographic tokens

Cryptographic tokens represent set of rules, encoded in a special type of smart contract, also referred to as token contract. A token contract is a smart contract that contains a map of account addresses and their balances. The balance represents a value that is defined by the contract creator: it can represent any existing digital or physical asset, or access rights to assets that someone else owns.

The validity and security of cryptographic tokens is managed by the token contract, together with the underlying distributed ledger by majority consensus of the network nodes (McDonald, 2017).

Cryptographic tokens are represented as an entry in the ledger and are mapped to the blockchain address which represents the blockchain identity of the token holder. Tokens are therefore only accessible with a dedicated wallet software that communicates with the blockchain network and manages the public-private key pair related to the blockchain address.

Tokens can represent anything from a store of value to a set of permissions in the physical, digital, and legal worlds. They facilitate collaboration across markets and jurisdictions and enable more transparent, efficient, and fair interactions between market participants, at low costs (Voshmgir, 2020).

From a technical perspective, tokens can be implemented on different layers of technology, either as (i) protocol tokens, (ii) second-layer tokens, like application tokens or tokens created on a sidechain, or as (iii) multi-asset ledger tokens.

Protocol tokens, also referred to as intrinsic, native, or built-it tokens, keep the network safe from attack by acting as block validation incentives (miner rewards), and for transaction spam prevention. Native protocol tokens might furthermore be needed to pay for transaction fees in the network and can be regarded as the “currency” of the distributed ledger. With the advent of Ethereum, tokens have moved up the technology stack and can now be issued on the application layer.

Application tokens, on the other hand, can have any function or property. They can represent anything from a physical good, a digital good or a right to perform an action in a network or in the real world. Standardised smart contracts such as the ERC-20 standard define a common list of rules for tokens, including how the tokens are transferred from one address to another and how data within each token is accessed. These token contracts manage the logic and maintain a list of all issued tokens and can represent any asset that has features of a fungible commodity. Fungibility refers to the fact that every token has an identical value with any other token of the same kind and can be easily traded. Due to network effects, the value of application tokens and other second-layer tokens is likely to be interdependent with the value of the underlying native blockchain token (Voshmgir, 2020).

Finally, multi-assets ledgers like “Ripple” and “Stellar” allow the creation of multiple tokens on the native level.

Different ledger systems have varying standards that are often incompatible. Token issued on one network are, for the most part, incompatible with other networks and cannot cross ledgers directly. This is considered a usability bottleneck. However, token interoperability and standardization are issues that are being tackled by interoperability protocols like “Cosmos” and “Polkadot” and other standardization efforts worldwide. Interoperability and standardisation will influence potential mass adoption of tokens and resulting network effects.

2.6.3 Non-Fungible Tokens

In 2013, "Colored Coins" was one of the first projects that attempted to attach unique properties to a token. The idea was to use Bitcoin tokens to represent real-world assets like stocks, bonds, commodities, or the deed for a house (Bradbury, 2013). With the emergence of the Ethereum network, a token standard [ERC-721] for Non-Fungible Tokens (NFT) was introduced. This started a movement of building more complex features into tokens. ERC-721 made easy to create a token that represents any type of collectible, artwork, property, personalised access rights, or voting rights.

In general, non-fungible tokens have special properties that make the token unique, or that are tied to the identity of a certain person. It allows the inclusion of metadata about an asset and information about ownership. When validated, such additional information can add value, guaranteeing the provenance of art, collectibles, or along the supply chain of other goods and services (Pawel, 2018).

NFTs enabled the emergence of a much richer spectrum of smart contracts that exceed the possibilities of the fungible tokens, which have been dominating the narrative in the early of the technology, paving the way for a diverse set of use cases (Voshmgir, 2020).

These include (i) crypto-collectibles and crypto-games, where NFTs are used to represent any in-game assets; (ii) asset tokens, which allow unique investments tied to a physical object, like unique artwork, real estate or any other real-world assets; (iii) credential tokens, certificates and reputation, such as IDs, university degrees or software licenses; (iv) access tokens, which are used to manage any type of access right that is tied to a specific person, property or even.

Table 2.1 presents the key characteristics and the main differences between fungible tokens and non-fungible token.

Fungible tokens	Non-fungible Tokens
Identical Tokens of the same type are identical to one another. They have identical attributes.	**Unique** Each token is unique and differs from all other tokens of the same type. They have unique attributes.
Interchangeable A token can be interchanged for another with the same value.	**Non-interchangeable** NFTs cannot be replaced with tokens of the same type as they represent unique values or access rights.
Divisible Fungible assets are divisible into smaller amounts.	**Non-divisible** Tokens that are tied to one's identity are not divisible.

Table 2.1: Fungibility perspective | Source: Voshmgir, 2020

2.6.4 Implications

The ability to distribute tokens relatively effortlessly over a public infrastructure makes it economically feasible to represent many types of goods and access rights in a digital way that would not have been possible before. Examples might be fractional ownership of art or real estate. Such fractional tokenization could improve the liquidity and transparency of existing asset markets. Increased tokenization of existing assets and access rights could have a fundamental impact on global economic dynamics, much more than might appear at such an early stage of the Web3.

The fact that tokens can be easily issued and securely traded on a public infrastructure without an intermediary or escrow service brings several implications. Voshmgir (2020) identifies the following:

- **Transparency:** tokens could bring more transparency along marketplaces than existing financial systems currently offer. This could significantly reduce fraud or corruption along the supply chain of goods, services, and financial transactions.

- **Transaction costs:** they also have the potential to reduce transaction costs of developing, managing, and trading cryptographic assets along distributed ledgers, as opposed to managing assets along state-of-the-art systems.
- **Efficiency:** increased liquidity, lower costs of price discovery, and less fragmented markets could reduce market friction, enabling more efficient marketplaces for certain assets.
- **Tokenisation:** tokenisation of the economy could enable completely new use cases, business models and asset types that were not economically feasible before, and potentially enable completely new value-creation models.

2.7 Decentralized Applications

Historically, new computing models tend to emerge every 10-15 years: mainframes in the 1960s, PCs in the late 1970s, the internet in the early 1990s and smartphones in the late 2000s. Each computing model has enabled new classes of applications that have been built on the characteristics of the platform. One example is smartphones, personal computers with built-in sensors such as GPS and cameras that enabled the diffusion of applications such as Instagram and Uber (Dixon, 2018).

As outlined in the previous sections, the blockchain provides trust thanks its mathematical and game-theoretic properties, without depending on the trustworthiness of individual network participants. Trust is a new software primitive from which other components can be constructed.

One of these innovations lies in Decentralized Applications (Dapp), trustless or peer-to-peer applications characterised by the absence of a single server or entity controlling it like in traditional client-server models. The origin of decentralized applications dates to the advent of P2P networks, distributed architecture that partitions tasks or workloads between peers. “Tor”, “BitTorrent” and “BitMessage” are examples of decentralized application that run on P2P networks (Voshmgir, 2020).

With the introduction of a new kind of p2p network, the blockchain, the potential of these applications has increased considerably.

A decentralized application running on the blockchain can be defined as:

> "An end-to-end application that solves a problem requiring blockchain services and infrastructure in order to realize its purpose and that depends on the functionality of the blockchain on which is running for its infrastructure and operations. (Ramamurthy, 2018)"

In its simplest form a Dapp has a client interface as a front end and a back end that includes a blockchain and a smart contract. The front-end channels any input from the users to the blockchain infrastructure and returns any response back to them. In particular, it initiates transactions to invoke functions on the smart contract that in turn, records the transactions and state transition and receipts on the blockchain (Ramamurthy, 2018).

Front-end

The front-end uses the same technologies as traditional application to render a webpage or a mobile app (e.g. HTML, CSS, JavaScript), but it communicates with a blockchain network instead of a server and, in the case of smart contract networks, also the smart contracts. At the time of writing (May 2021), most of the user interfaces of Dapps are still accessible in a centralized manner. This is consistent with the decentralisation philosophy since critical parts are stored on the blockchain. However, some Dapps are starting to use decentralized storage protocols, such as the InterPlanetary File System (IPFS), to store front-end files (Voshmgir, 2020).

The front-end also runs a special application, the "wallet", that manages the connection with the smart contract, keeping a record of the public-private key-pair and the blockchain address, to provide a unique identity for network nodes so they can securely interact with the network (for further details please refer to *Wallet*).

Smart contract and P2P network

The smart contracts represent the core logic of the decentralized application and processes data feed from inside and outside the network to manage the state of all network actors (Johnston, 2014).

At the bottom tier lies the peer-to-peer network, formed by the computing nodes of the participants, on which the blockchain operates. In some cases, a virtual machine can be developed, such as the EVM in the Ethereum blockchain. This creates an abstraction layer between the executing code and the executing machine, used to improve the portability of software, as well as to make sure applications are separated from each other, and separated from their host. For example, if the smart contract happens to have a bug, it won't hamper the normal functioning of the blockchain network (Ethereum.org, n.d.).

According to David Johnston et al. whitepaper (2014), for an application to be considered a Dapp it must meet the following criteria:

1. The application must be completely open source, it must operate autonomously, and with no entity controlling the majority of its tokens. The application may adapt its protocol, but all changes must be decided by consensus of its users.
2. The application's data and records of operation must be cryptographically stored in a public, decentralized blockchain in order to avoid any central points of failure.
3. The application must use a cryptographic token which is necessary for access to the application and any contribution of value should be rewarded in the application's tokens.
4. The application must generate tokens according to a standard cryptographic algorithm acting as a proof of the value nodes are contributing to the application. Tokens must be generated to prove the values nodes contributing to the application.

Figure 2.3 provide a comprehensive overview of the different layers that compose a decentralized application. The stack refers to any form of decentralized application, which, as seen above, is based on whatever kind of p2p network and not necessarily on blockchain platforms.

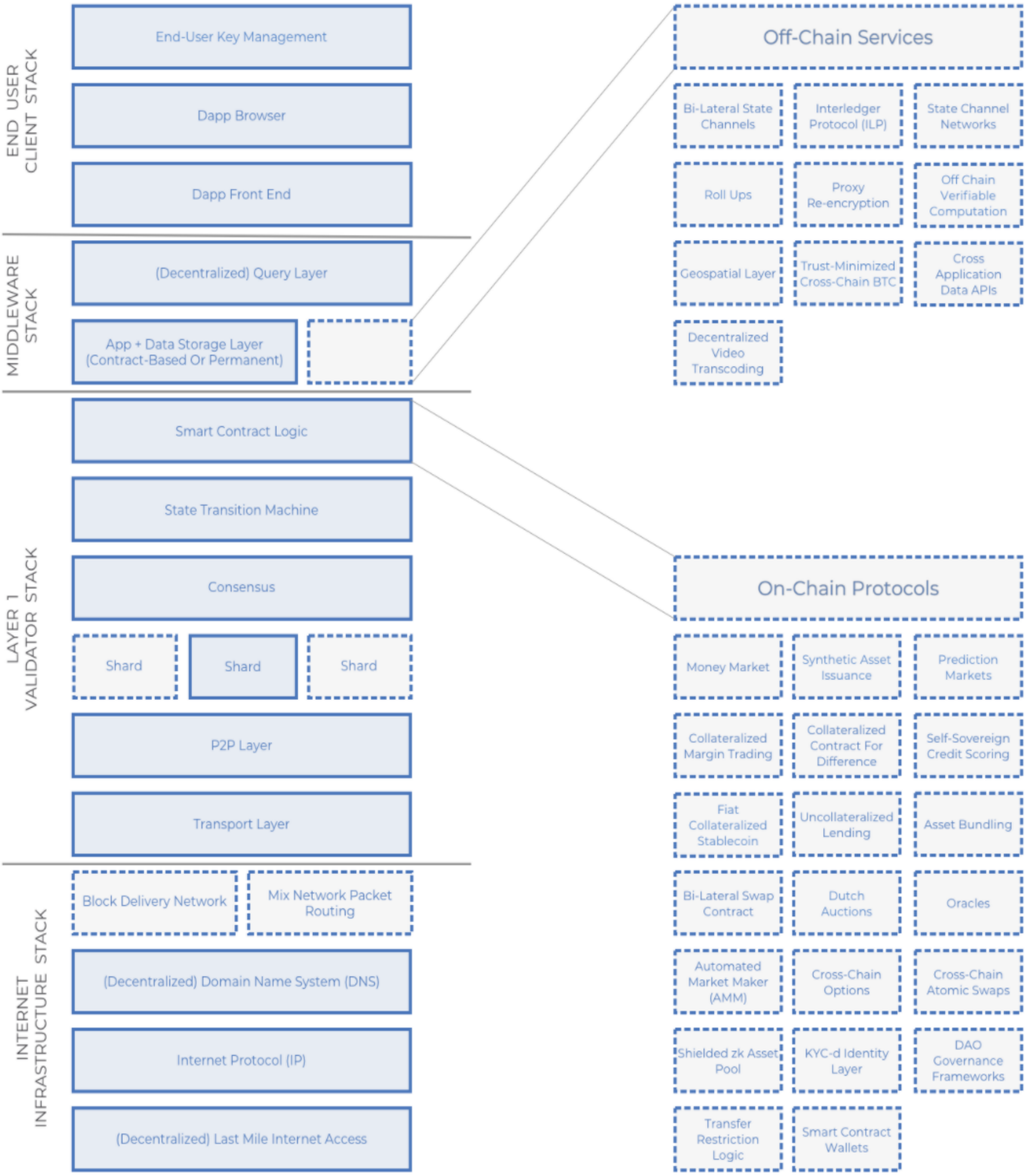

Figure 2.3: Dapp Stack | Source: (Swan, 2015)

2.7.1 Wallet

A blockchain wallet is a piece of software that stores a private key, a public key and a blockchain address, and communicates with the blockchain network. This wallet software can run on a computer or mobile phone ("Metamask", "Bitcoin Core") or a dedicated hardware device ("Trezor", "Ledger").

The wallet allows user authentication and token management. It enables users to send tokens and check the receipts of tokens sent to them. Each time a token is sent, a wallet must be used to sign the transaction with the sender's private key. Afterwards, the user's personal token balance is settled on all copies of the ledger (Voshmgir, 2020).

The private key must always be kept secret and should not be shared with other people unless one wants to give them access to the tokens. The public key is derived from the private key, and the address is derived from the public key. This mechanism is based on a one-way function, which is easy to calculate, but difficult to reverse given the image of a random input. For this reason, guessing the private key if one knows the address or the public key, using inverse mathematics, would require an enormous amount of computing power (Stallings, 2013). Because of the two-step process of deriving the public key from the private key and the address from the public key, it is sufficient to back up the private key; everything else can be derived from the private key with the cryptographic algorithm used in the network.

Wallets often incorporate a seed phrase: a method of binding private keys with an easy-to-remember combination of words, which can be provided and managed by the wallet software. However, if access to the wallet is lost, without having a backup of the seed phrase or private key, then access to the tokens is lost. In fact, while the tokens will continue to exist in the network, no one will be able to access them anymore.

Contrary to common belief, a blockchain wallet does not store any tokens. It only stores the public and private key pair associated with the blockchain address. It also keeps a record of all transactions in which the wallet's public keys are involved, along with other data.

There are two different types of wallets, custodial and non-custodial (Bhardwaj, 2019):

- **User controlled wallets [non-custodial]**: they offer personal control over their tokens. Private keys are in the sole custody and responsibility of the user and transactions are signed directly from the user's devices. With user-controlled wallets, however, the user becomes a single point of failure in the event of loss or theft of his or her keys.
- **Hosted wallets [custodial]:** custodial services, offered by online exchange services, where the service provider manages its own wallet on its own servers. In most cases, the private keys related to one's wallet are also managed by these intermediaries. The wallet software replicates the user's private key so that a third party can send transactions on behalf of the user. Many people, therefore, prefer to host their tokens on online exchanges and delegate key management responsibilities to these trusted institutions.

At the time of writing (June 2021), most wallets only allow the management of one type of token, and in some cases, a limited number of tokens. This is because the different distributed ledger systems are, for the most part, not interoperable. Most token systems have different technical specifications, which depend on the type of distributed ledger on which they are issued, and therefore require customised wallet development.

As mentioned above, the wallet is also an essential tool for interacting with decentralized applications. Instead of an API that connects to a database, as in traditional applications, a wallet triggers activities of a smart contract.

2.7.2 Dapp formation and development

There is no literature concerning the design and development of Dapps as the topic is characterised by a high degree of novelty. However, by examining secondary sources such as blogs, articles, and whitepapers of the most important Dapps, it was possible to outline three distinct phases concerning the launch of a decentralized application.

Step 1 | Whitepaper

A white paper is a persuasive essay that uses facts and logic to promote a certain product, service, or viewpoint (Graham, 2015). Its purpose is to informs readers concisely about a complex issue, to help them solve a problem, or make a decision.

The most common way by which a Dapp takes form is by the public release of a whitepaper that describes the protocol, its features, and its implementation. As opposed to the Bitcoin whitepaper, which described a technological solution, many whitepapers of recent token sales would often resemble business plans and often lack technical or economic specification (Voshmgir, 2020).

Step 2 | Token distribution

In a token sale, smart contracts are used to issue cryptographic tokens in exchange for existing tokens entirely P2P. As opposed to native blockchain tokens that are minted upon successful mining of a block (e.g. Proof-of-Work), for individual contributions to the network to keep it safe, token sales introduced a static mechanism for issuing tokens against a direct financial fee, often even before the project is operational (Johnston, 2014).

These first token sales were referred to as Initial Coin Offerings (ICOs), but as the term “token” became more mainstream, token offerings or ITOs have gained popularity (for further details please refer to *Decentralized Fundraising*). As new token sale mechanisms and third-party service providers are entering the market, token exchanges have started to offer their platforms for fundraising purposes. Initial Exchange Offerings [IEO] are intermediary services where token issuers can raise funds by offering their token on a token exchange, instead of offering the tokens directly on their website (Binance Academy, 2020).

Step 3 | Ownership distribution

As tokens from mining, fund-raising and collaboration are distributed to a greater number of participants, the ownership of the Dapp becomes less and less centralized and participants that held a majority stake at earlier have less and less control. As the Dapp matures, participants with more diverse skills are incentivized to make valuable contributions, and the ownership of the Dapp is distributed further. Through market forces the tokens of a Dapp are transferred to those who value it the most. Those individuals then can contribute to the development of the Dapp in the areas that they have an expertise (Johnston, 2014).

The latter step was initially proposed by Johnston (2014) and reflects the original vision of a decentralized application. However, over the years, practices have changed and only some of the development teams decide to distribute ownership over time. Some Dapps distribute a fixed share to the various actors that remains constant over time, others use deflationary mechanisms that reduce the share of tokens available, and some keep >51% of tokens in the hands of a few (Compound, n.d.; SushiSwap, s.d.; Synthetix, n.d.; Uniswap, n.d.; Wink, n.d.).

This 3-step roadmap should therefore be understood more as a reference than as a common approach, since not all steps are always followed. However, it proved to be a useful resource to describe some of the components of Dapps and the dynamics surrounding their implementation and launch.

2.8 Dapp categories

2.8.1 Decentralized Finance

The entire current financial system is based on the use of intermediaries to process transactions. These intermediaries often enjoy substantial power in shaping economic transactions, and they can leverage their power to maximize self-interests, raising concerns over their monopoly power (Cohen, 2019; Srnicek, 2019; Zuboff, 2019). These issues are particularly pronounced in the financial system, where financial transactions are facilitated and controlled by large financial institutions. For centuries, financial institutions have played important roles in mediating and structuring economic transactions that would otherwise be difficult to execute due to transaction costs (Benston & Smith, 1976). In fact, these actors often play essential roles in reducing transaction costs and expanding transaction possibilities (Roth, 2015). In some cases, digital technology can reduce transaction costs, expand transaction scope, and empower peer-to-peer transactions, spurring a new wave of innovation in FinTech (Chen, Wu, & Yang, 2019). However, although FinTech has reduced the need for financial institutions, it has not removed intermediaries.

Decentralized Finance (DeFi) is an emerging and rapidly evolving area in the blockchain environment. DeFi aims to reconstruct and reimagine financial services on the foundations of distributed ledger technology, digital assets, and smart contracts. Broadly, it is a category of blockchain-based decentralized applications for financial services. DeFi encompasses a variety of technologies, business models and organizational structures, generally replacing traditional forms of intermediation. DeFi transactions involve digital assets and generally operate on top of base-layer settlement platforms (Werner M, et al., 2021).

DeFi protocols define software specifications and interfaces to create, manage and convert digital assets, building on a blockchain settlement layer. DeFi services implement DeFi protocols to create financial services, and associated functions such as specification of risk parameters and interest rates (World Economic Forum, 2021). DeFi services may be made available to users through centralized web applications or permissionless interfaces such as programmable wallets or smart contracts. They may be provided by a traditional controlling entity, a community around a non-profit entity or a decentralized autonomous organization (DAO), in which rights and obligations are specified in smart contracts (Schär, 2021). An extensive description of DAOs is provided in *Governance.*

A DeFi protocol, service or business model has the following four characteristics (World Economic Forum, 2021):

1. **Financial services or products**: processing or directly enabling the transfer of value among parties
2. **Trust-minimized operation and settlement**: transactions are executed and recorded according to the explicit logic of a DeFi protocol's predetermined rules, on a permissionless basis
3. **Non-custodial design**: the assets issued or managed by DeFi services cannot be unilaterally expropriated or altered by parties other than the account owner, even those providing intermediation and other services
4. **Programmable, open and composable architecture**: there is broad availability of the underlying source code for DeFi protocols and a public application programming interface (API) enabling service composability, similar to open banking for centralized financial services.

These characteristics represent the aspirations of DeFi. Enterprises will exhibit each of these characteristics to a different degree, and this may be fluid over the life of projects. In general, the aim of DeFi solutions is to provide functions similar to, and potentially beyond, those offered by traditional financial service providers, without relying on central intermediaries or institutions.

Composability

Composability refers to the fact that these programmatic components can be combined to create financial instruments and services, including those incorporating multiple DeFi services and protocols. For example, a stablecoin can be used as the basis for a derivative that is used as collateral on a loan and subject to an insurance contract. All these services would be functionally interoperable, and the resulting instrument benefits from the common settlement layer of the underlying blockchain. As the number of DeFi service providers and available protocols grows and competition increases, specialisation, interoperability and composability can enable the growth of connectivity between these services, and economic activity between them (World Economic Forum, 2021).

The following "stack" [Figure 2.4] was initially devised by Schär (2021) and later deepened and expanded by the World Economic Forum (2021). Similar frameworks for defining the architecture of DeFi have been devised by various authors and provide similar perspectives (Samani, 2019).

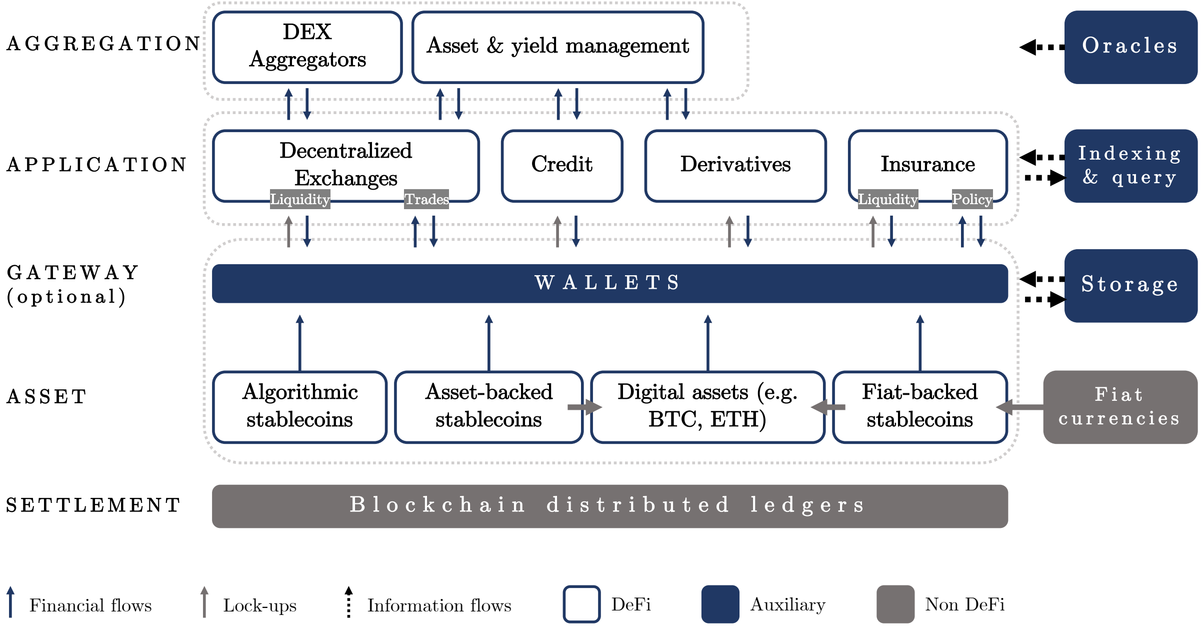

Figure 2.4: DeFi Stack | Source: World Economic Forum, 2021

Blockchain distributed ledgers at the basic level allow participants to securely store, exchange and modify information about the ownership of assets, replacing the execution and settlement layer of conventional financial services. They also enable the creation of digital assets in various forms, which are then embedded in DeFi applications. Additional layers of applications can function as aggregators, allowing users to move between DeFi services, such as choosing an exchange based on real-time market factors. In this environment, digital assets may be transferred freely, based on contractual logic (financial flows), or may be restricted by other uses to provide liquidity or guarantees (lock-ups).

There are also flows of non-financial information that support transaction activity. As mentioned in Oracles, oracle services provide reliable data that is recorded outside the settlement layer. Through these instruments, information and content external to the blockchain can also be incorporated into DeFi transaction flows. For example, a price feed may draw on external data and be provided programmatically through a smart contract (Chainlink, n.d.). Such information resources, as well as the wallet and interfaces that help users store, transfer, and manage assets that interact with DeFi services, are not themselves financial services and are therefore labelled as auxiliary to DeFi.

DeFi service categories

Due to their programmability and composability, the possible configurations of DeFi services are nearly endless. However, certain core functions, analogous to those in centralized finance, can be identified. Although the literature is limited, most scholars sort DeFi services into the following categories (Samani, 2019; Schär, 2021; Werner M, et al., 2021; World Economic Forum, 2021).

Stablecoins

Stablecoins seek to maintain a constant value for tokens relative to some stable asset – most commonly the US dollar. The ability to avoid the volatility of non-stabilized cryptocurrency such as bitcoin and ether is one reason for the growth in DeFi.

- Asset-backed stablecoins use smart contracts to aggregate and liquidate collateral in the form of digital assets
- Algorithmic stablecoins attempt to maintain the peg through dynamic expansion and contraction of token supply

Decentralized Exchanges (DEXs)

Exchanges allow customers to exchange one digital asset for another. The assets involved can be stablecoins or floating value tokens. Unlike centralized exchanges such as Coinbase or Binance, decentralized exchange protocols (DEX) are DeFi services as they do not take custody of users' funds and cannot control other aspects of the process such as order book management and matching. An important category of DEX protocols for DeFi are automated market-makers (AMM), where an algorithm continuously prices transactions based on orders and available liquidity, rather than matching through an order book.

Lending

Credit involves the creation of interest-bearing instruments that must be repaid at maturity. It is based on a mutual relationship of borrowers and lenders, which can be either bilateral (peer-to-peer) or based on pooled capital. The terms of credit can be quite complex, and these instruments can be securitised and traded. DeFi borrowing and lending replaces the intermediation function of financial service providers with automated, decentralized, and non-custodial protocols. While the lack of credit rating and legal recourse means that digital asset lending is almost always over-collateralised, DeFi also allows for uncollateralised flash lending where assets are borrowed and repaid (with interest) over the time span of a single block (Aave, 2021).

Derivatives

Derivatives create synthetic financial assets whose value depends on or is derived from an underlying asset or group of assets. Common financial derivatives include futures and options, which pay based on the value of an asset at some point in the future or deliver the underlying asset. DeFi derivatives can be programmed and compounded in virtually any configuration. For example, a derivative could create a synthetic asset that behaves like a stock, commodity, swap, or other digital asset. It might involve a non-fungible token (NFT) uniquely associated with an art or real estate asset. It could be linked to the activity of a business, creating a crowdfunding service. The value could be tied to a future real-world event, such as the outcome of a sporting event or political campaign, turning the exchange of derivatives into a prediction market. Prediction markets can also stimulate decentralized information generation or dispute resolution through the wisdom of crowds (Werner M, et al., 2021).

Mutual

Insurance pools risk by exchanging the payment of a small premium for the possibility of collecting a large payment in the event of a covered scenario. In DeFi insurance, decentralized transactional and governance systems are used to manage and structure the insurance lifecycle for certain types of risks such as smart contract hacks. Although technically insurance contracts are derivatives – they pay out based on some external event – insurance performs a distinctive risk hedging function in markets by spreading risks across a common capital pool of capital (Werner M, et al., 2021).

Asset management

Asset management involves the oversight of financial assets for others and seeks to maximize the value of the whole portfolio based on risk preferences, time horizons or other conditions. DeFi asset management promises greater transparency and efficiency in constructing and executing investment strategies, by incorporating the asset management life cycle into a Dapp.

In addition, there are auxiliary services that support DeFi activity but are not themselves financial services. There are oracles and other auxiliary services including wallets, data storage, data queries, identity verification and arbitration.

Incentive systems

Many DeFi services incorporate explicit financial incentives to promote market development, including the creation of liquidity (for trading) and collateral (for credit).

- **Fees:** lock-up yields pay interest or a share of trading fees for immobilizing digital assets to serve as liquidity or collateral for a service
- **Airdrops**: it rewards wallet addresses with tokens to promote awareness of new digital assets
- **Yield:** yield farming optimizes returns from liquidity mining and lock-up yields by automatically moving funds among services
- **Liquidation fees**: pay market-makers a percentage of the value of under-collateralized loans that they successfully liquidate (though not necessarily automatically)
- **Tokenomics**: application token holders gain from the appreciation of token value or from receiving inflationary rewards

These mechanisms are not necessary components of DeFi but have become widely identified with it. However, they may also distort investor expectations, generating unsustainably high returns as new capital is flowing in and token values are appreciating.

Stakeholders

The stakeholder surrounding the DeFi world can be grouped into four categories, though in some cases stakeholders may span multiple categories:

- **Builders**: create, implement, and support the protocol
- **Suppliers**: provide capital or a core service to the functioning of the protocol
- **Users**: use protocol functionality for intended use case
- **Governance**: make decisions on the development of the protocol

Their impact and responsibility within the protocols as well as their economic incentives are summarised in Table 2.2.

Category	Stakeholders	Responsibility/Impact	Economic incentives
Builders	Interface providers	Provide access to DeFi protocols, either directly or through aggregation	Receive transaction fees
	Auxiliary service providers	Support external data feeds, or offer development tools for DeFi services	Receive transaction fees
	Connected protocols	Other composable protocols integrated with the target service	Drive utility for their protocol, generate fees
	Wallet providers	Protect user funds	Fees based on assets
Builders and governance	Development teams	Drive development of a protocol and ecosystem	Receive inflationary rewards and transaction fees
Governance	Multisig signatories	Shape governance to ensure long-term sustainability	Earn proportion of fees generated by the protocol
	Governance token holders	Propose and vote on governance decisions	Earn proportion of fees generated by the protocol
	Miners or stakers	Verify transactions on the underlying blockchain	Receive inflationary rewards and transaction fees
Suppliers	Liquidity providers	Contribute collateral or other assets to facilitate DeFi activity	Receive inflationary rewards and transaction fees
	Liquidators	Liquidate under-collateralized positions	Obtain collateral at discount
Users	Protocol users	Use protocol functionality for intended use case	Low cost, peer-to-peer, trust-minimized financial services
	Application token holders	Use protocol functionality or purchase tokens on secondary markets	Profit from appreciation of token value, or receive inflationary rewards and transaction fees

Table 2.2: DeFi Stakeholder Map | Source: (World Economic Forum, 2021)

2.8.2 Decentralized Games

Blockchain games are any video game that uses some aspect of cryptographic blockchain technology. These types of games exploit the features of the blockchain to deliver digital ownership (Mozuch, 2021). Digital ownership already exists in the gaming world but is perceived to be far from the value or stakes that blockchain allows. In fact, traditional games – “Free-to-Play” or “Pay-to-Play” – usually provide simulated economies controlled by game operators. In most cases, these simulated economies do not offer a marketplace to trade or liquidate their assets (Toptal Research, 2021).

The items owned within the games cannot be sold – legitimately and openly – to other players. Creating a real-world economy in games that would include true ownership is seen as disadvantageous by game operators because they are competing against their customers/players when the latter are allowed to resell their assets (Upland, 2019). When players buy an asset in traditional model, they are only getting entertainment value out of it and consider their investment as a sunk cost.

As the gaming industry shifts its focus to gaming assets, blockchain could potentially solve several related problems: eliminating fraudulent items, creating scarcity, and incentivising more purchases by making items transferable through games (Toptal Research, 2021).

In addition to potentially revolutionising digital ownership, blockchain offers several solutions and possibilities including (Toptal Research, 2021):

- Shift the definition of a successful game away from revenue and toward in-game currency value, thereby refocusing game development efforts to benefit player
- Encourage game development competition outside of the monopolistic console and game-publishing industries
- Incentivise players by offering dividends and granting them a vote in development processes
- Protect players from unwanted actions by creators; players can extend the longevity of the game and encourage user content (e.g. Decentraland)
- Solving the high cost and low revenue problems of cloud gaming initiatives (such as Sony's PS Now) by deploying the server on a blockchain network

2.8.3 Decentralized Marketplaces

Over the last few years e-commerce has become an indispensable part of the global retail framework, accounting for 18% of global retails sales in 2020 (Statista, 2021). These platforms represent two-sided markets that are based on a network of participants. Over time, network effects inevitably yield a monopoly in which a single e-commerce manages the entire marketplace (Weyl, 2009). Moreover, matching characteristics of markets is not performed efficiently in today's marketplaces. Prices changes for example are facilitated by algorithms that can make certain goods pricier basing on several parameters.

Another issue that affects these players is security. Personal information including addresses and credit-card details has proven to be the most vulnerable source for security attacks. Every marketplace (such as Amazon, eBay, Sony and Target) in recent years has been targeted by at least on attack involving loss of information. Other disadvantages can include scenarios in which transaction costs are greater than the actual sale price, limitations to payment modes, and network infrastructure challenges.

All these issues can be potentially addressed by decentralized marketplaces. As illustrated in the previous chapters, blockchain-based platforms provide many advantages to all participants, including security, trust, privacy, lower transaction costs, and transaction integrity. Decentralisation provided by blockchain technologies alters the paradigms of conventional marketplaces in which a large intermediary firm that controls the platform is able to control every aspect of a trade, from product listing to price discovery, product search, logistics, and the customer experience (Subramanian, 2018).

There are currently (May 2021) a limited number of decentralized applications offering marketplace services. Given the high degree of novelty and the small number of real cases, the real benefits and implications, as well as the actors involved, are still scarcely explored.

2.8.4 Decentralized Social networks

Over the last decade, social media has become an important part of how people communicate with their peers and consume information. With the emergence of social media, traditional media has become de-professionalised. Everyone can contribute and curate content to influence public opinion, simply by creating a social media account. Facebook, Twitter, and Reddit replaced newspapers; YouTube replaced television. As these social media platforms gained traction, they transformed from an open space for free expression into an oligopoly of a few big players.

In the early years, the curation process on social media sites such as Facebook and Twitter used to be in the autonomy of the users (Edosomwan & Prakasan, 2011). This autonomy was replaced by data feeds based on algorithms developed by the platform providers, and the feeds are now being injected with an increasing number of ads. Social media platforms have become the curators of the content and are in full control of users' data feed. Very often, these socially engineered feeds are programmed to retain the user on the platform as long as possible, make them addicted, and optimize advertising revenue. While users contribute with valuable content and curation services, they have no way to directly monetize their contributions to the network. Furthermore, content that is posted on those platforms is subject to potential censorship and control by the companies that operate them, and in some countries, even by government authorities (Cardwalladr & Graham-Harrison, 2018).

Decentralized social networks have no data monopoly, meaning everyone has access to all transaction data, which is publicly visible on the underlying blockchain, and no advertising revenues are necessary, as the network is collectively managed by contributors who get rewarded with tokens for their contributions to the network. How much users are paid depend on the number of their contributions and the related popularity (Barbars, Narula, & Zuckerman, 2017).

Decentralized social networks have generally three types of users (Voshmgir, 2020):

- **Content creators**: this kind of users publish content and get rewarded with tokens if and when the post is upvoted (liked) by other users
- **Active users**: these actors curate content by upvoting (liking) the content
- **Passive users**: users that solely consume content

2.9 Business model implications

Business models are inherently exposed to changes. These stem partly from factors internal to the company and partly from external ones, such as changes in technology. The ability to use new technologies to create new innovative business models has proven to be an important source of competitive advantage (Chesbrough, 2010; Baden-Fuller & Haefliger, 2013). Thus, it is important to understand how new technologies, such as blockchain, can affect business models (Nowiński & Kozma, 2017).

2.9.1 Business model innovation

One of the early definitions of business model was provided by Osterwalder *et al.* (2005) defined it as:

> “a conceptual tool that contains a set of elements and their relationships and allows expressing business logic of a specified firm... a description of the value company offers to one or several segments of customers and of the architecture of the firm and its network of partners for creating, marketing, and delivering this value and relationship capital, to generate profitable and sustainable revenue streams. (Osterwalder & Pigneur, 2013)”

Despite the extensive literature on the subject, there is still no conclusive definition. Wirst et al. (2016) have tried to provide a definition in an integrated manner, defining it as “a simplified and aggregated representation of the relevant activities of a company”.

Overall, the literature indicates endogenous and exogenous sources of business model innovation. As for endogenous sources of business model innovation, they are related to the learning capabilities of the organisation (Sosna, Trevinyo-Rodríguez, & Velamuri, 2010), its strategic agility (Doz & Kosonen, 2010) and its organisational culture (Hock, Clauss, & Schulz, 2015).

When analysing the exogenous sources of innovation of a business model, technology is certainly one of the most important (Teece, 2010). The introduction of new technologies has led throughout history to major changes in the way industries operate: from the value delivery aspects, with the internet being one of the main drivers, to the supply side, and consequently the costs of business models, of which the Cloud is an example (Teece, 2010). Considering, for example, the value delivery dimension, it becomes evident how the development of new technologies, such as the Internet, has enabled companies to offer the same product in various ways and also to monetise the value delivered in different ways, whether through direct sales, advertising or freemium models.

Some scholars have explored the link between the development of new technologies and the success of a business. Baden-Fuller & Haefliger (2013) consider business models as crucial technology moderators since they shape the success or failure of an innovative technology. Business models mediate the link between technology and firm performance while deciding on the development of the right technology with regard to openness and user engagement. However, as Rayna and Striukova (2016) argue, innovative technologies can also be the main driver of changes in business models.

2.9.2 Business models and blockchain

As mentioned above, the branch of literature that studies blockchain from a business perspective is limited. However, there is a growing number of academics convinced that blockchain contributes to value creation in several ways.

In fact, it is starting to emerge how blockchain has the potential to create benefits beyond digital currencies and influence all sectors of the economy (Chen & Bellavitis, 2020). Moreover, it is important to note that blockchain will affect not only companies that apply this technology, but also companies that need to restructure their business because blockchain undermines their offering. Blockchain technologies offer many possibilities to grow entirely new businesses and pose direct threats of disruption to traditional incumbents (Morkunas, Paschen, & Boon, 2019). Moreover, blockchain may not only provide disruption in well-established business models, but it can offer solutions to industries with structural problems (Nowiński & Kozma, 2017).

This transformation can occur in various forms: from a straightforward improvement of the operational efficiency (Nowiński & Kozma, 2017) to the construction of open networked enterprises that disrupt or displace traditional centralized models, potentially evolving into distributed autonomous enterprises (Tapscott & Tapscott, 2016)

In the research paper "How Can Blockchain Technology Disrupt the Existing Business Models?" Nowinski & Kozma (2017) study the impact of blockchain on existing business models and industries. The authors use as a reference the framework developed by Wirst et al. (2016), which distinguishes three dimensions: strategic components, customer and market components and value creation components, each of which consists of partial models. Each component includes indeed three partial dimensions, as illustrated in Figure 2.5.

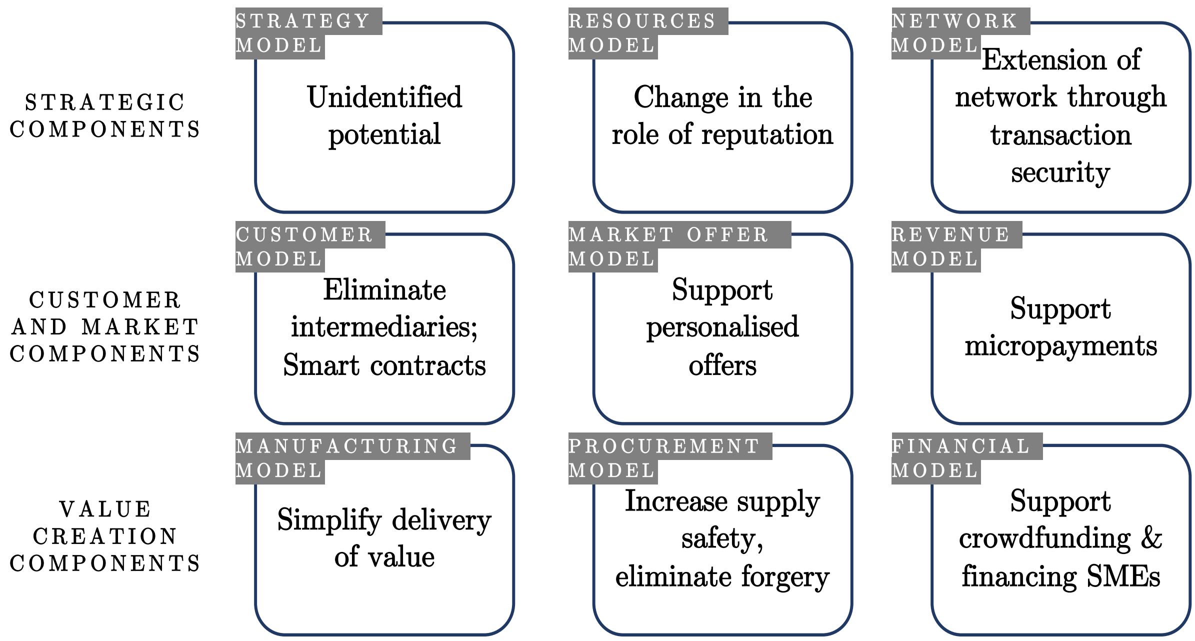

Figure 2.5: Potential impact of blockchain on business model | Source: Nowiński & Kozma, 2017

Although the framework provided is comprehensive and exhaustive, the inclusion of a strategic model as part of business models has been contested by some scholars (DaSilva & Trkman, 2016). According to them, strategy and business models should not be merged. In fact, while a business model is oriented towards short-term consequences, strategy is oriented towards long-term consequences (DaSilva & Trkman, 2016). Thus, the business model is not an answer to strategic questions but rather a description of "how the various elements of the business work together at a certain point in time" (DaSilva & Trkman, 2016). However, some scholars point out that a business model cannot be used effectively to gain competitive advantage unless a more dynamic approach is used (Gambardella & McGahan, 2010).

Figure 2.5 summarise the findings concerning the implication of blockchain for business models (Nowiński & Kozma, 2017). Blockchain seems to influence several of the constituent models defined by the framework.

An example is given by reputation, a key asset that can be eliminated as a guarantee for certain transactions. The level of transparency and security provided by the blockchain would in fact make reputation no longer necessary. As a result, the range of partners with which companies could be involved should increase and become more fluid. The procurement model will also be affected by the additional reliable information provided by the blockchain. This will in fact decrease the risk associated with a transaction such as falsifying the product.

Another major impact will be on the financing model, by facilitating access to small shareholders for whom crowdfunding will become more secure and therefore a more attractive way of funding new businesses (for further details please refer to *Decentralized fundraising*).

Summarizing, blockchain can create value and bring improvements at the business level by (i) facilitating disintermediation and consequently decreasing costs; (ii) improving operational efficiency e.g. by reducing settlement times or reducing processing costs; (iii) building transaction-related trust through authentication of assets that are subjects of the transaction. The list of impacts that this technology can bring to business models goes on and is not limited to the cases shown in the figure. However, this provides a useful overview that proves the high potential of the blockchain (Nowiński & Kozma, 2017).

A more recent study deepens the business implications of the blockchain (Morkunas, Paschen, & Boon, 2019), this time structuring the effects on a different framework. Using the well-known framework defined by Osterwalder & Pigneur (2013) the authors explore the possibilities of growing entirely new businesses and posing direct disruptive threats to traditional incumbents. For the purposes of this discussion, only those dimensions that have not been explored by other scholars are discussed here.

An organisation using blockchain can not only target existing **customer segments** in a market but also facilitate access to a target market that was previously unreachable (Larios-Hernandez, 2017) and thus access a group of 2 billion people who have limited or no access to financial services.

Customer value can be influenced by providing access to products or services that were previously unavailable or could only be obtained by spending a large amount of time or money.

As far as **key resources and activities** are concerned, the effect is twofold. First, there is an opportunity to make resources more fluid, allowing companies to move away from traditional ownership and access resources only when needed. This opportunity is particularly relevant to the application of public blockchain technologies where, as described above, anyone can transact with another party in a peer-to-peer network. In some cases, companies may refrain from investing in the construction and maintenance of IT infrastructure because, in the case of public blockchains, the network provides these resources and processes. In addition, both public and private/federated blockchain applications allow companies to automate processes that were previously manual, allowing human resources to focus on other, higher value-added activities. The second aspect concerns the provision of key resources and processes by users. For example, in the case of smart contracts in real estate transactions, resources such as human capital (e.g. knowledge, skills, experience) and physical capital (assets) are provided by the transacting parties while blockchain technologies facilitate peer-to-peer exchange of these resources (Morkunas, Paschen, & Boon, 2019).

Figure 2.6 provide a blueprint of how each of the nine essential elements could be affected by blockchain technologies.

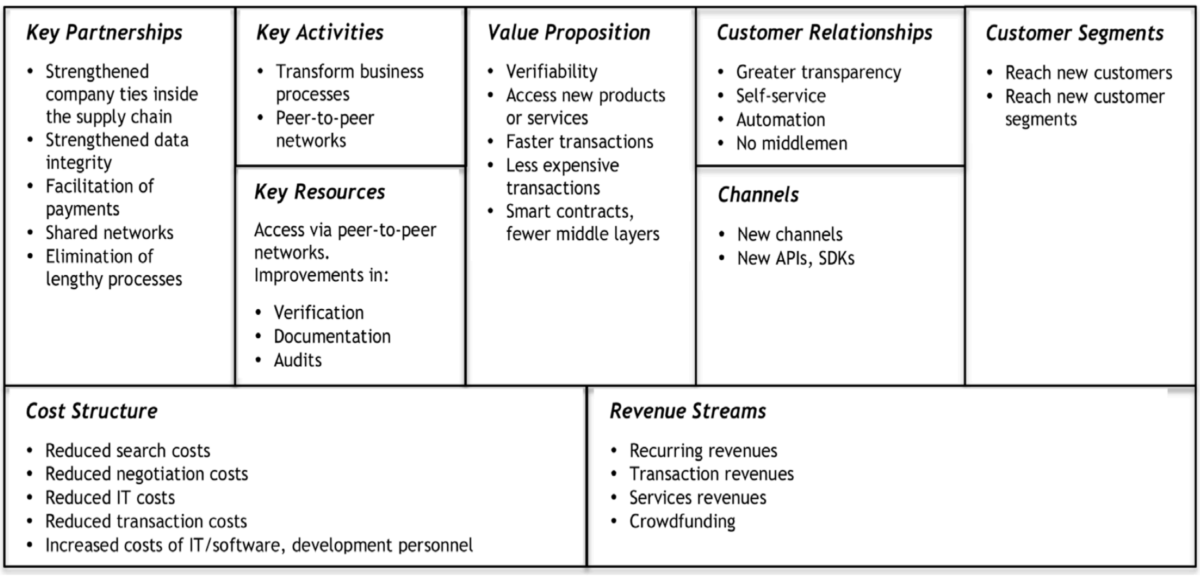

Figure 2.6: Blockchain impacts on business model canvas | Source: Morkunas, Paschen, & Boon, 2019

If successful, decentralized business models have the potential to reshape existing industries and create a new landscape for entrepreneurship and innovation. Moreover, they may challenge researchers to come up with new theories to explain the potential benefits and costs of decentralization (Chen & Bellavitis, 2020).

Decentralized fundraising

Traditional venture funding often results in substantial friction in the fundraising process, as investors can only trust and invest in projects with strong network ties (Hallen, 2008; Hallen and Eisenhardt, 2012). Blockchain technology is reshaping the fundraising landscape (Chen, 2018; Fisch, 2019). One primary form of decentralized fundraising is represented by Initial Coin Offerings (ICOs). An ICO involves the creation of a specific token by the project to be funded on a public blockchain and the subsequent sale of the token to potential investors to raise funds for early-stage developments. (Martino, Wang, Bellavitis and DaSilva, 2019).

An ICO is a potentially powerful way for a project to raise funds and create network effects. As a new form of crowdfunding, it allows a project to raise funds from investors across the globe – thanks to the transparency of blockchain technology, smart contracts, and open-source code (Chen & Bellavitis, 2020).

Moreover, an ICO is a new way for a project to engage stakeholders to start creating a new ecosystem. (Chen Y. , 2018). Often, an ICO can be especially valuable when a token has inherent utility in the project's products or platforms.

A recent new variant – initial exchange offerings (IEOs) – have recently emerged. Unlike ICOs, IEOs relies on cryptocurrency exchanges to ensure the trustworthiness of potential projects and to connect high-quality projects to potential investors. In IEOs, cryptocurrency exchanges often thoroughly examine potential projects, provide detailed information on promising ones, and endorse high-quality projects with their own reputation (Chen & Bellavitis, 2020).

2.9.3 Public blockchain as disruptors

The two types of blockchains defined on *Blockchain classification* are differentiated by unique selling propositions: a private blockchain can save an organization time and cut costs, whereas a public blockchain has the potential to disrupt an industry, either through disintermediation, as is the case in financial applications and other cryptocurrencies, or by the creation of new business models (Tamayo, 2017).

It is possible to summarise what has been seen so far through the Henderson and Clark (1990) framework, a tool that categorises innovation based on the impact that technological change has on the established capabilities of a firm. Blockchain projects led by consortia have the potential to lead to architectural innovations, while public blockchain projects can generate radical innovations. Architectural innovations reconfigure established systems to connect existing components in a new way (Morkunas, Paschen, & Boon, 2019). Radical innovation, by contrast, is based on different principles and leads to new applications and markets such as those fuelled by the recent surge in ICOs and Decentralized Finance. It also enables the successful entry of new firms or the creation of a new industry (Henderson & Clark, 1990).

In this regard, Tapscott (2016) identified new business models based on public blockchains that could innovate and create further value at lower cost, while enabling producers to share the wealth they create. These business models were initially devised by Tapscott & Williams in “Wikinomics” (2007) as frameworks enabled by p2p collaboration, and then expanded in “Blockchain Revolution” (2016) adding the implications of blockchains.

Three examples of these business models are presented below to provide an overview of the potential that public blockchains and its key innovations can provide in this field.

Peer production

Peer-to-peer production relies on volunteers working on innovative projects that sometimes surpass those of larger, better-funded companies (e.g. Wikipedia, Linux). Community members participate because of their hobbies, networking, or values. Peer production communities can be “commons-based peer production,” meaning that goods and services are produced outside the limits of the private sector and are not “owned” by a company or an individual (Benkler, 2002). Overall, peer production communities are at the heart of new, networked models of value creation. With blockchain technology peers can develop more formal reputations for effective contributions to the community. To discourage bad behaviour, members could ante up a small amount of money that either increases or decreases based on contribution. In corporate-owned communities, peers could share in the value they create and receive payment for their contributions as smart contracts drop transaction costs and open the walls of the firm.

Blockchain cooperatives

Most so-called sharing economy companies are actually service aggregators. They aggregate the willingness of providers to sell their excess capacity (cars, equipment, spare rooms) through a centralized platform and then resell them, all while collecting valuable data for further commercial exploitation.

Blockchain technology provides the providers of these services with a means to collaborate that gives them a greater share of the value.

Intellectual property

Blockchain provides a new platform for creators of intellectual property to get value for it. As with artists selling NFTs artworks, actors whose work can be digitised and watermarked as a final copy can use this technology to turn their intellectual property into a marketable asset. This model can also be applied to other fields. In science, a researcher might publish a paper for a limited audience of peers and receive reviews and credibility to publish to a larger audience, rather than assigning all rights to a specific journal. The study could be available for free, while charging for the raw data as part of a smart contract.

2.10 Governance

Governance is a political science term that refers to the formal or informal rules, norms, and processes of how people interact within a community or organization such as a government, market, family, tribe, or a computer network. The governance rules of an organization or group of people regulates the process of decision making among all stakeholders involved. This is achieved through laws, norms, force, or language (Voshmgir, 2020).

Blockchain governance can refer to two concepts: either the governance of a blockchain system or the use of a blockchain system to govern an external organization or process (De Filippi & Mcmullen, 2018). This section focuses on the former: the establishment and enforcement of rules and processes for the development and operation of blockchain systems.

In the context of blockchain, the issue of governance becomes particularly relevant as "the most successful blockchains will be those that can best adapt to their environments. [...] Assuming these systems need to evolve to survive, initial design is important, but over a long enough timeline, the mechanisms for change are most important" (Ehrsam, 2017).

2.10.1 Blockchain governance

As illustrated above, decentralized applications operate within a larger ecosystem of Internet applications that run according to their own protocols and rules – a stack of applications and protocols that build on layers. Each new layer of the stack inherits the protocols and rules of the layer below, including the lower layers' governance.

Blockchain systems operate on top of the Internet layer and inherit the capabilities and limitations of that underlying layer, including its technical architecture and governance processes. Because these networks operate on top of the Internet, their proper functioning ultimately depends on the Transmission Control Protocol/Internet Protocol (TCP/IP) – the protocols responsible for routing and transferring packets between nodes on the Internet (Stevens, 1994).

Internet service providers ultimately control the transportation layer of the Internet, and thus can discriminate against packets coming from or directed to any of these networks (Stevens, 1994). As a result, network management by Internet Service

Providers (ISPs) or censorship by nation-states can influence the operation of blockchain systems, either by deliberately targeting their operation or as an unintended consequence of unrelated network management practices (Geere, 2012). These consequences are ideally avoided by one of the fundamental principles of the Internet: net neutrality, the principle that all traffic on the network should receive equal priority. Net neutrality states that information should be transmitted as it is received, regardless of the sender or receiver, the port or protocol, the type of content or the application that created it (Pershing, 2008).

Net neutrality is fundamental to the functioning of blockchain systems and other decentralized, peer-to-peer networks, as these networks rely on participants having unrestricted access to the network. However, net neutrality in the United States has been a contentious issue since the 1990s and it was announced that it would be repealed in 2017. Without these rules, ISPs are free to interfere in any number of ways: from slowing down or blocking network activity toward or from blockchain networks to prioritizing packets toward or from competing electronic payment services that are not subject to filtering (Collins, 2018).

Blockchain systems also introduce their own mechanisms of governance specific to each blockchain network. These include the design of the underlying peer-to-peer network and the consensus protocol that facilitates agreement between the various nodes of the network (Hacker, 2017). While ISPs are responsible for routing packets through the Internet according to specific protocols (e.g. TCP/IP), nodes in a blockchain network are responsible for validating and recording transactions into the underlying blockchain according to a particular set of rules. Each blockchain network implements its own protocols, consensus algorithms, and fork-choice.

A nascent strand of literature shows that permissionless blockchains exhibit significant governance problems (De Filippi & Loveluck, 2016; Gervais, Karame, Capkun, & Capkun, 2014; Tapscott & Tapscott, Blockchain Revolution, 2016; Walch A. , 2015). One of the main challenges arise from one of the distinctive characteristics of the blockchain's core components: decentralisation (De Filippi & Mcmullen, 2018).

From a theoretical perspective, the more people involved in the process of decision-making, the more difficult it becomes to reach a consensus. Numerous academic disciplines have thoroughly studied the problems of coordination and collective action in decentralization systems, and none has found an effective solution so far (Agrawal & Goyal, 2001; Bardhan, 2000; Freeman, 1972; Runge, 1984).

Blockchain systems typically address the problem of distributed governance through Tokenomics, an economic mechanism derived from tokens and described in *Variable description.* Tokenomics focuses on the design of specific incentives structures to reward the behaviour that helps the network function properly, while discouraging behaviour that leads to undesirable outcomes such as network congestion, overuse, or other forms of abuse. The task of processing transactions, for instance, is driven mostly by an economic incentive system, whereby the higher the transaction fees paid to the network, the greater the chance miners will include these transactions in the next block. However, while transaction fees and mining rewards are a fundamental incentive for miners, they are not the only factors that might influence their behaviour. Other factors may come into play, coming from outside the blockchain infrastructure.

The question remains as to who will be responsible for creating the incentive structure that defines the Tokenomics and incorporating into a particular blockchain system (De Filippi & Mcmullen, 2018).

There are therefore several problems that need to be addressed for decentralized systems to work on a large scale. Emerging behaviours or unforeseen situations could render the incentives designed by Tokenomics ineffective. Moreover, as soon as these systems need to be upgraded or changed, for instance to facilitate scalability or to solve other technical challenges, decision-making processes may turn into contentious political issues related to governance or system design (Walch A. , 2017).

2.10.2 Dapp Governance

Ultimately, a Dapp is directly subject to its own governance rules and indirectly affected by the rules of the blockchain network on which it operates, the rules of the underlying blockchain that ensures the proper execution of relevant smart contracts, and the rules of the Internet network that makes everything run.

Even if Dapps can be designed to be completely decentralized and autonomous – in the sense that no single party has the power to control or influence their operations – they remain affected by the operations of their underlying blockchain network or Dapp framework (Hacker, 2017). There are two ways to alter the operation of a Dapp: change the state of the blockchain to overwrite the code of the Dapp or change a small piece of the code it relies on, that is, a smart contract library or a proxy contract, a smart contract that delegates call to other smart contracts.

The first case requires the participants of a blockchain network to intervene, with a coordinated action, to censor some of the transactions directed to a particular Dapp or perhaps even alter the code of a Dapp. For example, in response to the hack of TheDAO, the Ethereum community implemented a hard fork, changing the protocol and state of the Ethereum blockchain so that users could withdraw their (stolen) funds. Yet, because hard forks have the power to change the balance or code of a particular Dapp, or even to delete the Dapp entirely, this level of intervention is extremely rare and has been used only in exceptional circumstances so fa.

The second case arises whenever a Dapp is built upon or relies on a third-party smart contract for its operations. As a rule, in the context of software development, reusing well-established and tested code is good practice because it avoids duplication of effort. However, in the context of a blockchain system, if a Dapp makes an immutable reference to third-party code, it could lead to some issues such as a flaw in one of the smart contract libraries affecting all Dapps using that library.

Social and algorithmic governance

According to Voshmgir (2020), the governance of public blockchain and the decentralized applications built upon them consists of two parts: “social governance” and “algorithmic administration of governance”.

Social governance refers to the human decision-making process on when and how to conduct potential protocol updates in the smart contract. It is the decision-making process of how stakeholders in the network receive the necessary information to make educated decisions about future protocol updates. Discussion of protocol updates takes place on social media or other open or closed online forums, often on a dedicated section built on the front-end of the Dapp itself.

Since the decision-making process is driven by user feedback, the development of the protocol can be described as non-linear, interactive, and feedback-driven (Gervais, Karame, Capkun, & Capkun, 2014). Besides user feedback, however, there is also a central steering element that has become increasingly apparent in the recent development of cryptocurrencies (Hacker, 2017). For example, the reference implementation of the Bitcoin protocol, openly accessible at the code platform Github, is maintained by a small group of people – “core developers” (Dwyer, 2014). While anyone may make proposals for updating the code, only the core developers have the power to implement changes (Walch A. , 2017).

Nonlinearity and unpredictability in changes to the protocol arguably result from the lack of a procedure to accommodate dissent within the community of developers and, more broadly, of users and stakeholders (Hacker, 2017). Core developers use "informal processes that depend on rough notions of consensus and that are subject to no fixed legal or organizational structure" (Bayer, 2014).

However, they may coordinate their actions with operators of large mining pools. In this way, a small group of agents crucial to the development and maintenance of the network can change the protocol, even if they own less than 50% of the computing power, and independently of their financial holdings in the currency (Gervais, Karame, Capkun, & Capkun, 2014). While these agents effectively regulate the crypto economy, they are accountable to no-one, and users do not play any significant role in their appointment (Hacker, 2017).

A specific example is provided by the Bitcoin hard fork of 2013, which divided the blockchain into two chains that were no longer mutually consistent. This unintended event was resolved by coordination between the core developers and the largest mining pool – BTC Guild – together with other major pools via the bitcoin-dev IRC channel (Narayanan, 2013) without any coordination with users. In this way, a fundamental principle of the proof of work mechanism – the authenticity of the longest blockchain – has been violated. The operators of major mining pools and core developers informally colluded to take the blockchain into a novel, non-majoritarian, direction. This event marks a precedent that shows the vulnerability of the blockchain to possible coalitions.

In the same way, TheDAO incident described above exposed the lack of dispute settlement and governance mechanisms for "edge cases" induced by unforeseen events, both on the application level and on the level of the blockchain network itself. The event displayed the limitations of pre-defining and pre-regulating all possible human interactions, including potential attack vectors of bad actors (De Filippi, 2016).

Algorithmic administration of governance refers to the protocol rules written in machine-readable code – a blockchain protocol or smart contract code – which are automatically enforced by the P2P network of computers. These protocol rules also define how protocol updates are to be conducted. In an autonomous setup, tokenized incentives are at the core of the economic coordination game forming the protocol.

A challenge with current proposals for these governance systems is that they are plutocratic, which means that protocol upgrades are decided proportional to one's token holdings. Token holders with more tokens would therefore have more voting power than smaller token holders. This is a considerable design question, given that token distribution is often disproportionately uneven (Voshmgir, 2020).

Similarly, in the context of Dapp, the decision makers are typically individual token holders who participate in governance either by burning some tokens or by casting a vote, the weight of which will depend on the number of tokens that each individual holds at any given time. A few heavily invested token holders (termed whales) will hold a disproportionate influence in the system at the expense of less wealthy users.

Because of these market forces, these systems are ultimately subject to potential manipulation. Certain parties might try to collude, or simply purchase the necessary resources (i.e., tokens or hashing power) to influence the vote in ways that will promote their own interests rather than those of the larger community. This is particularly problematic if the interests of token holders are not perfectly aligned with those of the users of a blockchain-based platform.

This kind of conflict is all too common in many Dapp designs: token holders are often more interested in seeing the price of their tokens rise, whereas users would rather see a decrease in price so as to reduce the costs of using the Dapp. As a result, on-chain governance suffers from the same problem that it was trying to solve: users acting in their own self-interest can exploit Dapp rules technically or economically, regardless of whether these users qualify as malicious (Voshmgir, 2020).

Decentralising governance

Presently, a common design pattern for governance schemes is for most of protocols to be instantiated with a development team who has control over governance parameters, with a promise to eventually decentralise its governance process [Figure 2.7]. Such decentralisation of the governance process is most pursued through the issuance of a governance token, a fungible token which entitles token holders to participate in protocol governance via voting and possibly proposing protocol updates (Aave, 2021; Compound, n.d.; MakerDAO, n.d.; Rarible, n.d.; SushiSwap, s.d.).

Governance tokens are minted by the developers behind the Dapp and allow token holders to help shape the future of a protocol. Token holders can either influence decision concerning the project or even changing the governance system itself. In many cases, the changes proposed, vetted, and then voted on through on-chain governance accessed by using governance tokens are applied automatically due to smart contracts.

In other cases, the team maintaining the project is tasked with applying the changes or hiring someone who will. Based on the role users play in the governance system, a classification – the only one available in the literature concerning Dapp governance – has been defined (World Economic Forum, 2021):

- **Completely centralized**: only the development team that built the protocol can change any aspects of the system
- **Partially decentralized**: only some aspects can be altered by governance token holders; threshold for proposing governance change is low
- **Completely decentralized**: all aspects can be altered, and any token holder can propose change

Proponents of systems that use governance tokens believe that they allow for user control, which holds true to the original cryptocurrency ideals of decentralization and democratization. In most cases, organizations who let users control the development of their systems are called decentralized autonomous organizations (DAOs).

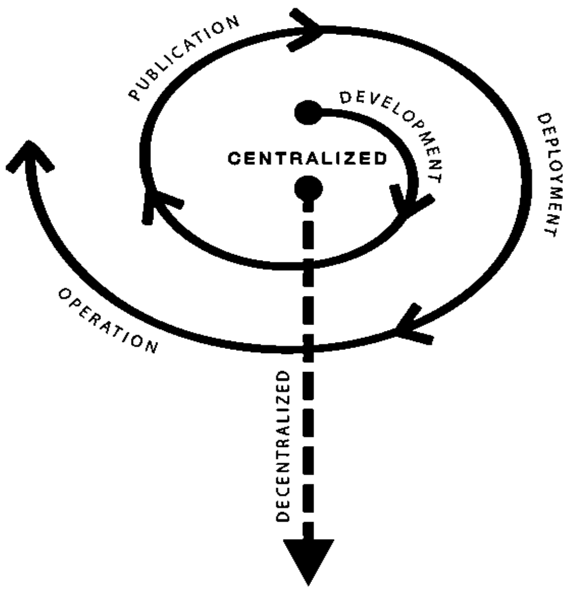

Figure 2.7: Dapp life cycle | Source: World Economic Forum, 2021

2.10.3 DAOs

In his book “The theory of the Firm”, Ronald Coase argued that firms arise if they can produce what they need internally more efficiently than through outsourcing – taking into account all costs, such as search, information acquisition, bargaining, and policing of business partnerships or engaging in bilateral trading in the marketplace. His theories explain the concentration of economic production, through vertical integration of production, and the subsequent rise of multinational corporations, from the industrial revolution until the late 20^{th} century. In recent decades, these highly structured, centralized, and bureaucratic organizations have given way to looser, flatter organizational forms. The internet has facilitated much of this organizational innovation, and started an outsourcing revolution, and reduced the size of companies. However, while products and services around those platforms have become more unbundled, bringing producers and platforms providers closer to each other, the terms of service are always dictated by those platform providers, mostly privately held companies which also control all user data.

Smart contracts have the power to disintermediate these platforms, introducing new ways of coordinating activities, such as task allocation, coordination, and supervision of a group of people who share common economic interests.

Decentralized Autonomous Organizations (DAOs) involve a set of people interacting with each other according to a self-enforcing, open-source software protocol in the absence of bilateral agreements. The blockchain protocol and the smart contract code formalize the governance rules of a DAO, regulating the behaviour of all network participants (Diallo, et al., 2018). DAOs offer the possibility to establish more fluid decentralized organisations over the internet and around a specific economic, political, or social purpose. Performing network task can be rewarded with a network token. Tokens can also be used for exercising voting rights. Once deployed, a DAO is independent of its creator and cannot be controlled by one single entity, only by majority consensus of the organization’s participants. The exact majority rules are defined in the consensus protocol, or the smart contract coded and vary from use case to use case (Voshmgir, 2020).

DAOs have the potential to resolve global coordination problems such as the low transparency along international supply chains and lack of enforceability of global policy making. This is one of the reasons why many UN organizations are already looking into smart contract applications (Mulligan, s.d.).

DAOs are open source, thus transparent, and if well designed, incorruptible. All transactions of the organization are recorded and maintained by a blockchain network. Code upgrade proposals can be made by anyone in the network and are voted for by majority consensus of involved network actors. As such, DAOs can be seen as distributed organisms, that exist autonomously, but also heavily rely on specialist individuals or smaller organizations to perform certain tasks that cannot be replaced with automation (Buterin, 2014).

2.11 Gaps found in literature

The literature review has highlighted several important aspects: several documents have been analysed dealing with the technical aspects of the blockchain technology and the novelties that this innovation has to offer and the impacts it is expected to have on business and governance.

The analysis first explored the most important studies in terms of technical aspects. In particular, the main consensus mechanisms and the mining process were analysed. These constitute one of the greatest innovations of the blockchain as they are able to guarantee its security and immutability, two fundamental properties of the blockchain. For these reasons, their discussion has been treated with peculiar care. Later, the evolution of the protocol form from a public to a private dimension is illustrated and shows the analogy with the Internet / Intranet of the 1990s.

Several papers have been identified and analysed in the literature that identify descriptive frameworks of the data access control possibilities that current platforms on the market offer. In this regard, generally recognised frameworks have been described that divide platforms according to the access allowed to users in validating transactions (permissioned and permissionless platforms) and reading transaction data (public and private platforms). Given the high degree of novelty of blockchain technologies, the literature has also highlighted several technological limitations that characterise the main public platforms. In this regard, the problem of scalability is treated extensively and the main solutions that aim to address it are presented.

Contextually within each section, the most significant features of the blockchain were highlighted, including how societies can take advantage of distributed ledgers without the need to trust a central authority that acts as a guarantor. This is what makes the blockchain a unique technology and many papers have shown how disruptive it can be in several different areas.

In this regard, during the study of related literature, the particular importance of programmability that characterises blockchain technologies emerged. This concept has been introduced with smart contracts, the game-changing element that allows for securing, enforcing, and executing settlement of recorded agreements. This element has been so revolutionary that some scholars have coincided its introduction with a new era of blockchain, referred to as blockchain 2.0 (Swan, 2015), because it allows the application of this technology beyond the mere payment domain, enabling the decentralisation of all markets.

The concept of smart contracts has been thoroughly explored from its inception to its implementation on the blockchain, where it expresses its full potential. In this regard, the analysis has moved to several critical applications that stems from smart contracts. First, the literature has highlighted the importance of tokens, powerful tools that provide many of the structural features of the blockchain: from keeping the network safe from attacks – by acting as incentives for block validation (rewards for miners) – to preventing transaction spam. With the advent of Ethereum, tokens have moved up the technology stack and can now be issued on the application layer. These application tokens have been covered starting with the underlying technology and moving towards the main use cases. In particular, their potential and implications have been further examined by introducing another revolutionary element of the blockchain: Decentralized Applications (Dapp).

In the analysis of the principal sources of innovation in this area, Dapp have emerged as completely novel applications that could change the nature of economic, social, and political systems. For these reasons, they have been treated with a holistic approach, starting with a technical analysis of the layers they are composed of, covering their formation and development, and moving on to their high-level implications. In this regard, study of the academic and grey literature has shown the different sectors that decentralized applications have the potential to disrupt.

Particular attention has been given to the sector of decentralized finance (DeFi). As the most widely adopted industry, DeFi was deeply explored highlighting its main services and the most innovative aspects, such as its composability. Research papers concerning other sectors (e.g. decentralized social networks, decentralized marketplaces) is missing and for this reason the grey literature has been relied upon.

However, some topics have also emerged regarding Decentralized Applications that have not been sufficiently explored in the present literature, or have been addressed in recent years, but the related research would need to be updated with more recent observations. In particular, the literature lacks empirical analysis concerning the sectors from which new Dapps are emerging. Some scholars are beginning to explore the main use cases of some sectors, but there is still no research that paints a picture of the Dapp ecosystem and its distribution across sectors.

In addition, the literature review has highlighted many documents that address the technical aspects of blockchain, even in high detail, but fewer papers have empirically observed which are the main impact of this technology on current business models. As Schneider et al. (2020) point out, there is still a lack of a solid theoretical basis for exploring the expected implications of blockchain technology on business models and ecosystems. In this regard, there is a complete lack of studies concerning public blockchains – which the literature recognises as the most disruptive – and decentralized applications. Only Tapscott (2016) devised new business models supported by public blockchains, but even this perspective suffers from gaps and should be updated considering the current state of Dapps. In fact, this classification attempt has been made with a theoretical approach, lacking an empirical analysis that verifies which of these models are actually exploited by blockchain-based applications.

Studies on decentralized applications that have emerged in the literature have not collected information on the revenue streams used, nor has any investigation emerged that clearly highlights how they are able to create value for their stakeholders. Only a recent paper (June 2021) by the World Economic Forum highlights the incentives that a Dapp offers to users, but the analysis is limited to DeFi and relies solely on a few Dapps, lacking solid empirical research.

It is clear that blockchain and smart contracts have the potential to create benefits beyond digital currencies and influence all sectors of the economy, but the documents analysed do not provide any specific explanation on how these elements would help Dapps to disrupt existing industries. There is no theoretical framework that defines the existing blockchain-based business models, and a general overview is missing on which of these business-side application models are the most used or the most effective.

Another element is of paramount importance for blockchain and Dapps is governance. Even for this specific topic, many papers have been found that technically describe the governance of public blockchains. There are many journal papers and descriptive dissertations about existing governance mechanisms, their effectiveness, and the impact they have at technical level (algorithmic governance) and social level (social governance). In addition, several critical issues concerning governance systems have emerged and will need to be addressed over the years in order to ensure potential mass adoption of public blockchains and network effects.

However, similarly to other technical aspects, although there are comprehensive theoretical descriptions of governance systems, the literature lacks a vision of how governance is used by Dapps in reality. There are no empirical analyses that show, starting from the observation of a real-world set of Dapps, which Dapps use governance mechanisms, at what level they are decentralizing their operations, how they ensure a fair distribution of power and above all how they implement decentralized governance.

In conclusion, the literature has highlighted plenty of analyses and descriptions of the technical elements of blockchain. Many studies that have involved business aspects have considered Dapps as applications that could reshape existing industries and create a new landscape for entrepreneurship and innovation. The main gaps that have emerged in the analysis of the literature are as follows:

- The literature lacks empirical analysis regarding the sectors from which new blockchain-based applications (Dapps) are emerging. Some scholars are beginning to explore the main use cases of certain sectors, but there is still no research that paints a picture of the Dapp ecosystem and its distribution across sectors.
- There is still not a valid and recognized classification framework of business models based on blockchain. Moreover, empirical analyses that explore the adoption of these models by blockchain-based application (Dapps) are missing in the literature
- There are no empirical analyses that shows which and how Dapps use governance systems, what role governance play in the business model of a Dapp and at what level Dapps are decentralizing their operations.

2.12 Objectives of the research

The literature review revealed a lack of academic articles dealing with blockchain, with most of them focusing on the technical aspects of this technology. Articles studying the impacts of blockchain on business and society are rather scarce and are mostly found in the grey literature.

From the previous chapter, it emerged how blockchain is gaining more and more interest in recent years, being studied by many scholars around the world, both for academic and corporate research. In this regard, knowledge and awareness surrounding blockchain is growing throughout society and companies and governments have realised its true potential beyond cryptocurrencies. This is evidenced both by the fact that major venture capitalists and technology solution providers are investing heavily in blockchain-related projects, and by the tremendous effort governments are making to design regulations.

The literature highlighted the disruptive potential of blockchain in several area. However, this technology is still in its early stages when considering the rate of adoption and technological development. There are still important unresolved challenges regarding the current limitations that these platforms present – such as scalability – and there is still uncertainty about the best choices to make from a technical point of view when implementing such a system in the real world.

If these challenges are solved, blockchain technologies offer many possibilities to grow entirely new businesses and pose direct threats of disruption to traditional incumbents. This transformation can range from operational improvements to the construction of open networked enterprises that disrupt or displace traditional centralized models, potentially evolving into distributed autonomous enterprises (DAOs).

In this regard, decentralized applications (Dapps) combine the two most disruptive elements: public blockchains and smart contracts. Dapp have therefore emerged as applications that could reshape existing industries and create a new landscape for entrepreneurship and innovation.

In particular, the sectors in which Dapps are growing can be considered an important means through which it is possible to draw indications on the directions of development of blockchain. The investigation of the sectors in which Dapps are developing and gaining momentum is therefore necessary. A similar reasoning can be applied to their incentive systems, which have the potential to disrupt existing business models, moving towards a stakeholder-oriented approach. For these reasons, the literature shows that incentive models, and broadly revenue streams, cannot be excluded from the analysis. Actually, any differences between them and traditional sources of income can lead to results that deserve to be investigated.

Finally, the literature so far lacks empirical studies conducted on the business models of decentralised applications and furthermore, none have analysed what choices have been made regarding their governance system.

Given the importance of this issue and the considerations just described, this study aims to:

Describe the current ecosystem of blockchain-based decentralized applications (Dapps).

To achieve this goal, an empirical analysis was conducted on decentralised applications that are built on public blockchains. The number of users was recorded and used as an indicator of community interest, to make assumptions about the development directions of Dapps and the future use of blockchain in business applications.

2.13 Research questions

Starting from the research objective and the main gaps identified in the literature, the following research question were defined:

RQ1: In which sectors are blockchain-based decentralized applications (Dapps) developing and which ones attracting the most users?

Then, to better describe the innovations brought by Dapps, two further research questions were included in the analysis:

RQ2: What are the revenue models adopted by Dapps?

RQ3: What are the governance models adopted by Dapps?

Chapter 3

Methodology

The research approach used in this chapter is the primary research approach. Primary research aims at clarifying the nature of a problem and at acquiring a greater understanding of a situation by collecting original data specific to a particular research project (Gratton & Jones, 2010). Due to the novelty of the topic the primary research was useful to define the state of the development of the Dapp's ecosystem and how it is evolving as well as what business models, Tokenomics and governance systems are emerging. This approach was used to find a framework providing a global representation of decentralized applications, through their components and key characteristics, regardless of the service they offer and the category they belong to. The methodology used for the research is a 3-step framework [Figure 3.1] consistent with: framework construction, Dapp selection and Dapp analysis.

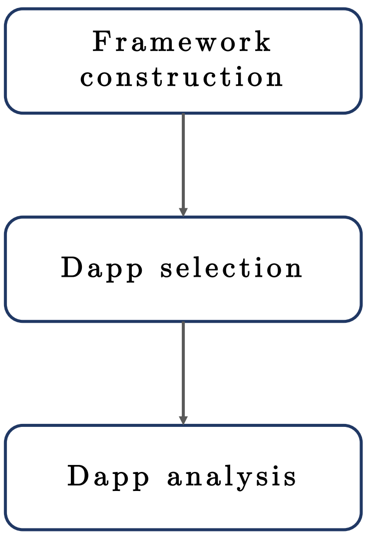

Figure 3.1: 3-step framework methodology

The framework construction phase consists of two activities: variable definition and framework design. Variable definition stands for the identification of the parameters of a decentralized application according to the research objectives. Instead, the framework design is the process that defines the structure of the framework in a way that facilitates data collection and most importantly its subsequent analysis.

Finally, the Dapp selection phase includes the definition of the decentralized application provided as input for the Dapp analysis. The overall methodology followed is described in detail in the following sections.

3.1.1 Framework construction | Step 1

Initially, the aim of this thesis was to acquire a satisfying understanding of the state of the development of the Dapps' ecosystem and afterwards, to contribute to the scientific research community for this topic in unexplored fields, like their revenue models or governance systems.

The first activity – the variable definition – seeks to identify certain parameters of the Dapp intended to address the research questions. The fields chosen for the analysis were selected following the MECE principle [Mutually Exclusive, Collectively Exhaustive].

Mutual exclusivity is an essential characteristic given the research topic: as already mentioned, its novelty makes its investigation difficult and consequently some information difficult to retrieve. The scarce literature and the premature level of development sometimes require the examination of technical documents intended specifically for developers as the only source available. During the construction of the framework, it has been considered the impossibility of censusing certain fields. For this reason, mutually exclusive variables have been chosen, allowing only some of them to be surveyed without compromising the overall analysis.

Collective exhaustiveness also plays a key role in the choice of parameters: they must be able to describe each application and its working logic, capturing its complexity, but also be general enough to be equally applied to all. For this reason, a first version of the schema has been drafted and compiled with a set of 40 Dapp. Based on this initial research, the framework was then revised, formalized, and enriched with new variables. This reiterative process has produced a framework of 32 variables that provide an overview of the field of decentralized applications, its state of development and its possible evolution. A comprehensive overview and description are provided in *Variable description.*

3.1.2 Dapp Selection | Step 2

This step involves the selection of applications serving as input for the Dapp analysis. At this stage, the level of adoption was considered as a decisive parameter to make assumption about the development directions of Dapps. As Dapps and the surrounding ecosystem are still in their embryonic phase, the best designed and performing protocols are usually those able to attract the highest number of users. Moreover, their open-source structure allows to easily copy the source code and create identical smart contracts. The number of users proves again to be useful, here to assess which copycat is also able to attract the audience of the Dapp it copied.

Finally, since this kind of application involve several kinds of stakeholders that are often incentivised or compensated (as emerged from the literature for DeFi), this parameter helps to identify the most effective incentive systems and revenue streams. For details on the number of users and how it was measured please refer to *Variable Description.*

For the purposes of this section, it is worth mentioning a particular type of decentralized applications: those labelled as “high-risk”. Jon Jordan – Communication Director of DappRadar – describes them as protocols that are based on an interactive experience which doesn’t always fully state its risks and rules. Most of them are based on some form of game theory or Ponzi schemes in which users pay their token into a prize pot and one of them wins it either by chance or using other strategies. These implications are not always clearly defined and on the contrary, these protocols often promise considerable returns with low risks.

For these reasons, decentralized applications labelled as “high-risk” from the major analytics websites were not considered because they are not relevant for the analysis.

During this phase, a sample of 100 blockchain-based applications was selected according to their level of adoption for the reasons mentioned above. The 100 applications with the highest number of users in February were then considered. This was because the available resources extended their time horizon by a maximum of one month in terms of the number of users (for further details please refer to *Variable Description*). The extraction was therefore carried out on 28/02.

The sample considered is limited to 100 because going beyond that, the number of users was considered insufficient to provide for useful assumption about the directions of the ecosystem. As will be shown in *Findings*, the top 100 applications, despite representing only 3% of the total number of Dapps, account for approximately 64% of the entire market in terms of users.

Moreover, the level of adoption in terms of users is often directly proportional to the number of "contributors" supporting the application. As most Dapps are open source, the more developers work on them, the more technical documentation is available. Since this type of source (as described in the next section) is the most reliable and the most common, more relevant data can be retrieved for the most adopted applications.

While reviewing whitepapers and smart contracts, five Dapps that according to the sources analysed were not "high-risk" were found to be in this category, and therefore removed from the dataset.

A second snapshot was taken on 30/04, updating the ranking and adding the applications that entered the top 100 in April. This has resulted in a total of 112 applications that provide an appropriate sample for the analysis.

3.1.3 Dapp Analysis | Step 3

This step mostly involves the gathering of information according to the primary research approach, i.e., first-hand collection of data and knowledge without relying on databases or other publications. Many of the fields defined during the framework construction investigate aspects that have not been explored in the literature or indexed by databases, hence they can only be filled in with a direct search.

Sources

The following sources were used for the research.

Whitepapers: a white paper is a persuasive essay that uses facts and logic to promote a certain product, service, or viewpoint (Graham, 2015). Its purpose is to informs readers concisely about a complex issue, to help them solve a problem, or make a decision.

The literature review showed that the development process of a Dapp also includes the drafting of a white paper which clarifies its functioning in non-technical terms and its use cases. For this reason, this document served as the main source at this stage of the research. However, the level of detail in a whitepaper varies in each case and often some parameters are not specified in the document. Furthermore, the following research has shown that the development of a Dapp is not always preceded by a whitepaper, which in some cases is missing. In order to provide a more comprehensive overview, several industry-specific websites were also analysed.

Analytics websites: an increasing number of websites tracking smart contracts and the related statics are emerging. However, since the variables they measure are recently designed (e.g. Total Value Locked), these websites have different ways of measuring them, thus resulting in different values. To overcome this problem, a thorough analysis was made by cross-referencing different sources to ensure the highest possible degree of accuracy.

- **DeFi Pulse**: it monitors each DeFi protocol's underlying smart contracts on the Ethereum blockchain. The team behind it devised the most widely used metric in the world of decentralized finance: the Total Value Locked (for further details please refer to *Variable description*)
- **DappRadar**: provides data and information about all the existing blockchain-based Dapps. It is the global leader in Dapp distribution and analysis.
- **Dapp.com**: offers the same service as DappRadar but with different tracking methods which often leads to different results. Used to integrate and perform sanity checks with the data found.
- **CoinGecko**: provides cryptocurrency and token data such as price, volume, market cap, trading volumes and exchange data.
- **CoinMarketCap**: data provider such as CoinGecko, it is the world's most referenced price tracking website for cryptocurrencies.
- **Defistation, Defillama**: provide data about DeFi projects.

GitHub: Internet hosting provider for software development and version control. It is commonly used to host open-source projects and in recent years has become the world's largest collection of open-source software (Metz, 2015).

The entire source code of blockchain protocols and decentralized applications can be accessed on this library as one of their main characteristics is to be completely open source. The functionalities of the source code can be understood by those with basic programming knowledge without the need for specific technical expertise. This is enabled by a coding best practice: attaching comments or entire technical documents to the source code in order to clarify its behaviour (Torvalds, 2005).

This source was accessed to check the accuracy of the information collected and to supplement missing data from other sources.

Others: secondary resources used if the above sources did not provide sufficient information, to sanity check the data found or to record fields not available from the other sources. These sources include:

- **Websites**: ICO Drops, Crunchbase, Twitter accounts, Blockchains (browsable via specific explorers such as Etherscan for Ethereum), Dapps' official websites.
- **Other documents**: research reports, journal articles, academic and scientific papers.

3.2 Research framework

This section provides a comprehensive description of the framework developed and how it addresses the research questions identified above. The information collected refers to technical elements of decentralized applications as well as their business applications and governance mechanisms.

Figure 3.2 shows an overview of all the variables analysed, linking each of them to the research question it was designed for. However, many of the variables collected overlap and some information was used to answer more than one research question.

RESEARCH QUESTIONS	VARIABLES
In which sectors are blockchain-based applications (Dapps) developing?	CATEGORY; INDUSTRY; MULTI-CHAIN; PROTOCOL; STAGE OF DEV.
	LAYER 2 SOLUTIONS; LAYER 2 NAME; LAYER 2 STATUS
	LAUNCH DATE; NUMBER OF USERS; USER GROWTH; MARKET CAP; TVL
	TOKEN FORMAT; TOKEN NAME; TOKEN FUNGIBILITY
How Dapps create value for their stakeholders?	CROWD SALE & TOKEN LAUNCH; OTHER SOURCES OF CAPITAL; CAPITAL RAISED; TOKEN DISTRIBUTION SHARE
	REVENUE STREAMS "DAPP"; REVENUE STREAMS "BUILDERS"; USER INCENTIVES
	FEE STRUCTURE; FEE/RATE; FEE RECIPIENT; CHARGED
Which governance models do Dapps adopt?	OWNERSHIP STATUS; TOKEN TYPOLOGY; GOVERNANCE PROPOSAL; PROTOCOL UPDATES; DECENTRALIZATION LEVEL

Figure 3.2: Variables' overview

Many of the variables attributed to the first research question do not strictly adhere to the objective but range over other fields. These provide contextual information necessary to provide an accurate overview of the Dapp ecosystem and specially to support and clarify further the other variables which are more focused on the research questions.

3.2.1 Variable description

This section covers the description of the variables, firstly defining a technical explanation of the field analysed, then moving on to the reason why it was surveyed and finally describing the sources used.

For the purposes of the discussion, it is necessary to specify how the stakeholders involved in the operations of a Dapp have been surveyed. This type of actors has not been identified within a single field, but rather spans several variables that define their roles and responsibilities. For the sake of clarity, a brief description is provided below, although a detailed analysis will be presented along with the description of the variables.

As seen in the literature review, only one paper (World Economic Forum, 2021) shows a first formal classification on the stakeholders of a decentralized application. The scope of the study is limited to DeFi and does not generally consider all other cases. However, the classification is rather general and being designed for DeFi – the most complex and most evolved category of Dapp so far – it is possible to use it regardless of the context. The stakeholders are as follows:

- **Builders**: create, implement and support the protocol
- **Suppliers**: provide capital or a core service to the functioning of the protocol
- **Users**: use protocol functionality for intended use case
- **Governance**: make decisions on the development of the protocol. For the sake of clarity, will henceforth be referred to as **Governors**

The variables analysed are the following:

Name

This field allows to distinguish the observations of the dataset and it refers to the Dapp's name in its most recent version.

Category

The Dapps within the dataset were divided according to the category they belong to and the service they offer. The classification process was carried out in a qualitative way, analysing the functioning of the applications described in the whitepapers and cross-referencing it with the classification provided by the following sources: DeFi

Pulse, DappRadar, Dapp.com. The categories were then formalised as per the literature review, as follows:

- **DeFi**: set of lending, borrowing, trading, and derivatives applications. The topic was extensively covered in the literature review along with the services provided, surveyed as follows:
    - **Asset management**: services that involves the oversight of financial assets for others and seeks to maximize the value of the whole portfolio based on risk preferences, time horizons or other conditions. By incorporating the asset management life cycle into a Dapp, these applications promise greater transparency and efficiency in constructing and executing investment strategies.
    - **DEXs**: applications that allow users to exchange digital assets.
    - **Derivatives**: applications that create synthetic financial assets whose value depends on or is derived from an underlying asset or group of assets.
    - **Lending**: services that involves the creation of interest-bearing instruments that must be repaid at maturity.
    - **Mutual**: applications that pools risk by exchanging the payment of a small premium for the possibility of collecting a large payment in the event of a covered scenario. Used to manage and structure the insurance lifecycle for certain types of risks such as smart contract hacks.
- **Gambling**: Dapps that offer any kind of gambling game. Although no scholars have yet recognised this category and there are no papers on it, the number of Dapps and the level of adoption of this type of application justifies a separate classification. This sector is gaining momentum thanks to its unique fairness, as the underlying smart contracts are open sourced and activity within the Dapp is recorded on the blockchain. Moreover, the traditional house-edge[13] is lower and the percentage is clearly specified.
- **Games:** applications that incorporate a gaming component into them. They range from simple video games to complex gaming platforms. Within this

[13] Mathematical advantage that the game, and therefore the commercial gambling venue, has over users

parameter, the cases in which the game is a *collectible* game were also recorded. This sub-category involves application that use NFTs for collection purposes or for exchanging them.

- **Marketplaces:** blockchain-based platforms where users buy, sell and exchange goods – mostly NFTs – enjoying lower transaction fees with respect to traditional marketplaces.
- **Social networks:** blockchain-based social media that aim to solve many of the critical issues of traditional ones. These networks are usually managed collectively by contributors who get rewarded with tokens.
- **Others:** all verticals that are built on the blockchain but application but are not widespread enough to be considered separately. Since it is expected a low number of applications classified as "others", these will be treated individually, contextually describing the service they offer.

Industry

The industries in which the Dapps operate is an important element to determine whether there are business areas that more than others are developing blockchain-based solutions. The main sectors have been identified by the Blockchain and Distributed Ledger Observatory of Politecnico di Milano, based on those most active in 2019 in the application of distributed technologies and are listed below:

- **Communication services**: telecommunications services or some combination of information and media services, content, entertainment and application services over networks, leveraging the network infrastructure as a rich, functional platform.
- **Finance**: includes Dapps that leverage the blockchain to increase the efficiency of financial services offered by major financial institutions.
- **Insurance**: Dapps that sells means of protection against financial losses.
- **Media Arts & Entertainment**: Dapps that operate on the management of artistic and multimedia content, both physical and digital. This sector also includes games or gaming platforms based on Blockchain.
- **Gambling**: all applications that fall under “Gambling” in the field *Category.*

- **Other**: all verticals that are not widespread enough to be considered separately.

Multi-chain

In order to address the research also around technical aspects, several variables have been taken into consideration in order to describe the technical choice made by developers when building a Dapp.

This field investigates whether the smart contract of a Dapp is stored only on one blockchain protocol or on multiple ones. The main sources used are the official Dapp website and DappRadar. The variable was added during the reiteration of the framework construction process. In fact, an initial analysis showed that some of the Dapps had developed their contracts on multiple blockchains. In an attempt to attract a larger pool of users, exploit the advantages of other protocols and improve scalability[14], some applications are landing on other blockchains apart from their original one.

This field therefore helps to understand the evolution of the ecosystem, spot trends and understand what opportunities the main decentralized applications are exploiting.

Protocol

This field indicates on which blockchain the smart contract is stored. It also helps to understand the technical choices made in the development phase, which protocols are most suitable for certain categories of services and why. If the Dapp is multi-chain, all protocols which host it have been recorded. The information can be found on any analytics website and has been added to the dataset for exploratory purposes. A detailed overview of the surveyed protocols and their main characteristics will be provided in *Findings*.

[14] By moving to PoS blockchain protocols

Stage of development

This parameter aims to define the development status of a Dapp. This has been categorised into two phases: beta release and stable release.

As already mentioned, smart contracts are, by design, immutable once deployed. As a result, it may be assumed that every Dapp – at least as far as the back end is concerned – is released as a stable version. However, there are exceptions: for example, a development team may release a beta of a smart contract which will then be replaced by a later version. This technique may allow a developer to delay offering full support and responsibility for remaining issues (Lapidos, 2009).

The variable was collected from various sources such as whitepapers, GitHub or Dapp's official website. This parameter has also been collected for exploratory purposes, as dealing with software development, it helps to understand how blockchain practices differ from the traditional web. Indeed, the literature review showed that the update model of smart contracts differs from traditional software, which is updated instantly and transparently by the application owner. Formal testing and verification, often referred to as "academic", plays a key role in their development. Techniques used in industry, aerospace, and other fields where errors have huge consequences can also be applied. Although this thesis goes beyond strictly technical aspects, it is worth mentioning this aspect as it provides valuable insights.

In addition, it can be considered as a starting point for further research and analysis on the business side. The activity of developing a smart contract is one of the most important in a Dapp lifecycle, and consequently has a great impact on the organisation that works on it – of whatever nature it may be. Understanding the evolution of this process can therefore be helpful to understand how software development organisations may evolve in the future. The AGILE method for example, whose use has grown exponentially in recent years, will be rendered obsolete in the development of smart contracts.

Layer 2

Layer 2 refers to a secondary framework or protocol that is built on top of an existing blockchain system. The main goal of these protocols is to solve the transaction speed and scaling difficulties that are being faced by the major cryptocurrency networks.

Scalability is an issue that rarely emerges when launching a Dapp, but rather in the later stages of its life cycle. Layer 2 solutions are therefore never explored in the white paper (unless a later version is released) and due to their recent nature, are not covered by the tracking sites. Data on this topic were collected from different sources: Dapps' official website, articles, papers and eventually GitHub.

The status of the smart contract implementation on Layer 2 was also mapped. A distinction was made between protocols that had already implemented the solution at the time of data collection (carried out in April 2021) and those that had only announced it. In the latter case, reference was made to announcements posted on the official Twitter page of the application. The research explores the scalability issue to understand which protocols are most widely adopted and why. The degree of adoption proves to be a powerful indicator of the effectiveness of these protocols, giving an insight into which are the most promising. Moreover, while Layer 2 solutions are much needed and logical solution to scaling blockchains, they come with their own question marks and potential issues that may hinder the platforms from reaching its true vision (Chang, 2021). This is particularly important at this stage of blockchain development and will be one of the determinants on which the success of the Web3 will depend.

Summarising, the following fields were surveyed:

- **Layer 2 Solution**
- **Layer 2 Name**
- **Layer 2 Status**

Launch date

This field refers to the date on which the first stable version of the core smart contract was released. The date was retrieved from the whitepapers, from the timestamp of the transaction generating the smart contract or from the announcements on the official Twitter page.

This parameter deepens the analysis by giving a time dimension to the research and offering further insights. In fact, the launch date allows to measure the growth in terms of the number of projects developed over the years, to identify the longest-lived projects or the most recent ones. This can lead to multiple streams of research, such as investigating the reason for the success of the latest Dapps, which have entered the top 100 thanks to an exponential growth of their users.

Number of users

Since the first objective of the research is to understand which apps and sectors attract the most users, particular care was taken to measure this parameter. The number of users provides a key metric as it directly measures the adoption of a given protocol or ecosystem and determines its level of development. The variable represents the number of unique wallet addresses interacting with Dapp's smart contracts.

As already mentioned in the previous chapters, the literature surrounding Dapps is very limited, and it becomes difficult to identify the ones that are able to attract and retain users. Moreover, their open-source structure allows to easily copy the source code and create identical smart contracts. The number of users becomes therefore crucial to recognize which protocols are backed by a successful business model and if the copycats are able to attract the audience of the Dapp they copy as well.

This variable was aggregated by month, taking a first snapshot in February and then a second in April. This parameter will also be referred to as AMU (Active Monthly Users) in the course of the discussion. If a Dapp were multi-chain, the number of users refers to the main blockchain, on which the first smart contract was written. An attempt was made to census users for the other chains as well, but no data was found in the secondary sources considered.

The top two analytics websites were analysed: Dapp.com and DappRadar. Cross-referencing the two sources with the data on the Dapp sites revealed that Dapp.com was less reliable and data varied by as much as 20%. For this reason, only DappRadar was maintained as the source for the user analysis.

User growth

This variable measures the growth in the number of users between the two extractions carried out (February and April). The metric is measured as a percentage and, although based on a limited time span, is useful for understanding which protocols are experiencing the greatest growth.

The number of users can be misleading in some cases, since it can depend on several factors and not only on the goodness of the protocol. In this regard, the degree of adoption can be related to the sector to which the application belongs: if a Dapp offers DeFi services, it is more likely to attract a greater number of users given the interest shown in the sector. Moreover, it may also depend on the launch date of the smart contract or even on the target audience of the protocol – if it addresses a niche audience, the absolute number of users is likely to be less relevant. Growth therefore offers a relative metric that analyses the potential of a Dapp and the interest around it, thus complementing the above metric.

Market cap

Market capitalisation is an indicator that measures and keeps track of the market value of a given token. It is a widely used indicator and it provides the dominance and popularity of cryptocurrencies, tokens, and the underlying applications. The market cap is determined by the current price multiplied by the circulating supply.

Even though the market cap of a project is still seen as the most important indicator of relevancy, the concept behind this is often subject to criticism. The reason is that the market cap of a cryptocurrency reflects the popularity of a coin over a longer term. If an application generates proprietary tokens, regardless their typologies, the relative market capitalisation has been recorded.

Market capitalisation also proves to be very important in answering the research question "What are the revenue models adopted by Dapps?". This is because part of the value that is created for them, as will be discussed in the *Revenue Stream Dapp* variable, is determined by the interest accrued by the tokens they own. If the price were to increase, the token holders would benefit from it. However, the price of a token alone is not sufficient to guarantee a complete view of the strength of a protocol. In many cases, there are tokens with above-average prices but a lower circulating supply. The solution therefore lies in the market capitalisation which is the product of the two.

The sources used for recording this metric were CoinMarketCap and CoinGecko. As with the number of users, two snapshots were taken, one on 28th February and the second on 31st March.

Total Value Locked

Total Value Locked [TVL] is one of the most used metrics within the DeFi ecosystem, representing the amount of assets that are currently being staked in a specific protocol (DeFi Pulse, s.d.). This variable was used to assess Dapp adoption and ultimately its impact in the DeFi ecosystem. Since decentralized finance is characterized by high volatility – both in terms of protocol usage and value of cryptocurrencies – an average has been made for each month, covering February and April.

The TVL measures the total amount of underlying supply being secured by a specific application and/or by DeFi as a whole. The following sources were considered in this order:

1. DappRadar
2. DeFi Pulse [exclusively for the Ethereum protocol Dapps]
3. Defistation [exclusively for the BSC protocol Dapps]
4. DeFi Llama

If the figure was unavailable from a source, the next one was considered in the order shown. Analytics websites were ranked in terms of reliability, taking into account their user base and the extent to which they are used by other platforms. This metric is often subject to criticism since a handful of users are responsible for most of the usage of DeFi Dapp. Thus, it’s important to look at the total number of users to complement total value locked and provide a more holistic view of DeFi adoption (Chen R. , 2020).

Token

The token argument has been another important gap identified in the analysis of the literature in the previous chapter. In particular, the need for more in-depth studies describing the role of tokens in Dapps business models has been highlighted. The frameworks provided by several papers describing the technical characteristics of tokens have been exploited to define the variables of this census, but the emphasis has been placed on the role that tokens play in the operations of decentralized applications.

In order to conduct this type of analysis on the technical choices that applications have made, it has been decided to define some variables specifically related to tokens, in order to empirically observe their utilization. The parameters analysed are:

- **Token name**
- **Token format**
- **Token typology**
- **Token fungibility**

For the sake of exhaustiveness, the token's name and format – which identifies the protocol on which it is born and whether the token is fungible or non-fungible – have been recorded.

The remaining variable identifies the typology of token used. In accordance with the principal types of tokens that have emerged from the literature review, the following framework has been applied that identifies three main classes of tokens:

- **Utility token:** these are intended to create the economic incentive within a platform to enable the use of the service, to pay transaction fees or to allow an exchange of value between users.
- **Asset token:** they represent the ownership of something that has a value. Typically, they are the digital representation of a real-world asset on the blockchain.
- **Governance token:** fungible tokens which entitles token holders to participate in protocol governance via voting on and possibly proposing protocol updates. This type of token will also be included in subsequent metrics to investigate research gaps in governance systems.

Another important distinction has been made between fungible and non-fungible tokens:

- **Fungible**: indicates that tokens are interchangeable in the representation of their value. As for the physical coins or banknotes, they are not distinguishable from each other.
- **Non-Fungible**: are tokens that have identifying attributes that make them unique. They can represent on blockchain unique collectible objects; therefore, they are recognizable and distinguishable.

Crowd sale & token launch

Blockchain technology is reshaping the fundraising landscape (Chen, 2018; Fisch, 2019). One primary form of decentralized fundraising is represented by Initial Coin Offerings [ICO]. An ICO involves the creation of a specific token by the project to be funded on a public blockchain and the subsequent sale of the token to potential investors to raise funds for early-stage developments. (Martino, Wang, Bellavitis and

DaSilva, 2019). For these reasons, this information and the related amount – converted into USD – collected by the crowd sale or the token launch was gathered.

The data were retrieved from several sources, cross referencing among them: articles, dedicated sites that census ICOs (e.g. Icodrops) and announcements on the official Dapp Twitter page.

The ICO is generally launched following the publication of the whitepaper. This is therefore a metric to assess the enthusiasm around a project and the perception of the community.

Other sources of capital

This field records other sources of capital than those mentioned in the previous variable. These include, for example, hedge funds and venture capitalists. The ability to attract these types of investors is often a clear sign of the quality of the project. Given their interest in strong teams, large potential markets, and unique value propositions with a strong competitive advantage, these players help to identify the most promising protocols in the long term. It also provides insights on a higher level: which ecosystem and which categories have more potential according to these investors.

Capital raised from other sources of capital

This metric measures the amount of funds raised by investors surveyed in the *Other sources of capital* field. It is useful to measure the interest of traditional investors as this is directly proportional to the sum of funds invested (Tyebjee & Bruno, 1984). The main source used is Crunchbase, which has been completed with information found in various articles

Revenue streams "Builders"

One of the objectives of the research is to investigate how a Dapp creates value for its stakeholders. To answer this research question, the revenue models of Dapps were included in the analysis, as they are a key component of the business model. The revenue model is in fact defined as a framework for generating financial income: it identifies what are the sources of revenue, what value to offer, how to price the value, and who pays for the value (Afuah, 2004).

However, the value offered by a Dapp, which is summarised in its value proposition, the service it offers and the way it is delivered, is mapped with other fields. The actors who pay for the service are also surveyed with other variables, which define their role and responsibilities within the Dapp. This variable thus focuses solely on the revenue sources.

When assessing how a Dapp generates value through its operation, a substantial difference emerged between the actors involved. A first analysis identified how the stream changes according to several factors, such as who is the beneficiary involved. This phenomenon is also supported by the grey literature, although the high degree of novelty and change characterising decentralised applications prevents the existence of a significant number of sources. For this reason, the classification concerning revenue streams is taken from several sources and integrated with some of the "traditional" models of the web 2.0.

In an attempt to formalize and better structure the framework, the revenue streams were divided according to the stakeholders involved. In particular, they were divided according to which stakeholders benefit from them.

The literature review identified four main stakeholders within the Dapp ecosystem. These can often overlap in their roles, but of these mainly two differ in the value they capture. The first category refers to the builders, the actors who create, implement, and support the protocol. They benefit from the following revenue streams:

- **Tokenomics**: application token holders gain from the appreciation of token value or from receiving inflationary rewards.
- **House-edge**: predominantly used for gambling Dapp, it is a mathematical advantage that the game has over the user. This is built into the logic of the smart contract and therefore results in a guaranteed percentage return over time.
- **In-app sales**: as its web 2.0 counterpart, it refers to the selling of goods and services from inside an application.
- **User fees**: describe the cost necessary to gain access to a product, service, or facility (Investopedia, 2019). A comprehensive break-down of the fee typologies will be provided in the following paragraphs.

The revenue stream of each application has been extrapolated from whitepapers, developer's documents on GitHub and scientific literature on decentralized applications and their categories.

Revenue stream "Dapp"

The second type of revenue stream refers to the value captured by the remaining three types of stakeholders: users, suppliers, and governors. Since these three categories represent the main pool of stakeholders, both in number and in volume, this variable is referred to as the Dapp revenue stream.

Research on this type of revenue streams is even more limited than that on revenue streams described in the paragraph above. This is because revenue streams that remunerate their stakeholders so extensively are rare in traditional business models. Their revolutionary components have not yet been studied, although some scholars have started to recognise the phenomenon.

Several scientific papers have defined various incentive systems that a Dapp offers its users. However, a first empirical analysis has shown that these streams look more like revenue streams than simple incentives.

The volume of these incentives sometimes exceeds that of traditional revenue streams and the ways in which they are delivered become increasingly complex (e.g. yield farming strategies). For this reason, they have been considered as revenue streams throughout the discussion. The incentive system classification provided by the literature has been taken and readjusted to include all categories of applications:

- **Tokenomics:** as described above, this stream depends on the interest earned on the tokens issued by the application.
- **User fees:** describe the cost necessary to gain access to a product, service, or facility (Investopedia, 2019). A comprehensive break-down of the fee typologies will be provided in the following paragraphs.
- **Interest rates:** lending Dapps remunerate their liquidity providers with a part of the interest rates collected. It has been split from "User fees" to provide a more granular overview.
- **Yield:** mainly applied by asset management applications, which offer value maximisation strategies, generating – in some cases – yields for its users.

The revenue stream of each Dapp was defined by whitepapers, development documents on GitHub and, in the case of no document available, an empirical analysis based on the use of the app.

User incentives

To complete the research on how apps create value for their stakeholders, the incentives for users were also included. These are designed by developers to promote the use of a smart contract or protocol token. All non-monetary incentives (e.g. showcases) and monetary incentives (e.g. lottery) belong to this category, but they differ from the revenue streams described above. In fact, the volume of incentives is very small in comparison, and their frequency also decreases, as they are most often occasional (e.g. rewards). The following have been identified from the grey literature and enriched with new elements not yet studied:

- **Showcase**: a place or occasion for presenting something favourably to general attention. They are mostly applications that offer collectibles (NFTs, tokenised assets) and give users the possibility to show them to the community.
- **Lottery**: some DeFi Dapps implement a lottery by giving away tokens (both protocol and application) to promote the use of the application or the holding of application tokens. Tickets are usually purchased via tokens, the type of which changes depending on the service offered by the Dapp. For example, a DEX will use LP tokens as a means of purchasing tickets, thus incentivising liquidity providers to deposit in pools (see *Findings* for more details).
- **Governance rewards**: rewards generated in the form of application tokens that are distributed to users when they propose a change to the protocol or vote on proposals.
- **Staking rewards**: incentive designed to promote the "staking" of application tokens. Rewards are periodically distributed to users who stake their tokens, proportional to the amount of value they stake.
- **Suggestion rewards**: rewards for identifying critical issues in the smart contract or suggesting technical changes to the protocol.

The user incentives of each Dapp were defined by whitepapers, development documents on GitHub and, in the case of no document available, an empirical analysis based on the use of the Dapp.

Fee structure

This variable is the result of the reiterative process employed during the framework construction. A first analysis revealed a considerable number of applications using fees as a source of revenue. For this reason, a focus was made on this category. The classifications provided by several papers, both focused on blockchain and web 2.0, have been exploited to define the type of fee employed by the protocol, as follows:

- **Flat trading fee:** traditionally, a brokerage fee (or trading fee) is charged by a broker to execute transactions or provide specialized services. In the financial securities industry, a trading fee is charged to facilitate trading or to administer investment or other accounts. These fees are usually paid to DEXs and asset management services. However, a further description of a full description of how they are used and to whom they benefit will be provided in *Findings*.
- **Marketplace fee:** fee associated with the sale or purchase of a product or service on a decentralised marketplace.
- **Performance fee:** payment made to an investment manager for generating positive returns. This is usually employed by asset management applications which charge users on the profit (yield) they make through the service. This fee is generally subtracted in the form of tokens when the yield is distributed. Part of the fee goes to the strategist, who oversees the strategy for that pool.
- **Positive slippage:** specific case of DEXs aggregators. Formally, slippage occurs because of changing market conditions between the moment the transaction is submitted and its verification. A DEX aggregator is most likely not to charge fees but to gain from positive slippage.
- **Membership fee:** fee paid once or periodically for granting access to a service.
- **Transfer fee:** refers to the commission charged on withdrawals and deposits.
- **Interest rate:** amount that a lender charges for the use of assets (typically tokens) expressed as a percentage of the principal.
- **Generic fee:** all fees that are not widespread enough to be considered separately.

Fee/Rate

This parameter measures the exact cost of each fee, either as a percentage or as a figure, charged by each protocol. It is used to understand what impact the fee has on the degree of adoption of a decentralized application. This is critical in testing an assumption that many blockchain enthusiasts have been making: blockchain-based applications have no switching costs (Johnson, 2018). When a new service takes off, there are strong incentives for the market to consolidate around a single leader. This is especially true in multi-sided platforms, where the fact that more users are using the service attracts more players on the other side. In addition, the data that the platform possesses about its users creates a considerable lock-in effect.

This phenomenon would be avoided thanks to the blockchain that might record all its users' metadata that services like Uber or Amazon use to encourage lock-in. Users would then be able to move from one application to another without any difficulties. These assumptions, however, lack empirical research to support them.

Measuring the fees – the main cost of using a Dapp for a user – is therefore crucial in testing this premise. It allows to understand whether, if several apps offer the same service, the user base shifts or concentrates towards the one with the lowest fees. Furthermore, many scholars claim that the cost of using blockchain-based applications is low compared to traditional applications. However, even these studies are based solely on a few Dapps and lack solid empirical research.

The fee/rate of each Dapp was defined by whitepapers, development documents on GitHub, specialize websites, and, in the case of no document available, an empirical analysis based on the use of the Dapp.

Fee recipient

Given the high number of applications using fees as a source of revenue, this research explores the beneficiaries of this kind of revenue streams. This provides a comprehensive view of a Dapp's revenue model and further bridges the research gap on how decentralized applications creates value for their stakeholders. They are as follows:

- **Builders**: create, implement and support the protocol.

- **Suppliers**: provide capital or a core service to the functioning of the protocol. Those who receive a part of the fee collected by the protocol can be divided in:
    - **Liquidity providers**: contribute collateral or other assets to facilitate DeFi activity.
    - **Token stakers**: those who stake application tokens in certain liquidity pools according to the above-mentioned mechanisms.
- **Token holders:** represent both the **users** and the **governors**. They receive part of the fees for simply holding tokens in their wallet.
- **Treasury:** wallet dedicated to the collection of funds. Its use and control vary between projects and will be deepened in *Findings.*

Charged

In order to complete the analysis of revenue models, the actors paying for the use of the service offering a Dapp were identified. The categories into which they were divided did not come from the literature - which is currently lacking any such classification - but were formalised during the analysis. The actors that are charged are the following:

- **Borrowers**: actors that takes out a loan under an agreement to pay it back later, with interest.
- **Farmers**: those who participate in yield farming activities, staking or lending crypto assets in order to generate high returns or rewards in the form of additional cryptocurrency.
- **Sellers**: actors who sell crypto asset on marketplaces.
- **Traders:** actors who exchange crypt assets on DEXs.
- **Others:** other categories that are not widespread enough to be considered alone. They will be deepened in *Findings.*

Token distribution share

This variable assesses how the builders ensure a fair distribution of power, filling the gap of the literature about Dapps' governance systems. However, although the main purpose of this field is to assess how effectively Dapp developers decentralize its operation, the token distribution share finds implications also in the analysis of revenue streams. As seen above, tokens become a key tool through which value can be distributed, and their allocation proves to have a significant impact on the possibility of capturing it.

The first analysis identified three main actors that owns from the application token:

- **Builders**
- **Investors**
- **Community**

The distribution share was retrieved from whitepapers, official Dapp sites and developer documents on GitHub. CoinGecko, which shows the distribution of tokens on the main wallets, was used to check these data.

Ownership status

This field is intended to define who is currently[15] responsible for technical changes and upgrades to the Dapp. These include changes to smart-contracts, front ends, changes to Tokenomics, and to the operational logic of the application (e.g. protocol upgrades). This field is relevant regardless of whether the Dapp provides for a decentralized governance system.

As emerged from the literature, a Dapp may provide a distributed governance system through the use of one or more tokens. Token holders can either influence decision concerning the project or even changing the governance system itself. In many cases, the changes proposed, vetted, and then voted on through on-chain governance accessed by using governance tokens are applied automatically due to smart contracts. In other cases, the team maintaining the project is tasked with applying the changes or hiring someone who will. The actors who undertake to implement the will of the token holders are different from the latter and are henceforth formalised as “builders” as defined by the World Economic Forum (2021).

From the literature and from an initial analysis, it emerged that the use of a governance token by a Dapp does not necessarily lead to the holders being the actual

[15] At the time of analysis, April 2021

"owners" of the application. This fields provides a distinction between the different types of owners, formalised as builders as per literature:

- **Private company**: any type of business entity in "private" ownership with some differences from country to country.
- **Team of developers**: autonomous team of developers. The organisation of the team varies as well as its composition. It emerged from the research that the team is often anonymous and was therefore specified in the data collection.
- **DAO**: set of people interacting with each other according to a self-enforcing, open-source software protocol in the absence of bilateral agreements. In this case changes are voted and managed through outsourcing. Once a change has been voted on and approved, an open-source bounty[16] is created, assigned to an external developer who, once the change has been implemented, is remunerated with DAO tokens.
- **Foundation**: non-profit organisation that typically provides funding and support the development of a decentralized application

In the course of the analysis, cases emerged where the builders designed a roadmap for converting the organisation into a DAO, if it is not already one (e.g. MakerDAO). The mechanisms by which this is accomplished include: Tokenomics policies that reduce the owners' share of tokens over time, implementation of DAO governance mechanisms, and other techniques that will be contextually described (for further details please refer to *Findings*).

Where the protocol foresees the conversion of its organisational form into a DAO, this has been specified in the data collection.

Governance proposal

This fields refers to the possibility for a holder of one or more governance tokens to submit a proposal of any kind. This parameter will be included to shape the *Decentralization level* variable.

[16] Monetary reward for completing a task in an open-source software project

Decentralization level

There are no empirical analyses that show, starting from the observation of a real-world set of Dapps, which Dapps use governance mechanisms and at what level they are decentralizing their operations. As seen in the *Literature review,* a first classification on the decentralization level of governance emerged (World Economic Forum, 2021). Even though the scope of that study is limited to DeFi, the classification provided in this area does not have any particular characteristics pertaining to this field but is rather general. Moreover, there are no other classifications on this topic in the literature. For these reasons, the following categories have been extended to all Dapps studied, regardless of category:

- **Completely centralized**: only the development team that built the protocol can change any aspects of the system. An application falls into this category if it has not issued and does not plan to issue governance tokens in the future.
- **Partially decentralized**: only some aspects can be altered by governance token holders. In this case, the application has a governance token, but the token holders cannot make proposals for change.
- **Completely decentralized**: all aspects can be altered, and any token holder can propose changes. The application provides for a governance token and gives the possibility to make proposals to all holders of at least one token.

Given the research gaps, it was necessary to survey detailed information on how governance is managed by decentralized applications and, above all, at what level they actually decentralize their governance.

Chapter 4

Findings

In this chapter the empirical research is presented along with its most significant results. The analysis is divided into three main sections: the first one aims at describing the Dapp ecosystem, in particular showing which are the main sectors in which they operate, and which are having more success, trying to investigate the reasons why. This introduction is essential to contextualise the subsequent research questions and understand their implications. The next section focuses on business aspects, providing a comprehensive overview of the main revenue models. Finally, in the last section the investigation has addressed how blockchain-based applications are managed, focusing on governance systems and assessing to what level they are actually decentralised.

4.1 Overview

This census includes the first 112 decentralized applications[17] that are built on the blockchain. Despite accounting for only 3% of the total number of Dapps, at the time of writing (July 2021), this sample represents approximately 64% of the entire market in terms of users. For this reason, it is used to provide a global representation of decentralized applications through their components and key characteristics, as well as their operational and business choices, regardless of the service they offer and the category they belong to.

[17] In terms of number of active monthly users (AMU) in April

4.1.1 Services

The sample of applications was divided into six main categories, closely related to the service they offer. These were then explored further in an attempt to formalise the complexity that characterises the ecosystem.

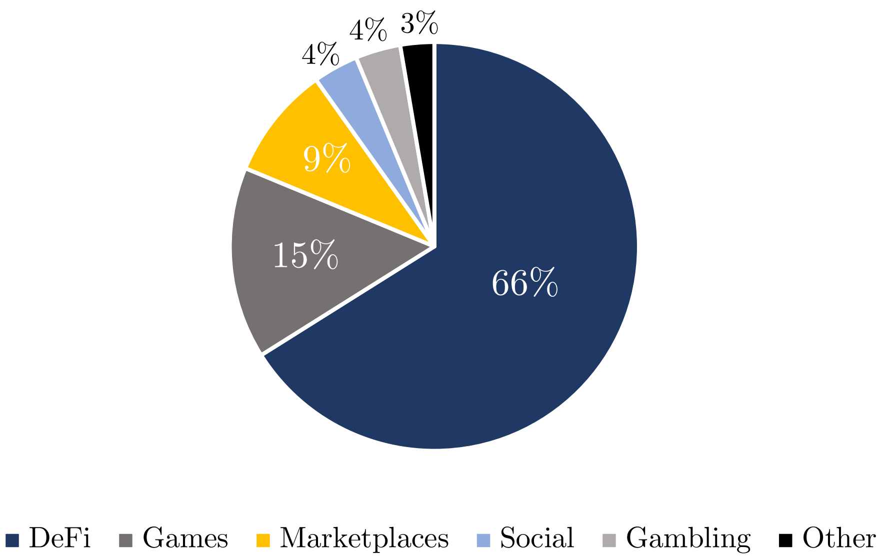

Figure 4.1: Distribution of Dapps by service offered

Most Dapps are concentrated in the decentralised finance sector with 66% of the total, followed by games (15%) and marketplaces (9%). Social networking applications and those offering gambling services equal each other with 4%. Finally, other applications that do not fall into any of the above categories as they are not widespread enough, account for only 3% of the total. In the course of the section, the different types of services will be analysed in more detail, but the overview in Figure 4.2 already shows the domain of the DeFi sector.

Analysing the number of users in April, it can be seen that the same ranking is maintained among the sectors, although the distribution changes considerably [Figure 4.3].

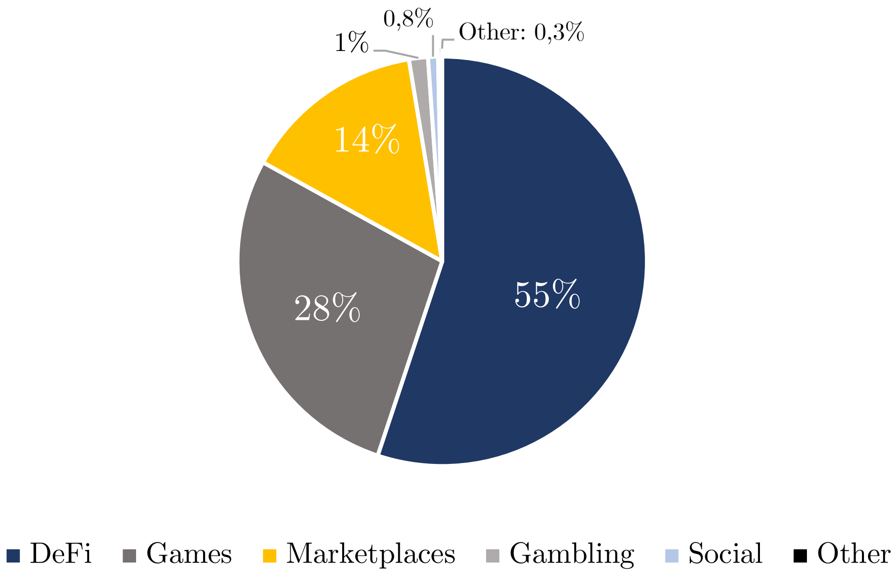

Figure 4.2: Distribution of AMU by service offered

Decentralized Finance

DeFi drops by 10%, although it remains first with over 50% of AMUs (Active Monthly Users). Proportionally, the number of protocols is higher than the level of adoption. The reasons behind this distribution are analysed below.

Category	% Dapp	% Users	User growth
DEXs	43%	72%	+ 41%
Asset Management	35%	15%	– 29%
Mutual	9%	4%	+ 32%
Aggregators	5%	4%	– 28%
Lending	3%	3%	+ 6%
Derivatives	3%	2%	+ 53%

Table 4.1: Distribution of Dapps, AMU, User growth by DeFi services

Table 4.1 highlights the different DeFi categories, analysing the number of application and the number, shown here as a percentage of the respective total. Due to the high number of applications in this category, it is possible to increase the level of detail while still ensuring a meaningful number of protocols per cluster. The distribution of users is more concentrated than the distribution of Dapps across categories, with 72% found on decentralised exchanges (DEXs). Finally, the analysis was extended by adding user growth over the period measured.

As mentioned in *Variable description* the number of users can be misleading, since it can depend on several factors and not only on the goodness of the protocol. In this regard, the degree of adoption can be related to the service the application offers. Moreover, it may also depend on the launch date of the smart contract or even on the target audience of the protocol – if it addresses a niche audience, the absolute number of users is likely to be less relevant. Growth therefore offers a relative metric that analyses the potential of a Dapp and the interest around it, thus complementing the above metric. In this respect, the best performing category is derivatives, which grew by 53% in just two months.

Decentralized exchanges

Decentralized exchanges are a class of DeFi protocol that facilitate the non-custodial exchange of on-chain digital assets. Based on the mechanism for price discovery, DEXs come in different variants, such as order book DEXs and automated market makers (AMMs). The latter provide liquidity algorithmically through simple pricing rules with on-chain liquidity pools in place of order books. In an AMM liquidity pool, reserves for two or more assets are locked into a smart contract, where for a given pool, each liquidity provider receives newly minted liquidity tokens to represent the share of liquidity they have provided.

The concentration of users in this category is partly due to the two main protocols in the industry, Uniswap and PancakeSwap, which are the top two apps for AMU. These two protocols account for 69% of all DEXs users and 50% of DeFi users.

In terms of user growth, decentralised exchanges prove to be able to attract an increasing number of users, a trend which burst out in July 2020 and appears not to be ceasing.

Asset management

When analysing Dapps offering asset management services, the number of users does not mirror the number of protocols. This category seems to be characterised by a greater number of applications in proportion to their users. Around 30% of Dapps in this category have seen their user numbers drop dramatically (-70% on average since February). Within a two-month period, these applications are not only no longer in the top 100 but are witnessing the demise of their user base. This situation is shared by most asset management protocols (58%), whose number of users dropped from February to April. Table 4.2 summarises the situation.

AMU Status	# Asset Management Dapp
Lowered AMU	58%
Retained or increased AMU	19%
New protocols (AMU = 0 in February)	23%

Table 4.2: Distribution of asset management Dapps by AMU Status

Only 19% of applications managed to maintain or increase their users. In the rest of the cases, the number of users has decreased, or new protocols have been introduced. Below is a brief description of asset management protocols and a possible explanation for this phenomenon.

Asset management protocols are decentralized investment funds that automate the management of on-chain assets. Tokens are deposited into a smart contract and an investment strategy that entails transacting with other DeFi protocols is encoded in the contract. Yield in DeFi is generated through interest (including accrued fees earned) and token rewards.

The analysis of the whitepapers showed that profit maximisation is becoming an increasingly complex activity. Due to the high volatility of the DeFi ecosystem and its novelty, yield farming strategies are constantly changing, sometimes even within a few days. This phenomenon is confirmed by what is shown above. Many protocols have disappeared or are disappearing as they have lost their competitive advantage (their strategies are no longer effective) and at the same time others have emerged to replace them.

The size of the other DeFi categories and their number of users does not allow for any kind of consideration to be made.

Decentralized Games

Another category worth exploring is decentralised games. They account for almost 30% of the total user base despite the relatively small number of applications (15%). The concentration of the sector is partly due to Alien Worlds, the first protocol for AMU, which represents only 6% of the total and gathers more than 77% of the users. The application increased by a factor of 33 within two months, making it the fastest-growing Dapp among those analysed, as well as the main app for AMU overall.

Alien Worlds represents an innovation since it embeds decentralised finance elements into the game. As described by CoinMarketCap:

> "NFT Defi metaverse that simulates economic competition and collaboration between players. This is achieved by incentivizing players to compete for Trilium [ed. native utility token of the application], which is required to control competing DAOs ("Planet DAOs") and to gain access to additional gameplay. Players can acquire NFTs (digital game items) to mine Trilium, engage in battles, and complete in-game quests. Depending on their strategy, players may purchase and assemble NFTs that best suit their gameplay. Additionally, players may engage in governance by electing the Councillors of six Planet DAOs, and thereby influence the direction of the game."

The size and number of users of the other categories of applications does not allow any considerations to be made at this stage of the analysis.

4.1.2 Blockchain Protocols

The following section analyses the blockchain protocols on which the smart contracts of the Dapps are written. Figure 4.3 shows the number of users and the number of applications for each protocol.

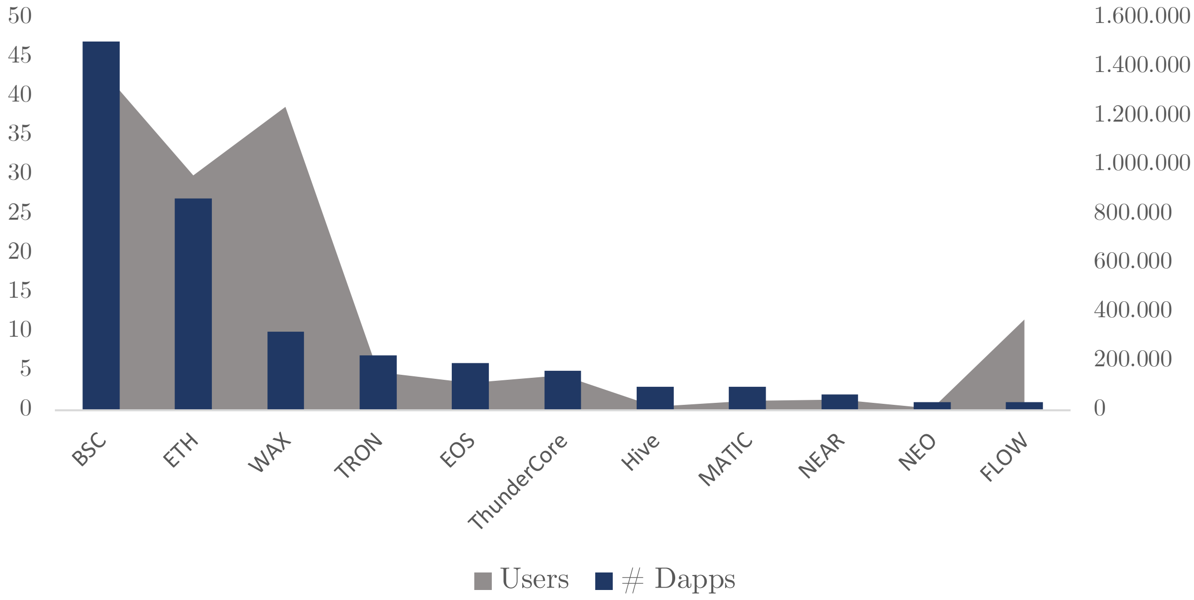

Figure 4.3: Distribution of AMU and Dapps by blockchain protocol

Binance Smart Chain (BSC) and Ethereum (ETH)

The blockchain that dominates the ecosystem is the Binance Smart Chain (BSC) both in terms of users (31%) and the number of applications running on it (42%). BSC is a blockchain platform parallel to the Binance Chain and compatible with EVM. The platform, directly supported by Binance, allows for very low transaction costs, but at the expense of a lower decentralization. It has grown rapidly thanks to the recent surge of DeFi, a category that represent 91% of all BSC Dapps. Its low transaction costs and high speed of processing make it particularly suitable for decentralized finance. This is particularly true when compared with the second most adopted blockchain, Ethereum.

As seen in the literature review, this protocol still must solve some scalability issues, which currently are making it cost prohibitive to use given the high gas fees. This is the main reason why the Dapp ecosystem is moving to this protocol. BSC being compatible with EVM allows copying many smart contracts components, without the need to write them from scratch. As confirmed by the analysis of whitepapers and other sources, these are the reasons why BSC has grown in a remarkable way, finding itself with more users than ETH, in the span of a few months.

However, the census shows that a substantial share of Ethereum Dapps is starting to adopt layer 2 solutions. Looking at ETH Dapps only, 48% have already implemented or plan to address the scalability issues of the Ethereum blockchain. Figure 4.4 shows the detail of these Dapps by dividing them into 4 main clusters.

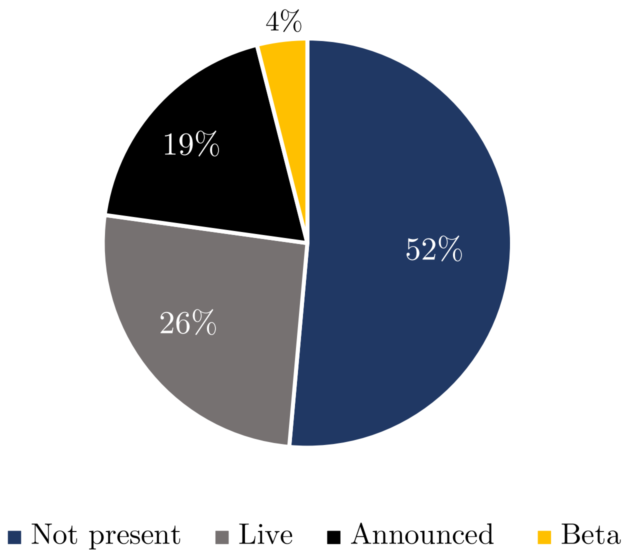

Figure 4.4: Distribution of ETH Dapps by Layer 2 solution status

26% of ETH protocols have already launched a layer 2 solution, while 4% are testing a beta version. In addition, 19% of protocols plan to launch their solution in the coming months. There is a strong interest among a significant segment of users in solving the problems that afflict Ethereum, without giving up its inherent decentralisation and security (as is the case for users and applications that have switched to BSC).

WAX and FLOW

The third protocol in this ranking is WAX (Worldwide Asset eXchange), a Blockchain platform designed to allow users to exchange videogames items and collectibles on a decentralized marketplace. It owes its success to Alien Worlds which accounts for 18% of its total users[18].

The other blockchain protocols are fairly aligned in terms of the number of applications and users. Among these, FLOW stands out, a Proof-of-Stake Blockchain created by Dapper Labs specifically developed to support the implementation of gaming Dapps and the exchange of NFTs and digital collectibles.

The reason why it enjoys such a high number of users compared to other Dapps on the FLOW protocol is because of its founders, the creators of Cryptokitties, NFT game that congested the Ethereum network in 2017, causing it to reach an all-time high in the number of transactions and slowing it down significantly. This event prompted the development of FLOW as an alternative in order to support NFT collectibles and large-scale crypto games. On the FLOW protocol, NBA Top Shot was launched, the only decentralized application on this blockchain[19], which constitutes 8% of the total users. NBA Top Shot is a digital collectibles marketplace where users can buy, sell, and trade NBA "moments" in the form of officially licensed and numbered video highlights.

Protocols by category

Figure 4.5 shows how the Dapp services are distributed across the different blockchain protocols. The number of Dapps in each category is shown as a percentage of the total number on the protocol. If the number of Dapps had been normalised to the total of the category, the results would have been highly influenced by the distribution of Dapps on each protocol which, as seen above, is highly concentrated. NEAR, NEO and FLOW were not considered as they did not collect a significant number of applications.

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[18] Computed considering all Dapps on the WAX protocol

[19] Overall, there are 5 Dapps on the FLOW protocol at the time of writing (July 2021)

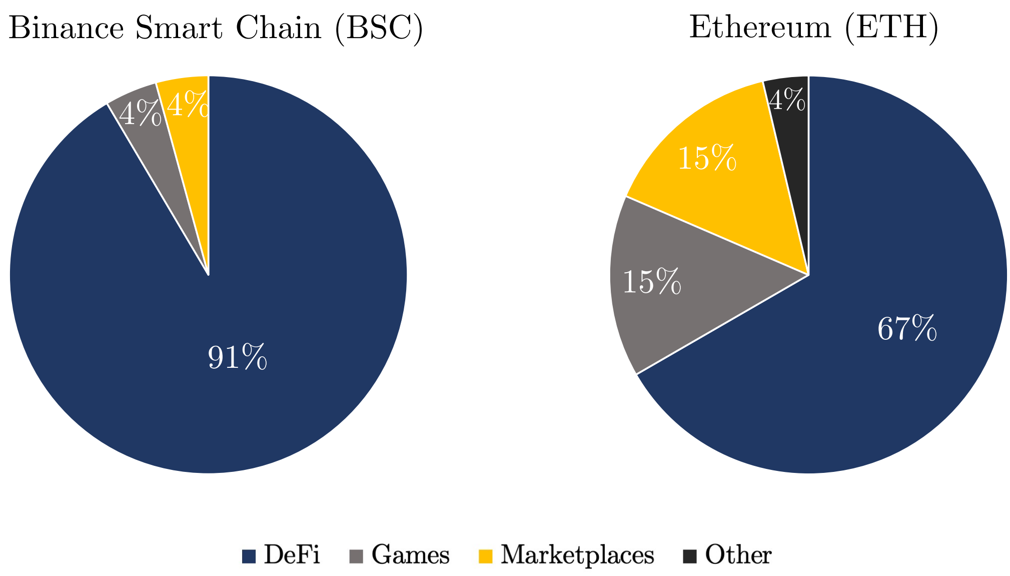

Figure 4.5: Distribution of Dapps by service offered (BSC and ETH)

The distribution mirrors the considerations made earlier about Binance Smart Chain, which is mainly used for decentralised finance (91%). Ethereum enjoys a more homogeneous distribution, although DeFi remains the main category (67%). These two protocols do not have any gambling and social networking applications. The latter are concentrated in the Hive protocol, which support 50% of them thanks to its native features.

The Hive platform runs on a Delegated Proof-of-Stake consensus mechanism, using a staking scheme to eliminate transaction fees. Hive has three native cryptoassets that run on it: HIVE, HIVE Power, Hive-backed dollars. HIVE is the main cryptocurrency; HIVE Power is voting influence that is awarded for staking HIVE; Hive-backed dollars is a stablecoin pegged to the USD. The protocol has a decentralized treasury managed by all users of the platform, rewarding content creators based on community voting.

As for WAX, it retains the characteristics for which it was designed, with 50% of its applications represented by Games and 30% by Marketplace.

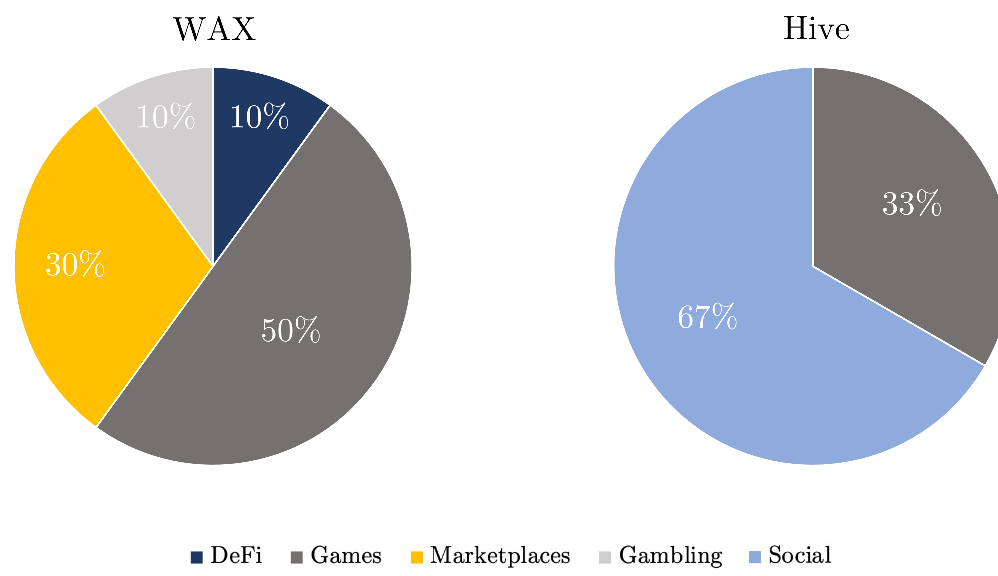

Figure 4.6: Distribution of Dapps by service offered (WAX and Hive)

Finally, it is worth mentioning MATIC which is used solely for decentralized finance. Formerly known as Matic Network, Polygon is an interoperability and scaling framework for building Ethereum-compatible blockchains. As an Ethereum sidechain, Polygon is designed as a platform for launching interoperable blockchains. Although the dataset shows that the solution has not yet reached a large enough adoption, it holds great potential and by solving Ethereum's scalability problems, could win back a share of the DeFi that had been lost to BSC.

4.1.3 Funding

This section discusses the funding leveraged by the ecosystem. For the purposes of the analysis, the different sources of funding were analysed, and formalised into two categories: token launch and traditional funding

- ICO, IEO, airdrop, token sales: collected from the field *Crowd sale and token launch.*
- Traditional funding: funding from traditional investors, which may be hedge funds or venture capitalists, raised from the field *Other sources of capital.*

	%Dapp	%Users	Avg investment	Avg investment (w/o top 1)
Token launch	10%	58%	\$6.5 mln	\$3 mln
Traditional funding	22%	32%	\$28 mln	\$13 mln

Table 4.3: Distribution of Dapps, Users and investments by type of funding

Among the Dapps analysed, only 10% of them sold pre-minted tokens at the time of launch through the above-mentioned strategies [Table 4.3]. These Dapps managed to raise an average of \$6.5 million. Among them, Synthetix, one of the most promising projects in the DeFi field, was able to raise \$30 million on its own, and WINk, a gambling application, raised \$16 million by selling its tokens. Without considering these two players, the average funding halves to \$3 million. Analysing the number of users of these Dapps, it becomes evident that, although the protocols that exploited the sale of a token to finance themselves are rather limited, they were able to attract the majority of users (58%). However, this discrepancy is mainly due to Alien Worlds, the outlier described in the previous chapters, without which the number of users drops to 30% of the total. The number of users of Dapps financed through token launches therefore remains above average.

Funding increases both in number and volume when analysing traditional investors. About 22% of Dapps are financed by these actors, most often in the form of venture capitalists (96%). The average funding of these protocols amounts to \$28 million. However, this figure is strongly influenced by the investment raised by NBA Top Shot, which alone represents 55% of the total investment made by traditional investors. The founding company, Dapper Labs, building on the success of Cryptokitties, enjoys great confidence from its investors, thanks also to the recent surge in NFTs and the collectibles market. Without taking this application into account, the average investment drops to around \$13 million. Even in the case of traditionally funded Dapps, the number of users that they are able to attract is higher than average, reaching 32% of total users.

4.1.4 Industries

The industries in which the Dapps operate is an important element to determine whether there are business areas that more than others are developing blockchain-based solutions.

Industry	**% Dapp**
Finance	66%
Media, Arts & Entertainment	32%
Gambling	4%
Communication services	4%
Other	3%
Insurance	2%

Table 4.4: Distribution of Dapps by industry

The most developed sector is Finance, which dominates the landscape with 66% thanks to the recent DeFi boom, followed by Media Arts & Entertainment with 23% of the total. The reason why the number of Finance Dapps is lower than the number of Dapps revolving around DeFi lies in Insurance apps, which have been classified separately in this section and make up 2% of the total [Table 4.4].

The remaining 9% is distributed in the categories Gambling, Communication services – which mostly includes social networking applications – and Other. The latter category includes three applications that offer particular services that cannot be formalised: Atomic Market, Bankroll Network, and Pulse. The former provides a shared liquidity NFT market smart contract, the second is a hybrid between DeFi and gaming with gambling components and finally, Pulse is an open-source application for prediction markets.

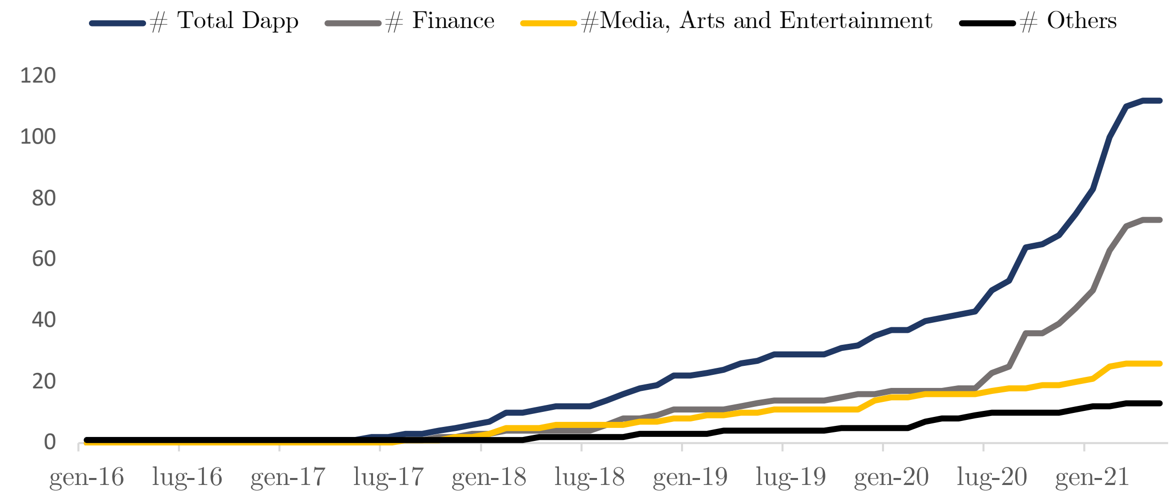

Figure 4.7: Cumulative frequency of Dapp launches by industry (Gen 16 - Apr 21)

Figure 4.7 shows the distribution of Dapp releases over time considering the last 5 years. Among the most successful Dapps in terms of users at the beginning of 2021, only 5% were founded between 2016 and 2017. Although at the end of 2017 the number of decentralised apps launched was around 800 (State of the DApps, n.d.), only 6 of these managed to maintain their user base and competitive advantage to be among the top 100 at the time of writing. The following months until July 2020 witness a steady increase in all categories with some peaks. From then until April 2021 there was a boom in the number of applications launched, generating half of the protocols in the dataset (55%). Breaking down the total into three categories, *Media, Arts and Entertainment* and *Other* (which in this case includes *Gambling*, *Communication services*, and *Insurance*) do not undergo any particular changes, but rather maintain a constant increase.

The industry responsible for the surge of Dapps is therefore Finance. In particular, DeFi has played a key role in boosting the number of protocols and driving adoption. Of the DeFi applications developed during this time span, 68% are built on the Binance Smart Chain, which in just a few months has managed to overtake Ethereum both in terms of number of protocols developed and user base.

4.1.5 Token

In this section of the analysis, technical aspects are addressed. The literature review has identified gaps in the token argument, highlighting the need to more in-depth studies describing the role of tokens in Dapps business models. Although the framework used classifies tokens according to technical characteristics, emphasis has been placed on the role that tokens play in the operations of a decentralised application.

Category	% Dapp with tokens	% Dapp w/o tokens
DeFi	89%	11%
Games	29%	71%
Marketplaces	20%	80%
Social networks	50%	50%
Gambling	25%	75%
Other	67%	33%

Table 4.5: Distribution of Dapps by service offered (w/ and w/o tokens)

Table 4.5 shows the development of application tokens among the Dapp categories. Overall, 70% of them make use of at least one application token. However, this distribution is influenced by the number of Dapps per category, whereby DeFi once again plays a key role. Decentralized finance uses an application token 89% of the time, representing the only sector that counts more Dapps using a token compared to those that do not. In fact, Games and Marketplaces account for a lower usage, with only 29% and 20% respectively. Even Gambling applications for the most part do not use tokens (75%), while social sees an equal distribution with 50% of applications developing an application token.

In an attempt to investigate the reasons behind this distribution, the analysis was deepened to include different token typologies. At this stage the token referred to is the main application token. If the Dapp have issued more than one, only the main one was considered for analysis.

Formalised definitions as per the literature review are given below for clarity:

- **Utility token:** these are intended to create the economic incentive within a platform to enable the use of the service, to pay transaction fees or to allow an exchange of value between users.
- **Governance token:** fungible tokens which entitles token holders to participate in protocol governance via voting on and possibly proposing protocol updates. This type of token will also be included in subsequent metrics to investigate research gaps in governance systems.

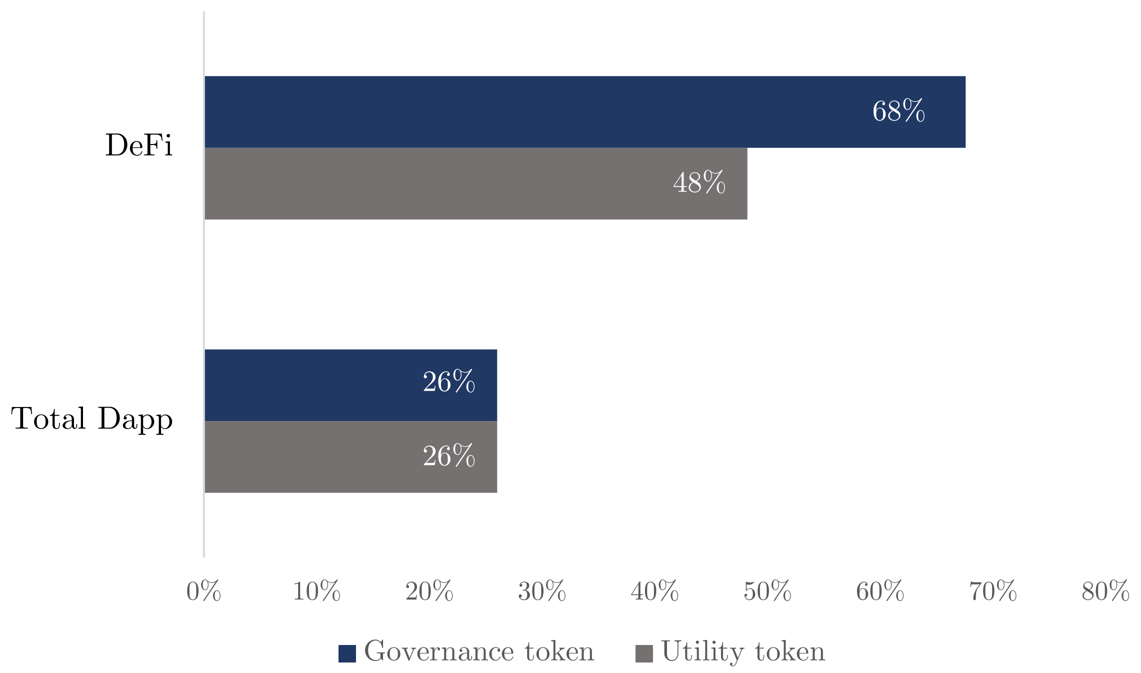

Figure 4.8: Distribution of Dapps by token typology (DeFi and Overall)

Figure 4.8 shows the use of utility tokens and governance tokens by all Dapps and DeFi Dapps. The analysis of asset tokens will be dealt with separately. As discussed in *Literature review*, the functions of a token may overlap, so the sum of the percentages may exceed 100%. Although Dapps offering DeFi services use application tokens extensively as seen above, it appears that this is not the case with utility tokens, which see little use by these applications (48%).

In order to provide a greater level of detail and attempt to motivate the differences between the use of token types, the analysis was extended by considering the different categories of DeFi [Table 4.6].

DeFi category	% Dapp with utility token
DEXs	24%
Asset Management	32%
Mutual	100%
Aggregators	0%
Lending	0%
Derivatives	100%
Collectibles	100%

Table 4.6: Distribution of Dapp w/ utility token by DeFi category

Aggregators and Lending applications do not make use of liquidity tokens. In the first case the protocol is limited to allow users to move between DeFi services, such as choosing an exchange based on real-time market factors; not redistributing any kind of fees, nor allowing the exchange of value between users. The Lending applications analysed distribute interest rates as tokens of the same type as those deposited by liquidity providers. Similarly, borrowers repay the loan plus accumulated interest with the same type of tokens they borrowed. The application token, therefore, has no role in currency exchange or fee redistribution.

Asset management applications and decentralised exchanges also use utility tokens in a few cases, in 32% and 24% of cases respectively. Here again, an explanation can be found by analysing the functioning of the two categories. Both protocol types collect and redistribute – in most cases – fees or yields in the form of LP tokens.

When tokens are deposited into a liquidity pool, the platform generates a new token that represent the share the depositor owns of that pool. This is called liquidity provider (LP) token, and it can be used for a multitude of functions both within its native platform and other decentralized finance applications. A trading fee is retained by a liquidity pool and paid out proportionally to the amount of liquidity provided by each liquidity token holder. Liquidity providers are required to give up their liquidity tokens in order to redeem their share of liquidity and accrued fees.

The other categories of applications all use utility tokens (100%) either to create an economic incentive within the platform (Derivatives) or to pay transaction fees (Collectibles and Mutual).

Governance tokens have not been analysed in detail as they do not depend on the characteristics of the service but rather on the choices made in the development phase. For this reason, they will be dealt with in depth in the next sections.

Category	**%Dapp w/ utility token**	**%Dapp w/ governance token**
Games	80%	12%
Social network	100%	20%
Marketplaces	100%	0%
Gambling	100%	0%

Table 4.7: Distribution of Dapps by token typology and service offered

Table 4.7 shows the distribution of utility tokens and governance tokens. The application tokens of all Games, Gambling and Marketplaces serve as utility tokens (100%) and see a consistent number of cases among Games as well (80%). In contrast, these applications do not benefit from decentralised governance, and the use of governance tokens is very low.

While the above analysis accounted for the application tokens of each Dapp, referring to the main one, the analysis of the remaining token type – asset token – was extended by taking into account all tokens used by each Dapp. In fact, as emerged from a first examination, in no case is the main token of the application an asset token, which from the literature review was defined as:

- **Asset token:** they represent the ownership of something that has a value. Typically, they are the digital representation of a real-world asset on the blockchain.

Category	% Dapp with asset token
DeFi	9%
Games	6%
Marketplaces	0%
Social networks	0%
Gambling	0%
Overall	**8%**

Table 4.8: Dapp distribution by service offered (Dapp w/ asset token only)

The category with the highest number of decentralised applications using asset tokens is decentralised finance (9%), followed by the gaming sector with 6% [Table 4.8]. None of the applications surveyed from the other sectors make use of this type of token.

The results of the token fungibility analysis are presented below. As in the case of asset tokens, all tokens used by a Dapp were considered, not just the main one. This way, if for instance a DeFi application used a governance token but at the same time allowed the exchange of NFTs, it would be reflected in the analysis.

Category	% Dapp that support NFTs
DeFi	15%
Games	71%
Marketplaces	100%
Social networks	0%
Gambling	0%
Other	33%
Overall	**30%**

Table 4.9: Dapp distribution by service offered (Dapp that support NFTs only)

Table 4.9 shows the percentage of decentralized applications that support NFTs. The analysis shows a considerable number of adopters, who make up 30% of the total. The categories that make most use of NFTs are Marketplaces (100%), where they are exchanged, and Games (71%) that often include NFTs in their gameplay.

Another category that has implemented NFTs as part of its service is DeFi, which in 15% of its protocols allows the exchange and sale of collectibles, in an attempt to attract users and promote the use of the application.

4.1.6 Market capitalization & Total Value Locked

This section presents the results of the analysis of the market capitalization of application tokens. This metric tracks the market value of a given token and is a widely used indicator as it indirectly measures its usage and popularity. Available sources measure market capitalisation for only 32% of the protocols analysed, of which 90% belong to decentralised finance. The average market cap as of 1 March 2021 is $630 million [Figure 4.9], of which the first 8 Dapps are above 1 billion.

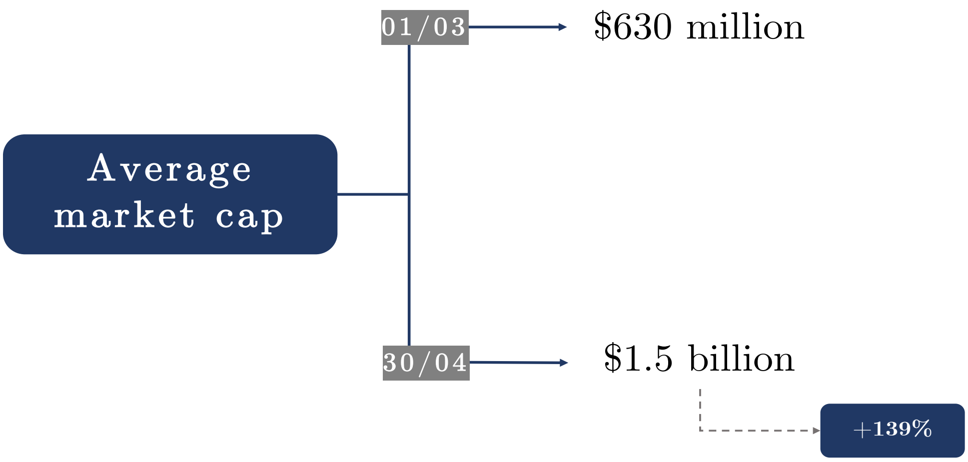

Figure 4.9: Average market cap (01/03 and 30/04)

It is worth mentioning Uniswap – the first protocol in terms of number of users – with a capitalisation of 6.9 billion, and Aave – one of the most important and innovative lending applications on the landscape – with a market cap of 4.4 billion. After two months, the average market capitalisation touches 1.5 billion, increasing by 139%, in line with the rise of the user base, which for these applications has increased by 58% on average.

Average increment market cap: 99% | **Average increment users:** 5%

However, when analysing the evolution in terms of adoption and market capitalisation for each individual app, a substantial difference can be seen. Measuring the variation for each Dapp and calculating the average of such values allows to reduce the impact of protocols with a high number of users (or a high market cap value) as well as those that have experienced high growth.

This results in an average 99% increase in market capitalisation, which is below the average total increase. One of the reasons for this difference are the protocols whose application tokens saw a decline in their market capitalization (20% of the sample measured). In addition, some applications increased more than others, including Axie Infinity – a collectibles game that increased by a factor of 7 – PancakeSwap (5x) – DeFi's first application on the BSC – and Uniswap, which, with a 3x increase, retains the top position in this metric. In terms of users, there was a variation of +5% (considering only this sample for which mkt cap was measured).

Hypotheses can be drawn on the reasons for the difference between market cap and number of users: the increase in market capitalisation may be due to an appreciation of the tokens as a result of increased usage by the user base, which in the meantime has remained almost unchanged. Another possible explanation is an increase in the circulating supply caused by the issuance of more tokens by Dapps.

However, according to this assumption, the price of tokens should have remained constant, thus implying an increase in demand (due to increased usage). The third hypothesis takes into account the possibility of trading these tokens within AMMs, which, similar to what happens in traditional finance, causes the price of tokens to soar without being directly affected by the performance or use of the corresponding applications.

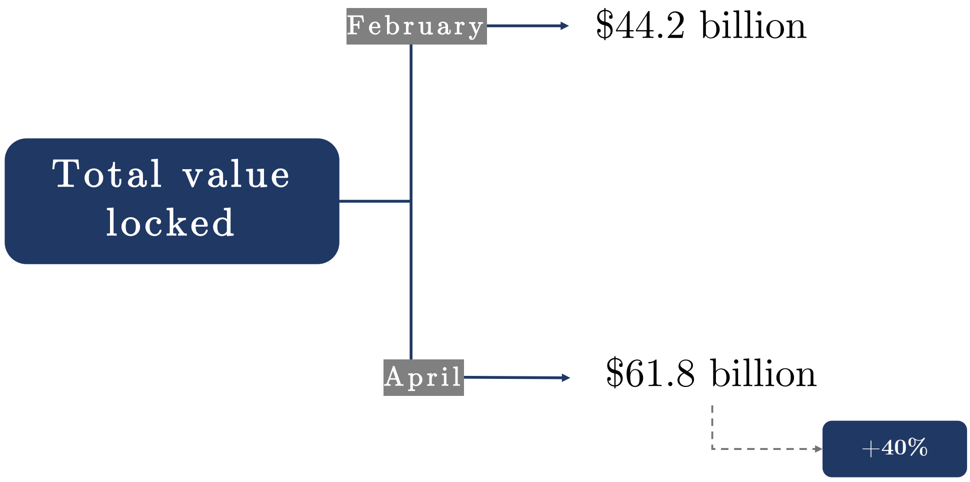

Figure 4.10: Total value locked (February and April)

Figure 4.10 shows the aggregate TVL in each period. Since this metric represents the amount of assets that are currently being staked in a specific protocol, the application measured belongs all to DeFi. However, due to the lack of data, only 51% of DeFi protocols were analyzed according to the methodology described in *Variable description*. For this reason, the TVL was not used to assess Dapp adoption but rather to draw qualitative considerations.

As in the case of market capitalisation, there is a significant increase in both the aggregate total (+40%) and the average (+165%). Among the first applications for TVL are Lending solutions and DEXs, the two types of service with the highest number of blocked funds.

Analysing these applications with a qualitative approach, it can be seen that Lending applications stand out in a particular way, collecting a higher TVL than the other DeFi protocols (+331%). According to the literature, TVL is often subject to criticism since a handful of users are responsible for most of the usage of DeFi Dapp. Thus, it's important to look at the total number of users to complement total value locked and provide a more holistic view of DeFi adoption.

DeFi category	% Users over DeFi users	% TVL over DeFi TVL
Lending	3%	35%
DEXs	72%	47%

Table 4.10: Distribution of AMU and TVL by DeFi category

In order to test this assumption, the TVL was compared with the number of users [Table 4.10]. In the case of lending protocols, a substantial difference emerges between the number of users, which constitutes 3% of DeFi users, and TVL, 35% of the aggregate TVL. To make a comparison we consider DEXs, the protocol type that excels in TVL. These Dapps collect 72% of DeFi users but are responsible for only 47% of the aggregate TVL. This substantial difference cannot be justified simply by the fact that lending protocols require more liquidity than others – which is not proven by any empirical analysis.

The most likely hypothesis, also supported by the literature, is a particularly concentrated use when considering DeFi applications. However, this does not imply a high concentration of users per number of applications, which is in fact not confirmed by the numbers above – DeFi applications are proportionally more than the number of users (66% of the total Dapps vs. 55% of the total users). The concentration refers to a large number of tokens per number of users, to the extent that some label decentralized finance as a *whale*[20] *game*. Results suggest that this assumption is particularly true for Lending protocols, whereas it does not apply to the other categories. For an in-depth analysis of this research stream, however, a larger sample

[20] Whale is informally referred to heavily invested token holders

of applications and dedicated surveys would be required, falling outside the scope of this thesis.

4.2 Revenue models

This section takes a closer look at the revenue models and user incentives implemented by decentralized applications, with the aim of answering the research question "What are the revenue models adopted by Dapps?".

As mentioned in the literature review, the revenue model is defined as a framework for generating financial income: it identifies what are the sources of revenue, what value to offer, how to price the value, and who pays for the value (Afuah, 2004).

The value proposition – what value to offer – has been partly described in *Overview* in terms of service offered by different categories of protocols. This section aims to conclude the description of the value offered and to describe extensively the sources of revenue. Then the stakeholders – who pays for the value – will be presented together with qualitative considerations.

4.2.1 Revenue streams

In an attempt to formalize and better structure the framework, the revenue streams were divided according to the stakeholders involved. In particular, they were split according to which stakeholders benefit from them. The literature review identified two main cluster of stakeholders, divided according to the value they are able to capture. The first category refers to the builders, the actors who create, implement, and support the protocol.

The second type of revenue streams refers to the source of revenue affecting the remaining three stakeholders: users, suppliers, and governors. Since these three categories represent the main pool of stakeholders, both in number and in volume, this variable is referred to as the Dapp revenue stream.

Revenue streams Builders

Starting from the analysis of builders, the main business solutions are examined in an attempt to understand how they bring value.

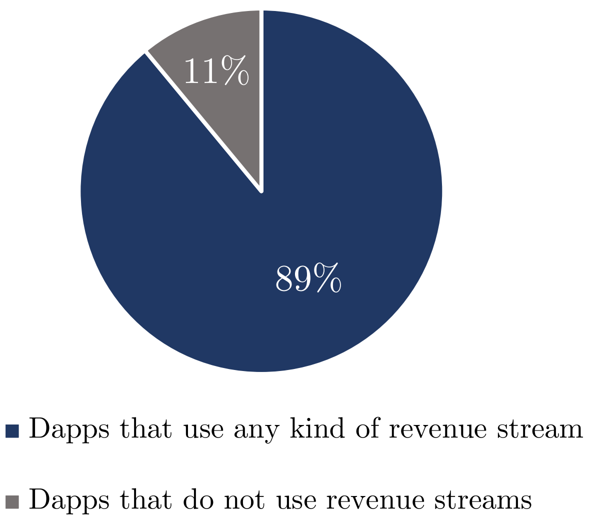

Figure 4.11: Distribution of Dapps by revenue stream usage

Figure 4.11 compares the protocols that implement a revenue stream with those that do not provide any kind of economic return. Several reasons have been identified as to why some Dapps do not feature any kind of revenue stream. Some applications are video games with a bare interface and simple game mechanics (e.g. Galaxy Blocks, a copy of Tetris.). These are created by anonymous developers who have not provided an application token or any kind of value capture mechanism.

Other cases include infrastructural services, offered by private companies to incentivise the use of other applications or platforms. An example is Venus, a lending application developed by Binance, where no tokens were assigned to its builders. Finally, builders can act as users or other types of stakeholders and benefit from revenue streams dedicated to them (for further details please refer to *Revenue streams Dapp*).

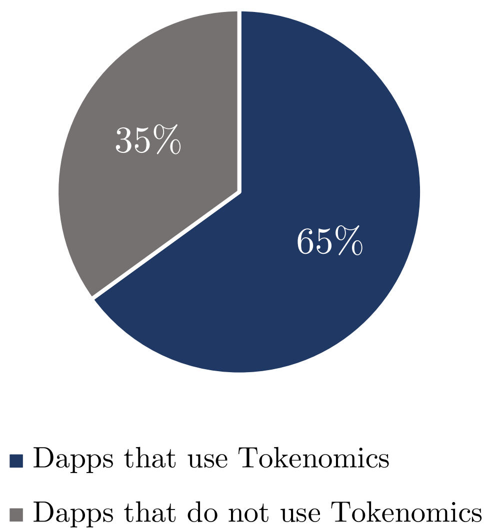

Figure 4.12: Distribution of Dapps by Tokenomics usage

The most common revenue stream is Tokenomics (65% of Dapps), in which application token holders gain from the appreciation of token value or from receiving inflationary rewards. This proves to be one of the easiest strategies to implement, with no cost passed on to users. Developers simply hold on to a portion of the application tokens – which are priceless at the time of issue – and wait for it to appreciate through trading or use of the protocol.

To support this reasoning, the analysis also considered the average token distribution. Although this variable has been introduced to investigate governance systems, discussed in the next chapter, it is here helpful in assessing the extent to which builders exploit Tokenomics.

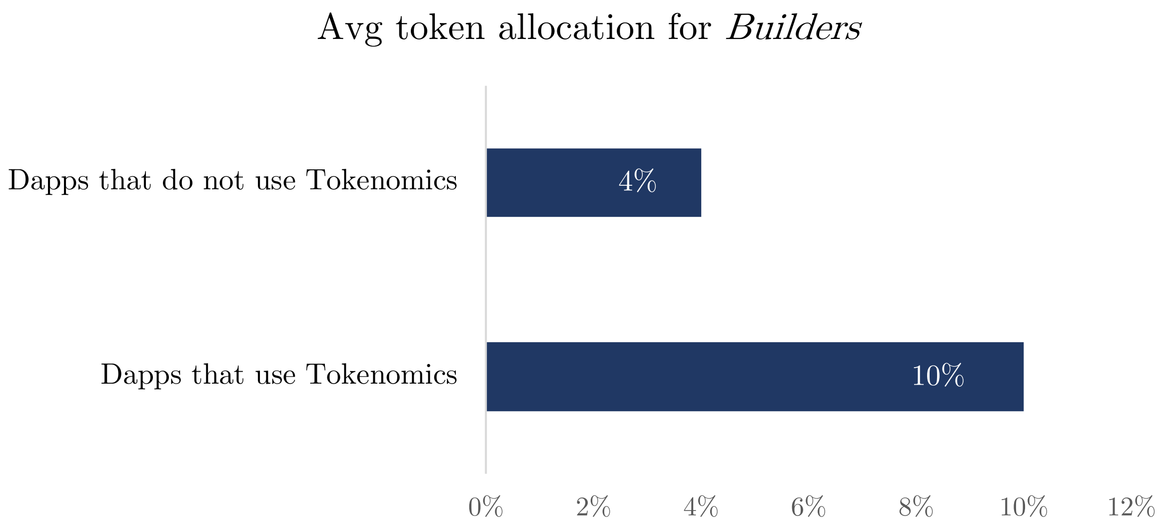

Figure 4.13: Avg allocation for builders by Tokenomics usage

Figure 4.13 shows the share of application tokens allocated to developers as a percentage of the total for each Dapp. It can be seen that builders developing applications that exploit Tokenomics retain a larger amount of application tokens, with an average token count of 10%. Protocols that do not take advantage of this mechanism distribute an average of only 4% of their tokens to builders.

This type of revenue stream is closely associated with the choice of implementing a token in the functionality of the protocol which can be either a utility token or a governance token. Consequently, the type of service offered and the organisational form of a Dapp, which are both decisive for the presence of a token, influence the use of Tokenomics.

The following is an analysis of the various categories, already introduced in *Overview*, and the percentage of protocols using Tokenomics out of the total category.

Category	% Dapp that use Tokenomics
DeFi	84%
Social networks	75%
Gambling	25%
Marketplaces	20%
Games	18%
Other	67%

Table 4.11: Distribution of Dapp by service offered (Tokenomics only)

The two categories that stand out are DeFi, which uses Tokenomics in 84% of its Dapps, and Social, with 75% of cases [Table 4.11]. The extensive use of tokens for these applications – both governance and utility – makes them particularly well suited to leverage Tokenomics. The same reasoning does not apply to the other categories of applications, whose cases decrease considerably. Finally, those clustered in "Other" are categories with smaller shares, too small to be considered individually, which in 67% of the cases gain from the appreciation of the application token.

Type of builders	% Dapp that use Tokenomics
DAO	89%
Team of developers	73%
Foundation	67%
Private company	54%

Table 4.12: Distribution of Dapps by type of builders (Tokenomics only)

Moving on to the ownership status [Table 4.12], DAOs are the organization in which Tokenomics occurs most frequently (89%), followed by teams of developers (73%) and foundations (67%). Private companies that develop Dapps do not see Tokenomics as a revenue opportunity, making use of it in only 54% of cases.

One of the reasons for this choice lies in the volatility and uncertainty of the token's value. There is no guarantee that the value of application tokens will increase steadily over time. The price is often subject to strong fluctuations due to market developments and trading in AMMs. Moreover, if the application does not achieve widespread adoption, the price of the application token may be limited.

For these reasons, Tokenomics is often combined with other means of creating value, as shown in Figure 4.14.

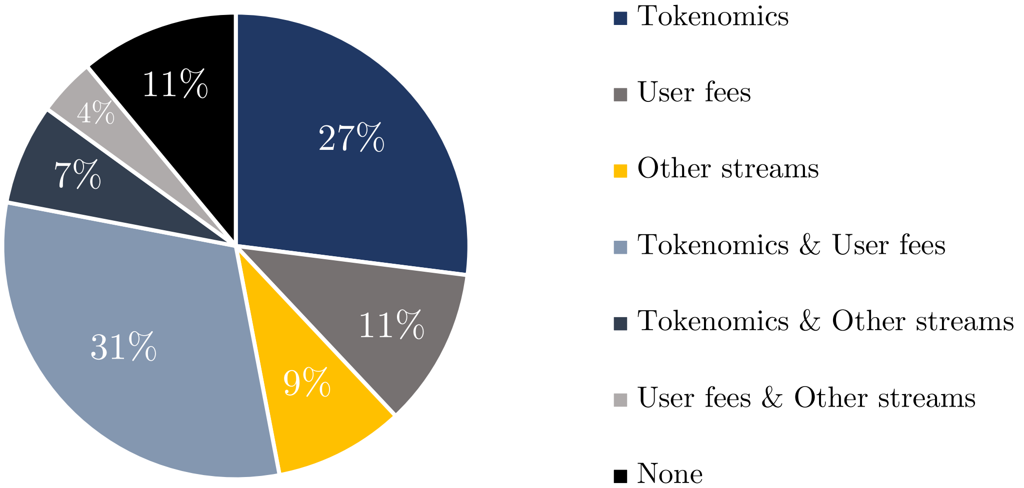

Figure 4.14: Distribution of Dapp by revenue stream

As a result, it appears that only 27% of Dapps are based exclusively on Tokenomics. Most protocols not only rely on the appreciation of their tokens, but also charge fees to their users (31% of Dapps). Moreover, 11% of protocols reward builders with just this stream. The remaining value capturing mechanisms consists of the "Other" cluster, a set of revenue streams that are not widespread enough to be considered individually. These are divided into:

- **House-edge**: predominantly used for gambling Dapp, it is a mathematical advantage that the game has over the user. This is built into the logic of the smart contract and therefore results in a guaranteed percentage return over time. All gambling applications are mainly based on this model, although some employ also Tokenomics. The limited number of such applications doesn't allow to further considerations to be made.

- **In-app sales**: as its web 2.0 counterpart, it refers to the selling of goods and services from inside an application. All applications that exploit this approach are games that feature collectibles or NFTs in their game mechanics, or that adopt the freemium model by giving the possibility to buy in-game resources to make faster progress. There are also a few cases of marketplaces which, in addition to charging fees for the transactions sell products generated by the builders, thus exploiting in-app sale (e.g. NBA Top Shot).

For the sake of completeness, two protocols that rely on advertising as their main source of revenue are also reported here: Steemit, a decentralized social network and one of the first apps founded, and Hive Blog, a social network running on the HIVE protocol.

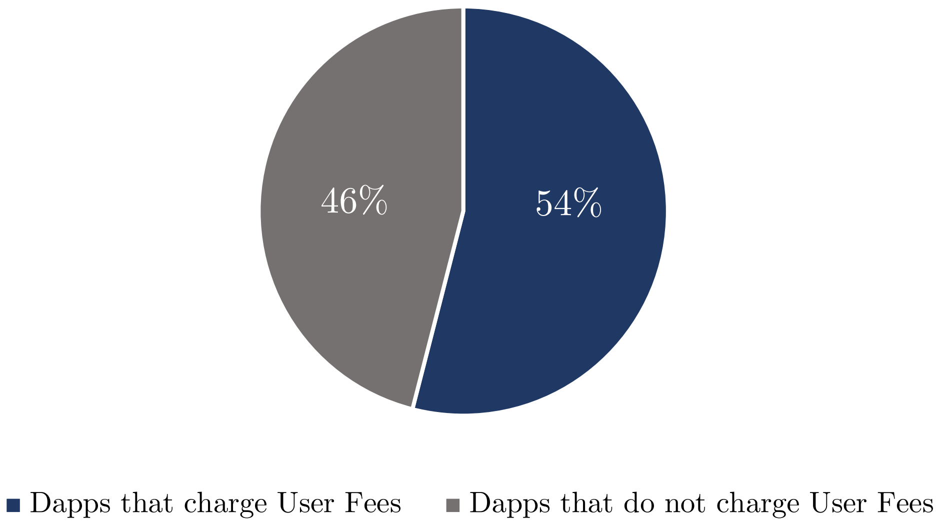

Figure 4.15: Distribution of Dapp by whether they charge User fees or not

The following section deals with another revenue model widely used by blockchain-based applications: user fees. Figure 4.15 shows how many Dapps charge fees to their users (46% of all Dapps analyzed). This section deals with protocols that distribute the collected user fees (or part of them) to builders

Category	% Dapp that charge fees
Marketplaces	70%
DeFi	57%
Games	24%
Gambling	0%
Social networks	0%
Other	0%

Table 4.13: Distribution of Dapp that charge fees by service offered

When analysing the different categories, marketplaces use this revenue stream extensively (70% of the marketplaces analysed). As seen above, this category makes little use of Tokenomics (20%) and therefore relies on this ploy to capture value. The functioning of web3 marketplaces, which involve the development of a blockchain-based platform where users buy, sell and exchange objects, is the reason why 70% of these choose to charge fees.

Applications offering financial services charge fees to users 57% of the time. DeFi, enjoying a high number of transactions, is particularly suitable for charging fees. The type of transactions and the rates charged will be explored in the next section *Stakeholder & User fees*, in an attempt to formalise the complexity that characterises the ecosystem.

Finally, the last category that uses fees are Games, of which only 24% choose to capture value this way. This may be motivated by the fact that their operation does not involve a large number of transactions, which occur when users exchange items or when the app sells items to its users. Builders decide to take advantage of the latter scenario and leverage in-app sales, which in fact involve 78% of games.

The other categories do not charge any fees as they rely on other revenue streams. As seen above, gambling applications all exploit house-edge, social networks leverage Tokenomics, while the other cluster will be explored in the next sections.

Type of builders	% Dapp that charge fees
DAO	56%
Private company	48%
Team of developers	44%
Foundation	33%

Table 4.14: Distribution of Dapps that charge fees by type of builders

The use of user fees by different types of builders is more evenly distributed. As seen above, the presence of this revenue streams depends mainly on the Dapp category. The distribution between the types of builders is therefore reflected in the types of application they develop.

Revenue streams Dapp

This section explores the revenue streams addressing the remaining three types of stakeholders: users, suppliers, and governors. Since these three categories represent the main pool of stakeholders, both in number and in volume, this variable is referred to as the Dapp revenue stream.

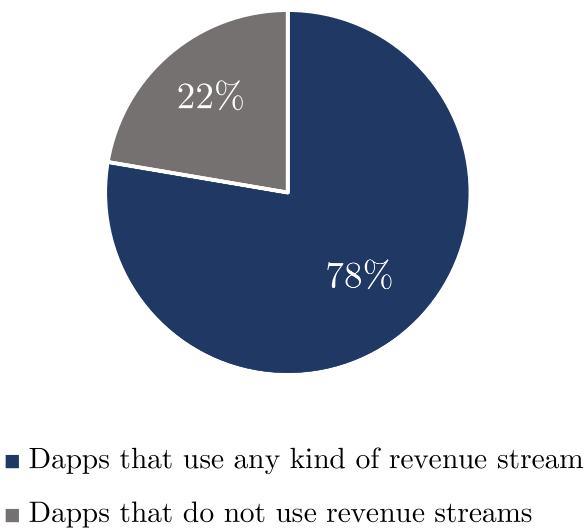

Figure 4.16: Distribution of Dapp by revenue stream “Dapp” usage

Dapps remunerating its builders are more frequent than those remunerating stakeholders – from 89% in the former case to 78% in the latter [Figure 4.16].

It can be inferred that some applications only remunerate their builders, without caring about their stakeholders. These actors see an opportunity in decentralised applications to capture value, without however fully embracing the values of decentralisation and peer-to-peer that characterise the ecosystem.

Type of builders	% Dapp that use Tokenomics
DAO	100%
Private company	65%
Team of developers	85%
Foundation	100%

Table 4.15: Distribution of Dapp by type of builders (Tokenomics "Dapp" only)

Breaking it down by type of builder, it can be seen that private companies are the most inclined not to distribute profits, implementing a revenue stream in only 65% of cases [Table 4.15]. The other categories differ considerably in this respect, distributing profits to their stakeholders in all cases of DAOs and Foundations and in 85% of the Dapps created by Developers. This difference cannot be justified, as has been done in other cases before, only by the fact that different builders develop different categories of applications, and consequently affecting the revenue streams that can be implemented. The choice of private companies not to redistribute value to other actors is therefore not purely technical. Among the protocols released by private companies that do not remunerate their users are mainly games, gambling apps and marketplaces.

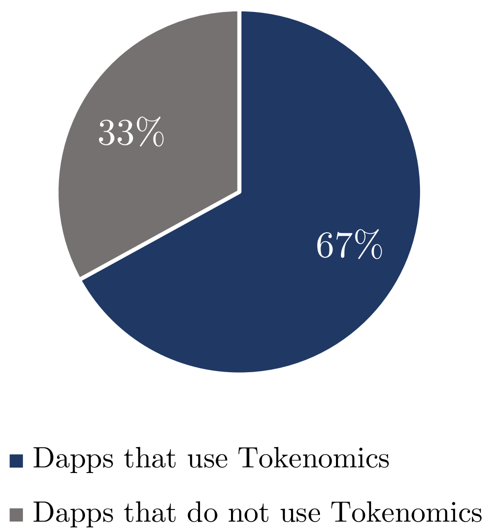

Figure 4.17: Distribution of Dapp by Tokenomics "Dapp" usage

Figure 4.17 shows the percentage of applications that use Tokenomics to remunerate their users, suppliers, and governors. The use of Tokenomics is very similar to that analysed for builders, deviating by only 2 percentage points (from 65% to 67%). Given this strong similarity, the analysis did not look at the different categories or types of builders, as it is not possible to derive any insights that have not already been extrapolated from the previous section.

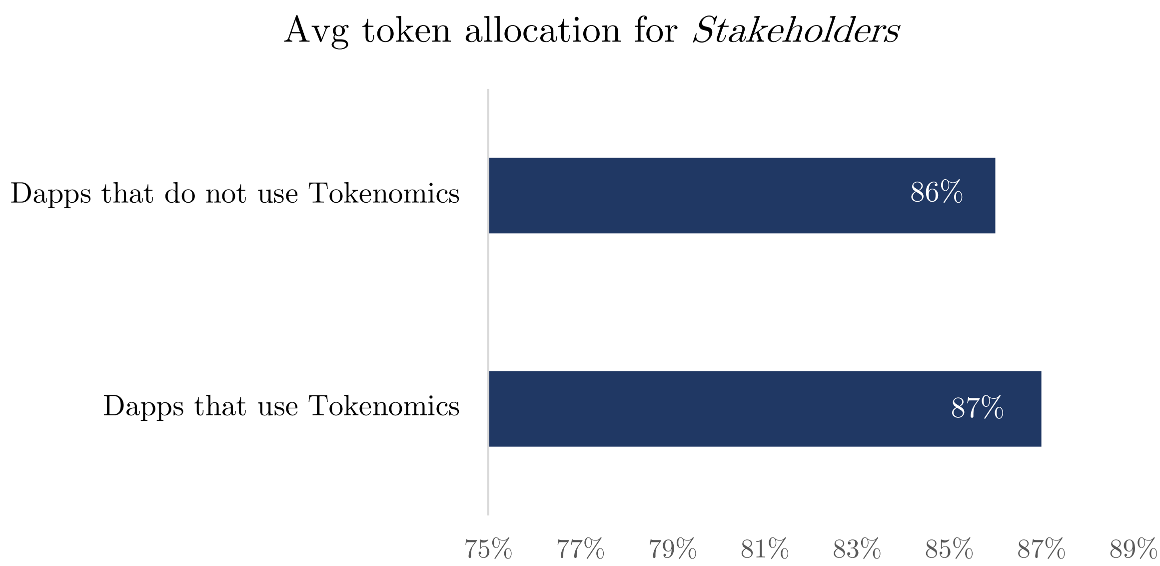

Figure 4.18: Average token allocation for stakeholders by tokenomics usage

Figure 4.18 shows the share of application tokens allocated to developers as a percentage of the total for each Dapp. As opposed to the builders' case, where the average distribution of tokens changed considerably between Dapps using Tokenomics and those not using them, the situation here is more distributed. Tokenomics does not seem to be a determinant of token distribution when talking about other stakeholders.

On average, 87% of application tokens are distributed to stakeholders. Analysis of the white papers and scientific articles showed that the choice, shared by most builders, to distribute a high number of application tokens to users is aimed at promoting the use and adoption of the protocol.

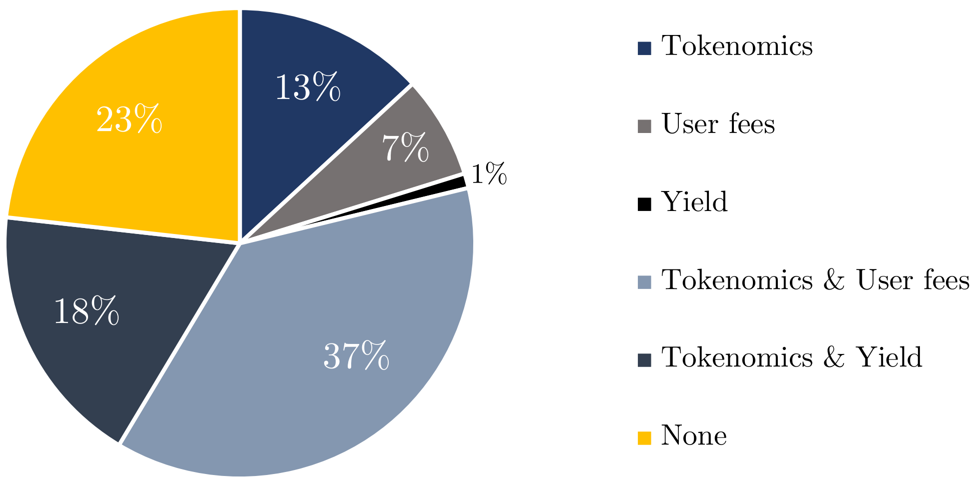

Figure 4.19: Distribution of Dapp by revenue stream "Dapp"

The different types of revenue streams are shown in Figure 4.19. User fees again play a major role, covering 44% of the protocols. They are often combined with Tokenomics – 37% of cases – and less frequently used alone – 7% of cases. This is where a new value creation mechanism comes into play, one that only affects the stakeholders of a Dapp, particularly the suppliers: yield. Mainly applied by asset management applications, yield is offered alone in 1%, while accounting for a substantial share of revenue streams when coupled with Tokenomics (18%).

It is worth mentioning Soteria, an application that falls under the Tokenomics cluster but also leverage another mechanism to create value. The protocol is a mutual that provides insurance cover for contract risk, while generating returns for cover and capital growth. Project developers and smart contract auditor will conduct decentralised risk assessment and fund an initial stake pool. The application tokens are used to purchase smart contract cover, claims assessment, underwriting and governance. All capital funds belong to Soteria members, which decide claims, ensuring completely decentralized operations. According to its developers, the economic model driven by tokens will ensure claims are handled for mutual long-term growth.

User incentives

To complete the research on how Dapps create value for their stakeholders, the incentives for users were also included. These are designed by developers to promote the use of a smart contract or protocol token. All non-monetary incentives and monetary ones are presented. These have been distinguished from revenue streams because of their volume, the frequency with which they are issued, and the actors involved.

Due to the low number of cases, this section has been treated with a qualitative approach, providing a high-level description of each category, and contextually including some insights from the analysis. Only 36% of the analysed protocols employ user incentives, which exclude gambling applications and social networks. Incentives formalised in the literature are presented below, integrated with use cases gathered from the census.

Showcase: a place or occasion for presenting something favourably to general attention. They are mostly applications that offer collectibles (NFTs, tokenised assets) and give users the possibility to show them to the community. This type of incentive is mainly found in games, which integrate the use of collectibles into the game mechanics, and marketplaces, which besides to the possibility of selling often offer a showcase through which to display user purchases.

In this regard, blockchain technology creates real-world economies for games and marketplaces and opens a completely new way for ownership of assets to be treated and assigned. It has the potential to provide a new kind of value proposition which better aligns players and game operator incentives. Decentralized applications offer true ownership of digital assets, unlike traditional platforms that only allow them to be used within their borders. Blockchain technology brings to fruition the transfer of value in a decentralized, peer-to-peer manner. For these reasons, the showcase incentive can be exploited by several applications, eventually showing on a game Dapp the purchases made on a different decentralized marketplace.

Lottery: some Dapps implement a lottery by giving away tokens (both protocol and application) to promote the use of the application or the holding of application tokens. Tickets are usually purchased via tokens, the type of which changes depending on the service offered by the Dapp. For example, a DEX will use LP tokens as a means of purchasing tickets, thus incentivising liquidity providers to deposit in pools. All protocols exploiting this incentive belong to decentralised finance.

Introduced by PancakeSwap, the lottery has spread to other BSC applications, which have forked or copied this feature. As the lottery is managed by smart contracts, whose rules are verifiable by everyone, the entire number of tickets is often raffled off as a jackpot, with nothing being retained by the builders. However, it can happen that part of the sum is burnt to counteract token inflation. Some types of tokens are inflationary since there is no supply cap. To reduce inflation, many protocols burn them regularly and thus reduce supply.

Governance rewards: rewards generated in the form of application tokens that are distributed to users when they propose a change to the protocol or vote on proposals. This incentive is also only used by DeFi Dapps, which encourage the use of governance mechanisms to improve the protocol, thus tackling token holders who merely stockpile governance tokens in the event that these will appreciate.

Staking rewards: incentive designed to promote the "staking" of protocol tokens. Rewards are periodically distributed to users who stake their tokens, proportional to the amount of value they stake. Staking differs from liquidity mining in that staking leverages the PoS consensus mechanism: in simple terms it involves locking protocol tokens for a certain amount of time in exchange for a chance to mine the next block (the probability of which is proportional to the number of staked tokens). Some DeFi applications have created pools of liquidity in which everyone can deposit protocol tokens and help mining new blocks. Token stakers are thus not remunerated with the transaction fees of users who use the pool for trading (as liquidity providers do), but with new protocol tokens mined with Proof of Stake.

Suggestion (or developer) rewards: rewards for identifying critical issues or suggesting technical changes to the protocol. It is the least used of the incentives described, although it is accessible to all, with no need for knowledge of smart contract development. Most frequently, builders offer open-source bounties for completing a task in a project or tackling a security issue of a smart contract. However, this reward was not included in the census as it is rarer and only reserved for developers who are able to solve this kind of problems.

4.2.2 Stakeholders & User fees

This section completes the chapter on revenue models by presenting the stakeholders involved and their respective roles. It then provides a detailed description of the ecosystem, trying to formalize its complexity. In this way it is possible to draw out qualitative insights into the topic.

Flat trading fee: traditionally, a brokerage fee (or trading fee) is charged by a broker to execute transactions or provide specialized services. In the financial securities industry, a trading fee is charged to facilitate trading or to administer investment or other accounts.

In decentralised finance, this type of fee is used exclusively by DEXs to remunerate suppliers – in this case liquidity providers – who deposit tokens within liquidity pools used for trading. When tokens are deposited into a liquidity pool, the platform generates a new token that represent the share the depositor owns of that pool. A trading fee is retained by a liquidity pool and paid out proportionally to the amount of liquidity provided by each liquidity token holder. Liquidity providers are required to give up their liquidity tokens in order to redeem their share of liquidity and accrued fees.

The players charged are traders, users who every time they exchange tokens with a liquidity pool pay a trading fee in the form of a percentage of the value traded. The percentage is fixed regardless of the type of transaction or its volume, which is why it is called *flat*.

Positive slippage: formally, slippage occurs because of changing market conditions between the moment the transaction is submitted and its verification. This type of fee is only used by aggregators of DEXs: they do not charge any transaction fees – other than those charged by the DEXs they aggregate – and therefore leverage this mechanism to capture value.

However, positive slippage is not the only source of revenue for these applications. They often into partnership with exchanges whereby they secure a percentage of the transaction fees. For example, if a DEX commissions a 0.3% flat trading fee and the transaction is done through an aggregator, the aggregator takes a percentage – usually not disclosed – of this fee. The aggregators analysed are all run by private companies and do not redistribute value to their stakeholders.

Performance fee: payment made to an investment manager for generating positive returns. This is employed solely by asset management applications which charge users on the profit (yield) they make through the service. This fee is generally subtracted in the form of tokens when the yield is distributed.

The performance fee is therefore only charged to "farmers", the users who use the asset management service and participate in yield farming activities. A part of the fee is allocated to the strategist, a user who conceives and oversees the strategy for that pool. It follows that the return on a yield farming strategy (in terms of performance fees) is directly proportional to its popularity.

The other recipients of the performance fee are the builders of the protocol, who often use a "treasury", a dedicated pool of liquidity into which the fees collected are deposited and whose purpose varies between protocols. The treasury is used to remunerate the builders, remunerate the token stakers, promote open-source bounty, and often also to burn some of the collected tokens, in the case of inflationary tokens.

Marketplace fee: fee associated with the sale or purchase of a product or service on a decentralised marketplace. The marketplaces analysed only charge sellers, while they rarely distribute fees to stakeholders. These are private companies that retain all the profits made.

Interest rate: amount that a lender charges for the use of assets (typically tokens) expressed as a percentage of the principal. Similar to decentralised exchanges, lending applications collect liquidity from suppliers – also liquidity providers – and make it available to users. The latter use it to make loans, usually over-collateralised, on which they subsequently pay interest fees.

Other fees: other fees formalised during the *Variable description* include **membership fee** and **transfer fee**, which are both used in DeFi protocols.

The average fees for each type are shown below [Table 4.1] to illustrate the orders of magnitude for each one. This brief overview aims to reveal the potential of decentralized applications and their low cost when compared to “traditional” applications and services.

Type of fee	Average value
Flat trading fee	0,25%
Interest rate	0,09%
Marketplace fee	5,42%
Performance fee	5,43%

Table 4.16: Fee average value by fee typology

Table 4.16 shows the user fees charged by the various categories of applications. These cannot be compared with each other because of their different nature and frequency. Asset management applications, for example, charge more than DEXs because, firstly, transactions are less frequent and also because the fees charged by yield farming protocols are only retained if returns are positive. The value of positive slippage has not been collected as it is variable and not predictable in advance.

Trading fees and interest rates are very low compared to traditional services. However, interest rates manage to stay so low also because the loans are overcollateralized. As for performance fees, these are significantly higher because, as described above, they are much less frequent, but also because the returns that yield farming applications manage to generate amply justify the fee.

The exact fee values were collected in an attempt to test an assumption that many blockchain enthusiasts have been making: blockchain-based applications have no switching costs.

Traditional multi-sided platforms are able to generate lock-in effects by owning user data or attracting users and consequently attracting more players to the other side.

However, thanks to self-sovereign identity[21] enabled by blockchain platforms, users would be able to move from one application to another without any difficulties. Measuring the user fees, which represent the main cost of using a Dapp for a user, is therefore useful in testing this premise. It allows to understand whether, if several apps offer the same service, the user base shifts or concentrates towards the one with the lowest fees.

When comparing fees and number of users, however, no evidence was found to support this thesis. For this analysis the fees were considered individually, so that they did not overlap with other types of service, and the number of users for both February and April. However, in none of the four cases was there a correspondence between the "cost" of a Dapp – here represented by the fees – and the number of users.

There are several hypotheses that can motivate this trend. First of all, the higher cost of a Dapp can be "justified" by a possible competitive advantage. Although the Dapps analysed belong to the same category and offer similar services, there were some differences that could make a difference in terms of adoption. For example, Uniswap boasts an extensive choice of tokens to trade with and is the most widely used DEX despite having a trading fee slightly above average (0.3%). The same can be applied to asset management applications, whose user base shifts according to which protocol can guarantee the highest returns.

These qualitative assumptions are based on the analysis of whitepapers and smart contracts. More comprehensive data and information would be needed to draw conclusions in this respect. The biggest limitation here is the premature level of development of the ecosystem which does not allow access to a large enough user base.

[21] Self-sovereign identity (SSI) is an approach to digital identity that gives individuals control of their digital identities

4.3 Governance

This chapter aims to investigate one of the most revolutionary elements of blockchain and decentralised applications: decentralisation. It is often referred to in technical terms, talking about databases and consensus mechanisms. However, one of the most powerful features which holds the greatest potential to change the socio-economic environment is the decentralisation of governance. The impacts would not only be limited to restructuring some business organisations as we know them, but also to a fairer distribution of wealth in the long run.

It is therefore investigated which Dapps use governance mechanisms, at what level they are decentralizing their operations, how they ensure a fair distribution of power and above all how they implement decentralized governance.

4.3.1 Builders

First, an overview is given of the different types of builders analysed. Figure 4.20 shows the distribution of Dapps according to who is currently responsible for technical changes and upgrades.

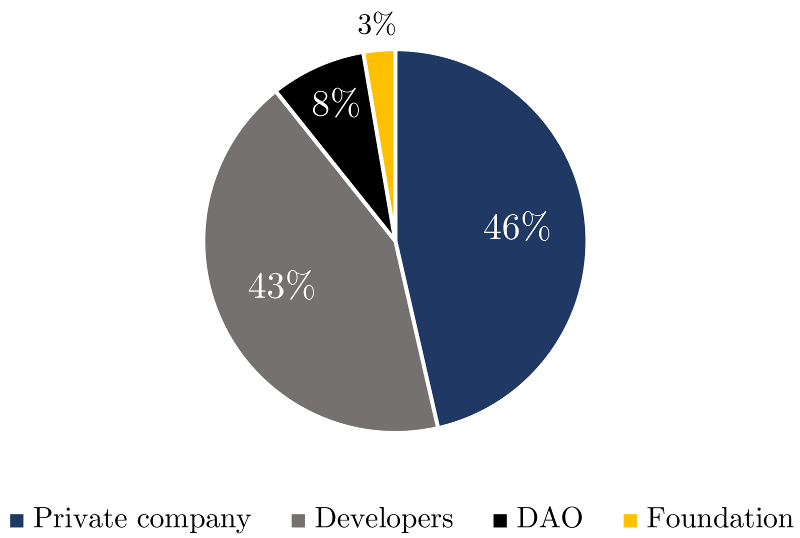

Figure 4.20: Dapp distribution by type of builders

Builders deal with changes to smart-contracts, front ends, changes to Tokenomics, and to the operational logic of the application (e.g. protocol upgrades). This field is relevant regardless of whether the Dapp provides for a decentralized governance system.

Of all applications, 46% are managed by a private company, followed by 43% managed by teams of developers. Both organisational forms have advantages and criticalities that will be described in this section at the same time. DAOs are still uncommon with only 8% of the total. However, this is partly due to the lifecycle of a Dapp, which starts with a development team that has control over the governance parameters and later decentralises its governance processes by issuing a governance token. At the moment, this is the most common design pattern for governance schemes. For this reason, the willingness to convert the organisation into a DAO was also noted.

Organisational conversion	**% Dapp**
Conversion from *Team of developers* to DAO	6%
Conversion from *Private company* to DAO	6%
Overall	**12%**

Table 4.17: Dapp distribution according to organizational conversion

In 12% of the Dapps analysed, builders plan to convert their organisational form into a DAO, either already announced or in progress [Table 4.17]. This percentage is divided equally between teams of developers (6%) and private companies (6%).

Although the literature does not provide any reference to the techniques used by Dapps to convert themselves into decentralised organisations, the analysis revealed two main mechanisms through which this is achieved. The most common involves a particular type of Tokenomics that reduces the share of application tokens dedicated to builders over time. Uniswap, for example, has allocated 20% of its governance tokens to the development team, and over 10 years plans to lower this to 17% through inflation mechanisms and liquidity mining, which rewards suppliers by increasing their relative share. Other protocols include in their roadmap the implementation of decentralised governance through technical changes to smart contracts, in order to automate those processes that in the early stage of the Dapp life cycle are managed by builders.

It is worth noting that most developer teams do not reveal their identity. Figure 4.21 shows that 94% of the developer teams surveyed are anonymous and only 6% are publicly known.

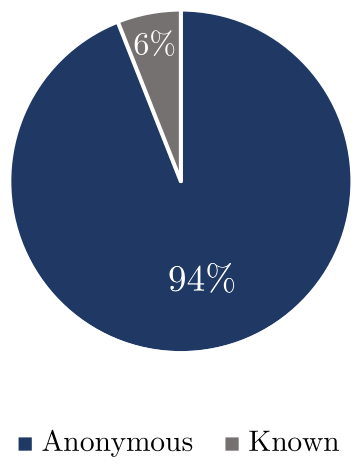

Figure 4.21: Distribution of Teams of developer by whether they are anonymous or known

Many developers place great value on the anonymity of their team, believing that this leads users to judge the service based solely on its quality, which ultimately lends further credibility to the project. As the team of Beefy.finance states:

> "Like many decentralized projects, we place great value in the anonymous nature of the platform. Personalities get in the way of projects, and we believe Beefy speaks for itself. By having a team that operates anonymously, even amongst itself, we can focus on providing the best experience for our users. That's because we believe the strength of Beefy comes from what we build, which is an opportunity for investors to both automate AND maximize the ROI of their holdings."

This is possible thanks to the trust offered by the blockchain, which places the "code at the centre and the humanity at the edge". Trust also enables new kinds of governance where communities collectively make important decisions about how networks evolve, what behaviours are permitted, and how economic benefits are distributed.

4.3.2 Governance token distribution

Table 4.18 shows the average percentage of tokens owned by each actor. Only three categories are represented for this phase of the analysis as they are the only ones with a complete data set. The other types of Dapps publish the number of tokens allocated to stakeholders, but not the amount reserved for builders and investors. For this reason, a comparison with the other categories would have been partial and not very useful to draw reliable insights.

Category	Builders	Investors	Stakeholders
DeFi	9%	4%	87%
Games	9%	1%	79%
Marketplaces	33%	0%	67%
Other	**10%**	**3%**	**87%**

Table 4.18: Average token distribution for each actor (by category)

As seen in the analysis of revenue streams, stakeholders (which comprise users, suppliers and governors) benefit from the largest number of application tokens, with an average of 87%. Review of whitepapers and scientific articles showed that the choice, shared by most builders, to distribute a high number of application tokens to users is aimed at promoting the use and adoption of the protocol.

In this phase of the analysis, investors are introduced, a type of actor that has recently made its appearance in the world of Dapps. They finance the project by obtaining part of the application tokens in exchange, instead of a share of the company's equity as traditionally done. As seen in the analysis of *Funding*, investors are mostly attracted by decentralised finance, which is why the average share allocated to them is higher in this category. They are virtually absent in the other categories, either because of a lack of interest or because a substantial number of Dapps take the form of private companies, which can offer a portion of their equity in exchange for funding.

Finally, the builders secure on average 10% of the application tokens, which in addition to a remunerative purpose, as seen above, constitute a substantial share of votes to influence the performance of the protocol. It is worth noting the case of marketplaces, which allocate on average 33% of their tokens to builders. This choice may depend either on the desire for greater control over the protocol or on the choice to capture more value. In this respect, the analysis was deepened by examining the distribution of tokens among the various types of ownership.

Type of builders	Builders	Investors	Stakeholders
Team of developers	7%	0%	93%
DAO	8%	5%	87%
Private company	15%	5%	79%
Overall	**10%**	**3%**	**87%**

Table 4.19: Average token distribution for each actor (by type of builders)

Developer teams are the builders with the smallest share of tokens, with only 7% on average [Table 4.19]. They show no particular interest in external investors and release all remaining tokens to stakeholders. DAOs are similarly positioned, although they divert an average of 5% from their community (87%) to attract investors and remunerate them with tokens. Finally, private companies are the builders that hold the largest amount of tokens on average, accounting for 15% of the total share. From the allocation analysis, investor interest remains strong, with 5% of tokens allocated. However, as mentioned above, many of these companies also offer a portion of their equity in return, making the perspective offered by this figure partial.

4.3.3 Decentralization level

The analysis goes on to examine how decentralised applications use governance tokens and thus decentralise their decision-making processes. In addition, those protocols that go further and give their users the possibility of making governance proposals were also surveyed. The extent of these can vary between different applications and the service they offer, and include changes and technical updates both on smart contract and front-end side, changes in Tokenomics policies (e.g. increasing the supply cap or decreasing the burn rate), changes in the Dapp operational logic and even changes of governance processes.

The following levels of decentralisation have been distinguished for the sake of clarity:

- **Completely centralized**: only the development team that built the protocol can change any aspects of the system. An application falls into this category if it has not issued and does not plan to issue governance tokens in the future.
- **Partially decentralized**: only some aspects can be altered by governance token holders. In this case, the application has a governance token, but the token holders cannot make proposals for change.
- **Completely decentralized**: all aspects can be altered, and any token holder can propose changes. The application provides for a governance token and gives the possibility to make proposals to all holders of at least one token.

The distribution of applications according to their level of decentralisation is shown in Figure 4.22.

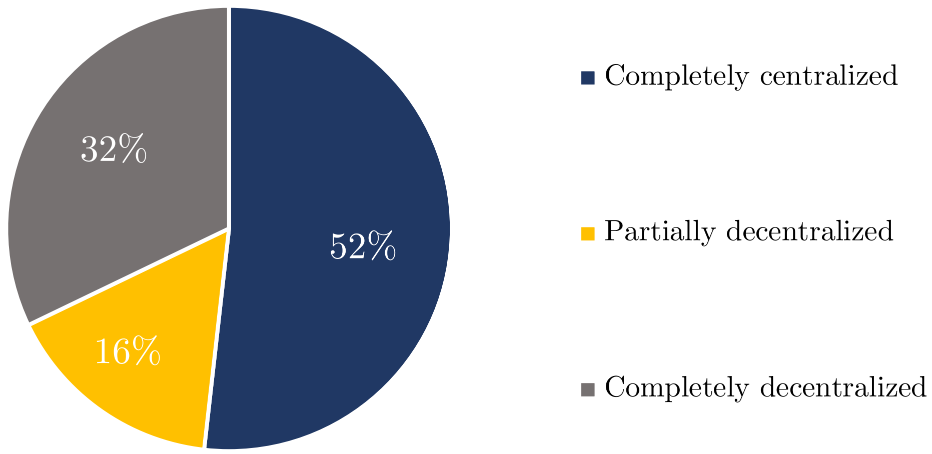

Figure 4.22: Distribution of Dapp by decentralisation level

A high number of Dapps that are fully centralised can be noted. This is partly due to a large number of applications that do not yet have an application token (30%) and partly to applications whose token does not give users any voting rights (22%). Both of these categories fall into the cluster of *Completely centralized* applications since their builders have full control over every aspect of the system and have not yet announced any change in their intentions in the future.

Among the protocols analysed, 16% involve the use of a governance token that grants users – in this case governors – the right to vote on certain aspects of the system. The proposals to be voted on are issued exclusively by the builders. The voting process and subsequent implementation of a change varies between applications. These processes include various parameters and differences that make their formalisation burdensome and outside the scope of this thesis. Voting is also taking different forms, with various methods based on game theory emerging. The most common is simple voting based on the amount of tokens held: the number of votes is directly proportional to the number of tokens. However, this runs the risk of devolving into a plutocracy as the richest members could easily collude and define the fate of a protocol. To address this problem, some protocols have established a maximum cap on the number of tokens that can be used in a vote, and others are exploring different methods such as quadratic voting.

Finally, 32% of Dapps can be defined as completely decentralized as they allow their governors to change every aspect of the system. They also have the opportunity to make governance proposals that can be voted on and implemented with the simple consent of their peers. In this type of application, builders have theoretically no role in defining the roadmap of an application. However, builders contribute to shaping the protocol by acting as governors and exercising their voting rights through governance tokens, which, as seen above, constitute on average a substantial part of the total.

At this point, it is worth clarifying a few points about the fully decentralised applications just described. The governance processes, which are completely automated, guarantee an evolution of the protocol within the limits of the existing smart contracts. While there is a great deal of flexibility in adding new functionalities, when it comes to making changes, it is necessary to take into account the existing smart contracts. If the smart contract allows it, it is possible to change some of its parameters. These can also heavily influence the operation of the protocol. Uniswap, for example, provides the possibility of changing the recipient of its flat trading fee, which, instead of being completely devolved to liquidity providers, would be divided into two parts, one of which (0.05%) would be allocated to future projects. In this case the smart contract provides for this possibility and can be implemented by means of a vote.

However, due to the immutability of smart contracts, it is not possible to make radical changes to the protocol if these have not been foreseen beforehand. Although this type of change is rare at the time of writing, cases are emerging where builders develop a new smart contract to replace the previous one[22]. This is the case of Uniswap, an application classified as fully decentralised, which has twice updated its protocol, skipping all the governance procedures involved. The choice to adopt the new smart contract will depend solely on the will of its users, suppliers, and governors. However, cases where builders develop a new protocol, without first consulting their stakeholders, leads to striking contradictions. Despite all the progress made in the direction of decentralisation, such as immutability of blockchain-based applications and subsequent automation, fully decentralised governance processes, incentive systems to support the protocols and improve them, further efforts are still needed.

[22] Of the Dapp analysed, 6% have completely revised and updated their protocol.

Chapter 5

Discussion & Conclusions

In this last chapter, the main findings of the empirical analysis have been presented in order to address the objective of the study and answer the research questions. After this review, the limitations of the research were addressed, suggesting relevant future research that could be pursued.

5.1 Discussion and main findings

In the first part of this thesis, a review of the existing literature on blockchain has been conducted. The technology and its underlying mechanisms are briefly analysed to explain its functioning from a technical point of view, with a focus on the different types of consensus mechanisms and mining processes. Later, the evolution of the protocol form from a public to a private dimension is illustrated and shows the analogy with the Internet / Intranet of the 1990s.

The chapter includes the blockchain classification of Buterin (2014) and highlights several technological limitations that characterise the main public platforms. In this regard, the problem of scalability is treated extensively and the main solutions that aim to address it are introduced. Then a short literature on the history and definition of Smart contracts is presented, along with a technical overview of tokens and a discussion of their implications.

Decentralized applications are treated with a holistic approach, starting with a technical analysis of the layers they are composed of, covering their formation and development, and moving on to their high-level implications. In this regard, study of the academic and grey literature has shown the different sectors that decentralized applications have the potential to disrupt. The chapter ends with a detailed analysis of the business-level impacts of blockchain and a thorough literature on governance, both at the platform level (Blockchain protocol) and at the application level (Dapp).

Finally, the main gaps found in the literature have been outlined, which are summarized below:

- The literature lacks empirical analysis regarding the sectors from which new blockchain-based applications (Dapps) are emerging. Some scholars are beginning to explore the main use cases of certain sectors, but there is still no research that paints a picture of the Dapp ecosystem and its distribution across sectors.
- There is still not a valid and recognized classification framework of business models based on blockchain. Moreover, empirical analyses that explore the adoption of these models by blockchain-based application (Dapps) are missing in the literature.
- There are no empirical analyses that shows which and how Dapps use governance systems, what role governance play in the business model of a Dapp and at what level Dapps are decentralizing their operations.

The review of the literature has underlined the disruptive potential of Blockchain technologies and has highlighted the interest of the scientific community towards them. In this regard, two elements emerged as the main source of innovation in this area: public blockchains and smart contracts. Decentralized applications (Dapps), or blockchain-based applications, are the union of these two elements. They represent completely novel applications that could change the nature of economic, social, and political systems.

The empirical analysis that has been performed on Dapps aimed to contribute to the limited literature on the subject, by providing a comprehensive framework that identifies how these applications affects business and governance innovation.

The results of the research are summarized below.

Overview

The sample analysed consists of 112 decentralised applications representing approximately 64% of the market in terms of users. Most of them are concentrated in the DeFi sector, with 66% of the total, which is not surprising since cryptocurrencies and peer-to-peer monetary exchanges were the first case of use of blockchain technology.

The number of DeFi users accounts for more than half of the total sample (55%), witnessing a growth of 64% in just two months. This trend is driven by decentralised exchanges (DEXs), protocols that facilitate the non-custodial exchange of on-chain digital assets. DEXs are able to attract 72% of the users in the DeFi ecosystem despite being only 43% of the total DeFi protocols.

On the contrary, asset management applications are characterised by a higher number of applications in proportion to their users (35% of DeFi Dapp against 15% of DeFi users).

One of the main reasons seems to be the high volatility of crypto assets, which has made profit maximisation an increasingly complex activity. Many applications offering asset management services are in fact disappearing (58% of these have lost users in the two months under review) as they have lost their competitive advantage, while other have emerged to replace them (23% of protocols born in the same period).

Binance Smart Chain (BSC) is the blockchain platform that has benefited most from DeFi's recent growth, leading both in terms of users and number of Dapp. Its low transaction costs and high processing speed make it particularly suitable for the industry, despite not providing the same level of decentralisation as the other platforms. For this reason, a large part of the DeFi ecosystem has moved to this protocol, on which most DeFi Dapps are based (58%). This is partly due to the scalability issues faced by Ethereum, the second most adopted blockchain, whose use is currently prohibitively – for most users – given the high gas fees.

However, a significant share of Ethereum Dapps is starting to adopt or have already adopted layer 2 solutions (48%) to address these problems without giving up its inherent decentralisation and security.

Generally speaking, the interest of the actors involved is high enough to guarantee full-time dedicated developers to tackle the main problems – like scalability issues – and nurture the ecosystem. To this end, the interest of traditional investors, directly proportional to the amount of funds invested (Tyebjee & Bruno, 1984), was measured. Dapps funded by these players (22% of the total) enjoys an average investment of $13 million. The ability to attract these types of investors is often a clear sign of strong teams, large potential markets, or unique value propositions with a strong competitive advantage.

However, blockchain is reshaping the fundraising landscape through ICOs, IEOs, airdrops and token sales. Among the Dapps analysed, only 10% of them sold pre-minted tokens at the time of launch through the mentioned strategies. Despite the low number of apps funded in this way (10%) and a low average investment compared to traditional investors ($3 million raised on average), these protocols were able to attract an above-average number of users (30% of the total).

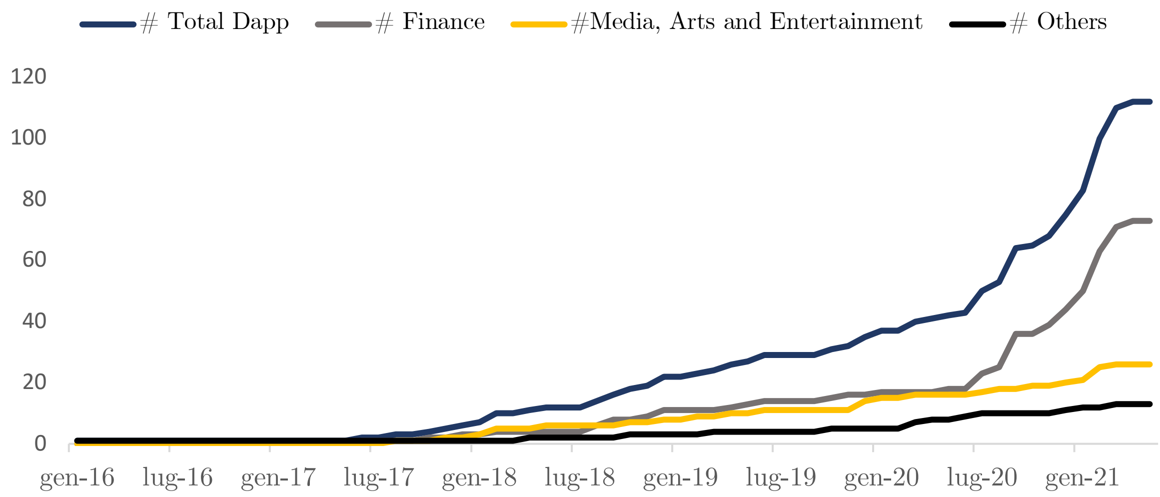

Figure 5.1: Cumulative frequency of Dapp launches by industry (Gen 16 - Apr 21)

Considering the time distribution of application launches, the most successful protocols at the time of writing are the ones that are comparably more recent. In fact, only 6 applications born before 2018 were able to maintain their user base and competitive advantage to be among the top 100 at the time of writing. July 2020 to April 2021 sees a peak in the number of Dapp launched, driven by Defi, generating half (55%) of the protocols in the top 100.

The research shifted to the use of tokens and the role they play in the operations of a Dapp. 70% of the protocols analysed make use of at least one application token. This distribution is influenced by DeFi, which uses an application token in 89% of the cases. This is mainly due to the high number of DeFi protocols using governance tokens (68% of the total). Regarding utility tokens, the number of protocols is reduced to

48%, due to the different functioning of the subcategories. Aggregators and Lending applications do not make use of liquidity tokens, while asset management applications and decentralised exchanges use utility tokens in a few cases as they both collect and redistribute fees or yields in the form of LP tokens. The other categories all use utility tokens (100%) either to create an economic incentive within the platform (Derivatives) or to pay transaction fees (Collectibles and Mutual).

The other sectors account for a lower usage with less than 30% of applications using tokens, except for social networks which show an even distribution (50%). Again, the distribution is influenced by governance tokens, which are rarely used by non-DeFi applications (20% by social, 12% by games and 0% by marketplaces and gambling applications). In contrast, these applications see a consistent number of cases of utility tokens, used by almost all of them.

A focus was made on Non-Fungible Tokens (NFTs), tools that enabled the emergence of a much richer spectrum of smart contracts, exceeding the possibilities of fungible tokens. The analysis shows a considerable number of adopters, who make up 30% of the total. The categories that make most use of NFTs are Marketplaces (100%), where they are exchanged, and Games (71%) that often include NFTs in their gameplay. Another category that has implemented NFTs as part of its service is DeFi, which in 15% of its protocols allows the exchange and sale of collectibles, paving the way for a diverse set of use cases.

The value of tokens was also measured to assess their relevance and popularity, as well as the goodness of the underlying protocols and their ability to create value for their stakeholders. The average market capitalization rose by 139% in the two months considered, from $630 million to $1.5 billion. This growth was mirrored by the user base, which for these applications increased by 58%.

However, the average of the market cap variations was +99%, below the increase of the total average just mentioned (+139%). The explanation is twofold: 20% of the protocols saw a decline in their market cap, while others increased by multiple factors.

While the average of the market cap variations almost doubled (+99%), the average change in the number of users has remained stable (+5%). One of the most plausible hypotheses explaining this contrast takes into account the possibility of trading tokens within AMMs. Similar to what happens in traditional finance, trading causes the price of tokens to soar without being directly affected by the performance or use of the corresponding applications.

This would confirm an issue mentioned by Voshmgir (2020), which describe a common conflict in many Dapp designs: token holders are often more interested in seeing the price of their tokens rise, whereas users would rather see a decrease in price so as to reduce the costs of using the Dapp. As a result, on-chain governance suffers from the same problem that it was trying to solve: users acting in their own self-interest can exploit Dapp rules technically or economically, regardless of whether these users qualify as malicious.

For the purposes of the following paragraphs, the stakeholders that are part of a decentralised application are listed below:

- **Builders**: create, implement and support the protocol
- **Suppliers**: provide capital or a core service to the functioning of the protocol
- **Users**: use protocol functionality for intended use case
- **Governors**: make decisions on the development of the protocol

Revenue models Builders

Among the protocols analysed, 11% do not have any kind of revenue stream for their developers, as they are either video games with a bare interface and simple game mechanics (e.g. Galaxy Blocks, a copy of Tetris), or are created by anonymous developers who have not provided any kind of value capture mechanism. Other cases include infrastructure services, offered by private companies to incentivise the use of other applications or platforms (e.g. Venus, developed by Binance).

The remaining applications (89%) use Tokenomics extensively (65% of the cases), a revenue stream in which application token holders gain from the appreciation of token value or from receiving inflationary rewards. This proves to be one of the easiest strategies to implement, with no cost passed on to users. Developers simply hold on to a portion of the application tokens – which are priceless at the time of issue – and wait for it to appreciate through trading or use of the protocol.

The builders of these applications retain an average of 10% of the application tokens issued, compared to 4% retained if the Dapp does not use Tokenomics.

This type of revenue stream is closely associated with the choice of implementing a token in the functionality of the protocol which can be either a utility token or a governance token. Consequently, the type of service offered and the organisational form of a Dapp, which are both decisive for the presence of a token, influence the use of Tokenomics. The two categories that stand out are DeFi, which uses Tokenomics in 84% of its Dapps, and Social, with 75% of the cases. The extensive use of tokens for these applications – both governance and utility – makes them particularly well suited to leverage Tokenomics. The same reasoning does not apply to the other categories of applications, whose cases decrease considerably.

DAOs are the organization in which Tokenomics occurs most frequently (89%), followed by teams of developers (73%) and foundations (67%). Private companies that develop Dapps do not see Tokenomics as a strong revenue opportunity, making use of it in only 54% of cases.

One of the reasons for this choice lies in the volatility and uncertainty of the token's value. There is no guarantee that the value of application tokens will increase steadily over time. The price is often subject to strong fluctuations due to market developments and trading in AMMs. Moreover, if the application does not achieve widespread adoption, the price of the application token may be limited.

For these reasons, Tokenomics is often combined with other means of creating value, as shown in Figure 4.14.

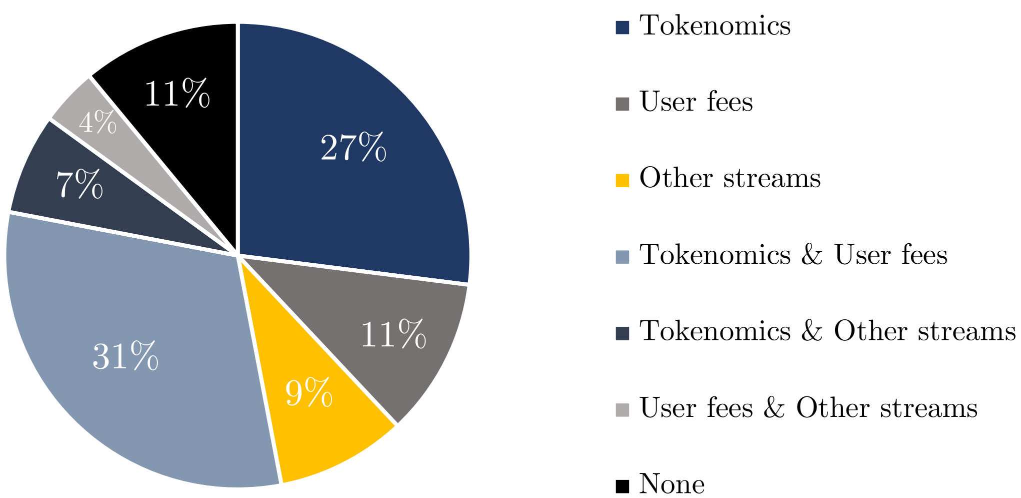

Figure 5.2: Distribution of Dapp by revenue stream

Most protocols not only rely on the appreciation of their tokens, but also charge fees to their users (31% of Dapps). Marketplaces are the ones that use this revenue stream the most (70% of them), followed by DeFi Dapps (57% of them). The latter category enjoys a high number of transactions, making it particularly suitable for charging fees. The same does not apply to Games, which instead leverage in-app sales (78% of the Games) which refers to the selling of goods and services from inside an application.

Finally, all gambling applications use the house-edge, a mathematical advantage that the game has over the user. This is embedded in the logic of the smart contract and therefore results in a guaranteed percentage return over time.

Revenue models Dapp

The analysis then focused on the three remaining stakeholders: users, suppliers, and governors.

Dapps remunerating these actors are fewer in number than those remunerating their own builders (78% vs 89%). It can be supposed that developers of some applications are not interested in remunerating their users. These actors see Dapps as an opportunity to capture value, without however fully embracing the values of decentralisation and peer-to-peer that characterise the ecosystem. In particular, private companies are the most inclined not to redistribute profits, implementing a revenue stream in only 65% of cases.

A detailed analysis shows that Tokenomics is also widely used here (67% of cases). However, it does not appear to be a determinant of token distribution, as opposed to the builders' case. In fact, the average token distribution is held around 87% for both Dapps using Tokenomics and those not using it. Analysis of the white papers and scientific articles showed that the choice, shared by most builders, to distribute a high number of application tokens to users is aimed at promoting the use and adoption of the protocol.

User fees again play a major role, covering 44% of the protocols. This is followed by yield (19%), a new value creation mechanism dedicated to suppliers. This is mainly applied by asset management applications, which offer value maximisation strategies, generating – in some cases – yields for its users.

In addition to these streams, some protocols provide user incentives, designed to promote the use of a smart contract or protocol token. These are different from revenue streams because of their volume, the frequency with which they are issued, and the actors involved.

Showcase: "a place or occasion for presenting something favourably to general attention". They are mostly applications that offer collectibles (NFTs, tokenised assets) and give users the possibility to show them to the community. This type of incentive is mainly found in games, which integrate the use of collectibles into the game mechanics, and marketplaces, which besides to the possibility of selling often offer a showcase through which to display user purchases. In this regard, blockchain technology creates real-world economies for games and marketplaces and opens a completely new way for ownership of assets to be treated and assigned.

Lottery: some Dapps implement a lottery by giving away tokens (both protocol and application) to promote the use of the application or the holding of application tokens. Tickets are usually purchased via tokens, the type of which changes depending on the service offered by the Dapp. As the lottery is managed by smart contracts, whose rules are verifiable by everyone, the entire number of tickets is often raffled off as a jackpot, with nothing being retained by the builders.

Governance rewards: rewards generated in the form of application tokens that are distributed to users when they propose a change to the protocol or vote on proposals. This incentive is mostly used by DeFi Dapps, which encourage the use of governance mechanisms to improve the protocol, thus tackling token holders who merely stockpile governance tokens in the event that these will appreciate.

Staking rewards: incentive designed to promote the "staking" of protocol tokens. Rewards are periodically distributed to users who stake their tokens, proportional to the amount of value they stake. Staking differs from liquidity mining in that staking leverages the PoS consensus mechanism: in simple terms it involves locking protocol tokens for a certain amount of time in exchange for a chance to mine the next block (the probability of which is proportional to the number of staked tokens).

Suggestion (or developer) rewards: rewards for identifying critical issues or suggesting technical changes to the protocol.

The analysis of revenue models was integrated with a breakdown of the different actors involved and their respective roles, including a description of the revenue streams involving them as well as an outline of how they are remunerated. The data collected at this stage of the analysis are characterised by a high degree of granularity and complexity. For this reason, this section has been treated with a qualitative approach, providing a high-level description, and contextually including some insights from the analysis. For further details please refer to *Stakeholder & User fees.*

Governance

The last section aims to investigate one of the most revolutionary elements of blockchain and decentralised applications: decentralisation.

Of all applications, 46% are managed by a private company, followed by 43% managed by teams of developers. DAOs are still uncommon with only 8% of the total. However, this is partly due to the lifecycle of a Dapp, which starts with a development team that has control over the governance parameters and later decentralises its governance processes by issuing a governance token. At the moment, this is the most common design pattern for governance schemes: 12% of Dapps plan to convert their organisational form into a DAO, either already announced or in progress.

The most common way to do that involves a particular type of Tokenomics that reduces the share of application tokens dedicated to builders over time. Others include in their roadmap the implementation of decentralised governance through technical changes to smart contracts, in order to automate those processes that in the early stage of the Dapp life cycle are managed by builders.

It is worth noting that most developer teams do not reveal their identity (94% of developer teams surveyed). Many developers place great value on the anonymity of their team, believing that this leads users to judge the service based solely on its quality, which ultimately lends further credibility to the project.

As mentioned above, one of the indicators of the quality, interest and credibility of a project is the amount of funding gathered. When analysing the average percentage of tokens allocated to traditional investors, they prove to be mostly interested in DeFi Dapps, owning on average 4% of the tokens. They are virtually absent in the other categories, either because of a lack of interest or because a substantial number of Dapps take the form of private companies, which can offer a portion of their equity in exchange for funding.

Moving to the builders, these actors secure on average 10% of the application tokens, which in addition to a remunerative purpose, as seen above, constitute a substantial share of votes to influence the performance of the protocol.

Private companies are the ones that hold the largest amount of tokens on average, accounting for 15% of the total share, while developer teams keep on average only the 7%. Moreover, they show no particular interest in external investors and release all remaining tokens to the other stakeholders (users, suppliers, governors). DAOs are similarly positioned, although they divert an average of 5% from their community (87%) to attract investors and remunerate them with tokens.

The analysis goes on to examine how decentralised applications use governance tokens and thus decentralise their decision-making processes.

In this regard, a large number of applications do not yet have an application token (30%) or provide a token that does not give users any voting rights (22%). More than half of the Dapps analysed (52%) are *Completely centralised* since their builders have full control over every aspect of the system and have not yet announced any change in their intentions in the future.

Only 16% of Dapps involve the use of a governance token that grants users – in this case governors – the right to vote on certain aspects of the system. The proposals to be voted on are issued exclusively by the builders.

The process of voting takes different forms, with various methods based on game theory emerging. The most common is simple voting based on the amount of tokens held: the number of votes is directly proportional to the number of tokens. However, this runs the risk of devolving into a plutocracy as the richest members could easily collude and define the fate of a protocol. To address this problem, some protocols have established a maximum cap on the number of tokens that can be used in a vote, and others are exploring different methods such as quadratic voting.

Finally, 32% of Dapps can be defined as completely decentralized as they allow their governors to change every aspect of the system. They also have the opportunity to make governance proposals that can be voted on and implemented with the simple consent of their peers. In this type of application, builders have theoretically no role in defining the roadmap of an application. However, builders contribute to shaping the protocol by acting as governors and exercising their voting rights through governance tokens, which, as seen above, constitute on average a substantial part of the total.

The results of the analysis thus show a rather low level of decentralisation, not only with regard to *Completely centralized* applications but also to those just described.

Governance processes ensure that the protocol evolves within the limits of existing smart contracts. Due to their immutability, it is not possible to make radical changes to the protocol if these have not been foreseen beforehand. Although this type of change is rare at the time of writing, cases are emerging where builders develop a new smart contract to replace the previous one. However, when builders develop a new protocol, without first consulting their stakeholders, striking contradictions arise. Despite all the progress made in the direction of decentralisation, such as immutability of blockchain-based applications and subsequent automation, fully decentralised governance processes and incentive systems to support the protocols and improve them, further efforts are still needed.

5.2 Limitations and future developments

The research presents limitations that offer insights for future studies, which are illustrated in the last chapter. Due to the low number of existing Dapps by category, the framework represents the ecosystem regardless of the service provided. The research framework is built on a dataset of 112 decentralized applications: 74 of them come from decentralized finance, 17 from games, 10 are marketplaces and 11 are gambling applications or social networks. The extent of the sample is mainly due to the DeFi applications collected. The advice for future research would be double: first, to expand the set of applications in order to integrate and/or change the current framework over time; secondly, to analyse the protocols by taking into consideration the category they belong. In particular, some individual sectors of particular interest could be the subject of specific analysis in the future, when a larger number of use cases are available. One example is the social networking sector, which has proved to be particularly relevant at certain junctures, to the extent that it could disrupt the current ecosystem.

Another limitation of the research is the early-stage nature of the implementations under discussion and the resulting small sample of active use cases. Many projects are early pilots and have not yet achieved full rollout. As more projects move from pilot stage to rollout, it will be interesting to explore which industries will create architectural innovations or generate radical innovations and to confirm whether these will be supported by public blockchains.

In addition, the empirical research has been approached in a descriptive approach, with the aim to illustrate the current state of development of decentralized applications based on public blockchains. From the results of this study, nothing can be said about the cause-effect relationship between the different variables. Indeed, the results of this study do not provide a statistical model explaining the causal relationship between the variables collected, for example, on the number of users or market capitalisation. According to the method of analysis, it is only possible to observe the business and technical choices that have been made by the most successful applications.

With regard to technical variables, the choice to focus the analysis specifically on applications that run on public blockchains has been addressed by the evidence found following the literature review, but it certainly represents a limitation. In fact, although blockchain-based applications have been analysed as the ones that hold the highest potential to disrupt existing economic models, other applications that don't run on public blockchains are emerging. These types of software exploit other types of technologies to run their code (e.g. IPFS), in some cases also exploiting tokens, thus ensuring a fair degree of decentralisation and giving rise to a wide set of use cases. These projects were not included in the research. It would be interesting to perform a similar analysis on a database of "off-chain" applications (i.e. technically outside the blockchain) and compare the results with the solutions offered by the blockchain-based applications.

Moving to governance systems, the analysis explored the Dapp's voting processes – and subsequent implementation of changes – with regard to the level of decentralization offered. However, these processes take different forms, with various game-theoretic methods emerging. The implications of the different approaches have only been hinted at in this thesis and certainly deserve further investigation. Furthermore, the literature, which has partially explored the topic, would require updating based on more recent use case. This is because decentralized governance is one of the most powerful features of Dapps, holding the greatest potential to change the socio-economic environment. The impacts would not only be limited to restructuring some business organisations as we know them, but also to a fairer distribution of wealth in the long run.

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