UNIVERSITA' DEGLI STUDI DI PADOVA

DIPARTIMENTO DI SCIENZE ECONOMICHE ED AZIENDALI "M. FANNO"

CORSO DI LAUREA MAGISTRALE IN BUSINESS ADMINISTRATION

TESI DI LAUREA

"BLOCKCHAIN APPLICATIONS FOR A SUSTAINABLE FUTURE"

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ANNO ACCADEMICO 2021 – 2022

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Introduction

The objective of this thesis work is to analyze and find new possible applications for the blockchain technology, aimed at reaching the sustainability of the processes to which it can be applied and for which its potential could be fully exploited, in a scenario as that which we are living in, that calls for a quick digitalization that has to be environmentally friendly too: a difficult task to accomplish, but that might have a huge impact on the markets and on global economy in general.

In the last years, sustainability has gained more and more attention both from a social/public perspective and from a private point of view, generating two forces that interact and move each other, contributing to what we now commonly mean as progress. As a matter of fact, in the wide sense of what could be defined as society, thus through public entities, it is crystal clear that individuals and their contribution to the market are being pushed to pursuing sustainability both in economic and environmental senses – for example introducing Corporate Social Responsibility applications in their organizations, or being called to a significant digitalization of processes in their productive chain. On the other hand, companies and the individuals participating to them have started to understand how such positions positively affect their businesses, whether these are desired just for an improvement of the company's reputation, or because they ease the way to run an economic activity.

More in general, it is possible to say that this trend is endorsed by an intimate will to a renewal of traditional and higher waste-producing techniques in the productive processes, driven by what have unfortunately become hot topic issues, such as climate change and the recent energy crisis and supply chain shortages. Along with such problems, during the last years the blockchain technology has grown in importance and in volumes of usage, reaching a wide range of applications to be involved into. Nevertheless, there is still a weak diversification in its usages, as nowadays it is mainly exploited and known as the technology that supports the market of cryptocurrencies and non-fungible tokens, whose principal focus does not seem to be on sustainability at all, but rather on profitability of investments and in some cases on collecting. At first, this would not seem to be a big deal for the purpose of this dissertation, which could potentially just cover the sustainability aspects and the power of blockchain technology in its implementations, but to start such a journey it is first necessary to understand how the current system works and what it is needed to make it run: only then it will be possible to explore newer and different alternatives.

As previously mentioned, cryptocurrencies and NFTs are the main utilizers of the blockchain, thus they are also its most discussed and studied applications. In a young and yet to be completely discovered field as this is, one of the most relevant issues that came up as the result of many analyses regards the energetic consumption of the two previously mentioned applications, that need an enormous supply of electricity in order to be fueled and to sustain their relative markets.

Although it seems that institutions are aware of this situation and that they are planning to face this problem, it is not possible to ignore such a relevant point when talking about blockchain, especially if, as it is for this thesis, the objective is to present it as a possible solution against - among other things - the energetic crisis and its related environmental issues whose level of emergency is increasing more and more. Also, this not only could suggest how this technology is based on high energetic consumption, but that its most intense-usage applications cannot be sustainable in the long run, if not already in a shorter span of time.

The goal could then be to first understand what it means to exploit the blockchain in simpler and less busy processes – such as supply chains -, where the number of users directly involved is significantly lower than that of, for example, worldwide used platforms such as Ethereum, and understand whether these types of applications could actually be sustainable in terms of cost/benefit, including both positive and negative externalities.

Also, considering the increasing popularity of cryptocurrencies and NFTs among both insiders and newbies, generating hype especially among young and less experienced investors, it would also be interesting to understand how much do people know about how blockchain works and if they are aware of its high level of energy consumption, whether they have already joined any blockchain-based application or not. In a hypothetical scenario, the highest level of sustainability reachable through the application of this technology must be based on a high level of knowledge and consciousness of the power it has, and of that which it requires. After that, it can be possible to interact with such a game-changing mean, eventually using it for business-related purposes.

An ethical and sustainable production must first pass through a correct education on the tools we are given: in this sense, the aim of this thesis is to make readers more familiar with the topic, analyzing and explaining how the blockchain could be used to reach sustainability, while being aware of its potential damage for the environment. This has a significant importance especially considering the current conditions of the market, for which it is necessary to form future market players in the usage of such a revolutionary technology, that is expected to evolve following the necessities that are expected to come up in the near future.

1. Introductive insights on Blockchain

1.1 What is the Blockchain technology?

The blockchain technology can be defined as an "open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way" (Iansiti & Lakhani, 2017), and consists of a growing list of records, which are called blocks, that are linked together through a strong cryptography system creating a complex structure which is impossible to decode. In other words, it can be intended as a database consisting of distributed, decentralized transaction ledgers that are operated and maintained in a peer-to-peer environment and stored in each node. Once each transaction has been registered in its related blocks, these are then hashed in pairs and incorporated in the chain, made up by all the prior blocks to which is assigned an alphanumeric string (called "hash") each. A huge strength point of blockchain is that this all does not require any intervention nor control of governments and central banks, while it is run by the contribution of individuals. Such people are also called "miners", and are the only ones allowed to see that a block contains information, having access to a general description about it but not to the whole of it, unless they own the required codes. This mechanism contributes to the creation of the so-called "consensus algorithm", in which there is the concatenation of each block to a previous one and all information is synchronized on all the copies belonging to each participant to the blockchain and encrypted. Thus, every exchange of information involves and moves the other blocks chained to those directly involved, requiring a continuous processing of data.

1.2 The types of blockchain

The first step required to go into detail and to present the topic is to make a classification, which will allow to define some ensembles to better analyze later. A detail that is often not considered when talking about blockchain, nor it can be intended as part of the common knowledge on this topic, is that there exist different types of it. More precisely, it is possible to define three different models (*Table 1*):

- *Public Blockchains*: also called “permissionless”, as they are accessible to whoever wants to join them. It is the most popular of the three types, as it is the one on which the Bitcoin and many other cryptocurrencies have based their systems. The main feature is the avoidance of mediation between trust mechanisms, thus not imposing specific requirements for joining the network. Conversely, it stimulates the participation basing the whole system on the large participation: the bigger it is, the stronger it gets;
- *Hybrid Blockchains*: or “consortium Blockchains”, where the mechanism is controlled by a previously selected ensemble of nodes, making it an only partially decentralized network, based on a system of nodes which are not equal in measure, defining a hierarchy that is based on the relevance of each different node;
- *Private Blockchains*: also called “permissioned”, these are the types in which all the operations are exclusively managed by one or more appointed individuals. It is a closed model of blockchain, that could be joined only after having obtained the required authorization.

Type	Also called	Controlled by	Main usages
Public	Permissionless	All nodes can exercise control over the chain	Cryptocurrencies, Non-Fungible Tokens
Hybrid	Consortium blockchain	A preselected ensemble of nodes, while other nodes have no controlling power	Logistics, Insurance and Healthcare, Banking and Finance
Private	Permissioned	One or more appointed individuals	Retail, Supply Chain, Logistics

Table 1- *Types of blockchain*

Once the three main types of blockchain have been presented, it is possible to have a clearer sight on the idea behind this thesis and better understand its further development. Even though the most popular and better-known model is the permissionless one, it is quite reasonable to think that, for the purposes of this thesis, the best fit for a sustainable application of the blockchain could be the permissioned model, as its dimensions are generally smaller and controlled by a central entity – for example a company -, thus having a reduced energetic consumption and consequently a weaker impact on the environment. In the next chapter, a more detailed insight on this specific issue will be presented, putting the basis for the search and presentation of an effective compromise. Notwithstanding this hint, it is not possible to state that there exists a better or the best blockchain model a priori, but rather it is necessary to understand which one best fits the needs required by the case of application and if it could optimally reach the intended aims.

Considering all the premises done, there are multiple concrete applications of the technology, all of them promising to improve or even revolutionize the fields of applications to which it can be involved. A meaningful example could be the document management or the certification of goods and products, usages for which it is commonly believed that a private blockchain could be the best solution, allowing the main user to modify the rules of the system, making it more effective than using a public one, where no control could be exercised.

1.3 Blockchain's self-defense system

Summing up, each block contains a set of data, such as the details of a transaction, plus its very own hash – the alphanumeric code that encrypts each block individually – and the hash of the previous block, a link that conceptually emulates the shape of a chain. Starting from the "*Genesis Block*", the first ever belonging to this complex structure, all of the other parts have been added in a timespan of fourteen years.

A brief explanation on the functioning of the security system of the blockchain could be given as a self-defense mechanism based on a real mathematical challenge, that requires to use computational resources. Together with the already extreme complexity of such a task, to accomplish the manumission of the blockchain there are also other requirements to fulfil and, most important, timing restrictions to respect – making it a time-consuming process -, as the calculation system for each block to be created is of about ten minutes. Such timeframe avoids malicious individuals to carry out their hacking activities and to damage the chain. After that, the new block generated has to fit with all the other ones in the chain – something whose level of difficulty is easily understandable – and can be contested by all the other members that have joined the network. Among the methods to avoid the penetration of an external party inside one or more blocks, breaking a ring of the chain, the blockchain generally exploits a cryptographic protocol called "*Proof of Work*".

1.3.1 The Proof of Work

Proof of Work is a decentralized consensus mechanism which requires members of a network – also called "nodes" - to expend effort to solve an arbitrary mathematical puzzle, whose aim is to prevent anybody from overtaking the system (Frankenfield, 2022).

It is used to validate transactions and for mining new assets, and does not require any monitoring of a trusted third-party to satisfy the transparency requirements, as it is based on a secure peer-to-peer process of control that involves all of the nodes interested in the validation of a new block, or in the change of one of them. This creates a race among all the interested parties, as "the nodes of the blockchain network really compete in finding a valid hash that can be validated and stacked in the blockchain, and the first one finding a valid hash is rewarded with a percentage of new mined assets – which often are cryptocurrencies -, making the nodes really motivated to sustain the blockchain" (Rana & al, 2019). Obviously, as this method involves potentially all the members of a blockchain to take part to the competition for the validation of the interested node, it requires a huge amount of energy, which increases as more miners join the network.

Going back to the functioning of the PoW mechanism, the peer-to-peer network, which guarantees the decentralization of the entire system, creates a macrosystem where all the participants own a complete copy of the blockchain itself. Thus, each member of the network is able to rebuild any type of operation that has been previously done, as each node automatically receives information on each block, every time one is created. This allow them to control that any block has not been manumitted, through a verification followed by the confirm of all the participants to the network that no block has been tampered. In case of any attempt to add a manumitted block, the other nodes will not give their green light to its approval, so it will be discarded. Thus, to negligently modify the blockchain it would be necessary to alter all of its blocks, and still would not be enough, as the saboteur would also need to get the control of at least more than the 50% of the whole network: an almost impossible scenario to be realized, both in terms of time and expenditure.

Together with the Proof of Work, which is the most used and implemented in many systems using the blockchain – such as the Bitcoin -, there are two other security mechanisms that represent a valid and more sustainable alternative to it: the "*Proof of Stake*" and the "*Proof of Elapsed Time*".

1.3.2 The Proof of Stake

In the blockchain systems using the Proof of Stake (PoS), each node has the possibility to validate the transactions thanks to a certain amount of assets that it has to contain, a less risky measure in terms of potential for an attack on the network, as it structures compensation in a way that makes an attack less advantageous (Frankenfield, 2022). Proof of Stake reduces the amount of computational work required to verify blocks and transactions that keep the blockchain secure, changing the way to verify blocks are verified using the machines of assets owners, with the latter offering their assets as collateral for the chance to validate blocks, thus becoming "validators". To better guarantee a higher level of security, validators are randomly selected to mine or check the block, avoiding a competition-based mechanism – more exposed to biases – which is used in Proof-of-Work. Blocks are checked by more than one validator, and when a specific number of them verify that the block is accurate, it is finalized and closed.

Proof of Stake is designed to reduce the scalability and environmental sustainability concerns surrounding the protocol of Proof of Work, which is a competitive approach to verifying transactions, so it encourages people to look for ways to gain an advantage, especially when it comes to the involvement of monetary value. In the market of cryptocurrencies, where an actual example is the network of Bitcoin, miners earn Bitcoin by verifying transactions and blocks. However, to do so they pay their operating expenses, such as electricity and rent with fiat currency, exchanging their money for energy, and the energy for cryptocurrency. In a cost-benefit evaluation that an individual is called to make – often seeming to be in favor of the value obtainable in form of cryptocurrency -, it has to be considered that the amount of energy required to mine Proof of Work assets deeply affects the market dynamics of pricing and profitability, as this type of mining brings a significant environmental issue. Giving a rough estimate as a benchmark, it is possible to say that the PoW mining model uses as much energy as a small country. On the other hand, the Proof of Stake mechanism seeks to solve this problem by effectively substituting staking in favor of computational power, whereby an individual's mining ability is randomized by the network. This leads to a drastic reduction in energy consumption, since miners cannot rely anymore on massive farms of single-purpose hardware to gain an advantage on each other, as there is not a specific hierarchy to follow when coming to nodes computation. In terms of security, many doubts have affected the opinion of people operating in the blockchain on whether it is safer to adopt PoS over PoW, as the former actually finds a weakness in the so called "51% attack" issue, briefly presented in the previous paragraph. Even if it represents a concrete possibility, to obtain the majority of the assets inside a blockchain network in order to gain the possibility to negligently alter the remaining blocks, it is a very unlikely scenario to be realized. Not only it would be too expensive to stake such a percentage of the whole chain, but it would also turn into the loss of all the staked assets of the miners trying to revert one or more blocks. This counterweight system creates an incentive for all the joiners of the blockchain, which are led to act in good faith for their own benefit and for the one of the whole network.

Summing up, the main difference between Proof of Stake ad Proof of Work systems is that the former uses randomly selected miners to validate transactions, while the latter is based on a competitive validation method to confirm transactions and add new blocks to the chain.

1.3.3 The Proof of Elapsed Time

The Proof of Elapsed Time (PoET) is another blockchain network consensus mechanism that keeps the process more efficient by following a lottery system, such as the Proof of Stake does (Frankenfield, 2022). It was created by Intel Corporation, and it is used in permissioned blockchain networks to determine who creates the next block. It aims at preventing a high resource utilization and energy consumption, and bases its validation process on the timespan required for the approval of each transaction.

To do so, the algorithm uses a randomly generated elapsed time to decide mining rights and who will be the block winners on a given blockchain network, with the selected lottery system equally spreading the chances of winning across participants, giving every node the same chance. The method also enhances transparency through the usage of a trusted code – which cannot be altered by any participant - within a secure environment, and ensures the verifiability of lottery results by external participants or other permissioned entities.

For what it concerns the mining process, it starts only after the PoET algorithm has generated a random wait for the nodes to respect, during which each of them must stand by. The wait time assigned is different for every unit involved, creating an order to be respected where the node with the shortest wait time will wake up first and win the race, thus being allowed to commit a new block to the chain only after the chosen timespan has elapsed. This workflow is similar to that of Proof of Work systems, but consumes less power as not only it randomly makes a selection of nodes instead of involving all the miners in a competition, but it allows the them to sleep and switch to other tasks for the specified time, thereby increasing the energy efficiency for the whole network. In other words, PoET controls the cost of the consensus process and keeps it nimble, so that it remains proportional to the value derived from the process, an essential requirement for the sustainability of the mechanism: no unnecessary processes and calculations are required, thus no waste is generated.

1.4 Past, present and future of the blockchain

An insight into the history of the development of the blockchain is useful to create a background knowledge on the topic and to understand why it is expected to change the global market. Moving from its first steps, the paragraph covers its phases of growth and expansion and present the hopes and expectations placed on the technology and its applications.

1.4.1 Past and present: how did we get to where we are now?

Despite we know very well how the blockchain works, the same cannot be said about its origins and who created it. Despite it is certainly known that the technology was invented in 2008, for what concerns the identity of its creator only some hints have still come to us. Just one name has reached the public domain: Satoshi Nakamoto, the nickname used by the still unknown person or group of people to which is attested the paternity of the technology, behind which a condition of anonymity has now been resisting for fourteen years. During this long period of time, many theories have been made in order to find who hides behind such a mysterious persona, that not only has become one of the most influent figures in the field of economics - due to the massive importance that blockchain and cryptocurrencies have earned, with Nakamoto also being the developer and inventor of Bitcoin, thus conceptualizing even the notion of cryptocurrencies – but that is also said to be the owner of one of the highest amounts of released Bitcoins, detaining about one million units on a total of 21 millions available. This would mean that, considering their average price in 2021 of 46.793,76 USD - our elaboration of Statista data (statista.com, 2022) (*Figure 1*) -, Nakamoto's wealth could be estimated to be around 50 billion USD - even though this calculation suffers from the high volatility characterizing the market of cryptocurrencies -, making him or her one of the richest people on Earth.

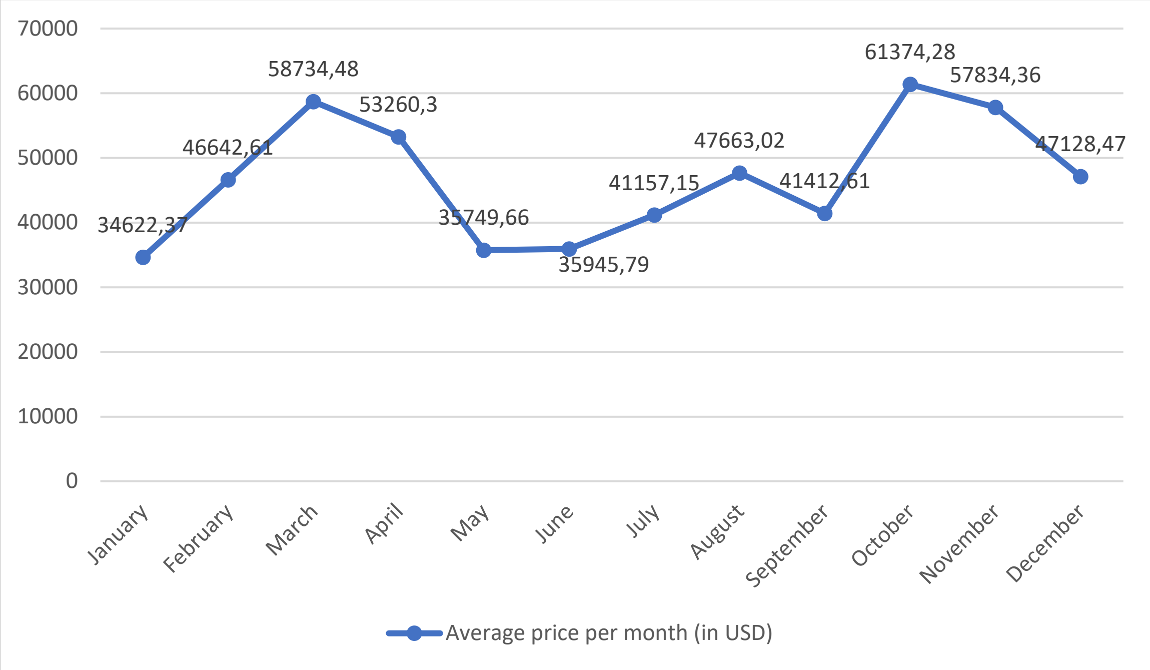

Figure 1 *- Bitcoin price per month in 2021*

If the mystery around the creation of blockchain may lead people to be wary of it, on the other hand it is the clear evidence of how strong and impenetrable this system is, ensuring users' data to be safe, and has indirectly represented a strong endorsement to the technology itself. This has represented a strong point favoring its expansion and popularity, especially after the global financial crisis of 2008 – the same year of birth of the blockchain – that has embittered the relationship between investors and banks and institutions, such as States whose treasury bonds released by Central Banks had returns suffering from a high level of uncertainty, leading to an increase in its interest rates. Such a scenario surely played a role in the search for alternative types of investments. From then on, a huge amount of questions raised, concerning the way the previously mentioned banks and financial institutions operate, with the key problem on top of all of them being the asymmetry of information characterizing the relationship between financial industry and investors (Schinckus, 2020).

As we have seen, the entering of blockchain inside what could be easily intended as the public domain knowledge has first involved only the strictly financial applications of it, meaning only the creation and expansion of the market for cryptocurrencies, in all of its declinations. It was not until 2014 when researchers began to study and identify the benefits of the technology for different usages in different industries. Among the first industries to analyze the theoretical applications there were covered sectors such as financial services, healthcare, energy and public administration, and obviously that of Distributed Ledger Technologies (DLTs) in general.

DLTs are all those digital systems used to record transactions of assets in which the transactions and their details are simultaneously recorded in multiple places, having no central data store or administration functionality (Troy & Pratt, 2020). This has then evolved in the past few years, and new, numerous applications have been experimented, with even more expected to come especially for what it concerns critical tools for the bureaucracy, which is more and more called to keep up with the economy's digital transformation, also being a perfect fit for the necessities brought by smart contracts.

In the words of professors Marco Iansiti and Karim R. Lakhani of the Harvard Business School, "With blockchain, we can imagine a world in which contracts are embedded in digital code and stored in transparent, shared databases, where they are protected from deletion, tampering, and revision. In this world every agreement, every process, every task, and every payment would have a digital record and signature that could be identified, validated, stored, and shared. Intermediaries like lawyers, brokers, and bankers might no longer be necessary. Individuals, organizations, machines, and algorithms would freely transact and interact with one another with little friction. This is the immense potential of blockchain". Still, in their 2017 article called "The truth about Blockchain", published in the Harvard Business Review, they claimed that "if there's to be a blockchain revolution, many barriers — technological, governance, organizational, and even societal — will have to fall. It would be a mistake to rush headlong into blockchain innovation without understanding how it is likely to take hold. True blockchain-led transformation of business and government, we believe, is still many years away. That's because blockchain is not a "disruptive" technology, which can attack a traditional business model with a lower-cost solution and overtake incumbent firms quickly. blockchain is a foundational technology: it has the potential to create new foundations for our economic and social systems. But while the impact will be enormous, it will take decades for blockchain to seep into our economic and social infrastructure. The process of adoption will be gradual and steady, not sudden, as waves of technological and institutional change gain momentum".

If we consider that we are now living five years after the publication of this article, it is easy to state how these words still hold the truth, as blockchain is still far from taking over the market and institutions. Having in our hands the possibility to exploit a power with a huge potential, still currently being only a promise and not a concrete reality, there are two paths to follow: the more prudent one is that of analyzing its applications in a controlled environment, so limiting its usage to experiments and study cases; the second one has started gaining more ground in the past few years, and regards all of those business realities and even public entities – for which the process is obviously slower, as it needs a detailed regulation to be sustained – that have decided to deep dive in this digital world, pioneering this field and a branch of the Industry 4.0. A more detailed insight on these realities will be given in the further chapters of this thesis, where many different applications in likewise environments will be shown, analyzing all the advantages and disadvantages that have been discovered in such concrete cases.

1.4.2 Future perspectives: where are we heading to?

Once we have presented how we have come to nowadays' market and environment around blockchain, the next step leads us to a foresight of future perspectives. In the last couple of years, everything has changed for blockchain, digital assets and financial services, and this is not only due to the COVID-19 pandemic. The proliferation of digitalization, touching many and many processes as both as a means of exchange and a store of value has expanded significantly, generating a seismic shift that has impacted the global financial services industry (FSI) in particular, and the organization of different types of companies as well, has recently been further challenged by new business models around digital assets. This has been efficiently stressed by Deloitte in its "Global Blockchain Surveys" (Deloitte, 2022), with the latest ones available – those of 2020 and 2021 – in which are presented the results of surveys that the firm has conducted, whose aim was to understand how the market currently sees this technology and which is the future scenario on its applications according to the companies that participated to the surveys. First, the 2020 Global Blockchain Survey (Deloitte, 2021) has succeeded in framing the market's opinion before the effects and consequences brought by the COVID-19 pandemic, as the study closed on the very first days of March 2020, right before the virus emerged as a global health crisis. Obviously, the result may present a situation that has later suffered from the impact of the pandemic, so only time will tell what long-term effects, if any, the global health crisis will have on blockchain and digital asset adoption practices. Deloitte conducted the 2020 Global Blockchain Survey between February 6 and March 3, 2020, as a research vehicle to gain greater insights into the overall attitudes and investments in blockchain technology. It highlights the opinions and perceptions around it and the potential impact that it could have in the future.

The survey pulled a sample of 1488 senior executives and practitioners in 14 different countries (Brazil, Canada, China, Germany, Hong Kong, Ireland, Israel, Mexico, Singapore, South Africa, Switzerland, United Arab Emirates, United Kingdom and United States), with the respondents having at least a broad understanding of blockchain, digital assets and distributed ledger technology, and were familiar with and able to comment on their organizations' blockchain and digital asset investment plans and perception. Also, to expand the respondent pool's diversity, a group of 100 respondents specifically and directly engaged in blockchain technology development projects was identified and inserted into the 1488 overall respondents.

According to the analysis on the survey given by Deloitte, the results suggested that, after the previous year's outcomes (2019) suggesting that companies had moved away from being just "blockchain tourists" – thus having interest only in understanding how the technology works and what could bring to their organizations – and were defining and developing more permanent implementations, in 2020 an increasing number of leaders expressed this will, saying that they started seeing blockchain as a top-five strategic priority, thus they started to increase their investments on it (*Figure 2*). The results then showed how the interest had grown in the years, with respondents considering blockchain as a top priority being more than 55% of the whole participants - showing a positive trend versus the 53% reached in 2019 and the 43% of 2018 -, while 26% answered that it will be important but not in the company's top-five strategic priorities, 14% saying that it will be relevant but it is not a strategic priority, then 3% of the respondents had not reach a conclusion and finally only 2% of them considered the blockchain as not relevant for the future of their companies.

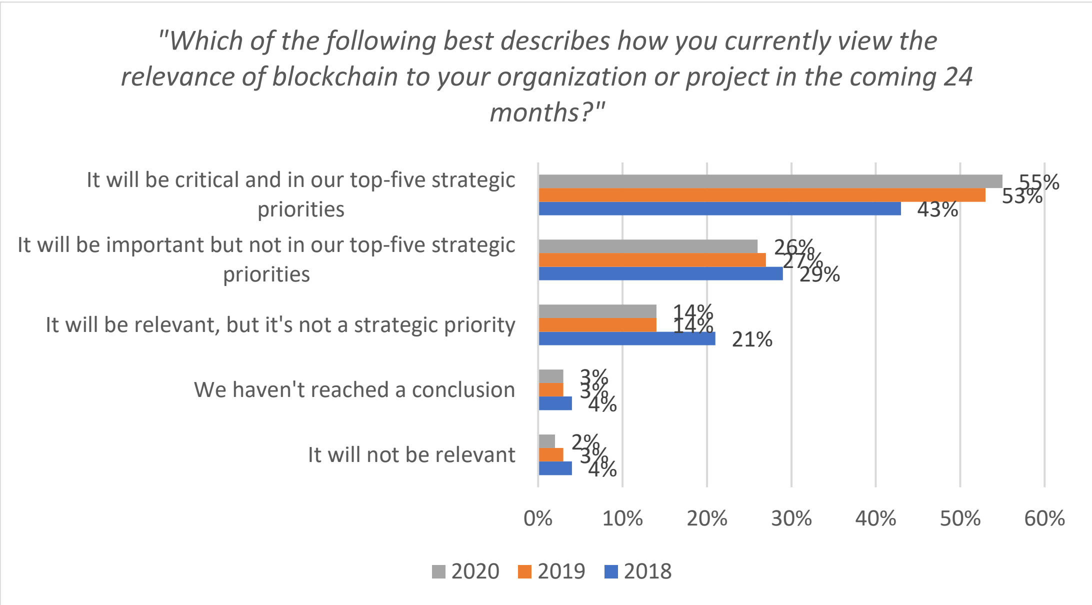

Figure 2 *- Blockchain relevance within organizations*

N= 1488 (2020); N= 1386 (2019); N= 1053 (2018). Sources: Deloitte's Global Blockchain Survey, 2018, 2019 and 2020.

These results are also supported by other evidences, as the survey reveals that companies continued to put money into blockchain initiatives, with 82% of respondents saying that their companies were hiring specialized staff with a specific blockchain expertise, or at least they were planning to do so within the next year (nevertheless, we must consider that the survey was conducted right before the COVID-19 pandemic took over, so results might be discordant to what the participants' companies actually did). Such a result is even more significant considering that in the previous year the same answer was given by 73% of the respondents.

If on the one hand the survey shows how the interest on the technology is rapidly increasing, on the other hand it demonstrates how there is still a considerable amount of uncertainty about its current and future applications. Even if this might result as contradictory, it is easily understandable how this depends on the common acknowledge that the digitalization process – thus including especially the implementation of new blockchain applications – will continue to take time, depending on industry, maturity, risk tolerance and budgets. This condition of skepticism is reflected through data, as the number of respondents who consider blockchain to be "overhyped" hit 54%, rising versus the results of 2019 and 2018, which are respectively 43% and 39% and the percentage of those thinking that it offers more security than conventional IT systems fell to 64% from 71% in 2019. This is also reflected in the answers that the participants gave to the question "How do cybersecurity issues affect your organization's blockchain or digital assets strategy?", in which stands out that more than a half of the respondents expressed concerns that cybersecurity issues may be further hampering the acceptance and use of these tools. The 58% of them answered that cybersecurity is one of several issues that affects their overall blockchain or digital assets related strategy, while only 21% said that cybersecurity issues are, in themselves, enough to prevent progress in such field. At a first glance, this obviously means that in the real-world organizations might be concerned by cybersecurity, but they may not fully recognize the importance of preparedness measures they should take to alleviate cyber threats. Surely digitalization exposes the security of companies, making them vulnerable to the theft of valuable private financial, health and other personal information, but, as far as we know, one of the best solutions to prevent hackings – if not the best – is given by the blockchain itself.

On the one hand, blockchain's inherently cryptographic character offers an excellent level of assurance that its foundational platform is safe from cyberattacks, and its distributed nature suggests a degree of transparency that would allow for quick detection of attacks. Still, even a system with such a design is at least potentially vulnerable to the kinds of attacks that have burdened legacy systems in industry and government in recent years, which could be even stronger and higher in number in the near future. As a matter of fact, it is thought that advancements in quantum computing may one day challenge and possibly overcome the existing methods of cryptography exploited by blockchain security platforms. Organizations' efforts to solve these issues remain a work in progress, and a viable solution has still to be found. Any progress in this field would help allay fears around increasing cybersecurity threats and the relative safety of blockchain-enabled systems. Obviously, these doubts regard potential perspectives, hypotheses which have relatively small odds to happen, but the mole of damage that would be caused if this scenario shall become reality represent a reasonably worrying concern. So, even though the participants were aware of the level of security guaranteed by blockchain, it is understandable how an intimate tendency to risk aversion may have affected their answers.

Nevertheless, it would not be realistic to say that the expansion of blockchain applications is not taking place, as new implementations seem to find expression on a nearly daily basis. These production proof points are clearly signaling that blockchain is making a tangible difference in how business gets done across regions and industries. Obviously, large-scale projects are those gaining media attention, but smaller-scale applications are the ones proving to be just as transformational in the way people live and how work gets done, affecting a variety of areas such as title transfer and protection, patient data storage and retrieval systems, platforms to make voting easier and more secure, and tracking food sourcing. All of these are nuanced but tangible proof that blockchain is finding footing in the stream of global commerce.

To strengthen the fact that this heightened production is meant to last in the future, the survey shows an increase in respondents saying that they have already incorporated blockchain into production (39%), versus the previous year's 23%. Obviously, the expansion and introduction of new blockchain-related technologies inside a company calls to an adaptation of the organization and processes for relevant parties, including regulators and standard-setters, who have to work on understanding, monitoring and addressing all the concerns anytime they emerge. All of the organizations and nations that do not find a clear path could risk to lose market share to others that have addressed such challenges. It is also worth noting an even larger point: when an organization integrates a blockchain platform into its core operations, virtually everyone who supports those core operations become a stakeholder: from C-suite to the board of directors, internal and external auditors, legal, compliance and financial professionals, ending with, of course, everyone else who is directly involved in the system.

The survey also highlights a relevant topic strongly linked to digitalization and to the usage of new cryptographic technologies (*Figure 3*). The topic is that of global digital identity, arguably the most important "business card" to be shown before any current and future digital transaction. The answers given by the respondents have shown how they see the global digital identity as very important (63%), having its greatest impact in global financial transactions (29%) and data privacy/ownership (27%). If this may seem an almost foregone fact, the same cannot be said for what it concerns the answers given for the importance of digital identity on other fields such as law enforcement (recognized by only 5%), health care (9%), international travel (7%) and regulatory compliance (7%), which are actually extraordinarily fitting fields for the application of digital identity recognition, all requiring processes that might strongly beneficiate from digitalization.

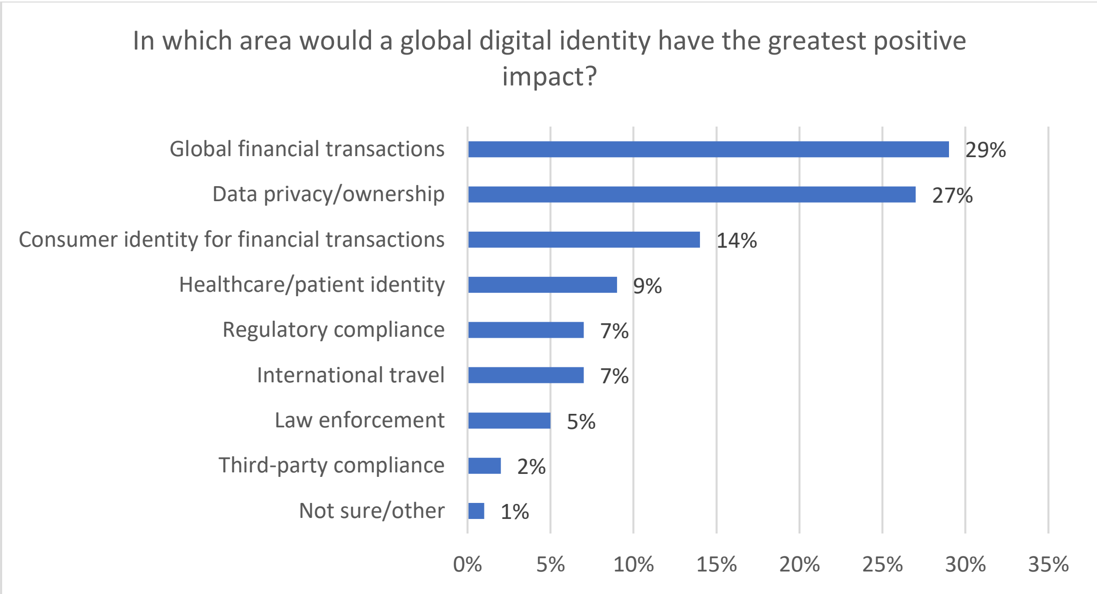

Figure 3 *- Areas of greatest positive impact of global digital identity*

N= 1488. Source: Deloitte's 2020 Global Blockchain Survey

Eventually, these areas may take on greater importance and play an increasingly important role on the impact that digital identity could have on people and businesses' daily lives, but this requires that the population develops a greater understanding and acceptance of the topic itself: until then, the full benefits provided by this technology will likely remain untapped. As we still are far from achieving success in this field, global digital identity needs to gain wider acceptance among the general public, and needs to address people's concerns about the safety and unauthorized dissemination of their valuable, personal data – two very harsh challenges to overcome. The core of the problem is that global identity is, in many ways, based on theory and reasonably still not ready for full-scale implementation. Nevertheless, new insights into how it could potentially affect different market offerings and blockchain protocols are emerging more and more frequently, and progress continues. While the current situation is far from a solution, at least for the time being, it is reasonable to believe that it won't be too long until it becomes a widely accepted and utilized protocol across most of, if not all, the business sectors.

Despite the results generally show a good level of confidence of respondents on their ability to meet blockchain-related regulatory requirements, these are still far from being developed enough to cover each issue in applications such as, for example, tax, financial reporting, industry-specific regulations, security and many others. An absence of regulatory harmony in a blockchain and digital assets construct offers management, regulators, standard-setters and professional service providers the chance to work together in forging a new common guidance and establishment of best practices. Even so, the previously mentioned self-confidence could belie deeper issues surrounding the regulatory challenges still to be faced.

Considering the features of blockchain, such as being based on a multiparty, cross-border architecture, spanning many geographies and their respective regulatory systems, the different governments will likely adopt different positions on the topic and how to deal with it. Geographic variability within a blockchain architecture brings a relevant level of complexity around which laws prevail in a case-by-case scenario, a dynamic that gets more and more challenging as regulations evolve and become in turn more complex. Indeed, the issue of properly certified financial and process records will only grow as blockchain becomes more widely used, especially in cross-border configurations. This plays a crucial role and has a special responsibility on all those who play a part in the financial reporting ecosystem to have the most current skillsets to identify and respond to new and different risks in this environment. Even more important is for those leading an organization to remain current in a fast-evolving and more and more confusing regulatory environment, because it is leadership that sets the tone about properly applied standards. For what it concerns their part, only professional service providers with a sophisticated understanding of the underlying technology and the evolving regulatory complexity governing its application will play the most critical roles in assuring compliance.

As previously said, the respondents showed to be confident to be able to satisfy a full array of blockchain-related regulatory requirements. The answers given present a consensus going from 83% to 76% on the ability to meet regulatory requirements on topics as: financial reporting, privacy, informational reporting, securities law, money transmission, tax, anti-money laundering, geography-specific regulations, smart contracts enforceability, industry-specific regulatory issues. Despite this overwhelming expression of confidence, a measure of complacency might be veiled, being unwarranted and, in the long term, possibly untenable.

More on regulatory measures taken or planned by public entities will be discussed in the next chapter.

1.5 Regulation and markets: a geographic analysis

To better frame this condition of heterogeneity generated by geographical variability, which brings with itself differences in regulatory systems, it is useful to present and analyze the current conditions of the market, dividing it per development conditions on the field (*Table 2*). This allows to make a quick comparison among some of the most advanced countries in the field of blockchain technology, reflecting the variety of approaches that different nations from every part of the world have adopted, whether these have already led them to the adoption of rules and laws concerning the topic, or if the legislative process is still a work in progress. The observation does not include those countries and regions where the blockchain market does not represent yet a relevant market – such as those of the African macroregion - and does not divide the groups of analysis directly into continents, as some realities represent a unicum, thus deserve to have a specific and reserved focus on them.

Among the pioneers of the field, laying the foundation for a market with a high level of traffic market, a seat is obviously held by the United Arab Emirates. Already in April 2018, the UAE initiated a national blockchain strategy whose goal was to conduct 50% of government transactions using this technology by 2021. Similarly, in 2016, the Emirate of Dubai defined a first-of-its-kind blockchain strategy across multiple verticals with the goal of becoming the first government in the world to conduct 100% of applicable transactions via blockchain. This obviously generated a general optimism for the emergence of a strong digital assets ecosystem in the region, and has already attracted many global players which have entered the regulated Middle East market to exchange digital assets.

A more prudent approach to the adoption of blockchain-based applications and its regulation is that of the European Union, where blockchain represents a priority, but its hybrid institutional nature allows different markets to adopt different approaches to the technology, even though all of them could be generally considered positive and proactive. As the multitude of Member States represent an ensemble of unique cases, a benchmark state will be analyzed here to give a significant example. The chosen state is Germany, where the blockchain has gained new momentum as policymakers have actively engaged the legislative process, such as the publication of a draft law to regulate the offering of tokens, as well as public support and promotion of lighthouse projects that exploits blockchain technologies in the national administration. A substantial activity is also present around the development of cryptocurrency regulation that might cast Germany as a safe regulatory environment for this type of activities, and eventually a lead to follow whenever the EU will create its own blockchain-based systems, a scenario which seems to be not quite far from where we are now. As a matter of fact, an attempt to harmonize and regulate the licensing system for banks and institutions releasing digital assets and cryptocurrencies in the European market is already being discussed and almost ready to be in act, and the perspective of the release of a "crypto-Euro" seems to be more and more close to become reality.

Finally, the last case regards what could possibly be considered as the most reluctant country on blockchain and digital assets applications among the world's most developed nations and strongest industrial realities, China. Despite being in the macroregion of Asia Pacific, where institutions express a strong belief in the strategic value of blockchain and there is a widespread recognition of it being an important strategic tool, and considering the width of the territory analyzed – both in geographical and cultural senses – it can be seen how some locations in the region are much stricter than others about the free flow of data and information across and within their boundaries. As a matter of fact, in China Mainland remains some trepidation over how cross-border, multiparty blockchain configurations can and will affect their control over businesses and governmental data. So, after having blocked all the channels for the exchange of cryptocurrencies and made them illegal (Soldavini, 2021), only recently the Chinese central bank has conceived a digital version of the yuan, as a national cryptocurrency used for internal transactions and regulated by the central bank. Thus, for what concerns the blockchain's usage and regulation, it is likely to think that future developments will be different from those regarding the rest of the world, as the current state of things prospects the creation of a Chinese blockchain-based market, differently regulated from a global one. Until now, private and permissioned networks do not seem to have caught on the market enough yet but should definitely remain a vital technology pursuit, considering the size of Chinese industrials, their typically large numbers of subsidiaries and the vast amounts of data they produce.

Outside of China Mainland, the situation on blockchain, cryptocurrencies and digital assets is significantly different, with Hong Kong SAR and Singapore among the others having a more accepting ethos as China Mainland's. They are competing for a different, freer kind of business and have been going head-to-head in developing a regulatory landscape that is more conducive to the growing acceptance of cryptocurrency and blockchain technology applications. While both locations remain highly competitive in this space – albeit at a relative startup stage – they are targeting the same type of investors, mainly being crypto players and similar. This healthy competition could help to accelerate blockchain expansion and acceptance in the broader marketplace.

Advanced	Prudent	Reluctant
United Arab Emirates, Israel, Switzerland	European Union member states	China, India

Table 2 *- Countries' approach to blockchain regulation*

1.5.1 Blockchain in Italy

To complete our analysis, a room shall also be made for Italy, in order to get familiar with the environment we are living in. The Italian blockchain industry has shown a rapid development in its early stages, now having a consistent number of entrepreneurs engaged in developing, testing and commercializing different Distributed Ledger Technology (DLT) based infrastructures and applications. The numerous use cases how entrepreneurs are exploring business opportunities for blockchain technology span from supply chain management to IP & Copyright protection, human resources and procurement, targeting a large number of sectors such as agri-food, ICT, arts and entertainment and healthcare. Among them, what could reasonably be meant as the most useful applications based on the technology are those belonging to the area of supply chain management and IP protection, whose relevance is given by the state of things characterizing the Italian economy, which is one of the major global targets for copyright infringements. As a matter of fact, blockchain solution can help Italian companies to face the challenge posed by counterfeiting and piracy, two elements that make it the third country in the world as economy of origin of right holders whose IP rights have been infringed, right after USA and France, with 15% of the seized counterfeited and pirated goods at global level. This obviously has a significant weight and impact on the Italian economy, amounting total losses of many billion euros, mainly affecting small and medium enterprises, which are the most exposed and susceptible to these attacks (Bianchini & Kwon, 2020).

All these premises made, the soil where to plant the seeds and make the market flourish seems then to perfectly fit the potentialities offered by the blockchain, as Italy is characterized by a large, diversified and export oriented industrial base and strong competitive firms operating in manufacturing and services markets at national and international level. This collocates it to a great position to access the benefits of DLTs applications and infrastructures. However, Italy still has many important policy challenges to face in order to fully take advantage of this technological transition, especially in relation to the uptake of digital technologies by SMEs, and the government has started taking action with several programs providing firms with incentives, financing, trainings and knowledge transfer.

As easily intuitable, this could only stem from the construction of a strong network sustaining the digitalization of companies, as wide as the number of small and medium enterprises (all those firms having respectively 1 to 49 employees and 50 to 249 employees) which stand for the 99.9% of the total businesses in Italy. The implementation of digital technologies offers SMEs an opportunity to enhance productivity and pursue innovative activities in an easier and cheaper way, while digital products enable small businesses to use their resources efficiently and to organize their business process in a leaner way. Even though the adoption of new technologies requires time and effort, the reductions in costs and the wide diffusion of complementary systems can make it affordable for all those smaller and more constrained businesses to join new processes involved in the digitalization. By using digital-based products and systems, SMEs get the potential to overcome all of the barriers they currently face in scaling up and innovating their processes, so it is important for the government to guarantee and ease the access to digital infrastructures.

First of all this passes through the access to the internet, a common feature to almost any firm, that reasonably cannot be limited to a weak and low-speed connection, which represents a problem that a very large share of companies still suffer from. Numbers say that in 2019 the 97.6% of Italian businesses were connected to the global network – a data which has very likely slightly grown in the last couple of years -, but this does not mean that all of them are completely able to benefit from this: about half of Italian firms, whether they are micro, small, medium or large enterprises, still have what can be defined as a basic broadband, with a download speed of less than 30 Mbps.

Also, a significant geographic disparity in access to broadband connection is registered between urban and rural areas, both in northern and southern regions, with the latter being generally poorer in internet connection distribution. While around 80% of the population is covered by fast broadband, coverage in rural area drops to around 40%, making it one of the largest gap coverages in the European Union. Although these calculations have been done on population coverage, it is still an easily adaptable benchmark, suggesting that businesses in rural areas could also have limited access to fast internet, being cut out of the digitalization process and all its related benefits.

Despite of that, Italy is one of the top four countries in OECD - the Organization for Economic Cooperation and Development – for private sector Information and Communication Technologies (ICT) spending, with an expenditure of 71 billion USD in the timespan between 2016 and 2019, following only the United States (748.4 billion USD), Japan (171.5 billion USD) and France (132.5 billion USD). The growth of firms investing in advanced technologies seems to be destined to grow, as it shows a more and more increasing trend, pushed by policies as the so-called “hyper-amortization measure”, provided by the national “Industry 4.0 Plan” (Impresa 4.0) which was approved in September 2016 and aimed at supporting investments in advanced technologies. The instruments given by this plan increased with firm size, getting more widespread among manufacturing firms, especially in the chemical and pharmaceutical sectors. The data collected before the Covid-19 pandemic regarding the share of firms that reported investment in advanced technology, show a growth going from 38% to 44% and investment in digital technologies has been estimated to account for around 15% of the total investments made by companies, according to Banca d’Italia.

Investing in internet-based ICT services and systems could provide companies with new opportunities to overcome size-related constraints – a common issue to a market almost completely made up by SMEs -, such as the possibility to exploit cloud computing, which would make ICT resources more flexible, and to explore the potential of big data and to manage them, a recurring issue in blockchain applications. This latter element touches a sore point, as Italian enterprises are still far from reaching a competitive level of knowledge in the field, which could eventually use data analytics that provide solid basis for data-driven decision-making, thus increasing productivity. Despite being one of the top four OECD economies for expenditure in private sector ICT applications, Italy also registers a significant countertendency for what concerns ICT training, having one of the lowest values in the group of OECD nations. The process of business digitalization requires more than just the simple adoption of digital solutions, so it is crucial to have employees that are ready and prepared to the change brought by the new digital systems adopted, in order to make an effective use of technology. Thus, the successful implementation of blockchain applications in business processes could suffer from this poor readiness of employees, not being trained enough to sustain the digitalization process involving their companies.

The main government body supporting digitalization of businesses in Italy, among the others, has undoubtedly been the Ministry of Economic Development – abbreviated to MiSE, as

Ministero dello Sviluppo Economico – whose main act of the last past years favoring the digital development has been the previously mentioned "Industry 4.0 Plan" approved in 2016, then applied from the sequent year. The plan aims to stimulate R&D investments and to develop new technologies, mainly focusing on supporting the integration of smart manufacturing practices, which would positively affect a huge majority of Italian companies. However, the supports provided by the plan are not limited to the manufacturing sector, and the scope of digitalization encompasses also investment in capital goods, intangible assets and processes, with policies aimed at guiding and assists SMEs to pursue digitalization. Together with that, financing instruments are provided to foster digitalization and innovative activities also thanks to the cooperation of MiSE and *Cassa Depositi e Prestiti* (CDP), an investment bank and promotional institution for economic development, which provides government guarantees to Italian enterprises concerning the upgrade and expansion of their digital capabilities. Concretely this translated into, for example, the adoption of a voucher program to provide incentives for companies who want to digitalize their processes, making it easier for them to start a phase of renovation, and through the implementation of technological hubs and competence centers for the transfer of digital knowledge to firms, which form a network that links companies with actors that can assist them in all the tasks required for the digitalization process.

Moving from the first steps made, the "Industry 4.0 Plan" also reached what then were considered as the new frontier of digitalization, and in December 2019 the MiSE launched the first "House of Emerging Technologies", promoting the adoption of new technologies related to Blockchain, Artificial Intelligence and Internet of Things. The aim of these "houses" was to support start-ups' R&D projects, whose new technologies developed could be eventually transferred to consolidated and more traditional companies, thus feeding the market on a larger scale.

As a result of the application of the above-mentioned policies, many effects have arisen. Before pointing them out, it is useful to remember that the Italian economy – is a large, diversified and export oriented one, which offers a conducive environment for the development, test and adoption of blockchain solutions in a variety of sectors. Among these, those that could arguably best fit and benefit the most from the features of transparency, security and traceability offered by blockchain are the ones which mainly base their market value on the origin of the product, which is labeled as "Made in Italy". More in detail, this regards industries of textile, furniture, white goods, footwear, mechanics and agri-food, principally. As blockchain systems are strong in ensuring optimal management of data, generally provided by traditional quality assurance providers on provenance and quality of products, which could add significant value to production processes of those companies that embed the technology.

At this point, some innovative Italian SMEs are testing DLT solutions with the intent of serving the cited sectors, with a part of them that has started to commercialize their services. For example, there is experimentation of the technology in ensuring that food products are cultivated in fields where there is no overusing of chemicals, or that meat is not sourced from intensive animal farming facilities, ensuring the quality and healthiness of the final product, demonstrating how these types of applications can actually bring value to the products and services offered by a company.

Other interesting innovations are being proposed as well in the financial, insurance and utility sectors, mainly by large state-participated companies, financial institutions, associations, and large Italian tech players, that are experimenting on distributed registries. A concrete case is that of, for example, the Italian Banking Association (ABI), which is building applications specific for the Italian market that are based on blockchain infrastructure offered by international market players. Another highly significant example is that of the energy company Enel, a multinational company and arguably the strongest player in the Italian market for energy, that has been experimenting different blockchain-based systems since 2016, although it still has not reached any interesting result, thus not yet exploiting them in a large-scale implementation. Despite the numerous endeavors made until now, it is still too early to identify with certainty where a possible Italian "blockchain cluster" could be directed to.

At this point, technology seems to be at a relatively early stage of development in non-financial applications, and its use in industrial projects is very limited at a worldwide level as providers of blockchain solutions - whether they are large, medium sized or small – compete to create, test and commercialize new applications aiming at outperforming other existing solutions. The lack of a defined path to follow is strengthened also by a multitude of challenges that still have to be addressed both at a technical and at a regulatory level for the technology to be more widely used. Even though it received a huge level of attention in the past years, mainly due to the rise of price and mediatic impact of cryptocurrencies, generating the consequent "bandwagon effect" not only in Italy but at a global level, the application of the technology outside of the domain of crypto-assets is proceeding at a slow pace.

For what it concerns financial markets, innovation must go hand in hand with investor protection and the respect of "Know Your Customer" (KYC) and Anti Money Laundering (AML) rules, all being challenges to the industry, that regulators and market players are currently trying to tackle, mainly by launching pilot projects and experimentation to identify what could be the most interesting and effective applications. At the same time, policymakers and regulators have been active to create balanced conditions for the development of DLTs, and government activity has accelerated in recent years. Together with the already mentioned activities carried out by MiSE, regulators as Bank of Italy, CONSOB and Tax Authority (Agenzia delle Entrate) have issued various official documents to clarify issues related to crypto-assets too. Not only they are trying to find suitable solutions for the Italian companies, but a consistent part of the objectives to pursue is aimed at aligning current laws and regulations with resolutions at European and international level.

Along with the public infrastructures created and used to form a solid network where to set the basis for a blockchain-based side of the Italian market, private initiatives shall be considered too, as they could represent pioneering realities for any possible newcomer. To sustain them, it is obvious that having access to equity funding is crucial, although in Italy it is very limited and among the lowest in the OECD as a share of GDP, but, putting this value into perspective, it has definitely registered a significant growth during the last years. Considering the Venture Capital market, the investments have more than doubled in amount from a total of 73 million USD in 2014, to 187 million USD in 2018, then continuing this positive trend until nowadays. Still, this represents a limitation for Italy, as the level reached is not high enough yet for the development of new blockchain projects financed through venture capitals, as most entrepreneurs have to rely on their own financial resources, making it very challenging to achieve scale.

At the same time, the above-mentioned phenomenon of continuous growth suggests how there is a will from entrepreneurs to exploit the technology, as in 2019 the total amount of investments in blockchain projects made was of about 30 million EUR, up by 100% with respect to 2018. Analyzing the destination of these investments, we see how the percentages reflect what has been discussed before about the main fields of application of blockchain in entrepreneurial activities, as the majority of them regards financial and insurance companies - about 40% of the total -, mainly focusing on systemic infrastructure accessible to all financial institutions, followed by applications in supply chain and product traceability – covering another 30% of the total -, which are often undertaken by SMEs in sectors such as textile and agri-food. The remaining 30% is distributed among different sectors, mainly belonging to the manufacturing industry.

For what it concerns the targets of these projects, most Italian companies seem to be developing B2B products focusing mainly on SMEs (58%), followed by a relevant share of start-ups whose aims are large businesses (27%) and by only 10% of start-ups creating applications or platforms for public institutions and agencies, a type of application which could enormously benefit from the technology and have a strong impact on the market and on the blockchain infrastructure itself.

Besides the main targets and fields of application, each having its own needs and specificities, a point of interest regards the preferences on the type of blockchain to adopt among the permissionless and permissioned models, and the related reasons behind these choices. More than a third (37%) of Italian companies adopting the blockchain technology in their processes opted for permissionless blockchain to ensure disintermediation and transparency, as it allows anybody to become a node in the network and to send and validate transactions. By exploiting the full innovative potential of the technology, this model can guarantee the highest level of decentralization of decision power within the network, completely avoiding the presence of any intermediary, so it better fits larger networks, with higher resilience and reliability. Also, it eases authentication processes and allows companies to introduce their own smart contracts with more advanced functions. More precisely, the possibility to use the "time-stamping" properties of large, permissionless distributed ledger allow for the notarization of private and public documents transparently and in a nearly immediate way, also opening for a number of possibilities to make a more efficient delivery of services – something that has proven to be particularly effective for public services, both at national and local levels. Eventually, it could also be argued that a permissionless network is cheaper to adopt, as the implementation costs are generally lower and less resources are required to manage the nodes, as there is no intermediary nor controlling figures are required, making it a more affordable choice for SMEs.

On the other hand, 63% of Italian firms decided different types of permissioned ledgers (public permissions, private "consortium" and private "enterprise"), implying that they have a central administrator managing the network. This option has proven to be quite popular for business applications as it ensures the benefits of blockchain in terms of transparency while giving the authority to take decisions over the network to a central node and the possibility to refer to it. Permissioned and private blockchains offer interesting applications for businesses and retail clients disposed to trust a third party, in the stead of the administrator, as products can be tailored in an easier way and the time of execution can be drastically reduced with respect to the permissionless alternative. Some of the main large international players proposing permissioned blockchain applications are offering blockchain-based solutions in some of the "Made in Italy" value chains. Among them, some very recognizable brands are offering solutions based on proprietary permissioned blockchains, which allow clients to have a clear counterpart guaranteeing the functioning of the network, such as the "EY Ops Chain" proposed by Ernst & Young, based on the Ethereum blockchain, which in Italy was applied for example to the tracking of products of large retailers in the food and beverage sector, and IBM's DLT solutions based on "Hyperledger Fabric" - a protocol developed by the Linux foundation -, which has been leveraged in Italy for a pilot project on "Made in Italy" in the textile sector.

1.5.1.1 The creation of a network

According to a study conducted in 2020 by "*Osservatorio Blockchain and Distributed Ledger POLIMI*", Italy has been among the top 10 countries in the world for number of blockchain projects developed in 2019. In that year, the registered number of new projects identified by researchers was of 488 units at a global level, an increase of 56% compared to 2018. Of them, only 158 have been actually implemented, while other 57 have only been announced, and among the former only 47 projects are currently in operation, with the majority still being at an experimental proof of concept stage. With a total of 215 between implemented and announced new projects all over the world, this scenario finds the USA taking the lead with more than 50 blockchain-based applications created, followed by South Korea and China, both around 30 projects, then Japan and the United Kingdom, having slightly less than 20 projects, and finally Italy and Russia, standing at 16 each. Even though we have seen how Italy still falls short on the standards set by other countries in many points, this puts it into perspective and defines a market that might have less resources, but which is finding its way through this competitive and fast-growing field.

A possible reason why Italy is doing the part of the chaser among the industrialized countries that have joined the world of blockchain could be found in its reaction to the so-called "ICO hype" of 2017-2018, generated by the huge enthusiasm on cryptocurrency markets, that in those years experimented the usage on a large scale of an alternative form to the Initial Public Offerings (IPOs), changing it to Initial Coin Offerings (ICOs), whose goal was not necessarily to sell shares, rather they were created to issue tokens with no need for stock exchanges or intermediaries like banks (Popov, 2019). This idea, made to ease the introduction of new blockchain projects to the market, was not well received by Italian entrepreneurs and investors, as evidence shows that only 23 ICOs were launched by firms based in Italy, against, for example, the 716 of the United States, or the 582 of Singapore and the 505 of the United Kingdom, just to cite some of the top-ranking countries worldwide. The ICOs launched in Italy during that period only generated funds for 7.6 million USD, an irrelevant amount of money compared to those of the above-mentioned countries – respectively 7.3 billion USD, 2.5 billion USD and 1.5 billion USD. Comparing the results obtained in Italy to those of other European countries, it is possible to see how also against similar countries which belong and must comply to the same entities and, even if in a general way, to the same regulatory system, Italy has launched fewer ICOs and raised less capital than most of the comparable countries in the EU.

As a matter of fact, observing three of the most used benchmark states for this kind of comparisons – Spain, France and Germany – we get a number of ICOs and the total amount of money raised of, respectively, 45 and 108 million USD, 79 and 169 million USD, 121 and 330 million USD (*Figure 4*). Considering how similar in terms of population and wealth these countries are, it is possible to hint how different regulations and nature of each state's markets might have played a role, especially considering that in the years of the ICO hype there was not a common European regulatory framework concerning this specific field.

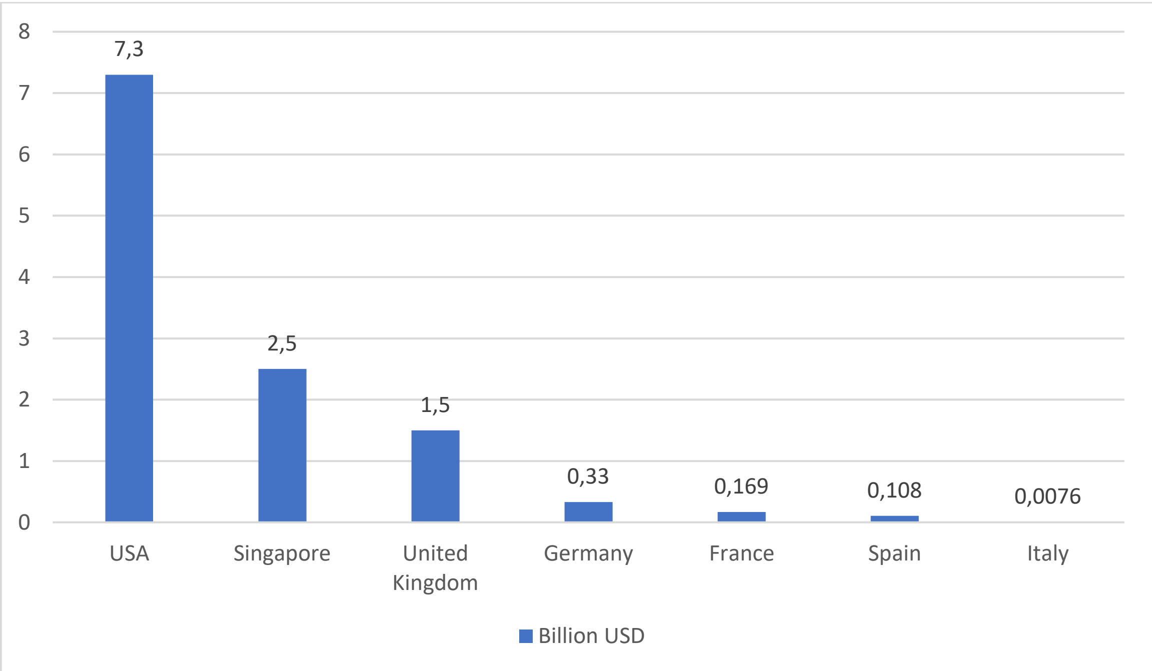

Figure 4 *- Obtained funds by countries in the "ICO hype" period (2017-2018)*

N° of ICOs launched per country: USA, 716 – Singapore, 582 – UK, 505 – Germany, 121 – France, 79 – Spain, 45 – Italy, 23

To not having ridden the wave, leading to the lack of ICOs in Italy, is not only relevant for the missed financing opportunity that ICOs represented, but also for the lost potential networking effect. Platforms working on open-source protocols need a strong community of developers and programmers to thrive, both for their contribution to the infrastructure and to create specific application. This means that building a network of stakeholders interested in investing around the proposed ideas is crucial to succeed. To do so, in many cases projects have resorted to “airdrops”, consisting in the free distribution of tokens issued through random allocation or based on some specific criteria, even if also in this case the incentive structure might not be strong enough to ensure participation. The poor success of Italian ICOs might have also affected blockchain-based projects that would have needed the network effect provided by the distribution of hybrid tokens, offering both a financing channel and a use within the network.

As the effects obtained through the launch of ICOs did not go as expected, some Italian entrepreneurs have launched ICOs outside of Italy, mainly looking for more liquid markets that would guarantee them an easier access to capital. Even though the estimation of the weight of this phenomenon is not precisely quantifiable, four of the most renowned ICOs of companies founded and managed by Italian – Eidoo, Aidcoin, Friendz and Xriba – were able to raise more than 70 million USD combined, almost ten times the total raised by all ICOs based in Italy: a significant fact in relation to the opportunities offered by the Italian market and business environment.

However, ICOs have proven to be not so resilient, as the number and value of ICOs at global level are now decreasing, making space for other, more regulated alternatives, such as the Security Token Offerings (STOs). STOs are similar to ICOs as in both cases the issuer provides investors with digital tokens, but with STOs the underlying tokens provide specific financial rights, being categorized as securities – such as stocks, bonds and dividends – so that they are fully regulated in most jurisdictions, thus they are more secure and protected by regulatory systems. This mechanism also ensures a higher protection for investors and Know Your Customer and Anti Money Laundering standards, encouraging the possible participation of traditional financial players. While ICOs registered a dwindle by the end of 2018, the number of STOs rose, putting together more than 700 million USD in a two-year timespan, between 2017 and 2019, stirring up a reaction from market regulators in Europe and abroad, in the effort of attracting the new market.

This suggests how Italian companies could leverage STOs as a complementary channel to traditional venture capitals, private equity and IPOs, exploiting this mean also to develop a solid network for future blockchain-based firms. Together with the benefits strictly related to a financial point of view, STOs could also be appealing for SMEs as they have better cost efficiency because they do not require to rely on intermediaries when compared with traditional security issuance, plus they allow for a large participation beyond qualified investors, banks and brokerage firms, while ensuring legally binding investor rights.

Completing this attempt to portrait the actual conditions of the Italian market for blockchain-based applications, a 2020 survey ran by "Osservatorio Blockchain and Distributed Ledger POLIMI" has shown that most Italian companies lack a detailed understanding of Distributed Ledger Technologies and blockchain applications. According to this research, only 14% of large companies have a deep understanding of the technology, while another 23% know them at a sufficient but more superficial level. The shares – already showing a non-flourishing scenario – decrease when considering SMEs, where only 4% of respondents have proven to have a deep understanding of the topic, and 16% with a superficial understanding. Not only this furnishes an idea on the aridity of this particular slice of the Italian market, being still very small, but shows a significant width of the gap between large companies and SMEs, with the former having an overall better understanding on the technology, even if they represent a consistently smaller percentage in number over the total companies in the market. Plus, the generally poor level of knowledge is reflected in low levels of application, with only 2% of large companies and 1% of SMEs having ongoing experimentations and projects in the area, meaning that an even smaller percentage of them is actually exploiting the blockchain technology in their processes.

The survey also estimated that in 2019 there were 67 Italian start-up companies working on blockchain-based projects, a number that has grown in the following years reaching a total of 116 firms in 2021, of whom only 90 are concretely active in the world of blockchain, having brought their contribution to it and playing a role in the market, rather than just studying and exploring the potential of the technology (Casini, 2022). Even if this data does not completely cover the totality of the public and private initiatives carried out in the field of blockchain, it surely gives the idea of how the process of growth and expansion of this type of business realities is proceeding, with a really slow but steady pace. Among the surveyed companies, the main type of services offered are in business solutions and supply chain, covering the 42% of the whole respondents, while the remaining part is made up by 15 different solutions and applications, including fields as payment, marketing, document authentication and others (*Figure 5*).

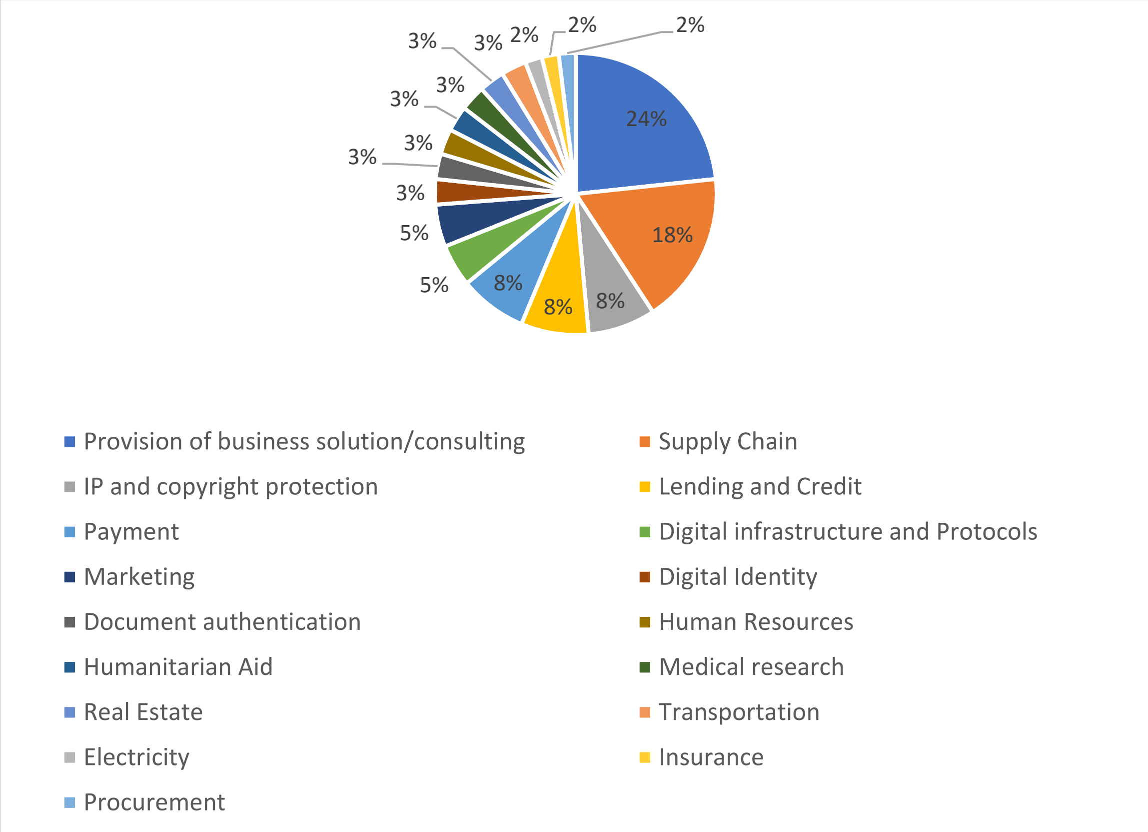

Figure 5 *- Blockchain companies in Italy per type of services offered*

The processes of understanding and development of blockchain-based solutions also passes through the collaboration between companies and universities, which definitely are playing a major role in the expansion of this ecosystem both by training future entrepreneurs and employees and by directly offering their knowledge and means to companies. Most blockchain companies have a strong relation with researchers and universities all over Italy – 63% of the respondents indicated an ongoing form of cooperation -, going from a less intense bond to a more organic and structural to the development of the products cooperation, not aimed to a single-shot support and easing a continuous improvement. Also, a consistent part of respondents signaled that this collaboration also happens with foreign universities and non-academic research centers, indicated as partners by almost 30% of the surveyed companies. This opens for a curious and significant point, as the same type of cooperation but with Italian supporting public or private institutions is still limited, with only 13% of the businesses surveyed saying that they were in contact with public agencies. Accelerators and incubators seem to be playing a slightly more important role, with one out of five companies cooperating with them. This not only shows how the infrastructure built is still too weak, but highlights again the gap between this and the foreign ones, which are preferred by a larger percentage of companies.

All of these that has been discussed in the paragraph find a sum up in the answers given to the question of the survey concerning the barriers to business development. Italian blockchain companies find that complying with regulations and the complexity of administrative procedures are the most important barriers, in particular in relation to smart contracts, hash codes and digital signatures. When asked about the main barriers to the doing business in Italy, "regulation and complex administrative procedures" were indicated as "an important obstacle" by the majority of firms (57%), and as "somewhat an obstacle" by another 20%, that concretely show how Italy suffers from many problems related specifically to the development and sale of blockchain products, due to the lack of a clear legal framework for the use of smart contracts. Another source of barriers and limits – which also recalls to the poor level of knowledge and education on the matter - is the complexity of managing hash codes registered in the blockchain in compliance with the General Data Protection Regulation (GDPR, EU 2016/679); and the different definitions at Italian and European level of "digital signatures". This situation is common to other EU members. The second most relevant barrier is to obtain financing - as hinted in the beginning of the paragraph -, while difficulties in explaining the new technology to clients and finding talents are considered less important barriers.

Surveyed businesses indicated the importance of the evolution of the regulatory framework at Italian and, consequently, European level for the development of their business and of the industry. The interplay between regulation and innovation seems to be relatively ineffective at the moment, as entrepreneurs do not feel safe in trying to develop new solutions for the lack of clear basic guidelines. Also, the complexity of the situation seems to be exacerbated by the overlapping of national and European regulation, which, despite the efforts, shall be better coordinated to solve the uncertainties created so far, limiting the action of operators in the market.

1.6 Summing up

The analysis done in this introductive part allows to face the following chapters having a detailed and general background on aspects of the world of blockchain applications that will later be encountered again. As from Chapter 2 on the core and objective of this thesis will be deepened, addressing topics as the main problems related to the energetic consumptions of blockchain, the regulatory elaborations studied and proposed by institutions and, finally, how private and public realities have found a definitive and sustainable application of the technology for their tasks and processes.

2. Addressing the problems

In the first chapter it was clearly hinted that, despite being a game-changing technology, the use of blockchain also has significant implications and drawbacks to be assessed before deciding if and how to implement any blockchain-based application in a company's processes. Before presenting concrete cases of firms that are currently exploiting the technology it is then at least useful – if not necessary – to go deeper in detail, to see how these problems could be faced and how to overcome them.

The most urgent and discussed issue is certainly that of blockchain being a highly energy-intensive technology, a case put at the center of the debate in the last past years when discussing on the expansion of the technology and its numerous possible usages. Advanced economies and industrial realities such as China, which is said to be the first nation for data-mining related energy consumption (Jiang & al., 2021) - despite official and detailed data are not released by any Chinese institution – represent an alarming case and highlights the need to contrast this trend, in a time where the global climate crisis and the energy crisis are becoming a more and more serious issue. Situations like this are a clear alarm sign for other realities such as countries or institutions, which have started to formulate and apply plans to reduce the entity of the phenomenon and represent a guide to follow for private initiatives too. What is arguably the most representative example of this state of things is the response given by a private sector-led initiative, called *Crypto Climate Accord*, which was inspired by the United Nations' *Paris Climate Agreement*, a legally binding international treaty created with the intent of contrasting climate change, adopted by 196 countries all over the world and active since 2016 (UNFCCC, s.d.). Following its footsteps, the intent of the Crypto Climate Accord is that of elaborating new policies and rules whose focus is the decarbonization of cryptocurrency and digital assets industry.

For what it concerns all that is related to the energetic consumption of blockchain technology and its main applications, a highly explanatory work was done by the European Union Blockchain Observatory and Forum in its 2021 publication called *"Energy Efficiency of Blockchain Technologies"*, commissioned by the European Commission. Despite its provenience, the paper does not refer exclusively to the European market for blockchain, but covers topics that are universally applicable in this field, such as the functioning of the different models of blockchain and their relative energetic consumption, and tries to give a prospect on how to reach sustainability in the near future. Given its completeness and width of arguments covered, the European Union Blockchain Observatory and Forum's publication represents the main guide to follow to discuss and analyze the topic of interest for this part of the thesis.

The other two main issues which could affect the integrity of a blockchain system are definitely related to money laundering practices and the identification of customers and stakeholders (Campbell-Verduyn, 2018), topics strictly linked to the need for a better regulation on the matter, which are allowed by the intrinsic nature of blockchain and by the reasons behind its utilization. Decentralization and anonymity can surely represent added values for some types of activities, but this often leaves space for otherwise illicit practices.

For the purposes of this thesis, these latter topics will not be treated in detail, rather this chapter will focus on the former issue, that of sustainability, which will be key to the evaluation of concrete cases presented in Chapter 3 and will put the basis for a solid knowledge of the readers and targets of this work.

2.1 Energetic Consumption of Blockchain

Energy efficiency is a term that refers to the energy consumption of a given process or application. For blockchain solutions, this is highly related to the underlying mechanism used to achieve consensus – given by verification processes run by the nodes or other authorities belonging to the system - between the nodes composing the network, which, as previously seen, can be different depending on the models adopted. Currently, the most popular one is that used by cryptocurrencies as Bitcoin and, until September 2022, Ethereum, the Proof-of-Work, which is characterized by the highest energy consumption among consensus mechanisms. Apart from PoW, there are several other approaches to achieve consensus, which guarantee both the required level of security and trust, being at the same time more energy efficient and allowing the scalability and performance of any application exploiting them. These alternatives are mainly Proof-of-Stake and Proof-of-Authority consensus mechanisms applied to companies' processes.

2.1.1 The consensus mechanism

The term consensus refers to the process of achieving agreement among different actors operating in the system they belong to. To be more precise, the blockchain consensus denotes all the procedures through which the different participants of a blockchain network agree on a specific state of data on the system referred to as the correct state, which in a more concrete fashion refers to each and every verification process to which the network is called to guarantee its own integrity, and the validity of any transaction and exchange of information happening between the nodes. In this sense, security, the main feature of blockchain, may also represent its biggest drawback as it requires the exploitation of a highly energy-consuming mechanism.

Consensus problems make multi-agent systems converge to a common vision and it leads all the agents of the network to share the same data, thus they prevent faulty nodes – whether they are acting rationally or irrationally – from manipulating the data. The mechanism varies between different blockchain implementations, depending on the chosen system's nature, whether it is permissionless or permissioned. There is a variety of consensus protocols, which could be categorized into three main classes: Proof-of-X (PoX), Byzantine Fault Tolerant (BFT) and Hybrid consensus protocols.

The origin of these models is older than that of cryptocurrencies and blockchain, as in distributed systems it has been studied long before Bitcoin's birth and the very first class of consensus protocols was one of "BFT algorithms". Byzantine Fault Tolerant algorithms were adopted to deal with Byzantine nodes, which are rational nodes acting maliciously. These protocols are based on voting procedures where network agents are called to accept or reject a specific condition of the network. These protocols generally work in systems with a limited number of participants since, according to them, the consensus *proposal* and consensus *decision* represent two separate events demanding the different system's participants to communicate with each other. Indeed, communication complexity represents the major downside of this protocol class. Hence, the necessity for closed-system adoption such as permissioned blockchains.

The advent of Bitcoin gave rise to a new technology based on a different consensus protocol, the Proof-of-Work, in which consensus could be reached by gaining the right to validate the state of ledger by proving to have worked from a computational point of view, therefore using a machine to work for the system. This gave any node the possibility to have a deciding role in the system, which in many cases degenerated into a sort of race between them, implying a considerable amount of energy consumption. From here, it was given rise to the larger category of Proof-of-X consensus algorithms, where X denotes the resource a network node is consuming or allocating to gain the right to propose and validate the agreement value. While in Bitcoin the X stands for "computational resources" for other consensus mechanisms it stands for a "stake" of the system (Proof-of-Stake), or memory "capacity" (Proof-of- Capacity) or again wireless network "coverage" (Proof-of-Coverage). All these alternative PoX schemes were born with the intent of replacing the energy consumption implicated by the PoW model with the consumption of other resources.

So, consensus theory evolved from the pre-Bitcoin to the post-Bitcoin phase, introducing the new category of the PoW consensus protocols. A second evolution of consensus took place when Bitcoin gave the way to blockchain, thus when other blockchains were proposed and Bitcoin was anymore a solo player in the ecosystem. This second phase corresponded with the birth of the second generation of blockchains adopting PoX schemes, creating alternatives to Bitcoin's PoW. Then, a third evolution was characterized by the advent of permissioned participation models and the raise of permissioned blockchains and DLTs. Here blockchains are no more peer-to-peer systems, and the chance to participate in the consensus of a blockchain is given to any node, but could also be closed systems as the traditional distributed ones studied in the 20^{th} century.

The consensus then evolved by reconsidering traditional BFT and by implementing such protocols in blockchains now considered as a branch of DLTs (i.e., a DLT structured as a chain of transaction blocks). The fourth evolution step was marked by consensus experimentations with BFT-based algorithms aiming to preserve permissionless consensus while keeping the process efficient by reducing the number of participating nodes to the consensus. Hence, the consensus is divided into two phases; the first one determines the formation of a committee of voters elected through a PoX mechanism and the second one where nodes vote according to BFT consensus.

The progressive alternance of these phases undoubtedly represent an improvement for the blockchain system, and has seen a growing homogeneity in the field of consensus mechanisms, which not only means to have a variety of models to choose among, but also allows to opt for more environmentally-sustainable ones, as the magnitude of energy consumption changes depending on the different models adopted.

2.1.2 Energy consumption per model adopted

Several components contribute to the energy consumption of blockchains in general, which can be divided into three main categories: the consumption deriving from consensus mechanisms – as abundantly discussed above -, the redundant computation and storage associated with the blockchain's operations, and the idle energy consumption of each node. While the consensus mechanism bears the lion's share of the responsibility for PoW blockchains' energy consumption, for non-PoW blockchains it is the idle consumption of the nodes and redundant processing of transactions that represent the main share of energy consumption. Contrarily to the common opinion, two immediate and significant implications of this result are that PoW blockchains' energy consumption does not grow significantly when the number of transactions or the complexity of operations - as it is for smart contracts - increases, thus the related consumption could be even considered negligible, and that non-PoW blockchains' energy consumption is so significantly smaller than that of PoW and in particular PoS and permissioned blockchains that it is questionable whether discussing the nuanced differences in their energy consumption is useful at all (*Figure 6*).

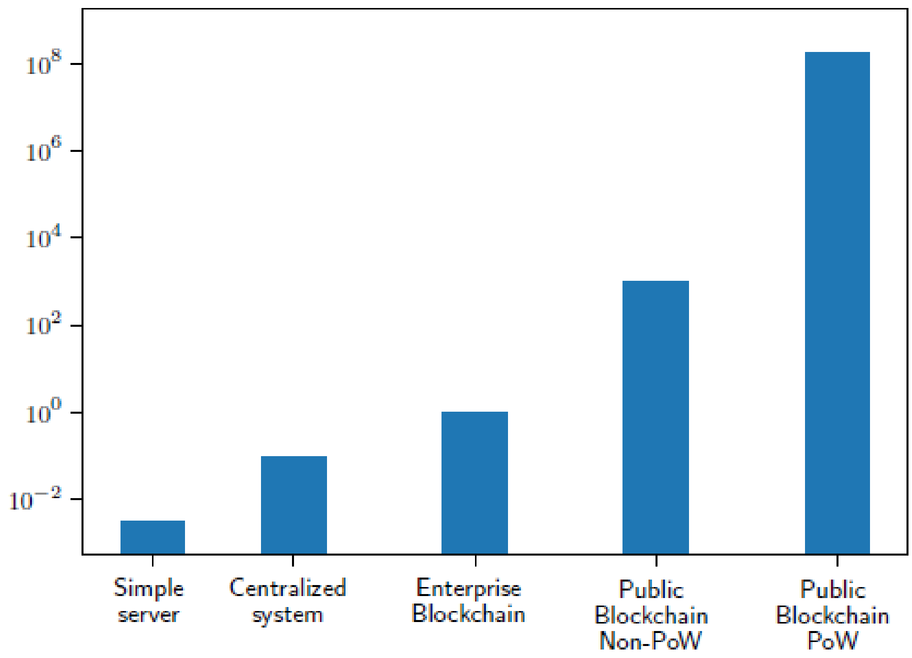

Figure 6 - *Approximate energy consumption per transaction (J)*

Source: J. Sedlmeir et al.: The Energy Consumption of Blockchain Technology, 2020

Due to the nature of permissionless blockchains, certain variables required for accurately estimating the energy consumption of PoW-based networks, such as the number of miners and the hardware specifications of each miner, cannot be measured easily. For the contribution of consensus, researchers must rely on approximations to provide a valid estimation on energy consumption. Nonetheless, reasonable results have been reached by many, but despite being reliable and useful in general terms, such approximations would not be useful enough for our purpose, if not compared to the results registered by a non-PoW model.

In this sense, a precious contribution comes from the well-known case of Ethereum, the second most popular and expensive cryptocurrency which recently moved from being based on a PoW consensus model to a PoS one. A lot has been said around this happening, as this may actually be the first step to another phase in the history of cryptocurrencies and large-scale applications of blockchain. The reason guiding this transition obviously was the sustainability issue that cryptocurrencies still bring with them, and to motivate it the team of researchers at Ethereum Foundation has run a study, later published on Ethereum's official blog (Beekhuizen, 2021). The results regard the PoS protocol, but seem to be applicable also to both Byzantine Fault Tolerance and Crash Fault Tolerance (CFT) models, where the consensus mechanism consumes orders of magnitude less energy than PoW, as they do not require any mining process, contrarily to the latter one, which bases its functioning, security and consensus mechanism on it.

The range is typically specified by a reduction between 99.95 % and 99.98 % or even higher in energy consumption – comparable to the at least 99.98 % that PoW is responsible for Bitcoin's electricity consumption. Clearly, these whole calculations refer to huge blockchain projects as those of Ethereum and Bitcoin, but gives a clear idea on the gap between the two models, referring to two stackable applications in terms of volumes and required infrastructure. Hence, it is possible to use this benchmark and apply it to smaller cases too.

To evaluate the energy efficiency of a network, the details depend considerably on the number of nodes and the hardware specifications for the blockchain under consideration. In BFT-based mechanisms, that are often used in consortia, consensus' complexity increases super-linearly with the number of nodes, which implies increasing amounts of energy as more nodes participate. However, their energy consumption remains very limited for practical network sizes.

In the end, in contrast to specialized mining hardware with high power consumption used in high numbers in PoW, CFT and BFT blockchains are usually running on commodity servers with an electricity consumption in the higher two-digit or lower three-digit range. As a result, a permissioned blockchain with 20 nodes will not consume significantly more than a few kiloWatts of electrical power when it is running - a quantity of electricity which is more or less equal to that required to charge a single electric vehicle -, which if compared to a double-digit number of GigaWatts for bitcoin would be more than a million times less, or to the same blockchain exploiting a PoW consensus algorithm, which would even be almost 100% higher in energy consumption. This example should easily clarify the advantages of a non-PoW application using the number of nodes as a parameter, which, as previously said, is just one of the three main causes of energy consumption.

In permissionless blockchains using non-PoW-based consensus mechanisms and in permissioned networks that do not operate consistently at high load, the major share of energy usage derives from idle power consumption and, typically to a lesser extent, from the network's redundant operations. Because of this, energy consumption per transaction would provide inaccurate estimates, as idle consumption remains a fixed value which is not affected by the number of transactions.

As a general guideline, a blockchain network with N nodes based on non-PoW consensus mechanisms consume approximately N times the energy of a centralized system using hardware similar to that of the nodes, without considering potential backups on the one side and a larger number of cryptographic operations on the other side. However, it is practically impossible to estimate the idle consumption of nodes as users, especially in public blockchains, tend to use a wide variety of hardware which consume different amounts of energy, so for example the difference between a desktop computer that runs only for a blockchain node – whose consumption is on the order of 50 W - and an even smaller device as *a raspberry pi* or a cloud instance that only consume about 5 W or less, is surely significant. For this reason, emphasis has to be placed on the consumption coming from the blockchain's redundant operations, which dominate the estimate as soon as the whole hardware setup is tailored to the requirements of a node. However, to date, a large number of blockchain nodes likely has much higher hardware specifications than would be required, also because their aim is to be prepared for any potential increase in requirements which is likely to happen in the future. Hence, this generates an unnecessary surplus in consumption, otherwise considerable as a waste.

According to Johannes Sedlmeir, two factors influence the energy consumption associated with redundant operations: the number of nodes performing specific operations concerning the consensus mechanism, and the complexity of the workload (Sedlmeir & al., 2020). Over the years, multiple methods have been developed to reduce the energy consumption of these two factors. For example, blockchains can employ *sharding* practices to reduce the consumption coming from the number of nodes that must perform the operations, thus reducing the degree of redundancy by scaling applications to empower them to support more data (Howell, 2022). Using sharding in a blockchain network means to divide the nodes into subsets, and the transactions are verified only in one of these subsets, spending only a fraction of the recourses. Implementing sharding is heavily consensus-specific so it can be challenging in blockchains using PoW but is rather straightforward in PoS-based ones, as the organization inside the network is not completely decentralized and authority is not spread all over it. However, since fewer nodes validate the transactions, sharding makes a system more centralized and, thus, less secure. So, sharding represents a concrete help in balancing the need for redundancy and efficiency, but allows only for a bounded factor of improvement.

At the same time, reducing the energy consumption associated with the verification of new blocks and the transactions included, specifically if operations are computationally intensive, can be achieved using *succinct proofs*. This method avoids having all nodes re-compute the operation, as only a single party performs the computation more intricately and generates a proof for the correctness of the computation that is much less complex to verify than re-computing the original operation. The necessary calculations are hence carried out off-chain with just the computationally light verification taking place on-chain, avoiding the total involvement of the network in the computational process. When the number of nodes is large, the cumulative energy savings for the verifiers significantly outweigh the additional energy consumed by the "prover", which is the client that computes the proof and sends it to a node in the form of a transaction. Consequently, this approach can help to save energy. However, it should be noted that since energy consumption is in non-PoW blockchains, the major interest in these possibilities is because they are beneficial from a privacy and performance perspective. So, despite this may not be a game-changing application for the infamous problem of public networks joined by a multitude of miners all over the world, such as Bitcoin and the NFT market, it definitely represents a way to go for private blockchains that companies could adopt for their businesses.

Thanks to a high-speed progress that has characterized this field in the last years, most public blockchains can now run also on low-end hardware, such as a raspberry pi - a low cost, credit-card sized computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse -, which consumes less than 5 W per device. Given that, for example, VISA and PayPal consume approximately 5,400 J (VISA, 2019) respectively 73,000 J (PayPal, 2022) per transaction considering the companies' overall consumption, a non-PoW blockchain with low-end hardware could consume as much energy as VISA while operating around 1,000 nodes, and 15,000 nodes in the case of PayPal, which counts more nodes than the 13,000 in the Bitcoin network, probably the blockchain with the most full nodes today.

Consequently, medium-sized blockchains that run on reasonable hardware are comparable in energy consumption on a single transaction basis, and with the stated optimizations, large permissionless blockchains like Ethereum shall now, after the transition to PoS, likely not consume considerably more energy than today's centralized payment systems. Permissioned blockchains, on the other hand, only have a low degree of redundancy and – despite being more energy-intensive than a centralized server – still have an energy consumption comparable to common software applications and will most likely generate energy savings rather than additional consumption when new workflows can be digitized.

2.2 The HashNET Blockchain case: increase efficiency to reduce consumption

In the previously cited paper “Energy Efficiency of Blockchain Technologies”, it is presented the case of a platform born with the aim of providing an alternative to the traditional blockchain systems, exploiting a more efficient and less energy-consuming protocols. The platform is called HashNET, and focuses on creating a new type of scalable, fast, secure, and fair decentralized solution, leveraging DLT and consensus algorithm which keeps all positive characteristics of blockchain technology - decentralized, transparent, pseudo-anonymous - while significantly increasing transaction throughputs, being able to deal with a higher number of transactions with a lower effort and required power.

HashNET runs on PoS and PoA systems, and finds its innovative character in the usage of an Improved Redundancy Reduced Gossip (Improved RRG) and “Virtual Voting" protocol for information transfer on a suitably designed network, which is crucial to achieve considerably lower traffic load than conventional push-based gossip protocols and traditional push-pull gossip. This required infrastructure sustains the consensus mechanism, which is what ultimately determines the level of security, speed of transactions and scalability of a network, making it possible to increase the number of transactions executed in a second for more than 50 times, keeping the time to finality up to three times lower, compared to other existing and tested solutions (seedeuproject.com, s.d.).

Scalability turns out to be often mentioned as one of the biggest challenges related to the widespread usage of blockchain technology. HashNET was built to support up to 50,000 transactions per second on layer 1 and is claimed to be able to support millions of transactions per second if sidechains – separate blockchain networks compatible with the mainchain - are used, lightening the calculation processes by dividing them among different chains. Even with hundreds of nodes, HashNET network should then be able to sustain and process all transactions in a matter of seconds, since the Improved RRG and “Virtual Voting” mechanism innovation eliminates inefficiency imposed by other based blockchain solutions. Usage of the sidechains ensures that user interactions are shifted from the blockchain layer onto a second layer, while guaranteeing risk-free Peer-to-Peer transactions between participants. Throughput of the blockchain would be a cumulative value of both main and sidechain, thus creating enormous scalability potential of HashNET technology.

Plus, the integrity of the mainchain does not depend on that of the ones belonging to the second layer, as if the security of a sidechain network is compromised the damage will not affect the mainchain or other sidechains. Both networks are linked to each other via a "two-way peg" and can transfer any state one another. This way, tokens can be exchanged at a predetermined rate between the mainchain and the sidechain, with the former guaranteeing overall security and dispute resolution, while the transactions are outsourced to the sidechain while the mainchain contains the information on each event alongside timestamp and transaction signature information.

Until now, this may seem to be an even more complex system than those seen so far. To better understand how it achieves scalability, it is now important to describe HashNET consensus mechanism. Let's consider that each node in the network keeps a representation of the HashNET in its memory. The HashNET that each node has can differ, but through the process of gossip, the yet unknown events to the node are added to its HashNET representation. Next, it is necessary to introduce the term of an event object as a data structure created by some node and containing the two hashes of the preceding events – parent event created by the same node ("self-parent") and the parent event created by some other node ("other-parent"). The node that creates the transaction also puts a timestamp to the event object at the creation time, and the event is thus digitally signed. Each event object can optionally contain a certain number of transactions, making the event a container for those transactions. Once the event gets gossiped, the signature is sent along with it. Events can also have zero transactions, either when a node receives a sync event or when it has just been spawned, thus creating the first event with no self-parent and no other-parent, and there are no pending transactions that this node is aware of in its transaction pool.

The goal of the HashNET algorithm is for nodes in the network to come to a consensus. As we know, the consensus is defined as agreement on the order of events, of which, by agreeing on the timestamps for each event, the order and timestamps for all the involved transactions are determined as well. Furthermore, to do so nodes can call each other at random for syncing and determining which events they don't have recorded yet in their instance of the graph, guaranteeing a double correct registration and the possibility to verify data at any time.

Since a green energy transition has become a central pillar of policymaking worldwide, it is necessary to adapt energy infrastructure to the future needs of the energy system, within decentralized network. It is clear that if building blockchain applications move toward less energy-intensive methods of verification, there should be a resultant decrease in blockchain energy consumption. It does not require miners to create a huge chain of blocks to record transactions, and thus, an enormous amount of energy is saved.

While Redundancy Reduced Gossip and other asynchronous distributed consensus protocols provide communicational and computational efficiencies, additional implementation improvements are necessary to handle large fast-growing systems. A direct implementation of such protocols could require exchanging as much as O(n^3) messages for reaching a consensus on a single binary outcome, which would make them not practical and unsustainable for systems with a large number of nodes. Thus, the imperative of HashNET development strategy was to implement the consensus protocol in a way that could minimize communicational load, due to information transfer among nodes. It leverages the fact that every node has information on the entire HashNET structure, including data about events and their propagation through the network to compute content of the vast majority of messages required by Improved Redundancy Reduced Gossip (IRRG) protocol, thereby eliminating the need for sending them and consequently, consistently reducing communication requirements.

A somewhat similar approach towards reducing communication requirements in an implementation of a different consensus protocol has been proposed before, but unlike the HashNET system, a critical requirement imposed by each was that the number of nodes had to be constant and must remain constant throughout. An important prerequisite for efficient computation of consensus is that the total number of voting nodes needs to be known. HashNET has overcame this difficulty by assigning to every node a vote weight, which is equal to their stake at a given point of time. By doing this, HashNET has achieved the ability to calculate votes instead of waiting for and/or sending actual votes over the network. Then, as long as two-thirds of the nodes are safe, consistency of consensus can be ensured, while in the worst scenario of cyber-attack of more than one-third of the nodes in the network, all history of transaction remains unchanged and can be replicated. Hence, all the servers at the same time would need to be destroyed to erase the history of all the movements recorder.

For high volume and velocity of the transaction, an additional note has to be made: HashNET poses specific functionality of ordering transaction, allowing fair execution. If the mainchain along with sidechains installed prove not to be enough for example in peeks of IoT based large number of applications, the HashNET will adjust to the terms. Additionally, if keeping it on layer 1, it allows for the creation of optimized size bulks of transaction proposals, so HashNET would make fair ordering action, imposing the ‘first in – first out’ method on transaction requests. The validation phase would then be executed for each bulk of transaction request, again imposing same the ‘first in – first out’ method to ensure fairness.

Hereby it is important to emphasize that the method of adding a sidechain and that of creating a batch of transaction bulks are not mutually exclusive and they add up to solution’s scalability. It is the matter of the use case the blockchain is used for that determines how many, if any, sidechains need to be used or if it is better to go for a batching option.

So, in general terms, we have seen how HashNET reaches high scalability with a limited increase of the energy demand, without compromising on security. Its used consensus mechanism requires a minimum electrical consumption while the way transactions are recorded needs minimum storage space, and efficiency-wise, this protocol eliminates many obstacles characterizing other blockchain models, thanks, for example, to the use of Improved RRG and the Virtual Voting. Also, the communication for consensus in the network is very energy-efficient, since information exchange is kept at a minimum, thereby needing no computing power. The gossip protocol allows to send a lot of information quickly through the network at low computing power input, making it even more suitable for energy-efficient applications and, unlike other consensuses that require every node to receive an updated graph that could lead to performance inefficiency with an increasing number of nodes, HashNET’s Improved Redundancy Reduced Gossip protocol achieves considerably lower traffic load than conventional push-based gossip protocols and conventional push-pull gossip protocols, still maintaining the same probability of successful delivery.

Using this mechanism, when the event gets gossiped, the signature is sent along with it. Events can have zero transactions either when a node receives a sync event or when the node has just been spawned - thus creating the first event with no self-parent and no other-parent - and there are no pending transactions that this node is aware of in its transaction pool. This eliminates potential performance inefficiency that the blockchain can face with an increasing number of nodes.

Alternatives to traditional protocols and algorithms at the base of blockchain as HashNET are undoubtedly starting to play an important role in the sector, and their relevance is surely expected to increase alongside with their likely future development and expansion. Most of all, they represent an upcoming trend of renewal of a yet young system, but that needs to undergo a significant change dictated by sustainability issues.

2.3 Algorand’s commitment to sustainable blockchain

The same inspiring will to create a more sustainable blockchain model characterizing the HashNET case is also shared by other realities. Among the proposals and offering in the field of sustainable blockchains, one seems to be particularly impacting in the current scene, deserving to be mentioned in this thesis: *Algorand*.

Algorand was built as a green blockchain, having a positive environmental impact focus in its raison d’etre – something that was shown from its very beginning -, and it pledges to be the greenest blockchain with a carbon-negative network, a status to be maintained also in the years to come (Algorand, s.d.). According to Algorand’s creator, its carbon neutrality is reached as it was designed as a highly energy efficient network from the start, and thanks to its partnering activity with organizations that are focused on sustainable use cases and in offsetting any small emission gaps. Despite being a public blockchain, its low environmental impact is due to its usage of a particular PoS consensus protocol, the *Pure Proof-of-Stake*, which takes the *finalized transaction energy per validator* as a parameter, according to which the PPoS drastically reduces the electricity consumption compared to both PoW and even PoS systems. By merely looking at the numbers concerning the energetic consumption per transaction, it is possible to make a comparison among the Bitcoin blockchain and those of Ethereum (with available data regarding its past PoW-based system) and Algorand. Presuming a full blocks application, we have that Blockchain’s consumption in kilowatt-hour (kWh) on the number of transactions (txn) made is of 930, followed by the PoW-based Ethereum at 70 kWh/txn and, with many orders of magnitude less, Algorand with 0.000008 kWh/txn (*Figure 7*) (Bassi, 2021).

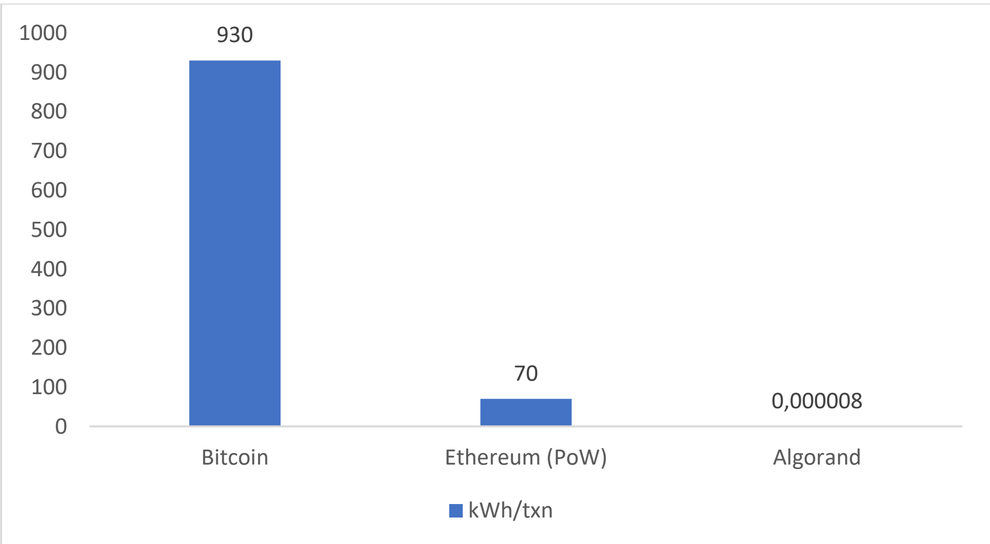

***Figure** 7 - Average energy consumption per transaction*

Despite this calculation was made considering the dimension of public blockchains only, and considering just the standard applications and models of the three above mentioned networks, it still gives a valid representation of the energetic gap among them.

For what it concerns the functioning of PPoS, it obviously recalls to the PoS mechanism, where only a selected number of nodes is called to verify the integrity of new entrants or that of any exchange of information inside the network. In Algorand's PPoS it is used a cryptographic sortition to select users to propose blocks for a given round of validation (Block Proposal phase). Then, after the block has been proposed to the blockchain, a committee of voters is selected to vote on each block proposals filtering them down to one (Soft Vote phase) and, if a super majority of the votes comes from what are reputed as honest participants, the block can be certified (Certify Vote phase). In the conclusive phase each node receives a certificate for the block and writes it to the ledger. Once the whole process is complete, a new round initiates and the cycle starts over with new block proposers and voters (algorand.com, s.d.).

By giving the authority to evaluate each proposal to only a few nodes, the system could be exposed to the negligence of malicious users. If on one hand this argument does have sense indeed, on the other hand the Algorand decentralized Byzantine agreement protocol allows to avoid this eventuality as it can tolerate an arbitrary number of malicious users as long as honest users hold a super majority of the total stake in the system. Two important features of the consensus protocol prevent powerful adversaries from corrupting enough users so as to control block generation: first, the adversary does not know which users he should corrupt, in fact the users who are called to certify a new block are secretly and individually selected; second, when the adversary realizes which users are selected, it is too late for him to benefit from attacking them, as those users have already fulfilled their responsibility in the consensus protocol, and in the next round of block certification, a new set of users will again be privately and individually chosen, making all the efforts of the malicious users useless.

The PPoS protocol enables Algorand to address the so-called *Blockchain Trilemma*, in which none of the three key elements of an ideal blockchain – scalability, security, and decentralization – are compromised. On top of that, PPoS is carbon neutral because it does not rely on massive electricity consumption needs, unlike PoW chains, and its algorithm has a straightforward principle. While it enables every user to become a block validator by staking the native token in the system - an approach typical for PoS blockchains -, the protocol selects block validators randomly and secretly for any given period, as discussed above. So, given that all users have equal chances to be picked by the system, the network is fully decentralized, as no one knows who the next block validator will be. Plus, in the Algorand network, there is no need for mining, as users can become validators simply by staking their own ALGO tokens. In this way, Algorand manages to achieve carbon neutrality. While other PoS blockchains also manage to minimize electricity consumption to negligible levels, they lack true decentralization. In "traditional" Proof of Stake chains, the wealthiest validators with the most tokens have the most control over the network, and receive the largest share of the block reward, increasing their share of the circulating token supply. As a result, PoS networks typically have a handful of validators who have the ability to control the network.

In this sense Algorand is unique, as it has managed to build a system that is decentralized, secure, fast, and environmentally friendly at the same time[27] (Algorand, 2021).

2.4 The Crypto Climate Accord: road to decarbonization

As just seen, this change might happen through the inclusion of new algorithms or procedures in the already structured blockchain models, thus in a lighter and in some senses more superficial approach, or could also change the aforementioned from their roots, exploiting different and completely renewable energetic sources with the aim of reaching the decarbonization of blockchain. This process would not only solve a huge problem, but would bring the technology to become a concrete solution for the decarbonization of the processes of companies that can afford – both in terms of energetic disposability and economically – to apply the usage of blockchain in their activities. In this sense, some are trying to follow this specific direction.

As long as the technologies underpinning cryptocurrencies and other electricity-powered technologies such as cloud computing, data storage and processing, social networks, and artificial intelligence are powered by electricity and will depend on its availability, the current prospected scenario characterizing the future sees a growing pollution and an increasing scarcity of energetic resources, with a consequent and considerable increase in price. Hence, industries from across the global economy are beginning to decarbonize their operations in order to facilitate a widespread and sustainable industry growth. This shared will is affecting society and markets in many way, and has motivated actions and behaviors of many, often leading to concrete results. In this climate of change, in April 2021 the *Crypto Climate Accord* (CCA) came to life.

As briefly shown at the beginning of this chapter, the CCA was inspired by the Paris Climate Agreement, and is a private sector-led initiative for the entire crypto community focused on decarbonizing the digital assets industry in record time. The three provisional objectives of the Accord are expected to be finalized together with all its supporting organizations, currently being more than twenty, and concern the development of an open-source accounting standard to measure emissions of cryptocurrencies and digital assets industry – an important task to address the actual main source of consumption in the world of blockchain -, then the second task is to enable all of the world's blockchains to be completely powered by totally renewable energetic sources by the 2025 United Nations Framework Convention on Climate Change Conference of the Parties (UNFCCC) and, finally, to achieve net-zero emissions for the entire crypto industry, including all operations beyond blockchains and retroactive emissions by 2040. All the activities carried out to achieve these goals will be focused on closing the gap between today's industry emissions and industry-wide decarbonization for all blockchains activities, service providers and other crypto industry activities such as non-fungible tokens, in the fastest possible way.

The Accord is organized around some core principles and keywords, reported below in the same order as published:

- *Build on existing forward progress*: The electricity that powers the sector is decarbonizing. Renewables have become cost-competitive in energy markets around the world. As a result, a growing share of the grid (and by extension the industry) is becoming cleaner;
- *Mind the gap*: recognize that significant work remains to be done. There is a substantial opportunity to close the gap between crypto emissions today and a net-zero emissions industry;
- *Move quickly*: Crypto's roots in open-source, agile, and technology innovation make crypto an ideal candidate to achieve something the world has yet to see: rapid industry-wide decarbonization;
- *Decentralized, open-source technology can accelerate progress*: The same open-source, decentralized technology underpinning the global crypto industry - blockchain - can bring transformational levels of data transparency and trust to decarbonization efforts;

- *Voluntary, market-oriented, and value-added*: Voluntary, private-sector led action on industry decarbonization should be powered by a shared vision and market-driven solutions that accelerate market growth and create long-term value for everyone;
- *Community-driven*: All crypto communities should work together, with urgency, to ensure crypto does not further exacerbate global warming but instead becomes a net positive contributor to the vital transition to a low carbon global economy. This process will be collaborative and based on shared interests and co-investment; no central body will dictate solutions.

2.4.1 A two-sided approach

To erase the carbon footprint of blockchain, the theorists guiding the CCA have found two high-level paths, considering the already existing innovation that is currently taking place, and coincide with the supply and demand for the technology itself.

First, for what it concerns the supply side the key should be to leverage the innate transparency of blockchain to fully decarbonize using a bottom-up approach. In a clearer way, this means that the solution to making crypto green is not to mark individual tokens as green or not green, creating any sort of conditioning. Cryptocurrencies and digital assets shall then remain completely fungible, as this is one of their primary benefits and main strength points.

The real long-term solution shall then be that of ensuring that all blockchains are powered by 100% renewables. For some blockchains, the industry can achieve this by further investing in consensus mechanisms and solutions that are more energy-efficient, for example adopting a Proof-of-Stake protocol as previously seen. For other blockchains, the Proof-of-Work consensus, until these days, seems to be here to stay. In this space, the industry has an opportunity to leverage the transparency of blockchains themselves to measure just how much entire networks are powered by renewables.

Today, innovative companies are launching crypto mining sites in areas with a strong availability of renewables, in some cases also using crypto mining to absorb renewable electricity that would otherwise be lost, optimizing the consumption. To accelerate green mining further, it should be possible to use open-source technology to measure and report — on a completely anonymous basis — how much mining is green. Strong precedent exists, as renewable energy certification schemes are already active in markets across the globe, tracking renewable power generation. Then, it would be possible to use a similar approach to measure renewable power consumption tied to crypto mining activities.

This concept is almost identical to what technology giants Microsoft and Google are currently experimenting on with regards to data centers. Their intention is to prove that their data centers are being powered twenty-four hours a day, seven days a week by renewable energy. By applying a similar technology approach to the crypto industry - if done successfully -, crypto producers will be able to verifiably claim and prove their contribution to making an entire blockchain green, while maintaining complete privacy for the businesses involved in the productive process.

Under the Accord it is supported the development of open-source software that crypto producers, together with grid operators and renewable energy companies, can install to prove the origin of the electricity they use in the data-mining process. This software will in turn help miners build stronger relationships with local, regional or national policymakers and regulators, since they can use the proof of their renewable energy procurement to show their support for decarbonization efforts and eliminate any concerns among policymakers and regulators about their energy use. The application of this technology, paired with already existing governance structures in the renewable energy industry, can enable the entire industry to track and prove the greenness of entire blockchains, significantly changing the way how data mining is done and its impact on the environment.

Now, moving to the demand side, the solution should come from enabling crypto investors and, more in general, blockchain users to decarbonize their digital holdings in a top-down manner. This is something that many companies around the world are already doing, trying to decarbonize their businesses by using renewable electricity. If on the supply side it was all about the superstructure, here the focus is on the corporate dimension, institutional investors and even retail cryptocurrencies and digital assets holders, who are called to choose to purchase renewable energy that is directly tied to their crypto investment.

Depending on the geography and crypto investor preferences for example around price or impact on the environment, there are many renewable energy options to choose from. In the end, investors will receive energy attribute certificates reflecting the proof of their renewables' procurement from existing or not-yet-built renewable energy facilities, from local or highest-impact geographies, and bundled or unbundled with their electricity bills from their electric utility, to name a few. To better understand the mechanism, some examples come to help.

First, let's consider a major corporate or institutional crypto investor with strong sustainability commitments, that calculates the amount of non-renewable electricity attributable to their current cryptocurrency holdings. Each of the two then enters into a bilateral agreement with a renewable energy developer to purchase renewables over a multi-year period. The size of the project is directly correlated to the amount of non-renewable electricity used behind their crypto holdings.

The second example sees a retail crypto investor purchasing crypto through an exchange, choosing a "green crypto" option. This option charges a small percentage on top of the crypto transaction and places that value into an escrow account. This account is then used to purchase renewables from qualified renewable energy projects just like the formerly done corporate example, creating a zero-impact circular financing system. In both cases, open-source technologies can be used to link these transactions to specific renewable energy projects around the world, proving their impact on the decarbonization process.

In this framework, the Crypto Climate Accord will be used as a coordinating guide to help crypto and renewable energy market participants, leading their choices to these types of investments. The joint between supply and demand, actively participating in shaping the market in a more sustainable form, promises to be the solution to blockchain's biggest problem and, at the same time, represents the mean through which it can definitely expand and change economy.

2.5 A sustainable model for sustainable applications

As written in the premises of this chapter, the aim of it is to explain which should be the parameters to respect when creating a blockchain network to be used for corporate applications. Starting from studies and proposals mainly meant for the market of cryptocurrencies, where the sustainability issue is running fast, it was possible to find some hints and hypothetical solutions to the problem that could well fit in a smaller contest as that the corporate one.

Repping up the content of the paragraphs above, it seems that the features of a sustainable blockchain, especially in the case of networks with few nodes, shall first of all include the adoption of a non-PoW protocol, rather preferring, for example, a PoS mechanism. Anyway, other solutions even involving the use of a Proof-of-Work system could find some space, but it would always depend on a previous evaluation on the consumptions deriving from how the chosen consensus mechanism fits with the system, considering also how much of the total consumption in due to redundant computation, the required storage associated with the operations run by the blockchain and the idle energy consumption of each node.

These sources of energetic overflow can be contrasted with the adoption of policies and mechanisms such as those provided by HashNET, which promises to regulate the network's requirements making it work in a more efficient way, reducing the quantity of inputs and at the same time increasing the productivity through a different organization of the work. A parallel path seems to be represented by the example of Algorand, whose model could be replicated with the application of its Pure Proof-of-Stake and by following its core idea of being carbon neutral from the ground up, choosing the path of environmentally-friendly projects only.

Finally, a sustainable blockchain-based system shall be completely fueled by energy coming from renewables only, requiring a direct commitment from companies, entities and investors in choosing the correct sources for their businesses. This calls for a supporting activity of public entities and regulatory systems too, that should both invest more in sustainable energy to create a solid infrastructure and adapt legislations to ease and encourage the adoption of green energy. In this sense, the plan of CCA represent a path to follow.

3. Sustainable applications of blockchain technology

After a first more theoretical half, the remaining part of this thesis will cover real life cases of entities and companies adopting blockchain applications for their businesses, sometimes being strictly focused on economic purposes, sometimes concerning organizational issues to be addressed in a leaner way. In any case, the solutions adopted all have a common feature, which is that of making more sustainable the processes and system to which they are applied.

As briefly mentioned in the first chapter, blockchain finds place in many fields of the market, being easily applicable in a wide number of sectors than can be even very different from each other, such as, for example, financial services, healthcare, food, energy and public administration, just to mention a few. The results reached in all of the studies mentioned in this chapter obviously show how the usage of blockchain generates considerable benefits to their adopting context, but might be more focused on the improvements in terms of performance, rather than on the reduction of waste and required energetic consumption. Obviously, this does not directly represent a sustainable application of the technology per se, but if it makes the involved process more efficient, it is implied that, by using the blockchain, the system involved is able to produce more with lower costs or to offer a better service avoiding errors and lowering waste.

In general terms, this could be already considered as a change for a more sustainable solution which, if combined to the findings shown in the second chapter, leads to the adoption of a sustainable blockchain system for a sustainable business application, whose energetic requirements will be environmentally friendly and will lead to an optimized and efficient performance.

The following paragraphs present blockchain applications in a variety of cases and fields of application, and the relative results obtained will be presented and commented to give a clear idea on the possibilities reachable through their implementation. This will involve blockchain solutions adopted by Italian companies, public entities or foreign firms working in the Italian territory, recalling to the content of the first chapter. The aim of this conclusive chapter is then that of giving the audience the possibility to consider and evaluate the positive effects of including blockchain in simple or even complex tasks composing the activity of companies or entities, especially considering the aspect of sustainability.

3.1 Italy's awareness of blockchain's contribution to sustainability

In the first chapter it has been abundantly discussed how the market for blockchain-based firms or companies that at least exploit this technology still represents a relatively small-sized reality in Italy, where the small number of applications is not homogeneous in terms of variety of fields and functions covered. This fragmentation sees one half of the total companies categorized by type of service offered occupied by only three of them: consulting (24%), supply chain (18%) and intellectual property and copyright protection (8%), with the remaining half composed by other categories with a weight of 5% or less, with the exception of lending and credit and payment, which are both at 8% (*Figure 5*).

By looking at this data, it is possible to notice how using the blockchain's capability to guarantee the authenticity of certain information is perceived as a very important factor to be implemented in business application. This not only recalls again to chapter one, where it is reported how Italian companies could benefit from blockchain's features of transparency, security and traceability, hence it could be a perfect protector of the "Made in Italy" products, but it is actually a point of interest for MiSE too, as in 2019 it has started a project in collaboration with IBM – a pioneer in this area, as it has endeavored to leverage blockchains in the supply chain since 2015 (IBM, 2015) - with the aim of understanding the problems and criticisms generally affecting the Made in Italy production chain, eventually finding a shared solution to them and trying to understand how the blockchain could play a role for this solution to work (MiSE, 2019).

The project has definitely led to positive results, giving a different model to approach the needs of traceability in a complex, structured and most importantly replicable environment. This latter feature is crucial as it represents a wealth of experience and collaborative planning which could be used and adapted in analogous circumstances, possibly becoming a value added for the industry of Made in Italy. Moreover, the project has demonstrated that it is possible to have a collective work experience, which allows for a joint problem-solving for purposes that are normally addressed to multinationals or big consortia, in order to be solved.

This experience has put the spotlight on the effectiveness of this type of applications, bringing a new method to the attention of a relevant public entity as the MiSE, and represents only the tip of the iceberg of blockchain applications for the traceability of products throughout the productive and supply chain of a company. As a matter of fact, many are the similar solutions that have seen the light in the past years, both in Italy and abroad. After a literature review on the topic with a focus on its sustainability features, the chapter will move to real cases of application in Italy, regarding both private companies and solutions adopted by public entities in collaboration with specialized firms.

3.2 Traceability and transparency for sustainability of supply chains

Blockchain technology has the potential to benefit from numerous supply chain concerns that could address the adopting company through the path of sustainability. Just to mention a few, its application could bring important features to reach this objective, such as real-time communication, ensuring trust amongst partners, building secure relationships, faster payment processing with lessened transaction fees, lower product costs, reduced lead times, improved forecasting, reduced bottlenecks, and resources conservation and recycling (Saberi & al., 2018).

Modern supply chains are inherently complex comprising multi-echelon, geographically disjointed entities competing to serve consumers. Globalization, diverse regulatory policies, and varied cultural and human behavior in supply chain networks make it almost impossible to evaluate information and manage risk in this intricate network. Inefficient transactions, fraud, pilferage, and poorly performing supply chains, lead to greater trust shortage, and therefore, a need for better information sharing, and verifiability. Traceability is becoming an increasingly urgent requirement and a fundamental differentiator in many supply chain industries including the agri-food sector, pharmaceutical and medical products, and high value goods. Luxury and high value items, products with a specific categorization such as those branded as Made in Italy, whose provenance might otherwise be reliant on paper certificates and receipts can easily be lost or altered. In fact, lack of transparency in the supply value of any item prevents supply chain entities and customers from verifying and validating the true value of that item. The cost involved in handling intermediaries, their reliability, and transparency further complicate managing this traceability in the supply chain. Strategic and reputational competitive issues arise from these risks and lack of transparency.

Current supply chains heavily rely on centralized, sometimes disparate and stand-alone information management systems, that are within organizations - for example, enterprise resources planning systems, which has its own pitfalls. Also, they require significant trust for relying on one single organization or broker for storing their sensitive and valuable information, thus they are exposed to “single point failure”, another disadvantage of centralized information systems, which leaves the whole system vulnerable to error, hacking, corruption, or attack.

Supply chain practice and strategy is also facing emergent pressures to consider and certify supply chain sustainability, a concept defined by the triple-bottom-line concept that includes a balance of environmental, social, and business dimensions when managing the supply chain. An important strategic and competitive issue for sustainability in supply chains is the confirmation and verification that processes, products, and activities within the supply chain meet certain sustainability criteria and certifications. Such issues touch a nerve and evoke questions not only on whether traditional supply chain information systems can support information required for the timely provenance of goods and services, in a secure manner that is clear and robust enough to trust, but also if they can guarantee any of the points concerning sustainability issues. Surely, the solution to these complicated problems lies in improving supply chain transparency, security, durability, and process integrity, and the answer to this problem could be found in blockchain technology.

Despite blockchain technology implementation to support sustainable supply chain is still a novel and difficult task, the experience and knowledge of users is growing, reducing the difficulties of integrating these systems into legacy supply chain systems. In this environment of discovery and uncertainty, some companies have initiated blockchain investigations by considering its uses for their business, showing caution and weighting the potential benefits of this technology against the barriers to its implementation. To evaluate and balance pros and cons of adopting this system, the first task of implementing blockchain technology is to analyze and select a suitable blockchain technology, considering its performance and technical outcome characteristics. As far as we know, there is no scientific and systematic performance measures system in practice and academia for blockchain performance, especially for transparency evaluation. Nevertheless, literature studying the application of blockchain solutions in supply chain management is growing, covering aspects of the subject that were previously not taken into account.

As research went far, the characteristics of many points of discussion have become clearer. For what it concerns transparency, which “is the extent to which information is readily accessible to counterparties in an exchange and also to outside observers (Awaysheh & Klassen, 2010), its features slightly change when talking about it in a supply chain context, as it refers to information readily available to end-customers and companies within a supply chain, so it is likely to be considered a necessary supply chain performance metric, given the emergent “trustless” environment associated with blockchains and organizational context issue.

Even before reaching the end consumer, products travel through a vast network of extractors, manufacturers, retailers, distributors, transporters, storage facilities, and other service providers that participate in design, production, delivery and sales. Lack of transparency can lead to several problems in the supply chain, especially those involving business, environmental and social responsibility issues. These issues are given greater credence with increased pressures put on organizations and their products from different worries, including supply chain cost performance, safety concerns, and ethical production. Due to these complexities, many challenges to providing more information about product origins and processes arise. These problems could be faced with the application of a blockchain-based supply chain, that will allow to reach sustainability through its transparency feature.

According to Bai and Sarkis, a sustainable supply chain transparency comprises three dimensions (*Table 3*) (Bai & Sarkis, 2020):

1) Range of transparency, including dimensions such as supply chain partner information participation degree, scope of operations, environmental and social information of the supply chain;
2) Product transparency, such as tracking product components, tracking product process (from the place of origin to the end customer), tracking product sustainable information;
3) Participant transparency, with participant operations, situation information, and participant sustainability conditions visible.

Transparency dimension:	
Range	e.g. scope of operations, environmental and social information
Product	e.g. raw material origins, recycling and carbon emissions data
Participant	e.g. operations, situation, sustainability conditions of the participants

Table 3 - *Transparency dimensions of sustainable supply chains*

First, for effective supply chain transparency all companies and partner agents need to participate across the supply network. Supply chain transparency, especially beyond one tier in the network, is a key business challenge, with most companies generally having little or no information on their own second and third-tier suppliers. Moreover, due to the lack of sustainability information transparency in the supply chain, customers cannot fully ascertain product or service characteristics such as, for example, food safety or the type of processing of a specific phase of the productive process.

Secondly, transparency relates to products and supply chain tracking and traceability. This information would include raw material origins and provide context to a final product or service. Tracking product components can provide consumers more confidence that the products are genuine, of high quality, and processes are followed in ethical ways. The benefit of this transparency aspect will make consumers more confident in the product, significantly increasing willingness to purchase the product (Kshetri, 2017). Tracking product processes, by analyzing data on the products processes and paths can also help companies in a supply chain know whether the product was in a wrong place, processed incorrectly, or whether it has been managed poorly from a timing aspect. Tracking product sustainability information has become a crucial tool to motivate green consumption by providing consumers with a better understanding of the product life cycle and product and process sustainability implications.

Third, there are many potential negative consequences of the operations and conditions of every partner in supply chain, such as production crises and disruptions, unethical and illegal practices, environmental burdens, end of life waste, forced labor and poor conditions in factories. These issues have often left supply chain networks with potential risk and the need to build resiliency, and some of them have become a no more tolerable hot topic especially in the past decades. Hence, several operations and conditions related to the supply chain need be tracked, such as legal and environmental incidents.

Obviously, to insert a new technology inside established supply chain systems is often not an easy task to accomplish, as integration challenges are some of the largest barriers to overcome. From a supply chain integration perspective, information and software technology needs to meet some basic requirements, and in this sense the blockchain will have a far-reaching impact on supply chains to meet them.

As a matter of fact, to solve the abovementioned problems, with the adoption of a blockchain-based solution it is possible to:

- increase transparency and traceability of products and processes to keep track of almost all data – price, date, location, quality, certification, and all the other relevant information;

- make transactions faster and cheaper, ensuring that different partners are meeting their obligations with the use of smart contracts almost in a trustless way;
- reduce paperwork and bureaucratic effort, also making it more precise;
- reduce the potential losses from human error and uncertainty and grey market trading;
- create greater connectivity across and amongst relevant supply chain stakeholders.

Four major entities play roles in blockchain-based supply chains, with some of them not seen in traditional supply chains: *Registrars*, who provide unique identities to actors in the network; *Standards organizations*, who define standards schemes, such as Fairtrade for sustainable supply chains or blockchain policies and technological requirements; *Certifiers*, who provide certifications to actors for supply chain network participation; *Actors*, including manufacturers, retailers, and customers, that must be certified by a registered auditor or certifier to maintain the system trust (Steiner & Baker, 2015).

Also, there are many influences affecting the supply chain product and material flows. Hence, every product may have a digital blockchain presence so that all relevant actors can have direct product profile access. Security measures may be set in place to limit access, where only the parties with the correct digital keys have access to a product. There is a range of data that can be collected, including the status of the product, the type of product, and the standards that are to be implemented for a product. An information tag attached with a product represents an identifier that links physical products to their virtual identity in the blockchain.

One interesting structure and flow management characteristic is how a product is “owned” or transferred by a particular actor. Actors gaining permission to enter new information into that product’s profile or initiate a trade with another party will likely be a significant rule, where gaining permission may require smart contract agreements and consensus. Before a product is transferred or sold to another actor, both parties may sign a digital contract, or meet a smart contract requirement to authenticate the exchange. Once all parties have met contractual obligations and processes, transaction details update the blockchain ledger. Then, the records of data transactions would be automatically updated by the system when a change is initiated.

The application of blockchain technology can highlight and detail at least five key product dimensions: the nature, the quality, the quantity, the location and the ownership (*Table 4*).

Key product dimensions:	
Nature	What it is
Quality	How it is
Quantity	How much of it there is
Location	Where it is
Ownership	Who owns it at the moment

Table 4 - *The five key product dimensions highlighted by the blockchain application*

In this way, the blockchain removes the need for a trusted central organization that operates and maintains this system, allowing customers to inspect the uninterrupted chain of custody and transactions from the raw materials to the end sale. This information is recorded in ledgers as transactions occur on these multiple blockchain information dimensions with verifiable updates.

Blockchain reliability and transparency are meant to facilitate material and information flow more effectively, through the supply chain with automated governance requirements. This transformation may result in a broader shift from an industrial durable, commodity, products economy to an information, customization economy. Production will rely more heavily on knowledge, communication, and information and not necessarily on materials characteristics (Pazaitis & al., 2017). For example, customers are given the possibility to track the detailed information of products, which would increase costumers' trust associated with product characteristics.

Also, smart contracts are present as written rules stored in the blockchain, which can help to define network actor interaction amongst each other and within the system. Smart contracts influence network data sharing between supply chain participants and continuous process improvement. For example, certifiers and standards organizations digitally verify every actor's profile and products, which are digitally registered on the network for each of them, displaying information such as description, location, certifications and association with products. Hence, each supply chain player can log in key information about a given product and its status on the blockchain network. Smart contract governance and process rules in a blockchain-based supply chain can also manage actor certification and approval and what processes they are allowed to access and are needed for execution. Actor data changes can occur depending on supply chain type, position and trigger defined by a smart contract. Plus, just like in any blockchain network, the actors – which could otherwise be called nodes - cannot change the rules without some form of consensus process, ensuring the integrity and security of the whole system.

Smart contract process characteristics portend potential business process continuous improvement for supply chain processes. The potential for supply chain business process improvements can be situated in blockchain information that may capture performance metrics in ledgers, linking them to agree upon processes. This type of approach and information has great potential for supply chain design and real-time implications, going beyond the mere product delivery and governance concerns. Blockchain impacts both supply chain process and product management, and financial transactions between different network parties.

A key potential blockchain supply chain advantage is the disintermediation of financial intermediaries, including payment networks, stock exchanges, and money transfer services. This will make trading processes among partners more efficient. Inefficiencies in supply chain financial flows can be reduced through supply chain finance instruments and techniques such as reverse factoring and dynamic discounting, which could help in saving a considerable amount of money. Smart contracts can also organize financial arrangements and would ensure that sufficient funds are available to the projects and that everyone is paid in a timely manner. They provide a connection for transaction between different currencies or mix them from multiple sources in global supply chain in a secure and timely manner.

This whole amount of information shows how supply chain could benefit from being paired with blockchain technology, suggesting that its features would allow to be more sustainable even if it is not directly concerned with tracking potential social and environmental conditions. Moving the attention to cases in which blockchain-based supply chains are adopted precisely to reach sustainability, it is easy to imagine how its features would perfectly fit with cases such as, for example, the food and beverage industry supply chain sustainability pressures, equipping a food supply chain with traceability system for real-time food tracing based on Hazard Analysis and Critical Control Points (HACCP) rules (Tian, 2017).

Blockchain technology has the potential to contribute to social supply chain sustainability. Making information stable and immutable is one way of building supply chain social sustainability. Given that information cannot be modified without consent by authorized actors, blockchains can prevent corrupt individuals, governments or organizations from seizing assets of people unfairly. Also, blockchain technology can block nefarious agents and hold the corrupt accountable for both social and individual misdeeds. Blockchain traceability helps sustainability through better assurance of human rights, and fair, safe work practices. For instance, a clear record of product history helps buyer confidence and shows that goods being purchased come from ethical sources. Blockchain technology also aids in environmental supply chain sustainability, being able to di it from many different perspective applications.

First, tracking substandard products accurately and identifying further transactions of the products can help reduce the rework and recall, which helps decrease resource consumption and reducing greenhouse gas emissions. While traditional energy systems are centralized, a peer-to-peer network based on blockchain technology for energy system can reduce the need to transmit electricity over long distances and subsequently save a big portion of energy wasted going through this wide space transmission. At the same time, it would also allow to reduce the need for energy storage which saves its resources.

Second, blockchains could be used to ensure that purportedly green products are environmentally friendly. The processing information for green products is often unavailable and difficult to verify. If the manufacturing process of a product is verified to be green in terms of greenhouse gas emissions level, environmentally conscious customers may be more willing to purchase green products. For example, Ikea has a desk product made from wood cut in a sustainable Indonesian forest. The company must follow the wood from the time it is cut through manufacturing to the final product to guarantee that the are desks really made from this specific wood. This process is complex but can be managed with blockchain technology. One such example is the Endorsement of the Forestry Certification program, which traces the provenance of around 740 million acres of certified forests all over the world using blockchain technology.

Another example, maybe even more relevant and explicative, is related to carbon tax. In traditional systems, the carbon footprint of each product is difficult to measure, while though the adoption of blockchain technology, tracing the footprint of products of particular company becomes easier, as it can help determine the amount of carbon tax that should be charged of a company. If a product is more expensive with a large carbon footprint, the final consumers may buy a product of low-carbon footprint. This additional information, together with consumer or market pressure, may cause firms to reevaluate and restructure their supply chain to reduce the carbon emissions in order to meet the demand of buyers. Blockchain technology can help reduce carbon emissions in the journey of products by providing the fundamentals for supply chain mapping and applying low-carbon product design, production, and transportations. The *Supply Chain Environmental Analysis Tool* (SCEnAT) proposes a framework to assess carbon emissions of each entity involved in supply chains and life-cycle of products (Koh & al., 2013). SCEnAT 4.0 is a new tool that integrates novel technologies such as blockchain, Internet of

Things (IoT), Artificial Intelligence, and Machine Learning to manage big data and link organizations in the supply chain more effectively to support industry 4.0 policies, carbon reduction, and green assessments.

Blockchain technology also has the potential to transform carbon assets trading. As an example, IBM and Energy Blockchain Labs Inc. in China are developing a green assets blockchain-based platform that helps companies to track and measure their carbon footprint, meet the *Carbon Emission Reduction* (CER) quotas, and facilitate carbon asset development and trading. Transparent, secure and real-time information on the blockchain gives organizations the opportunity to cooperate and trade their carbon assets in a more efficient way in the green assets markets, making the whole system more sustainable.

Third, blockchain can improve the recycling, whereas people and organizations may not be motivated to participate in recycling activities. Blockchain technology has been used to motivate people in Northern Europe through financial rewards in the form of cryptographic tokens in exchange for depositing recyclables like plastic containers, cans, or bottles. Meanwhile, it is difficult to track and compare the impact of various recycling programs – a task that could be eased by using blockchain. For example, *Social Plastic* is a project based on blockchain technology to turn plastic into money and aims to reduce the plastic waste, or *RecycleToCoin*, another blockchain application, that enables people to return plastic containers. The possibilities for this type of effort for closed-loop supply chains make blockchain amenable also to emerging concepts such as the circular economy.

Fourth, blockchain benefits the emission trading process by improve *emission trading schemes* (ETS) efficacy. With the application of blockchain technology, fraud can be avoided due to the fidelity and transparency of blockchain. Thus, a reputation-based system is created, solving the inefficiency of ETS and encouraging all the participant to figure out a long-term solution to the emission reduction, stimulating them through the economic benefits of good reputation.

The use of blockchain technology as a supply chain governance and information management mechanism will be challenging specially in a sustainable network, as disruptive technologies typically face difficulties, whether in the short-term or long-term. Therefore, participants of supply chain need to be prepared for it to have it as an opportunity, rather than a threat, as it might challenge the relationships through supply chain.

These examples present just some cases showing the potential for economic, social, and environmental influences that can be managed in a blockchain-enabled supply chain, whose contribution to the processes allows to reach sustainability. Still, the full power and exploitability of the technology has yet to be discovered and completely understood.

3.2.1 Blockchain technology in global food supply chains

As clear as the examples reported above could be, a detailed insight on a possible application that could actually change world economy, thus being framed not only inside the corporate dimension, would be more impactful and show the real potential of blockchain for sustainable applications.

The work done by Friedman and Ormiston for their 2022 paper "*Blockchain as a sustainability-oriented innovation?: Opportunities for and resistance to Blockchain technology as a driver of sustainability in global food supply chains*" (Friedman & Ormiston, 2022), surely represents a case with such a huge impact to clearly show how blockchain could help the environment. The objective of the authors was to demonstrate how blockchain is used within food supply chains as both a tool for sustainability as well as a broader philosophical mindset for addressing sustainability challenges. Also, the article reveals the opportunities for blockchain technology as a sustainability-oriented innovation that can ensure fairer supply chains, enhance food traceability, and drive environmental sustainability in a global scenario.

Obviously, the type of application of blockchain technology described relies on the capacity of facing the main, big challenges affecting food supply chains. As a matter of fact, The interconnectedness and globalization of the food supply network creates vulnerabilities if food products cannot be tracked and traced throughout every level of the chain. This is mainly due to the nature of the products, as perishable goods require precise management to meet high standards of food safety and quality. Traceability is also essential for effectively managing recalls in supply chains, as it can minimize risks and contain hazards which could compromise food security.

Blockchain has the power to enhance traceability in food supply chains through decentralized and secure databases that ensure trust and safely store data allowing for better food security. It is argued that the absence of intermediaries in its applications can contribute to simplified and integrated supply chains, reducing the risks associated with recalls, as even acknowledged by the Food and Agriculture Organization of the United Nations (FAO, 2019). Furthermore, smart contracts could play an important role in blockchain's contribution to traceability improvements in agricultural value chains as they can better track products allowing for better verification of the product's origin and quality.

Also, the distributed trust mechanisms embedded in blockchain technology has the potential to make supply chains considerably more transparent. As the data in a blockchain is immutable and relies on the consensus of the network, unauthorized changes are not possible, assisting in reducing fraud and corruption by ensuring the authenticity of agricultural products. By enhancing trust and multilateral collaboration among supply chain actors, blockchain technology can also assist in creating an enabling environment for verifying and monitoring supply chain activities and ensure sustainable labor practices, controlling any eventual human rights abuses in the labor practices adopted.

For what it concerns the environmental impact, the two main drivers of an unsustainable food supply system are the waste creation and the pressure on planetary boundaries. It is estimated that one third of food produced is lost or wasted in supply chain activities such as harvesting, shipping, storage and the retail level. Alexander et al. find that overall food system losses are the highest in agricultural residues and other losses prior to the harvest, however, the highest rates of losses are associated with livestock production (Alexander & al., 2017). For affluent economies, food waste and waste associated with packaging remains particularity high in the post-consumer stage, and total food loss and waste account for about 8% of global anthropogenic greenhouse gas emissions and therefore, represent a significant contributor to climate change.

An expanding world population has raised the demand for food which in return has led to an increasing pressure on Earth's biophysical limits, with agricultural production being the major driver of the earth system exceeding planetary boundaries, particularly to the two transgressed planetary boundaries of biosphere integrity and biochemical flows. Agricultural food production accounts for about 30% of global greenhouse gasses and occupies about 40% of the Earth's land, making food production one of the largest contributors to climate change (Swinburn & al., 2019). Besides the release of emissions from food production, transportation also contributes to raising greenhouse gas levels as food often travels long distances – the so-called "food miles" - before reaching the consumers plate industry.

By offering a secure and verifiable record that can be used to reinforce entitlements to natural resources and incentivize environmentally sound actions, blockchain can help address environmental sustainability challenges. Many have also highlighted the potential of blockchain applications for the implementation of United Nations Organization's *Sustainable*

Development Goals (SDG), of which the most promising cases were found in the context of affordable and clean energy (SDG 7) and responsible consumption and production (SDG 12). Together with them, the potential of blockchain to advance impact monitoring is another example of improving environmental sustainability. Creating possibilities to show where food originates, how food is processed and distributed, and under which environmental conditions food is produced, blockchain can reduce environmental impact and encourage the concept of a circular economy.

The features analyzed by Friedman and Ormiston for this case align the usage of blockchain to the requirements characterizing the so-called *Sustainability-Oriented Innovation* (SOI), which are defined as the solutions that, in the words of Richard Adams, "involve making intentional changes to an organization's philosophy and values, as well as to its products, processes or practices, to serve the specific purpose of creating and realizing social and environmental value in addition to economic returns" (Adams & al., 2016).

The academic literature on SOI defines three different types of innovation to be satisfied: technological, organizational and institutional/social (*Table 5*).

	Technological	**Organizational**	**Institutional/Social**
Innovation Objective	Doing the same thing better	Doing good by doing new things	Doing good by doing new things with others
Innovation Outcome	Reduction of harm	Creation of shared value	Creation of net positive impact
Innovations relationship to firm	Incremental improvements to business as usual	Fundamental shift in firm purpose	Extends beyond the corporate dimension to drive institutional change

Table 5 - *SOI's three types of innovation*

Based on Adams et al., 2016; Klewitz and Hansen, 2014[43]; Jay and Gerand, 2015

(Klewitz & Hansen, 2014); (Jay & Gerard, 2015)

By taking into account the above mentioned SOI criteria, it seems reasonable to say that blockchain technology has the potential to be more than a tool for sustainability, due to its underlying philosophy that aligns with the objectives of sustainability. Blockchain proponents are guided by the principles of democratic participation and decentralization, both having important contributions to sustainability.

Democratic participation provides the freedom to defend basic rights, protect justice, ensure equal representation and exercise common responsibilities to respect life on earth, which as a principle of the blockchain mindset strengthens its capacity as an innovation for sustainability. Through its democratic features, blockchain shows potential to move beyond a technological innovation to become a social/institutional innovation. As "technological innovation will be necessary but not sufficient for sustainable development" (Jay & Gerard, 2015) the need to understand blockchain's democratic features in addition to its technological capacities is essential. The democratic philosophy of blockchain should not be underestimated for delivering impact as equal involvement of all supply chain participants in innovating for sustainability is necessary to expand to societal change and go beyond incremental improvements to business as usual.

Blockchain's decentralization principle is also beneficial for sustainability outcomes as it can drive the distribution of value to farmers and other marginalized supply chain actors. The absence of a central authority helps for the empowerment of the individual actors, which in turn helps to overcome corruption. Decentralization can lead to higher co-operation over competition and can facilitate strategic partnerships which can be beneficial for distributing sustainability responsibilities (Biswas & al., 2018).

However, a more critical examination of the philosophy suggests possibilities for unsustainable practices to emerge through the implementation of blockchain technology. Hence, it is necessary to question to what extent decentralization provides equal opportunity for all supply chain actors. For example, granting farmers/users access to the blockchain does not automatically translate into more decision-making power and could also be perceived as a form of coercion through requirements to provide necessary data. We need to examine how democratic blockchain applications actually are, and if they indeed fulfill the philosophy of equal opportunity. When it comes to advancing sustainability, centralization may even be beneficial for enforcing good governance and responsible resource management. Taking this argument into account, a centralized regulatory body may be necessary for achieving sustainability as it reduces "free-riding" by punishing those who pursue exploitation.

The blockchain philosophy must therefore be embraced with caution and must reveal clear objectives for sustainability, rather than a push toward a pure free-market ideology – a path that could instead promote an unsustainable market model.

Summing up, the study of Friedman and Ormiston reveals five opportunities for Blockchain to advance sustainability within food supply chains:

1. Address fraud and human rights violations;
2. Ensure fairer supply chains;
3. Enhance food traceability;
4. Deliver environmental benefits;
5. Generate shared economic value creation.

The findings on blockchain's environmental benefits reflect the literature on waste and resource management but practice still seems to lag behind more conceptual conversations. Also, in comparison to the social and economic dimension, less evidence was found for blockchain's contribution to environmental sustainability. The findings did highlight blockchain's potential for reducing food waste, however, this is often the result of economic ambitions to save costs rather than actively seeking environmental benefits.

Finally, a critical evaluation must be given again to its claims of achieving financial and sustainability objectives simultaneously. Findings suggest that blockchain may also offer opportunities for greenwashing, meaning conditions of poor environmental performance compensated by positive communication about environmental performance. Supply chain actors should then be wary of the potential for greenwashing through blockchain, which could dilute the momentum of blockchain for sustainability applications.

As blockchain provides ways to legitimize sustainable practices in supply chains, companies can misuse this opportunity for a financial benefit. This criticism resonates with the finding that blockchain can be applied for both sustainable and unsustainable practices and highlights the need to consider any challenge that may limit blockchain as a sustainability-oriented innovation.

As for the case of deciding which blockchain model to adopt in a certain type of business, it is then necessary to make some considerations and evaluate the possible drawbacks before entering this world. In any case, a responsible use of the technology has been demonstrated to ease the processes and increase the efficiency of supply chains, smart contracts-based systems and many other fields of interest inside the corporate life and the market in general.

3.3 Blockchain solutions in the Italian market

Using the processes described in the previous paragraph, many Italian companies have started to adopt blockchain-based solutions in their productive processes, consequently modifying their technological, organizational and institutional structure.

3.3.1 Carrefour Italia

Proceeding in the same way of blockchain applications to supply chains in the food market, maybe the most relevant case in terms of dimensions and variety of products involved is that of *Carrefour Italia*, that has been using blockchain technology since 2018, after a one year explorative period to understand whether to definitely jump into the IBM Food Trust, which is a supply chain network based on the Hyperledger Fabric, which allows to exploit a data management system that guarantees a higher level of traceability, transparency and efficiency, for retailers, suppliers and even farmers (Bellini, 2018). In this way, consumers are given a sort of digital identity card of the products they have bought, containing all the relevant information gathered throughout the productive chain. This makes Carrefour a pioneer not only in the Italian blockchain market, but in the global one as well, as it has now been a considerably amount of time since it started to adopt the technology.

The first application of a blockchain solution from Carrefour regarded a quality supply chain, linked to the breeding and sale of a particular type of chicken – called "pollo d'Avernia" – for which it had to be guaranteed that the animals were raised free, outside in the farms, without using genetically modified organisms or antibiotics to feed them and supplement their nutrition. The technology allowed to collect and archive data on the four most relevant categories of information required to guarantee the sustainability of the whole production:

1. *Incubation*: including name and location of the hatchery from which the chick was born, plus the dates of birth and transfer to the farmer;
2. *Breeding*: including name and location of the farmer, plus the dates of the arrival and transfer to the slaughterhouse. Furthermore, any vet certification regarding the absence of traces of antibiotics and fodder factory notes detailing the composition of the foods used by the farmers, attesting a quality label, are registered too in the chain;
3. *Slaughter and transformation*: includes any information on the identity, batch number and dates of departure to the depots and expiration of the product;

4. *Distribution*: the final stage of the chain, in which the receiving deposits memorize the date of arrival of batches and that of their delivery to the stores.

After that, the retailers will apply the traditional tags with price and expiration date, to which a QR Code is added. Scanning the code with a simple smartphone, it is then possible to have access to the blockchain and to verify and control all of the information registered in it.

In this way, Carrefour has managed to inform its customers about the origin, breeding processes and most of all quality of the product they are about to buy, guaranteeing for their sustainability. Also, according to Giovanni Panzeri, the Private Label Director of Carrefour Italia, this project has tested the efficiency of this blockchain-based supply chain solution, which has allowed to double the revenues from the sales of chicken (distribuzionemoderna, 2019). After the company begun using this new method and technology, it moved to apply it to many other products, with the aim of adopting this system for all of the goods they sell by the end of 2022. Future reports will show if and how Carrefour has managed to accomplish this task.

3.3.2 Other companies and entities adopting blockchain solutions

As written at the beginning of the chapter, many are the companies that are currently exploring and pioneering the blockchain market in Italy for sustainability issues and purposes other than those strictly linked to cryptocurrencies, finance and anything related to the mainstream world of this technology, such as Non-Fungible-Tokens. By listing them, it is possible to make a clearer idea on the high applicability and versatility of the blockchain technology in our country's market

Continuing with a similar trend to that of Carrefour Italia, *FoodChain* is another Italian project and was founded in 2016. Just as IBM's blockchain solution, it is a blockchain-based platform that allows to track food products along production chains, making data available to anyone who desires to consult them. FoodChain promises to guarantee transparency and trust, real-time traceability of the products, anti-counterfeiting standards, interconnection between users and companies and legal validity in all of the jurisdictions that have adopted new laws and rules concerning the DLTs and blockchain market (FoodChain, s.d.). The project finds its peculiarity and point of strength in the fact that it approaches also to public entities, and helps the prevention of counterfeiting of the "Made in" products – a point whose importance was stressed in paragraph 3.1.

Another important case, mainly for the magnitude that it could have due to the size of the company, is that of *Barilla*, that has collaborated with IBM Food Trust just as like Carrefour Italia, this time to guarantee traceability and sustainability of the production of basil. The success of the project was such that it was awarded by Forbes in 2019, with the first *Forbes Blockchain Award* (Morgantini, 2019).

Moving on to other markets, an interesting case is the one of *TRAME*, a project started in 2020 from the collaboration between four companies in Lombardy - Top Digitex, SAIT, Tessitura Uboldi and, again FoodChain -, with the aim of developing a sustainable production chain model that could be standardized and applicable for the whole field of textile (UboldiGroup, s.d.). As this industry particularly suffers from having a significant environmental and social impact, TRAME is trying to fight these issues by improving transparency and traceability. Collecting and monitoring data linked to fabrication processes would allow companies to cut both the energetic consumption of their plants and the production waste. This is also encouraged by the system of reward based on the adoption of exchangeable tokens (OsservatorioCQuadra, s.d.) – a process similar to that offered to miners participating to the PoW consensus mechanism.

For what it concerns public entities, there are different solutions adopted by them, or that are at least in a developing phase, going from a strictly local dimension to a national one. For the former, an example is that of *Comune di Bari*, which has started a project based on blockchain with the aim of digitalizing the surety policy management process, trying to dematerialize the proceedings for the release of guarantees from banks, financial intermediaries and insurance agencies, certifying them in a unique and irrevocable way. Instead, an example of blockchain application in a public entity at a national level is the case of *Crea*, an entity controlled by the Ministry of Agricultural Policies, whose objective is to develop an application for wood traceability, from the sowing phase to the final product (Morgantini, 2019).

Finally, posed at an intermediate level between the two abovementioned cases, there is the *Nidi Gratis* program of Regione Lombardia, whose application stands as a unicum among the examples shown, because it represents a case of blockchain project for social sustainability[53] (OpenInnovationLombardia, 2019), as its aim is to provide childcare services to families that are faced with economic and social vulnerability. The local government recognized lack of information sharing within the public sector as a challenge for citizens in accessing public services, as it puts a burden on individuals to provide similar information repeatedly when applying for government supports. The pilot project launched in 2019 was set up to simplify application process to childcare services, where blockchain technology was selected as an enabler for streamlining the public service offering. After having recognized limits of creating a common database in current system where ownership of data is fragmented between different parts of the government, the regional government decided to create a data federation. On the contrary to data lake that are centralized data repository established and managed within enterprises, data federation refers to a system of heterogeneous databases that are interconnected via network. The program focused on creating a blockchain-based meta-database system that could verify validity of the data stored across government functions, and the system was developed to conform to the *European General Data Protection Regulation* (GDPR), especially when designing data ownership and privacy architecture.

When a government function certifies validity of information in their database, the data verifying authenticity of government-owned information is anchored to the blockchain network and time stamped, allowing for verifiable claims that can be accessed by other counterparts. Doing so, the regional government orchestrates the process to improve accessibility and interoperability of the system.

The pilot began in September 2019, with municipality of Cinisello Balsamo selected as a trial region. Citizens were also given an option to apply for the government support via mobile app, by logging in with the national public digital identity system credentials, having the possibility to access to the required procedures even by using a simple smartphone. Algorithm gathers information of the applicants from all relevant data providers in the federated system, and stores verified claims in their digital wallet. With automated verification process, families that met the requirements were provided with financial support in significantly short time.

As a result, numbers talk about 15650 children benefitting from Nidi Gratis program in 2020 and an expansion in about 130 towns from the beginning of the project. The growth was surely eased and promoted by the easily accessible platform, that required less than 8 minutes to complete the necessary procedures, which would then be automatically verified by the blockchain system (RegioneLombardia, 2021). Also, it was calculated that implementation of the blockchain-based system in Nidi Gratis application process resulted in reduction of 3900 hours of work in the administration.

With the system being a relevant example of the “once-only” principle, the Lombardy regional government is now planning to expand the use to other public services, trying to replicate the success of this initiative and continue to explore the potentials of blockchain.

3.4 What will come next?

By looking at each of the examples presented, it is reasonable to imagine how all of the reported cases will likely catch on the market and become an important benchmark for many other companies' organizational systems. Besides, the current challenges affecting the global economy may play a role in quickening the process of transition from traditional models to modern and more sustainable ones, as not only they allow for the creation of positive externalities outside the corporate dimension, but they may also represent a way to increase the adopting companies' revenues: an always important driver for the growth of any new project.

4. Conclusions

As reported in the introduction, the intent guiding the writing of this thesis was that of trying to understand whether the energy-intensive nature of blockchain could find a compromise with the huge potential that this technology has. To do so, it was necessary to adopt a procedural approach, starting from understanding how the current situation is going and understanding what cannot be sustainable in the close future.

In this sense, the research work done has clearly shown that the problem linked to the energetic consumption can at least be buffered even by using what could be considered as a traditional systems in the world of blockchain, as for the case of Proof-of-Stake consensus mechanism. Still, this may not be enough, as the energetic consumption problem is also caused by the redundant computation and storage requirements associated with the blockchain's operations, and the idle energy consumption of each node of the blockchain network. Thus, every new blockchain initiative must evaluate and weigh up each of the components on which a project is based that could generate and increase these sources of energy consumption, as an incorrect estimation could turn the amount of energy fueling the system into a waste, if compared to the existing possible alternatives that could allow to save electricity and, consequently, money.

Some easy and accessible existing systems, allowing for a responsible and sustainable use of blockchain technology, already exist and are provided, among the others, by the HashNET platform and Algorand network, proposing two different yet valid ways for the creation of green blockchains. The most immediate and possibly cheapest way to reach carbon-neutrality when creating a new blockchain-based application could then be to rely on them and exploit their already existing infrastructures, which promise to change the current market and traditional blockchain systems for a greener one, based on sustainable applications.

Finally, despite the Italian blockchain reality has still to catch up other countries' level of development, there are glimpses of progress both in terms of regulation, which is necessary to build the foundation for a solid market, and of innovation coming from private and public initiatives, which promise to define a path and leave a mark for newcomers to follow. Both from small and medium enterprises and large multinationals, the signs suggest that Italy may play a role in blockchain market in the years to come, also thanks to the contribution and efforts coming from the bottom as well as from the top, as the recent effort of public entities operation is showing.

Despite the environmental conditions affecting worldwide and local economy, and the effects of energetic crisis on the corporate business dimension, the future perspective still appear bright, as the elements currently representing drawbacks of blockchain technology applications could be managed and turned into strengths through the application of the technology in companies’ operations for sustainable and carbon-neutral processes.

So, the key for a sustainable future does not pass from the mere reduction of the business dimension and cutting consumptions, but is to optimize processes also by using an energy-consuming-born technology as blockchain is, exploiting the existing innovative systems and models to increase its efficiency and reduce waste at the minimum.

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