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SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

Master of Science in Management Engineering

Blockchain as an enabler of Circular Manufacturing: an analysis of real cases

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Abstract (English version)

The recognized importance of the “Circular Economy” paradigm – an industrial system regenerative and restorative by intention and design – in innovating the Manufacturing industry is central to the achievement of the UN Sustainable Development Goal.

Blockchain technology is a new protocol designed to ensure sharing and storing of data in a transparent, secure and irreversible way, with the potential to support the manufacturers through the green transaction during the Industry 4.0 era.

The subject of the presented thesis enters in a nascent stream of research, within the intersection of the two macrotrends: sustainability and digital innovation.

Among the review of the literature, the interest focuses on the benefits of the blockchain technology in both the circular economy and manufacturing industry, under a theoretical perspective. Few empirical studies have been conducted in the intersection of those fields.

The objective of this thesis is to contribute to fill the gap in the literature by investigating blockchain technology’s current and potential contribution to the circular economy in the Manufacturing industry.

The work consists in the collection, analysis and classification of real initiatives, through a framework including variables on Circular Manufacturing and on Blockchain application. To classify the projects, a scheme of variables was created, pointing out aspects related to the subsectors, the circular strategies adopted and the main characteristics for which blockchain is exploited.

Within the sample considered, main considerations are drawn from the projects spread into different Manufacturing subsectors, where the application of blockchain supports circular strategies alongside the whole supply chain. The main benefits of blockchain are related to the possibility to record information transparently enabling a trustworthy environment, without the need of intermediaries. In this environment, blockchain can enable circular sourcing of renewable inputs and support responsible recycling.

The hype and potential benefits associated with blockchain technology provide substantial motivation to identify future applications. To conclude the work two main thoughts are suggested: how blockchain can bring benefits to Manufacturing, maximising product use, and whether blockchain applied to circular manufacturing can improve social responsibility, alongside the economic contribution.

This thesis is composed by four sections: (1) an introduction with a review of the literature on the main topics, (2) a description of the variables and the database created and (3) a section describing the results of analysis, identifying the actual uses of blockchain to support the Circular Economy in Manufacturing. To conclude the analysis of the results, a qualitative overview of the impact of the projects according to their economic contribution, environmental performance and social responsibility has been provided. (4) We conclude this work with recommendations for future research in this field.

Keywords: Circular economy; Circular Manufacturing; Blockchain; Sustainability; Blockchain Application; ReSOLVE

Abstract (Italian version)

L'importanza riconosciuta all'Economia Circolare – un termine generico per definire un'economia pensata per potersi rigenerare da sola – nell'innovare l'industria Manifatturiera rappresenta un passo fondamentale verso il raggiungimento degli Obiettivi di Sviluppo Sostenibile, (SDGs) sottoscritti dalle Nazioni Unite.

La tecnologia Blockchain è un protocollo innovativo, progettato per garantire la condivisione e la memorizzazione dei dati in modo trasparente, sicuro e irreversibile, in grado di supportare le aziende manufatturiere nella cosiddetta "Transazione Verde" durante la Quarta Rivoluzione Industriale (Industria 4.0).

Il tema della tesi presentata rientra in un nascente filone di ricerca, collocato nell'intersezione dei due macro-trend: sostenibilità e innovazione digitale.

Durante la revisione della letteratura, l'argomento più studiato a livello teorico sono i benefici della blockchain sia nell'ambito dell'economia circolare sia nell'ambito industriale.
Nell'intersezione fra questi argomenti, invece, sono stati condotti meno studi empirici.

L'obiettivo di questa tesi è indagare il vuoto nella letteratura attuale, evidenziando il contributo – attuale e potenziale – della blockchain applicata all'industria circolare.

L'analisi è composta da una fase di raccolta di progetti ed iniziative e da una successiva classificazione attraverso uno schema di variabili, volto a descrivere sia l'aspetto sostenibile (Circular Manufacturing) sia quello digitale (Blockchain).
Per classificare i progetti è stato creato uno schema di variabili, in grado di evidenziare il sottosettore, le strategie circolari adottato e per quali proprietà la Blockchain è stata sfruttata.

Partendo dal campione scelto, le principali considerazioni sono tratte progetti in diversi settori, in cui la blockchain è utilizzata per implementare l'economia circolare lungo tutta la filiera produttiva. La blockchain è in grado di registrare e trasmettere le informazioni in modo trasparente creando un ecosistema affidabile, senza la necessità di intermediari. In questo ambiente, la blockchain può garantire l'approvvigionamento di risorse rinnovabili e supportare un sistema di riciclaggio più responsabile.

Il clamore e i potenziali benefici associati alla tecnologia blockchain forniscono una valida motivazione per cercare applicazioni future. Per concludere il lavoro vengono suggerite due riflessioni: in che misura la blockchain possa portare benefici all'industria manifatturiera, massimizzando l'utilizzo e la vita del prodotto, e in quale modo la blockchain possa migliorare la responsabilità sociale delle aziende manufatturiere secondo una prospettiva circolare.

Questa tesi è composta da quattro sezioni: (1) revisione della letteratura per fornire una definizione comune riguardo agli argomenti trattati, (2) una descrizione delle variabili e del database collezionato e (3) una sezione dedicata alla descrizione dei risultati, per identificare come la blockchain supporti effettivamente il Circular Manufacturing. A conclusione dell'analisi, viene fornita una panoramica a livello qualitativo dell'impatto dei progetti, valutando il loro contributo economico, le prestazioni ambientali e l'impegno sociale. (4) L'ultima sezione comprende dei suggerimenti riguardo a future possibili direzioni di ricerca.

Parole chiave: Economia Circolare; Circular Manufacturing; Blockchain; Sostenibilità; Applicazioni Blockchain; ReSOLVE

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Executive Summary

In the last decade Circular Economy (CE) has been receiving a growing attention worldwide, as a way to overcome unsustainable production and consumption patterns, especially in the Manufacturing industry.

Circular economy represents “an industrial economy that is restorative and regenerative by intention and design”, and in the context of Manufacturing it relies on various strategies as recycling, reusing, reducing and remanufacturing to extend products lifecycle and eliminate wastes. It is associated with the concept of Growth Within, which aims at decoupling economic growth from environmental pressure.

The increased attention towards Circular Economy is rooted in the strong interest for climate change, linked with UN Sustainable Development Goals, and in the understanding of technologies as enablers of more circular business models.

To realize the potential of Circular Economy, some barriers must be overcome, as quality issues related to materials used, lack of information and need of protocols, as well as coordination among companies. Blockchain technology can provide tools and characteristics to solve some critical issues.

Blockchain is an emergent technology, often discussed within the framework of Industry 4.0, characterized by decentralization, immutability and openness. A wide number of Blockchain applications and platforms are becoming known, along with the emerging interest of its benefits to sustainability.

Around the world, an increasing number of studies and initiatives are conducted to understand the potential applications and the benefits achievable: this trend is confirmed by the nascent literature on the subject and the new funding opportunities.

The objective of this work is to analyse the state of the art of the research at the intersection between Circular Economy, Manufacturing and Blockchain and then to investigate the current adoption of blockchain-enabled initiatives for Circular Manufacturing.

Literature Review

This thesis begins with a review of the literature, conducted on Scopus, to explore the state of the art of research on Circular Economy and Blockchain, their interplay and their application in the Manufacturing industry.
After the description of the methodology adopted to identify, collect the papers and once the overview picture has been drawn, it has been outlined what is missing from the literature.

Circular Manufacturing (CM) can be defined as “the concurrent adoption of different CM strategies, which enable to reduce resources consumption, to extend resources lifecycles and to close the resources loops, by relying on manufacturers’ internal and external activities that are shaped in order to meet stakeholders’ needs”. (Acerbi and Taisch, 2020)

Blockchain, instead, can be defined as a secured decentralized transaction and data management technology. While most of research projects are still focused on the technology itself and applications in the finance industry, the interest to exploit blockchain in the manufacturing industry is increasing.

Research question and Research methodology

Despite the growing literature on the subjects, empirical studies and use cases analysis are limited, as well as a consistent review and summary of the full potential of Blockchain technologies once applied to Circular Manufacturing.

From this gap found, the research question is presented:

(RQ) *How can blockchain attributes enhance the sustainable performance of circular manufacturing?*

To answer the research question, it has been elaborated a census of real projects and initiatives, collected from different sources among which: Forbes, CORDIS, EU Blockchain, as well as some sites on blockchain, as CoinMarketCap and Blockchain4Innovation.

All projects respect three main criteria: direct or indirect implementation of one or more Circular Strategies within the Manufacturing sector, made possible or improved by adoption of Blockchain.

Fifty-five projects were collected. The projects were thus analysed according to the set of variables summarized below.

The General Section provides an overview of each project, defining Project name, born year, subsector to which the project belongs and website.

The Development Section includes variables as Developing stage, to describe the level of maturity of the projects, Developing companies, aimed at describing not only the entities involved, but also the relations between actors, or the Implementation scale of the circular strategies.
This section defines also which innovation is introduced within the projects thanks to blockchain.

The Scope Section investigates on the value proposition of the projects, according to different circular frameworks, as the 9Rs’, ReSOLVE framework or Circular Economy pillars.

The Technology details Section explores Blockchain and its uses.
In this section, the most significant variable is the Uses of Blockchain, which indicates the features of blockchain for which this technology has been adopted. For each project, it is possible to select one or more benefits of the blockchain among the following: Transparency; Openness; Authentication; Digital currencies and Smart contracts.

The Impact Section has been defined to evaluate the environmental contribution, the environmental performance and the social responsibility of each project.

Results and discussion

Descriptive analysis

To begin the analysis, an overview of the projects is provided, in terms of Born Year and Subsector of Manufacturing, while a brief description of the projects can be found in the Annex.
The results confirmed a growing diffusion of initiatives towards the integration of Blockchain within the Circular Manufacturing world. In the last two years, it seems that the growth is slowing down, but it is reasonable to think that some projects postponed their launch due to the current Covid-19 pandemic.

Projects were classified according to the manufacturing Subsector in which they operate. Three main subsectors are the most active: Food production (18,2%), Petroleum, chemicals and plastics (16,4%) and Clothing and Textiles (14,5%). Overall, the most significant portion of projects is within the category "General" (20%) that was defined to include those projects in which the company, usually a technology provider, implements circular approaches in more than one manufacturing subsector. (Chart I)
Even though more modestly, a trend in this direction can be highlighted also in the Metal manufacturing industry.

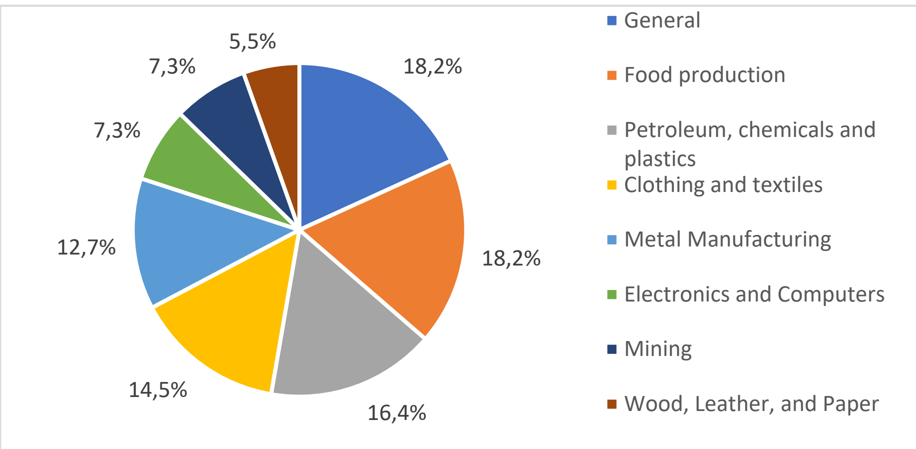

Chart I – Manufacturing Subsectors

Regarding the development aspects of the projects, the first element considered is related to the stage of the projects, being mainly Operative (43,6%) or Pilot (43,6%).

Projects based on blockchain tend to involve different actors: in 50,9% of the cases their partnership is based on the supply chain. The actors create a network of industries, interacting as producers or suppliers and client. (Chart II)

When discussing about Circular Manufacturing, it is useful to describe at which level the strategies are adopted. In the context of this study, the vast majority of projects implement their strategies to reduce resources consumption, to extend resources lifecycle or to close the loop at Meso level. (Chart III) Under this category fell projects adopting reverse logistics and closing-the-loop strategies to reduce wastes and give more valuable life to end-of-life or after-use products and materials.

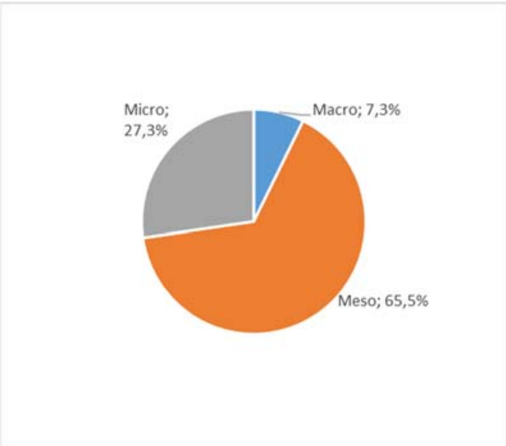

Chart III – Implementation scale

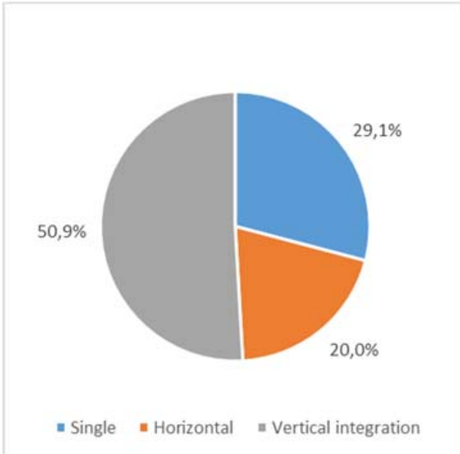

Chart II – Connection between parties

The sample of projects was analysed deeper to understand in which processes Blockchain technology has been able to introduce an innovation or an innovative approach. As confirmed by the literature, the main innovation developed is within the way “Tracking and management of the supply chain” are performed. The reason behind this is the unprecedent collaboration across multiple stakeholders required and the fact that blockchain has the potential to build those trust and transparency within the supply chain.

With this consideration, it was investigated how the projects analysed achieved to comply to Circular Economy paradigm. To do this, different circular economy frameworks were applied, such as the 9Rs, the ReSOLVE framework and the three Circular Economy pillars.

To start the discussion, it was important to define whether the company or the organization launched the project with the explicating willingness to solve a solution related to sustainability or the innovation apported by the project had collateral beneficial effects: from the sample, 56,4% of projects are directly implementing circular approaches.(Chart IV) This information was further analysed, according to the born year of the project, and it was interesting to notice how this percentage followed a positive trend.

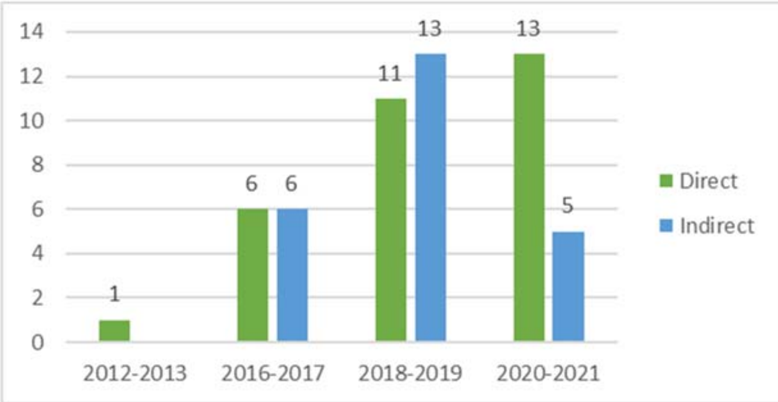

Chart IV – Born Year and Intentionality

The section dedicated to Technology details defines that among different Uses of blockchain, the most exploited in the sample are Transparency and Authentication. With the variable "Uses of Blockchain", it was defined the features of the technology for which blockchain is adopted in the project.

45 out of 55 projects analysed exploit blockchain to share data and information in a transparent way, to foster trust among the ecosystems. Authentication instead is used by 37 projects to tokenize natural resources and sometimes used combined with digital currencies to incentivise greener consumers behaviours. (Chart V)

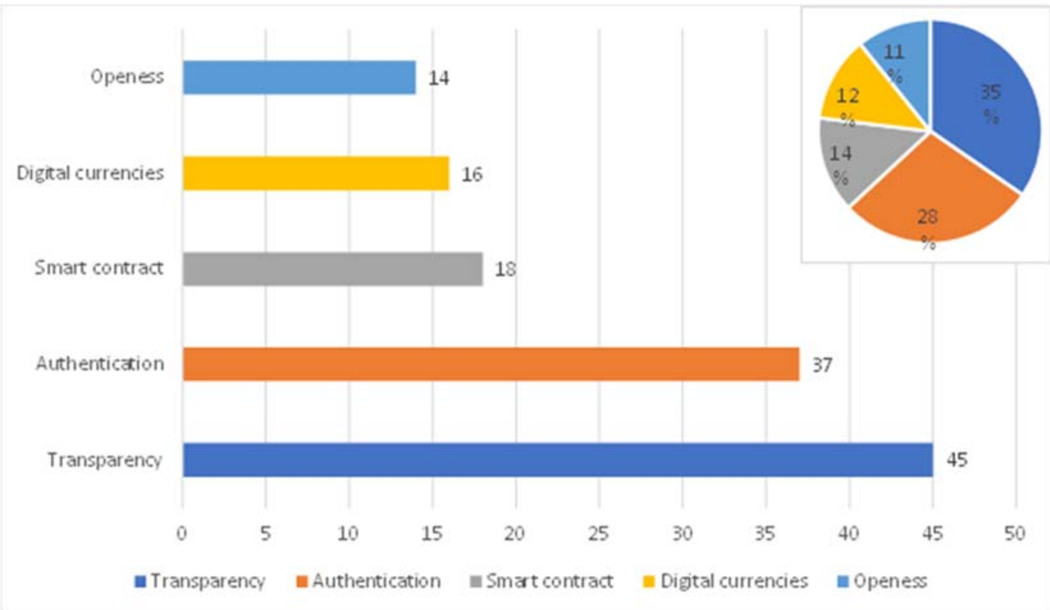

Chart V – Uses of Blockchain

Analysis of variables intersection

The scope of this thesis is within the intersection between Circular Economy, Blockchain and Manufacturing, thus, to support the definition of the projects profile, the variables have been analysed in combination.

Combining the subsector with the ReSOLVE model, it is relevant to notice how for "General" projects, Optimize is the most adopted strategy, while for "Food Production" and "Petroleum, Chemicals and Plastic", other strategies also are implemented, impacting more the way in which materials are extracted or how end-of-life products are treated.

When the focus is on Blockchain, despite the subsector selected, Transparency is the predominant features to adopt this technology, followed by Authentication: those attributes allow for real-time information visibility from a trusted source of data, which appear fundamental characteristics in guaranteeing trust and best practises along the supply chain.

Once fixed the variable of Manufacturing, diffusion of the projects is analysed according to Uses of Blockchain and Circular Economy Pillars.

As can be appreciated from the Chart reported below (Chart VI), the concentration of projects is higher upstream of the supply chain and downstream: projects claim to use blockchain technology to trace origins of raw materials and production practises, such as use of renewable energy or technologies preserving nature.
To achieve these objectives, Transparency and Authentication foster positive consumption and incentivize manufacturers to more responsible procurement of resources.
In the end-of-life phase, consumers must be involved to achieve better recycling results: authentication as well as digital currencies are used within circular projects as a way to incentivise greener behaviour.

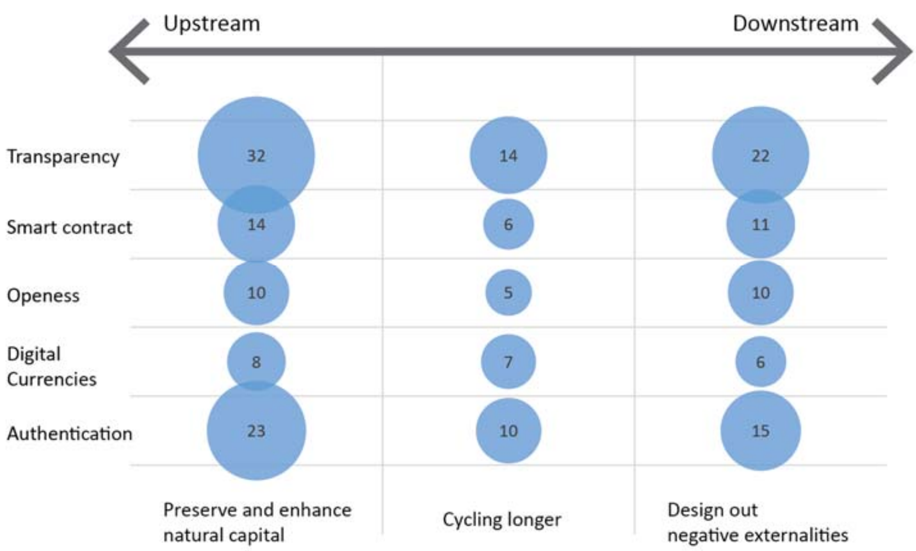

Chart VI – Uses of Blockchain and ReSOLVE framework

To conclude the classification of the projects, the research provides an overview of environmental, economic and social impacts. Considering the aggregated dimensions, it emerges that blockchain is more effective in economic and environmental sustainability rather that social sustainability.
The economic contribution of blockchain, similarly to other technologies, is discussed and is confirmed to be a strong driver for motivation of all actors involved: quality standards and performances are guaranteed by traceability, as well as financial performances and reliability are optimized by transparency and usage of smart contracts for disintermediation.
About environmental sustainability, blockchain is fundamental to avoid greenwashing activities: all transactions are immutable and data are accessible and transparent. Those characteristics have potential in eliminating unsustainable practises, improving inventory management and reducing wastes as well as polluting materials or activities.
While the use of blockchain within supply chain can promote ethical behaviour and better working conditions, as fair payment for producers and healthier environment, projects within the sample considered lack in explain how social issues are tackled.

Conclusions

Among the other digital technologies, research on blockchain is developing rapidly in different fields. Even though it is just a nascent trend, it is relevant to understand whether and to which extent blockchain implementation in Circular Manufacturing industry is able to enhance environmental sustainability and social responsibility, alongside the economic growth.

From the results it is possible to understand that most of the projects implement blockchain within the supply chain to foster circular practices. In this respect, blockchain can innovate the way in which tracking, and management of supply chain is performed. The main benefits are related to the possibility to record information transparently enabling a trustworthy environment, without the need of intermediaries.

The study shows that additional benefits and potential application are researched, in terms of both increasing literature materials and funding initiatives: these enter in the call for action of the UN Agenda 2030 for Sustainable Development.

While climate changes and socio-economic conditions have been strong drivers for transitioning from a linear to the circular economy, barriers towards Blockchain are still various: the main to mention are the lack of awareness, institutional barriers and shortage of experts. In fact, in order to implement blockchain and new technologies enhancing circular manufacturing systems, new skills and competences are needed.

The contribution of the presented work supports the creation of a bridge between Circular Economy and Blockchain, in the Manufacturing industry, through exploring the current discussion of academics about the subjects and building common understanding.

In terms of practical contribution, the analysis of the projects contributed to the research, allowing to explore the current successful application; moreover, this thesis created a framework, to further investigate projects in the future.

Given the limited size of the sample under analysis, the results cannot represent a complete overview of opportunities and challenges existing.
The hype and potential benefits associated with blockchain technology provide substantial motivation to identify future applications. More critical examination is needed

To conclude the work two main future directions of research are suggested. The state of the art shows how blockchain-enabled projects work on the sourcing of renewable materials and on a more responsible collection and disposal of end-of-use products: from this, it emerged the possibility to investigate on how blockchain can bring benefits to Circular Manufacturing, maximising product use and the whole usage phase (remanufacturing, refurbish, reuse..)
While investigating the Blind Spot from (Böckel, Nuzum and Weissbrod, 2021), related to lack of implications of blockchain applications in the circular economy regarding sustainability, the results highlighted how the nature of Circular Economy puts more emphasis on the environmental improvements and with blockchain it is possible to manage and guarantee also the economic growth. Under this perspective, it could be interesting to study whether blockchain applied to circular manufacturing can improve social responsibility.

1 Introduction

Today's economy is surprisingly wasteful in its model of value creation and - for all practical purposes – continues to rely on the take-make-dispose pattern.
The limited availability of resources present on our planet is drastically increasing and primary materials consumption is expected to double, reaching 167 gigatons in 2060 (New Circular economy Action Plan, 2021).
Among many actions taken, in order to promote a more sustainable development, United Nations developed 17 sustainable development goals that are urgent actions to be undertaken by all countries (United Nations, 2019). In particular, the 12th, "responsible production and consumption", refers to the need to identify new and sustainable strategies to run systems. This impacts not only on consumers' behaviours but also on industrial actors among which manufacturers, considering that the manufacturing sector is one of the most polluting and resource greedy sectors (Acerbi and Taisch, 2020).

The manufacturing industry can and has to address these challenges by improving resource efficiency through the integration of approaches that ensure that natural resources are saved, by-products are reused, waste is prevented, harmful substances are not used, and the wellbeing of humans in the value creation process is secured (Halstenberg, Lindow and Stark, 2017).

To pursue this objective, one of the most promising sustainable paradigms identified is the Circular Economy (CE), as "an industrial economy that is restorative and regenerative by intention and design" (Ellen MacArthur Foundation, 2013), and it relies on three principles: (i) preserve and enhance natural capital, (ii) optimize resource yields and (iii) foster systems effectiveness (Ellen MacArthur Foundation, 2015).

While companies and policymakers globally are increasingly placing more importance on environmental sustainability and building competitive circular economies as a response to the ongoing climate crisis, unsustainable consumption of goods, and worldwide resource depletion, another important transformation is taking place: the digital transformation.

The importance of the subject is confirmed by it being the subject of the "2021 World Manufacturing Report", a dynamic platform, bringing together stakeholders confronted with the evolving paradigms of manufacturing.

In the Report "DIGITALLY ENABLED CIRCULAR MANUFACTURING" (World Manufacturing Forum, 2021), it is outlined, how digital technologies can support the transition to circular manufacturing at the firm level - which includes product development, production, and new business models - as well as at the network level.

According to a recent Gartner survey (World Manufacturing Forum, 2021), there are some key technologies that advance circular economy activities in manufacturing: advanced analytics, 3D printing, IoT and machine learning are already quite diffused. Blockchain is used by few organisations, but many are planning to explore the use of it in the next future.

Blockchain a distributed database (ledger) that is shared among the nodes of a computer network. As a database, a blockchain stores information electronically in digital format. More than the definition itself, the characteristics of the blockchain and the benefits they could bring to Circular manufacturing are relevant: transparency, traceability and trust.

Blockchain's design supports two main uses for the Circular Economy: proving product origins and incentivising positive behavioural change. Blockchain has the potential to tokenise natural resources by giving them a unique digital identity, and this makes the value of resources more apparent, facilitating a new system of pricing and trading natural resources, and incentivising people to adopt circular behaviours.

The objective of the thesis presented is to investigate the state of the art and examine blockchain current and potential contribution to the circular manufacturing, with a focus on sustainability.

This objective has been tackled in two main steps:

- A literature review describing first circular economy and its manufacturing strategies, then the blockchain technologies and its application to circular manufacturing
- An analysis of existing projects and use cases on the topic.

Accordingly, the thesis is structured as follows: (2) literature review with methodology in which the review process is described and results in term of descriptive analysis and content; (3) description of the research question and the research methodology, with a detail on the framework created; (4) results of the research and discussion of the result from the analysis of projects; (5) conclusions, including contributions of the thesis, its limitations and suggestions for future research.

2 Literature Review

The aim of this first chapter is to review the existing literature on the main topics of our research: the circular economy, the blockchain, their interplay and applications in manufacturing.

The chapter is composed by two sections: the first one describes the method adopted to perform the literature review, while the second and main part reports the results of such review.

Specifically, the descriptive analysis is intended to highlight the relevance and evolution of the different research streams, while the following subsections provide an explanation of the main themes and concepts found in the literature.

2.1 Method

In the following sub-sections, the entire process, which is based on the approach proposed by (Sucharew and Macaluso, 2019) is explained. The main steps undertaken are:

1) Identification of the research question
2) Identification of relevant studies
3) Study selection
4) Chart the data
5) Collate, summarize and report the results

2.1.1 Identification of the research question

In the context of this research, considering the novelty around both the term of Circular Economy and Blockchain, the goal of the literature review was to provide a common definition of Circular economy and Blockchain. Furthermore, the literature review was used as a starting point to understand the interplay between blockchain and circular economy as well as the potential implementation of blockchain as support of the different circular strategies in the manufacturing industry. Finally, it allowed to identify current research gaps.

2.1.2 Identification of relevant studies

Circular economy is a broad term, usually shortened with "CE" or referred to as one of the strategies it includes. When the circular economy or one of its strategies is applied to a manufacturing process or project, it is often referred to Circular Manufacturing.

Blockchain, instead, is often interchanged with the term "distributed ledger" or included in the broader concept of "Industry 4.0".
For this reason, in a first phase synonyms and associated words for the two subjects were found. Those are listed below (Table 1)

CIRCULAR ECONOMY	**BLOCKCHAIN**
Circular Economy	Blockchain
CE	Distributed ledger
Sustainable Development	Industry 4.0
Sustainability	Tokenization
Circular Manufacturing	Decentralisation
Closed Loop	Decentralised application (D apps)
All strategies of CE: reduce, reuse, repair, remanufacture, recycle, ReSOLVE	

Table 1 – Keywords definition

Below there are reported the structure of the queries performed in Scopus. Keywords were searched in "keywords, abstract and title":

- TITLE-ABS-KEY ("circular economy")
- TITLE-ABS-KEY ("blockchain")
- TITLE-ABS-KEY ("circular manufacturing")
- TITLE-ABS-KEY (blockchain AND manufacturing)
- TITLE-ABS-KEY (blockchain AND "circular economy")
- TITLE-ABS-KEY (blockchain AND "circular economy" AND manufacturing)

Other queries have been searched, using the synonyms as in Table 1 above, but for simplicity they have not been reported.

During the definition of the queries, there were included the limitations to articles written in English and publication year between 2014 and September 2021. As for example:

TITLE-ABS-KEY ("blockchain") AND PUBYEAR>2013 AND (LIMIT-TO (LANGUAGE, "English"))

Not scientific papers have been added to the final pool of papers: the so called "grey Literature". This term includes reports (annual, research, technical, project, and so on), working papers, government documents, white papers and evaluations.
The grey literature selected to support the drafting of the literature review complies with the criteria used for scientific papers, but it is not included in the analysis below.

2.1.3 Study selection

The selection of the eligible papers has followed a screening process as in Figure 1.

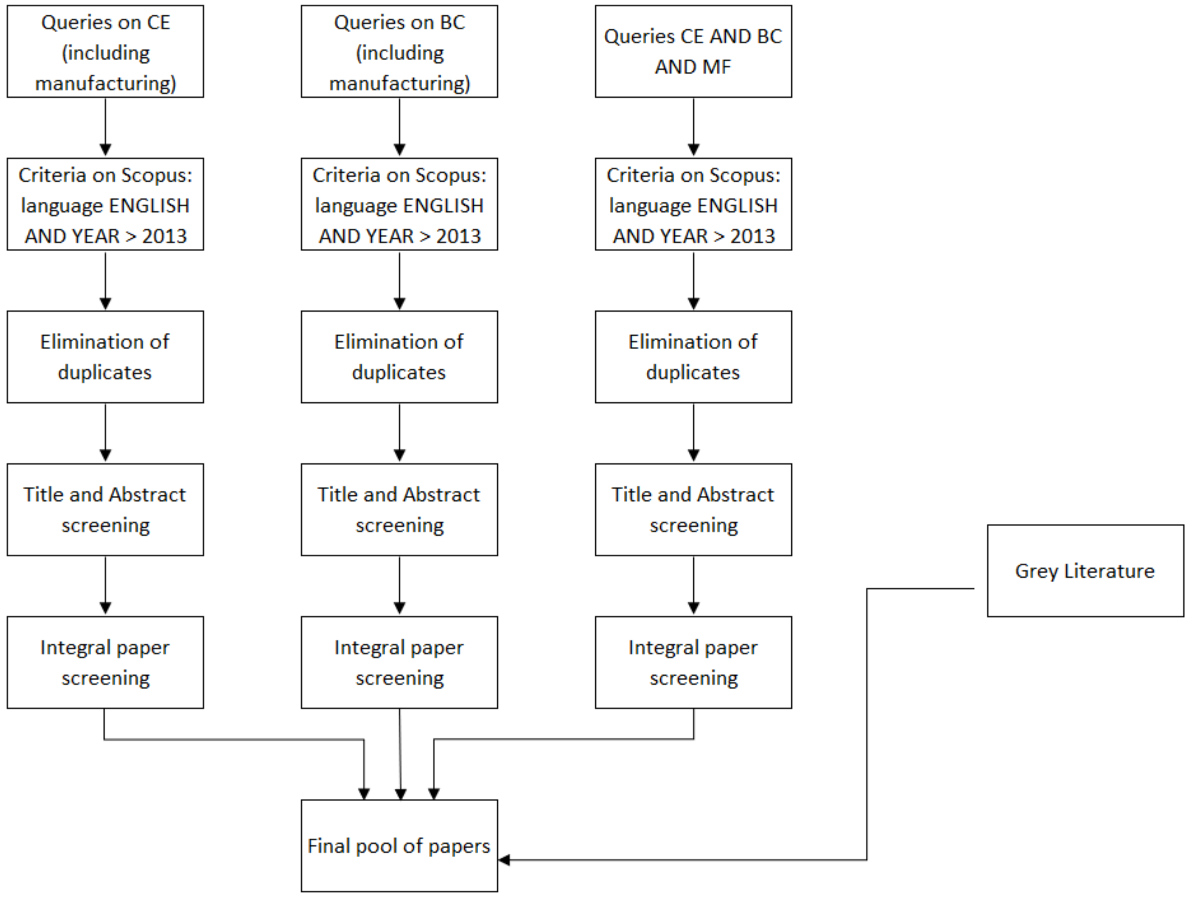

Figure 1 – Screening process

Given the choice of the keywords, it was necessary to perform a step of elimination of the duplicates and then last screening was performed by first reading the title and the abstract, and second by reading the entire document.

2.1.4 Chart of the data

Subsequently to the collection of the papers, the first part of the analysis consisted in the extraction of some standard information, repetitively found in reviews, (Acerbi and Taisch, 2020). Articles were organised in a spreadsheet including the following information:

- Title
- Author(s)
- Source (i.e., journal name)
- Publication year (i.e., year in which the contribution was published)
- Type of study (i.e., literature review, theoretical framework, empirical case study...)
- Number of citations
- Pertinence to the topic (to identify whether the paper was related to circular economy, blockchain or both)

Moreover, a thematic analysis was carried out in order to identify main concepts, recurring themes and research trends.

2.1.5 Collate, summarize, and report the results

The results are reported and summarized in terms of:

- descriptive analysis (census) and discussion
- main themes and theoretical contents.

2.2 Results of the literature review

In the following sub-sections, the results of the literature review are outlined. First the results of the descriptive analysis are reported in Paragraph 2.2.1. Then, the definitions and main theoretical contents related to the circular economy and blockchain technology research streams are illustrated as well as their interplay in the context of manufacturing.

2.2.1 Descriptive Analysis

The analysis aims at evaluating the state-of-the-art of research related to the subjects.

Circular Economy was the starting point: first the interest was on the evolution and then the research followed its digitalization trend. Current studies report how different technologies in the fourth industrial revolution support the green transaction, but the blockchain has the potential to integrate many technologies while supporting CE.

The first consideration regards the concentration of research developed during the years on each single subject: this show how actual and relevant the topic is and helps to delimitate the gap in the literature.

Chart 1 shows how the attention for both “blockchain” and “circular economy” is increasing over time: it has been obtained by searching only the main keywords (Circular economy, blockchain and circular economy & blockchain).
The research interest for “circular economy” has increased by 36% in the last year, reaching a total of 3965 scientific papers. On the other hand, the trend for “blockchain” shows a sign of slowing in the last two years.
At the intersection of Blockchain and Circular Economy, searched together, it was possible to find a much narrower space of discussion, but, as highlighted by Chart 1, the research is intensifying with a year over year growth of almost 100% for the last 2 years.

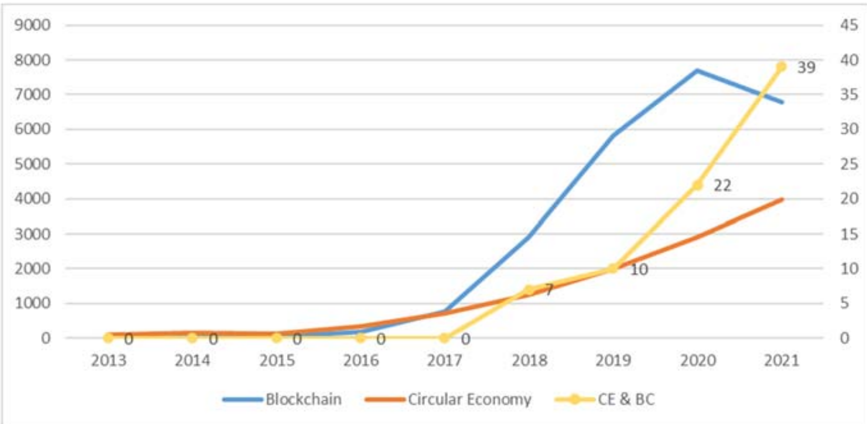

Chart 1 – Number of scientific papers per subject

The call for action of the United Nations Sustainable Development is involving all the countries and all the sectors: being the manufacturing sector among the most polluting ones, it must not be exempted. The second part of the review aims to understand how manufacturing field was interacting with both BC and CE.

Using the same criteria explained in the Paragraph 2.1.2, the word “manufacturing” has been added to the Scopus research.
Chart 2 shows how the research for “CE & Manufacturing” has more results compared to the one for “Blockchain & Manufacturing”: considering the increase in the papers on blockchain, this data shows that while the subject is studied and analysed deeply, its application within the manufacturing sectors still has to be explored.

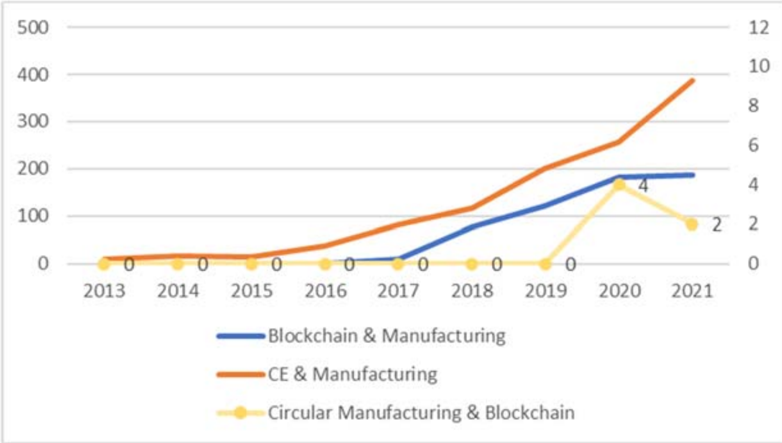

Chart 2 – Number of Scientific Papers

From that point, the research moved to the intersection of the three topics, where the literature is scarce and some interest appears only in the last two years.
For the purpose of this thesis, the identified gap enabled to begin deeper research: in the final phase, not only main keywords have been used but also their synonymous.

The results find confirmation in a study called "Blockchain: the hype is over, get ready for ecosystems" (A. Perego and D. Sciuto, 2021). The study underlines how the research around blockchain to discover "what is blockchain" and "what are the characteristics" is exploited enough and the technology is ready to be implemented. The study highlights that the research can now focus on "how to apply blockchain". A similar result is presented by (Gartner, 2021) in the following Figure 2 where it is highlighted how blockchain is reaching maturity.

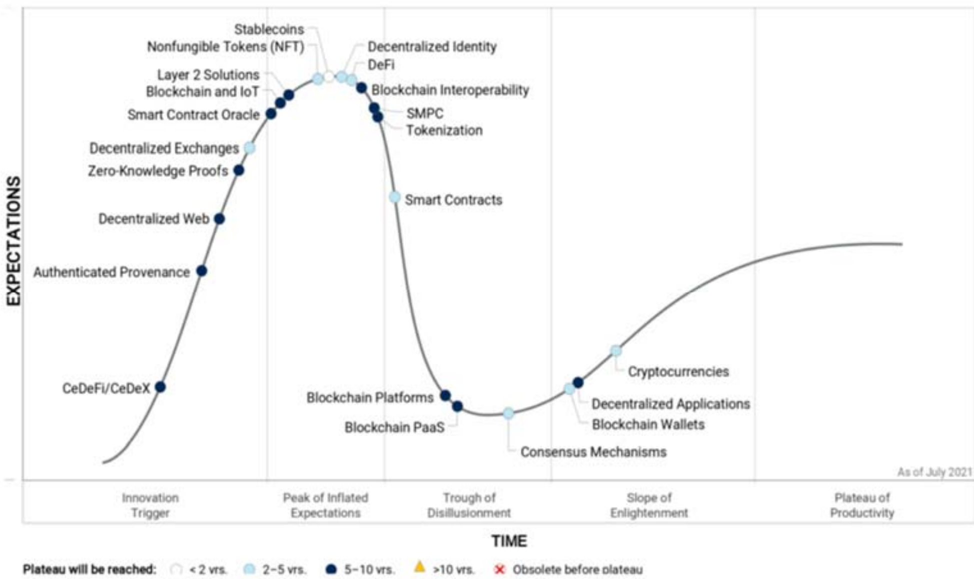

Figure 2 - Blockchain hype cycle 2021 - Source Gartner

The analysis that follows considered only the papers classified as eligible from the screening process: the total number of scientific papers collected after the selection is 103.
The considerations are presented are related to the demographics of the papers collected in terms of type of study, topic, citations and journal.

The literature intersection between the three subjects of research gained consistence after using all possible synonymous of the main keywords. To provide an example, the 36 papers, in Chart 3, in the intersection between manufacturing and circular economy is due to queries combining "manufacturing" with different the circular strategies (Recycling, Remanufacturing, Rethink etc.).

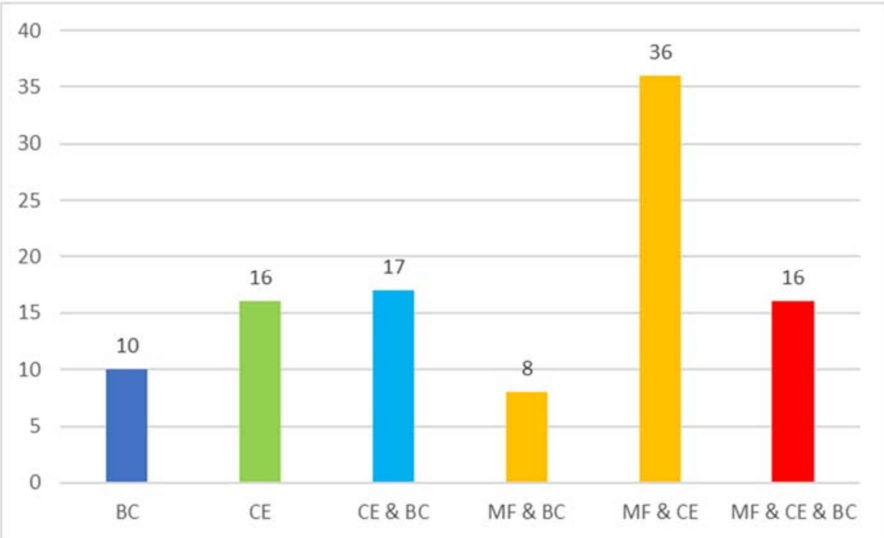

Chart 3 – Number of Papers in the Final Pool

Another important parameter to classify the documents is the type of study: the Chart 4 aims at representing a classification of the type of study according to their topic.
The categories created are five:

1. *Theoretical framework creation*: it aims to create a framework to support future studies, providing an organized and defined set of parameters to classify either variables, examples or results.
2. *Statistical analysis*: papers collecting, exploring and presenting large amounts of data to discover underlying patterns and trends.
3. *Literature review*: usually it synthesises and presents literature and information gathered in an organized way
4. *Empirical study*: under this category, we collected papers with real or use case studies and example, trying to draw conclusion from concrete evidence
5. *Literature review and empirical study*: this type of study includes those papers in which after a detailed review of the existing literature tried to provide an exhausting overview of real case studies related to the subject.

It is possible to identify a lower number of (1) frameworks compared to the number of (3) literature review and empirical studies used. This is justifiable by the idea that while writing a literature review, existing literature review (and in many cases, systematic ones) were more useful and comprehensive.
The research on the application of Blockchain to Circular Manufacturing is still low; only some papers on case studies and real case examples have been found.

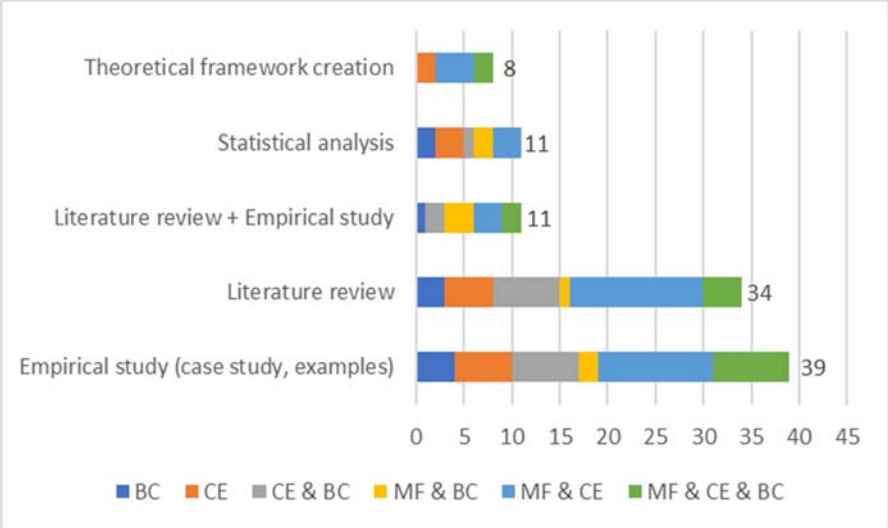

Chart 4 – Type of study

Being Scopus a wide database from different sources and authors, there were many sources involved.
The most relevant journals are reported below and other journals used for the dissertation of these topics are reported in Chart 5:

- Sustainability is an international, cross-disciplinary, scholarly, peer-reviewed and open access journal of environmental, cultural, economic, and social sustainability of human beings. It is published online by MDPI.
- Journal of Cleaner Production is international, transdisciplinary journal focusing on Cleaner Production, Environmental, and Sustainability. It is an academic peer-reviewed journal

93 out of 103 papers were journal articles, while others were extracted from Conferences and books.

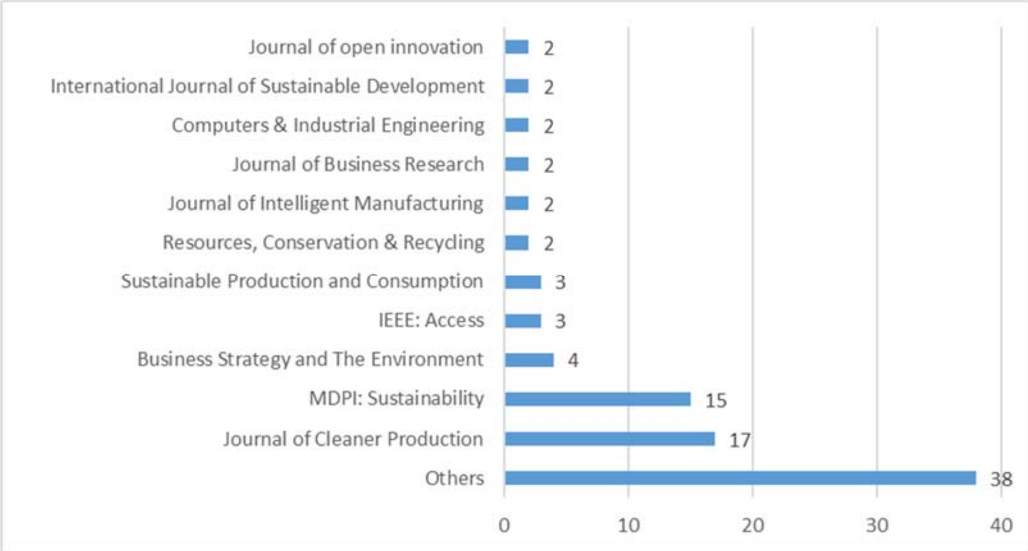

Chart 5 – Sources of selected papers

The last dimension considered is the number of citations and the year of publication of the selected literature. The average number of citations per paper has been reported on the Chart 6, but while it was useful for understanding the relevance and the success encountered by the different papers, no consideration can be provided according to the overall number. About the year of the documents collected, it is relevant the increasing number of papers selected in recent years where the intersections between Manufacturing & CE and Manufacturing & Blockchain are attracting research attention.

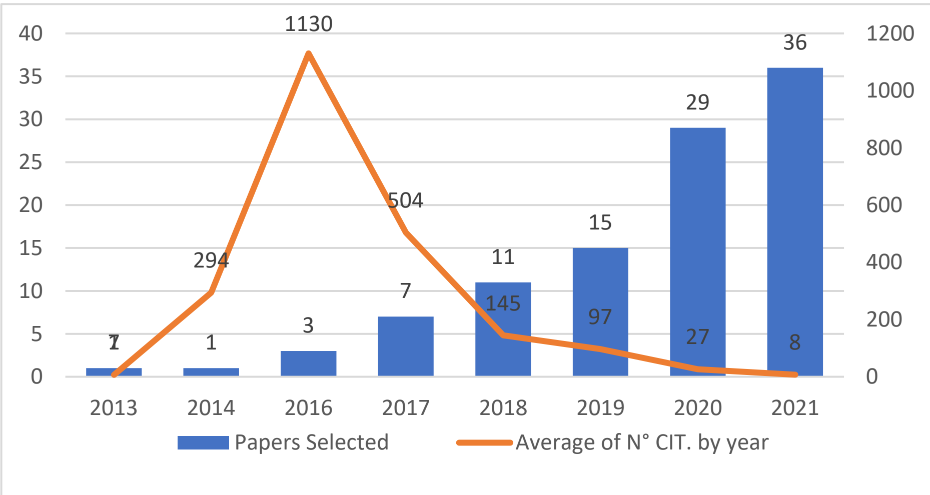

Chart 6 – Average number of citations

The following sections summarize the main findings on the subjects:

(0) Circular economy and its implication in Manufacturing;

(2.2.3) Blockchain and its application in Manufacturing; and

(2.2.4) Blockchain as an enabler of Circular Economy.

2.2.2 Circular Economy

The concept of the circular economy originates in the inability of linear production models to reconcile current levels of production and consumption with the limited availability of resources (Bradley et al., 2018).

Several definition and frameworks have been developed to explain the circular economy and to assist organizations in the implementation of circular products and processes. For this research, it has been selected the definition of Ellen MacArthur Foundation and its framework: ReSOLVE.

Circular economy is defined as “an industrial economy that is restorative and regenerative by intention and design". It is a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing the material and energy loops. The focus is on retaining as much value as possible of products, parts and materials. This can be done creating a system that allows for the long life, optimal reuse, refurbishment, remanufacturing and recycling of products and materials.

The roots of this concepts date back to the 70s from different schools of thought: (Ellen MacArthur Foundation, 2013)

Regenerative design: thought by John T. Lyle as a way in which society would limit the resources usage to the available renewable resources, in order to establish processes able to renew or regenerate the sources consumed.

Cradle to cradle: Micheal Braugart and Bill McDonough developed this philosophy with consists in designing product components to enable their continuous recovery and reutilization. This design is used also as a assessment of Life Cycle, where the materials re-introduced into the cycle are counted.

Performance economy: Walter Stahel (1970s) developed some sustainable strategies to sell performance rather than goods. In order to do so, he promoted product-life cycle extension, long-life goods, reconditioning activities and waste prevention.

Industrial ecology: this is at the basis of designing closed-loop processes, in which waste of one industrial activity serves as input for another.

Biomimicry: Janine Benyus designed an approach with the aim of replicating and imitating the nature, to solve human problems.

In the last decades though, the urgency for a more sustainable development put the circular economy and its framework in highlight.

Circular economy is based on five main principles: (1) Design out waste, (2) Build resilience through diversity, (3) Rely on energy from renewable sources, (4) Think in 'systems' and (5) Waste is food. (Ellen MacArthur Foundation, 2013)
The circular economy practises are moreover strongly linked to the UN Sustainable Development Goals, enabling a reduction of structural waste and of the demand for virgin material and avoiding, or at least reducing, pollutions and resource extraction. (Kristoffersen et al., 2020a).
The UN Sustainable Development Goals are the heart of the "2030 Agenda for Sustainable Development": it is an urgent call for action by all countries, related to many thematic issues, including water, energy, climate, oceans, urbanization, transport, science, and technology.

Below, the Butterfly Diagram (Figure 3 - Ellen MacArthur Foundation, 2015), a powerful tool that helps us to understand the application of the Circular Economy model in practice: a holistic view of the main assumptions of the model, the proposed changes, and the several solutions that facilitate the transition.

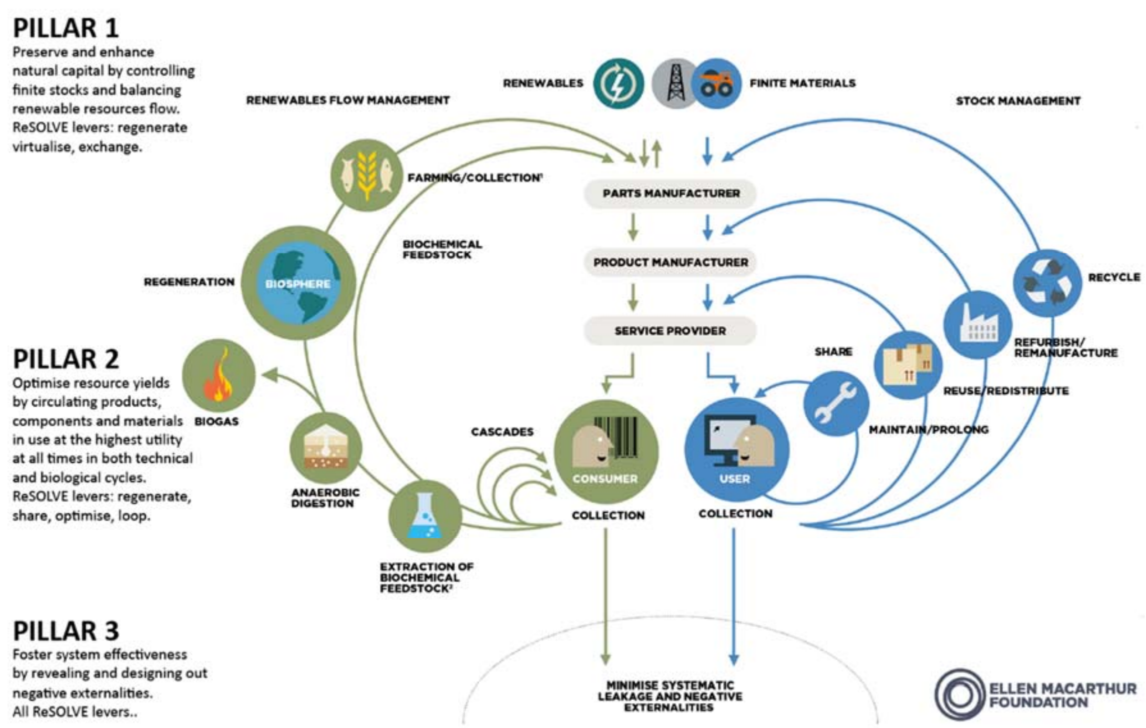

Figure 3 – Butterfly diagram, source Ellen Macarthur Foundation

The central part of the diagram represents the Linear Economy, in which the flow of materials and energy goes from extraction, through production to incineration or landfill. On the right and left of the diagram, the flows (feedback loops) typical of the Circular Economy are described. Within these, the materials, seen as nutrients, continuously circulate in the system. so as to minimize losses.

Circular economy is driven by three main pillars:

1. preserve and enhance natural capital, by controlling finite stocks and balancing renewable resource flows (focus on the design and rethinking of product and processes)
2. optimize resource yields, by circulating products, components, and materials in use at the highest utility at all times in both technical and biological cycles: green streams relate to biological nutrients such as food and natural materials. The blue ones describe the path of technical materials such as plastics and metals.
   Different paths correspond to different strategies, adoptable in a combined way. In both cycles, whenever possible, the alternatives closest to the user/consumer should be favoured, since the closer to the user these are, the smaller the resources, time, money, and people needed and the greater the integrity and quality of the materials are maintained and respected.
3. foster systems effectiveness by revealing and designing out negative externalities, such as water, air, soil, and noise pollution; climate change; toxins; congestion; and negative health effects related to resource use.

To adopt these three pillars, the Ellen MacArthur Foundation developed the ReSOLVE framework: regenerate, share, optimize, loop, virtualize and exchange. A brief description of these actions can be found below (Ellen MacArthur Foundation, 2015):

- Regenerate: A broad set of actions that maintain and enhance the Earth's bio capacity. This includes the transition from finite fossil fuels to renewable energy. It also includes land recovery and the restoration or protection of ecosystems.
- Share: Sharing efficiently exploits the use of goods. In this way, ownership is not necessary in order to enjoy a product's value. Car-sharing schemes, tool renting, and web sharing platforms are all examples of sharing practices.
- Optimize: Improvements in the efficiency of resources, components and materials, in both technical and biological cycles. Additionally, tools derived from big data, automation and sensing are applied, in order to reduce waste without changing the product or technology. For example, preventive maintenance of equipment is supported by collecting and analysing temperature and vibration parameters.
- Loop: Aims to keep components and materials in closed loops. This means promoting remanufacturing and recycling, as well as reuse and composting (for organic material). The principle is to avoid landfilling or incineration as far as possible, and to promote the return of the waste to the economy, by exploiting its value internally or in another chain.

- Virtualize: The virtualization process aims to deliver value without the need to materialize it as a physical asset.
- Exchange: New technologies are adopted, improving the way society produces goods and services. Among the technologies that can support this circular model are new renewable materials and recycling methods, and more energy-efficient processes.

During the research, the focus has been on circular economy in Manufacturing.

Circular Manufacturing can be defined as "the concurrent adoption of different CM strategies, which enable to reduce resources consumption, to extend resources lifecycles and to close the resources loops, by relying on manufacturers' internal and external activities that are shaped in order to meet stakeholders' needs". (Acerbi and Taisch, 2020)

In a circular manufacturing industry, products and parts are not thrown away or recycled at low levels but, after inspection and processing, are reused at high quality. This means a drastic change in the current way of producing and selling: designs aimed at optimal durability, products that can adapt every time, so that they remain relevant to the user and, if there is no other option, recover the purest and most precious metals possible.

Circular manufacturing can be adopted at micro, meso and macro level: (Ghisellini, Cialani and Ulgiati, 2016)

- Micro level is referred to the application of CE to a product or a firm. Strategies for CE implementation at this level involve eco-design, cleaner production, consumers' responsibility, and waste management. The strategies are adopted internally to the company in terms of processes, design for or circular business model
- Meso level instead refers to the application of CE strategies within a network of firms, that interact and collaborate
- At Macro level, circular economy is considered in terms of definition of new regulations to be adopted by countries

Figure 4 – Circular Strategies

Source: I.S. Jawahirand Ryan Bradley; 2016

To provide an explanation of micro level, some examples are presented of circular economy measures implemented in the different phases of the production process.

- Circular design models: decisions made in the design phase of manufacturing strongly influence the use- and after use-phase of a product.

- Use and life extension models: shift of the business model from selling products to providing services under product-as-a-service contracts, facilitating repair, remanufacturing or resell.
- Value recovery models: suitable infrastructure to guarantee separate collection and sorting are needed to facilitate value recovery at end of life.
- Circular support models: Recent developments in Information and Communication Technologies (ICT) can contribute to the success of many circular manufacturing models. The use of QR-codes and the Internet of Things simplify digital material banks and support repair and recycling by providing insight into the material composition of products. In cities, the 'urban mine' concept is useful as it provides a good understanding of the material stocks and flows present in urban areas.

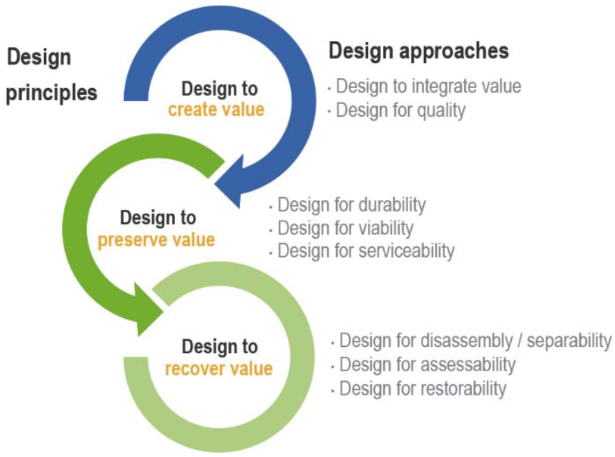

Figure 5 – Circular strategies at Micro Level

At meso level instead, the most common strategies are:

- Industrial symbiosis: This concept was born in 1947 to describe organic relationship among companies operating in different sectors/industries. Companies involved in industrial symbiosis are required to develop a collective approach to gain competitive advantages involving physical exchanges of materials, energy, water, and by-products. It aims to create an interconnected network to keep material valuable and reduce waste generation
- Close-loop supply chain: loop supply chain refers to all forward Logistics in the chain (like procurement of materials, production and distribution) as well as the Reverse Logistics to collect and process returned (used or unused) products and/or parts of products in order to ensure a socioeconomically and ecologically sustainable recovery The closed-loop supply chain management is the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time

- Reverse logistics: a broader perspective includes all issues relating to logistics activities carried out in source reduction, recycling, substitution, reuse of materials and disposal. It implies efficient product return management and activities for value recovery so that secondary materials can be used as input for ''new'' customer product

At macro level, it is possible to mention some program for sustainable development as the Green Deal, Zero waste program for Europe or The Agenda 2030. To provide an example, the European Green Deal provides an action plan, to boost the efficient use of resources by moving to a clean, circular economy and to restore biodiversity and cut pollution. One policy area is the "EU action plant for Circular Economy", with measures covering the full life cycle of products from production and consumption to waste management. (Switchtogreen, European Commission).

Although increasing numbers of companies have begun their journeys towards circularity, a more widespread implementation of circular business models is needed. To facilitate this process, it is important to identify key enablers and barriers.
As already mentioned, the pressure to reduce negative environmental impacts is main cause for accelerating the willingness to adopt CE.
From the economic perspective, Circular Economy can be described as a way to achieve growth within (MCKinsey and Ellen MacArthur Fundation, 2015): possibilities for new value creation, business growth and increase in margin and profits and finding synergy benefits. (Tura et al., 2019)
Despite the evidence of the need for action toward a circular system, economic barriers still exist including lack of financial capability (Ilic and Nicolic, 2016; Rizos et al., 2016), as well as high costs of new technologies (such as re-processing of metals)(Gumley, 2014). Other than the economic uncertainty in the long-term, the implementation of CE business is harmed by the complexity of laws and regulations (Gumley, 2014)
Going back to the drivers, in the following chapters, much attention is given to the technological aspect: new technologies not only provide cleaner solutions for the future, but also help in avoiding and overcoming problems caused by the current technologies (Ghisellini, Cialani and Ulgiati, 2016). Information sharing platforms support cooperation with many stakeholders and enable better information transparency, thus helping in the adoption of CE business models. (Ellen MacArthur Foundation, 2013)(Tura et al., 2019)

This subject has been analysed in depth in the (World Manufacturing Forum, 2021), "Digitally Enabled Circular Manufacturing", investigating the role of digital technologies to create competitive edges and boost competitiveness, and discussing other enablers for Circular Manufacturing which could be successfully integrated into business strategies.

Circular Economy and Digital Transition are two major developments transforming both the economy and the society. The last decade has experienced an increasing trend towards the adoption of digital technologies by big companies to increase their competitive advantage (Figure 6**Error! Reference source not found.**).

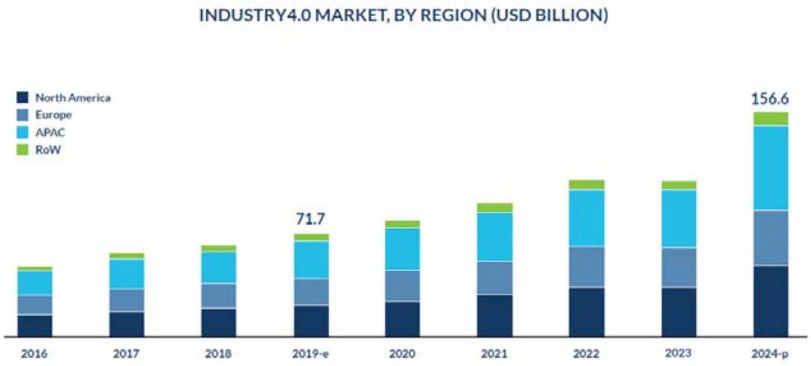

Figure 6 – Industry 4.0 Worldwide Diffusion (Source WMF Report 2021)

At the same time, small and medium enterprises (SMEs), traditionally more resource constrained, are exploring innovative ways of adopting new technologies, reimagining their processes, and addressing the sustainability challenge (Figure 7).

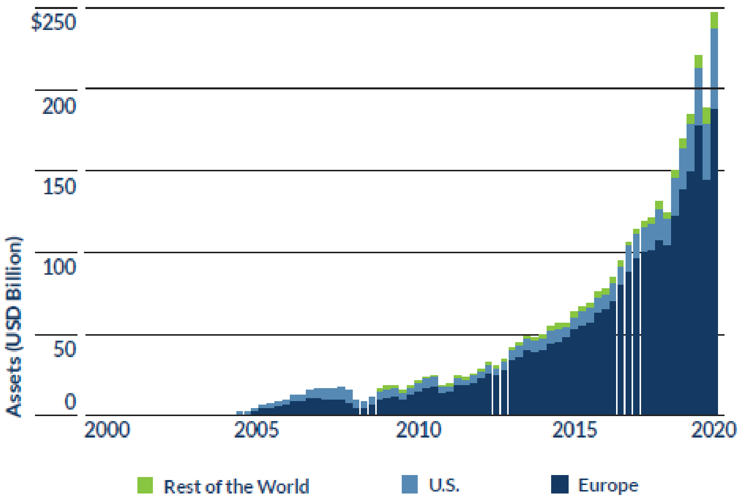

Figure 7 – Sustainability-oriented investments (Source WMF Report 2021)

Their alignment fosters higher level of sustainability and competitiveness. Indeed, managing them together can contribute to long-term sustainable economic, social and environmental prosperity. (European Policy Centre, 2019)
According to (New Circular economy Action Plan, 2021), digitization, if guided according to sustainability guidelines, can contribute positively towards circular economy by:

1. improving connections and information sharing
2. making products, processes, and services more circular
3. influencing and empowering citizens/consumers

Further discussion about use cases is proposed in the last subsection of the literature review.

2.2.3 Blockchain Technology

Since its introduction in 2008 in the form of Bitcoin cryptocurrency (from an unrevealed inventor called Satoshi Nakamoto, 2008) (Nakamoto, 2008), blockchain technology came into the spotlight as a secured decentralized transaction and data management technology. The invention finds a system that overcomes the double spending problem in the monetary system. (Nowadays it is overcome by centralizing the transaction to a unique entity that "certifies" the transactions from A to B and check for double spending occurrence.)

Blockchain technology pivots on technological features to create distributed digital ledgers that are self-authenticated using predefined consensus mechanisms among participating entities. BCT, although defined in a variety of ways, has four basic characteristics: decentralized consensus, information-sharing, incentivizing and negotiating mechanisms. (Nandi et al., 2021)

From now on a brief dive into blockchain is necessary to further understand the following chapters and the aim of this research.
In the next section the explanation of the blockchain technology follows the scheme reported below (Figure 8).

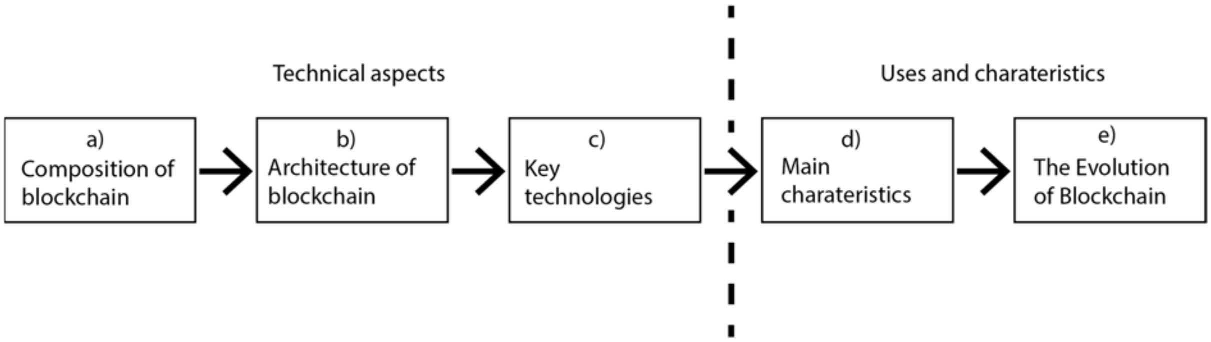

Figure 8 – Blockchain explanation scheme

Technical blockchain aspects

The next few paragraphs give and idea on how blockchain is from a technical point of view to understand the second part where the main characteristics of blockchain are explained.

a) Composition of Blockchain

Blockchain could be regarded as a public ledger and all transaction are stored in a list of blocks. Each block contains: a header and a body. The header contains all the information to recognize the parent block and the unique cryptographic solution of the previous block, so that it exists only one single block that can be placed after the current one. The link between the blocks is established by the only cryptographic solution of a problem arising from the previous block. This establishes a link between the blocks, thus creating a chain of blocks.

The block body part instead is where transactions are recorded. The transactions are validated by asymmetric cryptography through a system of digital signature with private and public keys.

b) Architecture of Blockchain

Blockchain is not a single technology. Rather, it is a family of technologies used to develop and maintain distributed ledgers (i.e., databases that are massively replicated on all the “nodes” or machines in the system). In contrast, traditional databases are centralized, meaning that there is only one master copy of the database at any given moment.

The technological architecture of the blockchain is structured in different layers.
It consists of the data layer, network layer, consensus layer, incentive layer, contract layer, and application layer.(Wu and Tran, 2018)

1) The data layer contains the underlying data blocks and timestamps and stores all of the transaction data and information records in blockchain form.
2) The network layer mainly includes peer-to-peer (P2P) network technology (also known as point-to-point transmission technology or peer-to-peer network technology), propagation mechanisms, and verification mechanisms. It is the layer that complete consensus algorithms, encrypted signatures and data storage.
3) The consensus layer mainly includes a consensus mechanism, which enables nodes to reach consensus on the effectiveness of block data efficiently in the decentralized system where decision power is highly decentralized.
4) The incentive layer integrates economic factors with blockchain technology, mainly including the issuance mechanism and distribution mechanism of economic incentives.
5) The contract layer where script codes, algorithmic mechanisms and smart contract, and establishes regulated and auditable contract specifications.
6) Application layer where users can interact with the blockchain, and applications built in top of it.

c) Key Technologies

Blockchain it is a comprehensive technical system that integrates various research results. It includes key technologies such as a consensus mechanism, encryption algorithms, the smart contract, and distributed data storage (Wu and Tran, 2018)

- Consensus mechanism: The consensus mechanism refers to the algorithms, protocols and rules that define the constants updating process of the distributed ledger. Common consensus mechanisms include proof of work (PoW). proof of stake (PoS). delegated proof of stake (DPoS), practical byzantine fault tolerance (PBFT) etc. (Torelli, 2019)

- Encryption algorithm: Asymmetric encryption algorithms are mainly applied in the blockchain. This encryption algorithm completes encryption and decryption by using two asymmetric ciphers, the 'public key" and the 'private key."
- Smart contract: Smart contract is a computer processed trading protocol that allows the contractual clauses to be executed. The application of smart contracts can not only reduce the cost of management, but also avoid unnecessary disputes. In fact all actions can be performed accurately under smart contracts that is coded and stored in the chain of blocks.
- Distributed data storage: The distributed storage in the blockchain means that each participating node has an independent, complete data store. Its uniqueness is mainly reflected in two aspects: Firstly, each node of the blockchain stores complete data in a blockchain structure. Secondly, the storage of each node of the blockchain is independent and equal in status. It relies on a consensus mechanism to ensure the consistency of storage.

Each of these key technologies can find different purposes and uses in the real-life case, alone or mixed with other technologies from outside the blockchain structure.

Uses and Characteristics

The key technologies previously explained are all present inside the blockchain technology and they, combined, give the blockchain some useful characteristics.
Following, a description of this characteristics is made together with and evolution of their uses.

d) Main Characteristics

The blockchain key technologies exist by definition in the blockchain structure as a part of how it is composed. Based on the four key technologies, combining their properties, five characteristics emerge. (Wu and Tran, 2018)

- Decentralization: Since the blockchain system adopts the P2P networking mode, there is no mandatory control centre. Every node in the network has equal status in the system. The data blocks generated are maintained by all of the nodes in the system. All of the nodes have recorded and stored transaction data, increasing the robustness of the database.
- Openness: The blockchain system uses trusted mathematical algorithms to regulate the behaviour of data exchange. The data exchange between nodes in the system does not require mutual trust. Anyone can query the blockchain data information at any time. The update of information requires the mutual authentication of multiple nodes, so the information of the entire system is secured and highly transparent.

- Automatic execution contract (smart contract): The blockchain can be formed into smart contracts by writing code, which stipulates the obligations to be performed by each party in the contract and the conditions for the execution of the contract. When all the agreed conditions are satisfied, the blockchain system automatically enforces the contract terms. This increases the efficiency of contract execution, and more importantly, it effectively ensures the implementation of the contract without the supervision of a third party.
- Traceability: Traceability means that the records added to the blockchain are permanently stored. The complete transfer path of the object of transaction can be fully recorded and traced. Thanks to the different consensus algorithm used by blockchain technologies the transactions are highly secured and immutable.
- Anonymity: Data exchange between nodes in a blockchain system follows a fixed algorithm, so both parties need not disclose their identities. Instead, the procedural rules in the blockchain are used to give each other trust.

e) The Evolution of Blockchain

The scope of blockchain applications has increased from virtual currencies to financial applications to the entire social realm. Based on its applications and evolution in time, blockchain can be delimited to Blockchain 1.0, 2.0, and 3.0.

2008 – 2015: Blockchain 1.0

The first generation of blockchain had just three of the four key technologies embedded, in fact smart contracts were not able to run on this kind of blockchain. Blockchain 1.0 was related to virtual currencies, such as bitcoin, which was not only the first and most widely used digital currency, but it was also the first application of blockchain technology (Mainelli and Smith, 2015).

The focus of blockchain in its early stage has been the decentralization of money and payments.

2015 – 2021: Blockchain 2.0

Blockchain 2.0’s most significant contribution is the smart contracts that happen with the creation of Ethereum, the first blockchain to support them.

The application of the smart contract, together with other blockchain key technologies, broadens the capabilities of this technology to facilitate the decentralization of markets in general, allowing for the exchange of other types of assets such as certificates, rights, and responsibilities in real estate, intellectual property, cars, and artworks.

Blockchain 2.0 introduces concepts like: smart-property, decentralized applications (dApp), Decentralized Finance (DeFi), decentralized autonomous organizations (DAOs), and decentralized autonomous corporations (DACs) (Swan, 2015).

A brief explanation of the application of the blockchain technology in these new forms is given here.

- Decentralized applications: a dApp is an application (like the one on smartphones or platform on computers e.g., Facebook) that is completely hosted by a P2P blockchain system. Ideally, a deployed dApp needs no maintenance and governance from the original developers. In other words, an ideal blockchain application or service should be operable without any human intervention, which forms a Decentralized Autonomous Organization (DAO) and Decentralized Autonomous Corporation (DAC).
- Decentralized Finance: Decentralised finance also known as DeFi is the ecosystem of financial applications built on top of some public blockchain. DeFi aims to enable all the financial instruments of the traditional financial ecosystem like options, futures, derivatives etc, all the financial services like lending, borrowing, transfer etc in a decentralised world. Third parties like banks, exchanges are replaced by cryptocurrency wallets and smart contracts.(Manoj Kumar, 2020)

Blockchain 3.0

Blockchain 3.0 is described as the application of blockchain in areas other than currency and finance, such as in government, health, science, culture, and the arts (Swan, 2015). Blockchain 3.0 aims to popularize the technology, and it focuses on the regulation and governance of its decentralization in society.
The integration of blockchain with tokens is an important combination of Blockchain 3.0. Tokens can serve as a form of validation of any right, including personal identity, academic diplomas, currency, receipts, keys, event tickets, rebate points, coupons, stocks, and bonds. Consequently, tokens can validate virtually any right that exists within a society.

- Tokenization: Token represents the right to do some operations in software. In blockchain, there are three types of tokens: utility token, security token (Non fungible tokens) and asset-backed tokens. They endow the items of token more value in blockchain world.

The use of blockchain technologies within manufacturing is already seen as adoption of blockchain 3.0 and in the next sections an analysis of the existing literature is reported here.

Blockchain in manufacturing

Figure 9 – Industry 4.0 Technologies

As mentioned in the methodology Section 2.1.2 Blockchain is often included in the broader concept of Industry 4.0.

Industry 4.0 or the so called Forth industrial revolution enables the manufacturing sector to become digitalized with built-in sensing devices virtually in all manufacturing components, products and equipment. (Chakrabarti et al., 2019)

Industry 4.0 as umbrella name, includes different technologies (see Figure 9) that are not the focus of our research.

Although Industry 4.0 technologies can offer many advantages for the manufacturing sector, there are some challenges that need to be addressed to fully realize these benefits. The challenges are mainly related to the connectivity and information exchange among different machines, units, locations and across the various firms and entities involved in the manufacturing value chain. In this gap, blockchain, with its characteristics of security, trust, traceability, is able to emerge and support in a better integration the different technologies.

Blockchain has the potential to be more impactful by combining cyber and physical systems through integration with Industry 4.0 technology platforms such as the Internet of Things (IoT), Robotics, 3D Printing, Augmented Reality and Smart Sensors. (Capgemini, 2018)

Although a fairly new technology, blockchain has many practical use cases and new applications of the technology are continuously introduced. The most diffused use cases are related to cryptocurrency, smart contracts, crowdfunding, prediction markets and smart property (Dieterich et al., 2017) and while the majority of research projects is still focused on the technology itself and applications in the finance industry, the interest to exploit blockchain in the manufacturing industry is increasing. (di Francesco Maesa and Mori, 2020)

In the literature, it was found a diffused investigation on the application of blockchain for supply chain management and auditing; the role of blockchain for industry 4.0 is also discussed.

While talking about manufacturing, a key is the fourth industrial revolution which leads to factories becoming increasingly interconnected. In this environment the influence of blockchain is becoming more prevalent due to his capability to bring greater trust and transparency to manufacturing. In fact, today manufacturers face the challenge of securely sharing data within and outside factory walls. (PWC, 2018)

BCG's article "Blockchain in the factory of the Future" (BCG) and (Torelli, 2019) help in summarizing the ways in which blockchain can create value in the manufacturing industry now and in the next future.

Enhancing Track and Trace: Blockchain can provide an immutable, permanent digital record of materials, parts, and products, thereby promoting end-to-end visibility and providing a single source of truth to all participants.

Protecting and Monetizing Critical Intellectual Property: in the competitive task of protecting IP, company to utilise blockchain technology to help prove that it owns IP in the event of a patent dispute.

Simplifying and Safeguarding Quality Checks: the focus is the enhancement of the value for customer, using blockchain to support quality control. In addition to helping customers track and trace inbound parts along a supply chain, blockchain creates immutable documentation of quality checks and production process data.

Advancing Machines as a Service: Blockchain accelerates the possibilities of using an innovative pay-per-use model for machinery, often known as machines as a service (MaaS). In this model, instead of selling production equipment, a machinery provider charges for the equipment's use on the basis of the output that it generates. This model could allow manufacturers to improve their flexibility significantly.

Enabling Machine-Controlled Maintenance: the opportunity here is associated with the possibility to create a digital twin of the machine or device to maintain. Blockchain technology can then enable the automated execution of and payment for scheduled maintenance.

Authentication of IoT devices: to provide a network in which IoT devices are authenticated, monitored and through which information can be exchanged in a secure and immediate manner, the combined use of the Blockchain with IoT becomes fundamental. A recent example is (Xage, 2019) a Blockchain-protected cybersecurity model for industrial operations which provide a security layer for industrial IoT.

Configuration Management: Blockchain can be used for creating, on an immutable ledger, a list of all the components, settings, parts versions, software firmware etc. of a unique product, creating and managing respective certificates of functionality or performance. Any mismatch between components can be easily detected.

Other opportunities are related to the possibility to prove the origin of parts and to verify that the parts meet the appropriate specifications.

Analysing more papers from the query "Blockchain" AND "Manufacturing", it emerged that supply chain traceability is one of the most promising use cases of blockchain characteristics in the manufacturing industry: this purpose is achieved with traceability and tokenization of components or products.

The last section of the literature review explains the extent through which the blockchain is able to support and enhance Circular Economy.

2.2.4 Blockchain as an enabler of Circular Economy

The last section of this literature review argues the extent and potential alignment of blockchain with circular economy.

The objective is to summarize which characteristics of Circular Economy provide the input for applying blockchain and vice versa, so which features of Blockchain are appropriate to overcome Circular Economy barriers.

Circular economy is a domain producing a considerable amount of data, coming from highly standardised dynamics, wide range of KPIs and material streams from different actors. (Oropallo et al., 2021). Blockchain and smart contracts, if well implemented, can deal with a massive quantity of data, avoiding intermediaries and reducing the costs of transactions, always guaranteeing transparency, and preventing counterfeiting.
Literature diffusely agreed (Saberi et al., 2019; Kouhizadeh, Zhu and Sarkis, 2020; Oropallo et al., 2021) that the characteristics of Blockchain [Section 2.2.3] that better support Circular economy are transparency and traceability in combination with reliability and immutability. (Böckel, Nuzum and Weissbrod, 2021)

The circular economy is able to help different UN Sustainable goals. Thanks to literature from (Parmentola et al., 2021) the potential help of blockchain is declined for each sustainable goal related to circular economy. The main benefits for each Sustainable goal are presented.

Clean Water and Sanitation (SDG N°6): with the goal to ensure access to water and sanitation for all, benefits from blockchain come from supporting peer-to-peer trading of water rights.

Affordable and Clean Energy (SDG N°7): with the goal to ensure access to affordable, reliable, sustainable, and modern energy for all, blockchain helps to develop smart contracts for renewable energy producers and consumers.

Industry Innovation and Infrastructure (SDG N°9): to build resilient infrastructure, to promote inclusive and sustainable industrialization and to foster innovation, blockchain can be used to develop smart contract for transport and logistics.

Sustainable Cities and Communities (SDG N°11): with the aim of making cities inclusive, safe, resilient, and sustainable, blockchain has the potential for creating more liveable cities implementing platforms to monitor energy consumption and waste.

Climate Action (SDG N°13): since it is needed to take urgent action to combat climate change and its impacts, Blockchain can provide support developing platforms for monitoring and exchanging information (e.g., greenhouse gas, carbon footprint).

Life Below Water (SDG N°14): to conserve and sustainably use the oceans, seas and marine resources, blockchain can provide mechanisms to monitor water pollution and to support preservation of water resources.

Forests, Desertification and Biodiversity (SDG N°15): to sustainably manage forest, combat desertification and halt biodiversity loss, Blockchain can offer small cash payments in exchange for conserving nature.

Responsible Consumption and Production (SDG N°12): this goal is the most connected to the manufacturing industry and refers to the need to ensure sustainable consumption and production patterns. The following considerations are related to the potential implementation of blockchain in circular manufacturing found in the literature.

As mentioned, circular economy requires the support of all the individuals involved in the supply chain. The interactions between the partners are based on trust relationships between them: each player should believe in the others' good practice to increase the responsiveness of the network. (Oropallo et al., 2021) Blockchain as the potential to build that trust. Considering consumer green behaviours, it is possible to classify those in three main clusters: purchase behaviour, usage and end-of-use behaviour. (Böckel, Nuzum and Weissbrod, 2021)

About the first, blockchain is able to offer greater information sharing and less information asymmetry: it plays a particularly important role in monitoring sustainability by tracing in a transparent way actual footprint of products. This is fundamental in supporting actual green purchase behaviour of consumers, which means either purchase from verified suppliers or remanufactured or used products, with quality guaranteed.

Another support offered by the blockchain are rewards, in the form of tokens or coins: they can incentivize green behaviour in both usage and end-of-use phases. E.g., Blockchain facilitates recycling behaviour by incentivizing individuals to participate in deposit-based recycling programs.

During usage phase, Blockchain can also increase consumer involvement in sustainable energy consumption: a demo of blockchain-powered refrigerator, which allows consumers to monitor and control their energy usage in a 'safe and transparent manner' (Kouhizadeh, Zhu and Sarkis, 2020) has been introduced in the Australian market by Wien Energy and Bosch.

Lastly smart contracts define which information and how data related to product lifecycle are collected, therefore enhance overall visibility.

Two examples discussed in the literature are related to (Esmaeilian et al., 2020):

- the capability of blockchain to reduce the so called "bullwhip effect": transparent information sharing and automation of smart contract, mitigate over-ordering or misalignment in inventory
- the increase of safety in the food industry: through blockchain it is possible to track the whole product's journey and eventually recollect all products from a defective stock.

To summarise, blockchain could change the way in which materials and natural resources are extracted, produced, and then valued, incentivising both individuals and companies to attribute economic value to waste and full disclosure. The potential extends beyond changing behaviour and could also incentivize companies to design and manufacture products in ways that make it easier to manage the product lifecycle and to re-harvest materials and unlock their embedded value. (PWC, 2018)

2.2.5 Challenges

The principal challenges addressed in the literature for what regards blockchain technology are reported and discussed here.
The challenges refer to the previous sections 2.2.3 and 2.2.4, and are related to Blockchain as a technology, Blockchain applied to manufacturing and Blockchain applied to circular economy.

The blockchain trilemma (Ku et al., 2018) is to develop a blockchain technology that offers security, decentralization, and scalability without compromising any one of them.

In fact, in order for blockchain to be an acceptable solution for business applications, the system should be able to handle a large number of transactions in a reasonably short period of time (scalability) but to be censorship proof and remove the single point of failure of centralized systems (decentralization) while being sure the transactions are correct and the information immutable (security).
Many different attempts have been made to build the next generation of blockchain able to overcome the trilemma, in research and practice, resulting in different protocols with specific characteristics: secure and scalable or scalable and decentralized or decentralized and secure. From the point of view of BaaS (Blockchain as a Service), the blockchain trilemma, still unresolved, raised a common challenge for the future blockchain application (both in manufacturing and circular economy) which consists in finding a blockchain protocol that best adapt to the context and needs of the project between the ones available. In a broader aspect, when various entities collaborate in a blockchain system and have to choose a Blockchain

protocol, it should be kept in mind that all the entities involved must be on the same protocol. [Complex protocol selection, (Lohmer and Lasch, 2020)]
In some projects, the applications are designed and developed for some specific needs in isolation, and later when required to collaborate, interoperability and compatibility issues come up. [Interoperability/compatibility, (Alam et al., 2021)] [Creation of individual technical silos, (Lohmer and Lasch, 2020)]

Other general challenges arise when the application of blockchain is implemented in real cases, as in the manufacturing industry.
The first to mention is the lack of awareness of the technology, especially in sectors other than banking, and a widespread lack of understanding of how it works. This challenge is associated with a cultural issue: blockchain is a quite revolutionary technology. It places trust in a decentralised network rather than in a central institution, which is sometimes perceived as unsettling. (Deloitte Survey, 2021)

Blockchain is designed for application with large adoption: if we consider its application in supply chain management, to receive benefits it requires widespread development and acceptance among every chain participant. [Setup complexities and costs, (Yildizbasi, 2021)] [Missing standards, (Lohmer and Lasch, 2020)]

Regulators worldwide are still examining the potential responses to the ever-increasing influence of blockchain-led solutions: since many actors are involved, the protocols should be strictly respected. This issue is strongly interconnected with the scepticism related to the disclosure of crucial company data and legal uncertainties related to smart contracts.
Other regulatory barriers are about the acceptance and use of cryptocurrencies still to be decided. [Regulatory uncertainties, (Lohmer and Lasch, 2020), (Yildizbasi, 2021)]

Given the extreme novelty of blockchain application into Manufacturing, another aspect to consider is the lack of talent: though Blockchain developers are high in demand, an acute shortage of blockchain experts and developers is a significant concern for all organizations. The lack of professionally trained and skilled developers for managing and solving the complexity of peer-to-peer networks further leads to a sluggish rate of development. [Lack of talent, (Alam et al., 2021)]

False information being entered in the blockchain is another challenge to overcome. In fact, the validation of the data thanks to immutability, authentication and transparency happens once the data are recorded in the blockchain and it creates a point of weakness at the start and of the process and, thus, the necessity for a validation and certification process outside of the blockchain. This challenge is much relevant in projects trying to address the carbon footprint of products and materials in Circular Manufacturing. [Point of failure, (Böckel, Nuzum and Weissbrod, 2021)]

Related the circularity aspect instead, the issues with more critical importance are the following.
The first to mention is the need for participation not only of all employees and companies, but often also of the customers. Therefore, with a large number of different actors involved in a Circular Economy project and the complexity of the infrastructure could arise together with the number of data exchanges. The existing solutions to the blockchain trilemma could not completely fit a large circular project and scalability can be a challenge still to overcome. [Scalability challenge, (Alam et al., 2021; Yildizbasi, 2021)]
The high energy consumption coming from certain consensus protocols (Proof-of-Work) to validate transactions. This challenge is partially overcome by way less energy-intensive protocol Proof-of-Stake, but for the blockchain to respect the UN Sustainable goals (N° 7 and 13) a solution based on alternative energy is still to be found. (Parmentola et al., 2021)

To summarize, the challenges to the blockchain and its applications in Circular economy and Manufacturing projects are both technical [Scalability, Interoperability, Need of validated data] and non-technical challenges. The non-technical ones regard the social aspects [Regulators, Technology acceptance, Missing skills] and the economic ones [High setup costs].

3 Research Question and Methodology

The aim of this chapter is to introduce the research question this thesis work wants to answer, as well as to provide information about the research methodology followed to answer it. Section 3.1 describes the research gap found in the literature and introduce the research question, while Section 3.2 describes the methodology adopted in order to answer it.

3.1 Research question

The research started from a literature review of the main topics involved in the analysis carried out. There is an extensive part of literature related to Circular Economy and its application in Manufacturing, in both theory and use cases.
Another mainstream of research is focused on Industry 4.0, the so called Forth Industrial Revolution, a trend towards automation and data exchange in Manufacturing.
The two subjects are strongly interrelated and there are current studies on digital technologies as an important catalyst to achieve Circularity in Manufacturing value chains.

Alongside this line of research, it is evident an intensification of interest in the Blockchain technology. Due to its rapid diffusion, academics are exploring possible directions for the blockchain and, while theory on how blockchain can deliver transformative solutions to circular economy challenges is starting to become popular, practical case studies and application of blockchain are still at early stage. Empirical studies are very few, there is little research based on practical experience and real projects, as highlighted by (Böckel, Nuzum and Weissbrod, 2021), where the authors extended the systematic literature review into the area of practice, in order to gain insights into the research- practice gap beyond academic perspectives.

Therefore, the aim of this thesis is to offer a different perspective by answering the following research question:

(RQ) *How can blockchain attributes enhance the sustainable performance of circular manufacturing?*

To answer the research question a classification and analysis of blockchain-enabled projects was carried out. To achieve the purpose, it was created a dataset of projects, collected from different sources, which belonged in the intersection of the three topics of the study: circular economy, blockchain and manufacturing, as highlighted in red in Figure 10.

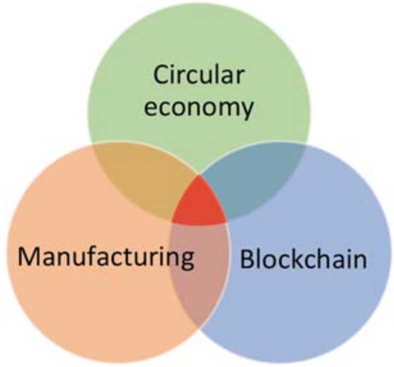

Figure 10 – Research Gap

These projects were analysed according to a framework, as explained in Section 3.2 and the main results of the research are shown in Chapter 4.

In future research, it will be possible to repeat the data collection to understand whether new application fields have emerged.

3.2 Research methodology

In this section the methodology adopted to answer the research question is presented.

To have a concrete understanding of the actual state of the art, we created a census of projects and some use cases of implementation of the blockchain in manufacturing to support the circular economy.

The selected cases were chosen from:

- Forbes' "Blockchain 50 - 2021",
  - Forbes is a global media company, focusing on business, investing, technology, entrepreneurship, leadership, and lifestyle.
    The magazine is well known for its lists and rankings: e.g., the Forbes Global 2000, to rank the world's top companies
- "B-hub Blockchain for Europe",
  - B-hub for Europe is an EU-funded project dedicated to connecting blockchain innovation ecosystems. It is an ambitious project that brings together blockchain technology providers, public actors, companies, blockchain enthusiasts and leading actors of European innovation towards a common goal: fostering the use of blockchain for the benefit of public services, companies and citizens of Europe.
- "Blockchain4innovation"
  - It belongs to the journal Network DIGITAL 360, the Italian biggest network of B2B journals dedicated to digital transformation and entrepreneurial innovation.
- "EU Blockchain: Observatory and Forum"
  - a European Commission initiative to accelerate blockchain innovation and the development of the blockchain ecosystem within the EU and so help cement Europe's position as a global leader in this transformative new technology.
    Created as a European Parliament pilot project; the second edition of the observatory is led by Intrasoft international, the University of Nicosia, the Institute of Information Technology/ CERTH, White Research, Bitfury, OpenForum Europe and PLANET S.A. .

- “CORDIS”.
  - The Community Research and Development Information Service is the European Commission's primary source of results from the projects funded by the EU's framework programmes for research and innovation
- “CoinMarketCap”
  - Coin Market Cap is the world's most-referenced price-tracking website for crypto assets. It plans to acquire more in-depth data into projects, reduce information asymmetry in the crypto industry and bring higher-quality data.

Additional use cases were found through snowballing approach. This method is used sometimes as a way of finding literature by using a key document on the subject as a starting point. Consulting the bibliography in the first document enables to find other relevant titles on the subject. In the case of this research, while gathering the information on a project, it was possible to find other relevant projects, with the same subsector or process of the first one.

During the selection of the use cases, we classified only projects respecting three keywords:

Circular Economy AND Manufacturing AND Blockchain

Each project has been categorized using the framework described below: the following sections is used to list and define all the variables used.
The variables are divided into 5 main groups: General, Development, Scope, Technology details and Impact. Figure 11 reports all the sections with the respective variables.
The scheme presented has been built through an iterative approach, using as starting point the following papers:

- (Vadgama and Tasca, 2021) and (Perego, 2019) provided a list of variables to classify the application of blockchain within a project: those variables have been screened to be more suitable to the classification of manufacturing projects. A further sorting has been performed after the analysis, based on the significance of the results.
- (Chardine-Baumann and Botta-Genoulaz, 2014) instead offered a tool to evaluate and analyse the potential relationships between circular strategies and their impact on performance: this framework has been adapted for the scope of this research, to enable to highlight the role of blockchain in achieving more sustainable performances along the triple bottom line.
- For the draft of the final framework, support has been provided by (Kouhizadeh, Zhu and Sarkis, 2020), to further investigate the transformation apported by blockchain within Circular Manufacturing.

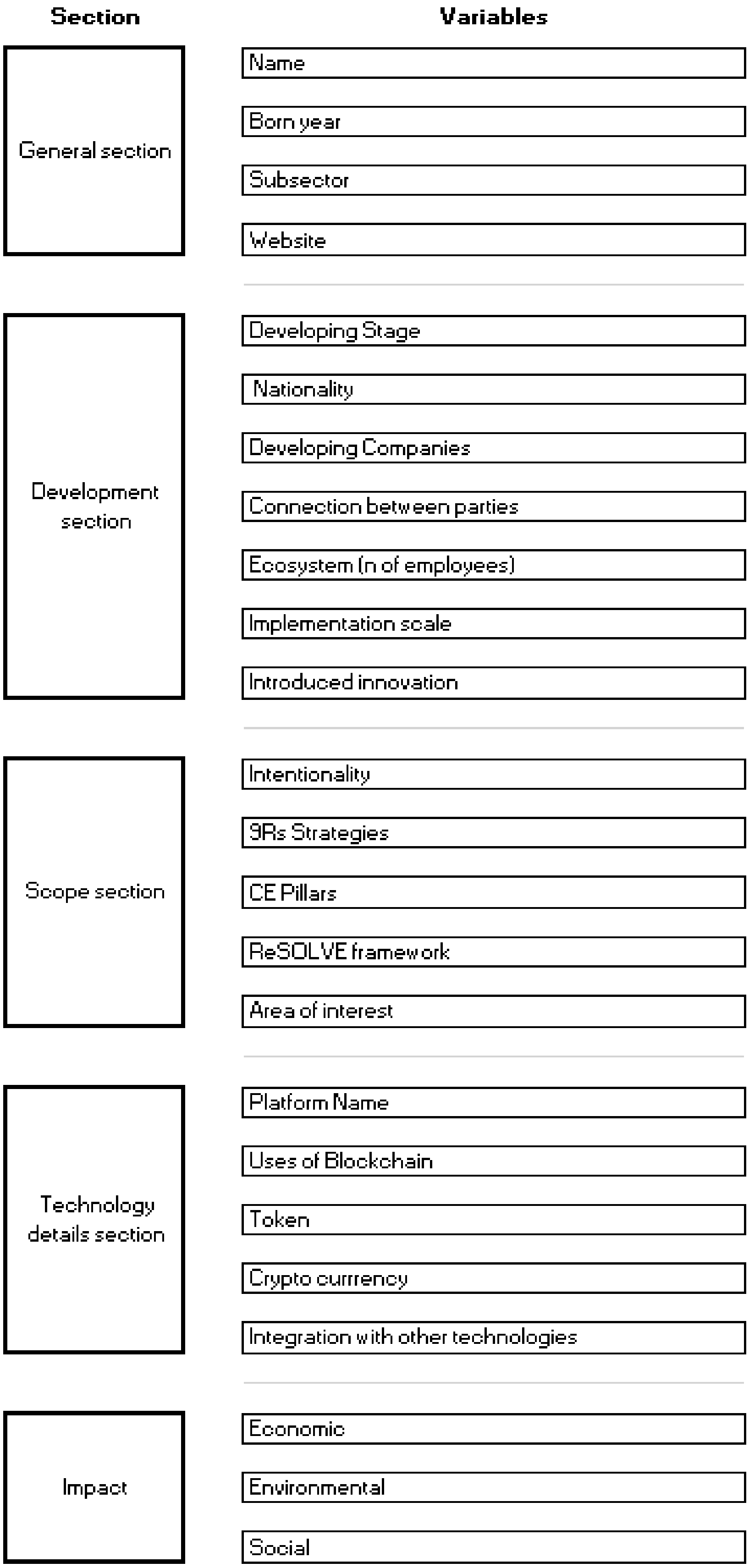

Figure 11 – Variables collected in the database

3.2.1 General section

This section contains variables that provide an overview of the project: demographic details of the project and website information to trace the source of the projects and help further researcher to follow their evolution.

<u>Project name</u>

<u>Born year</u>

It identifies the year from which the project can be defined active. According to different nature of the companies and the projects, the born year is defined as follow:

> When a company is created to develop a project: born year = foundation of the company itself.
> When an established company implements a project: born year = date of announcement (as well as when the project starts without a creation of a company).

Due to the size of the data set, the years have been coupled (<2016, 2016-2017, 2018-2019, 2020-2021).

<u>Subsector</u>

Given that all the projects belong to the sector "Manufacturing", we used the classification NACE to specify the subsector in which the company operates.
The Statistical classification of economic activities in the European Community, abbreviated as NACE, is the classification of economic activities in the European Union (EU).

According to RAMON, Reference And Management Of Nomenclatures, Manufacturing *"includes the physical or chemical transformation of materials, substances, or components into new products, although this cannot be used as the single universal criterion for defining manufacturing (see remark on processing of waste below). The materials, substances, or components transformed are raw materials that are products of agriculture, forestry, fishing, mining or quarrying as well as products of other manufacturing activities. Substantial alteration, renovation or reconstruction of goods is generally considered to be manufacturing."*

This classification identifies 22 types of subsectors and a 23rd category to include “other manufacturing”. (See Figure 12)

Subsectors - Manufacture of:	
Food Products	Rubber and plastic products
Beverages	Other non-metallic mineral products
Tobacco products	Basic metals
Textiles	Fabricated metals products, except machinery and equipment
Wearing apparel	Computer, electronic and optical products
Leather and related products	Electrical equipment
Wood and products of wood and cork, except furniture	Machinery and equipment
Paper and paper products	Motor vehicles, trailers and semi-trailers
Printing and reproduction of recorded media	Other transport equipment
Coke and refined petroleum products	Furniture
Chemicals and chemical products	Other manufacturing
Basic pharmaceutical products and pharmaceutical preparations	Repairing and installation of machinery and equipment

Figure 12 – NACE Classification of Manufacturing subsector

During the selection of the projects, we realized that some categories could have been merged to increase the significant of the variable itself. The final categories are the following:

1. *Food production*
2. *Petroleum, chemicals and plastics*
3. *Textiles, Clothing and Wearing appeal*
4. *Metal Manufacturing* (including both basic metals and fabricated metal products)
5. *Electronics and Computers*
6. *Mining*

Website of the project (usually with the domain of the project or the company implementing it).

3.2.2 Development section

This section provides an “as is” description of the project (November 2021).

Developing stage

It indicates the level of maturity and implementation of the project.

4 different stages have been identified:

1. *Announced*: the project has just been announced. Through press or website, the company has announced the beginning of a project, without describing

technicalities or further details (only a brief description of actors involved and purpose).

2. *Proof of concept*: it consists in an incomplete realization of the project. During this phase, the company tries to demonstrate the validity of the project, realising some information about technologies and strategies. Projects in this developing stage have written a white paper or more information related to benefits and how-to achieve them.
3. *Pilot*: frequently carried out before large-scale, in an attempt to avoid time and money being used on an inadequately designed project. During this stage, the companies involved in the project have decided to implement it in a controlled environment to highlight unexpected problems or challenges.
4. *Operating project*: in this category we collect all projects that are actually implemented in a large scale, performing commercial activities or operations. Being open source, many projects are public and ready to be further implement in other context.

<u>Nationality</u>

This variable defines the country in which the companies implementing the project are from. (Not where the project is going to be applied).

<u>Developing companies</u>

This variable aims to describe not only the entities involved in the development of the project but also the relations between those actors.

For most of the cases we identified the service provider (platform/blockchain), the companies implementing and adopting the project and those in the same supply chain (either suppliers or customers).

The number of employees of companies involved has been collected to provide an information related to the project's dimension. It has been identified with the variable <u>Ecosystem</u>: <u>Number of employees:</u>

1. *1-10*
2. 11-*50*
3. *51-200*
4. *201-1000*
5. *1001-10000*
6. *>10000*

Moreover, we found it useful to highlight the eventual <u>Connection between parties</u>:

1. *Single*: in case there is a company implementing the project alone

2. *Vertical digital integration*: we used this term to define the use of the blockchain to implement the same project along different actors of the same supply chain e.g., the project involves a company and its suppliers and/or clients.
3. *Horizontal digital integration*: the same project is implemented among actors at the same level of different supply chains.

Implementation scale

Here we consider that the projects selected take advantage of the potential of the blockchain to put in practice circular strategies in the manufacturing sector. Therefore, we classified the projects, highlighting if circular manufacturing has been adopted at micro, meso and macro level:

1. *Micro*: if the project applies a CE strategy to a single product or a firm.
2. *Meso*: if the project refers to the application of CE strategies within a network of firms, that interact. This level is usually equivalent to what can be defined supply chain.
3. *Macro*: if the project implies the definition of new certifications or regulations adopted by countries.

Introduced innovation

This variable defines which process is performed in an innovative way, thanks to blockchain. It explains how the organization exploits the blockchain to improve its efficiency or create more value.

1. *Data & document management*: Sharing of sensible documents and details in an encrypted and secure way
2. *Payments*: exchange of value
3. *Property registry*: digitalization of properties in a transparent way
4. *Rewarding activities*: allowing companies to reward their clients for participation in certain programs
5. *Supply chain finance*: set of tech-based business and financing processes that lower costs and improve efficiency for the parties involved in a transaction
6. *Tracking & Supply chain management*: monitoring and transmitting data of raw materials, products, shipments and their movement.

3.2.3 Scope section

This section collects the value proposition of the project, and which circular strategy has been implemented to achieve it.

Intentionality

This dimension refers to the explicit willingness of the organization to address a solution to the problem (Tiresia, 2020) opposed to the generation of a consequential positive externality: therefore, this variable aims to define if the circularity is an ex-ante purpose of the project or a consequence of the intervention of improvement:

1. *Direct*: intentional impact
2. *Indirect*: consequential effect

The 9Rs Strategies

To describe which CE strategy or strategies have been used in the project, we selected *one or more* options among "the 9R Framework of Circular Approaches" (Bocken et al., 2017).

0. *Refuse*: make product redundant by abandoning its function or by offering the same function with a radically different product
1. *Rethink*: make product use more intensive (sharing, multi-functional product)
2. *Reduce*: increase efficiency in product manufacture or use by consuming fewer natural resources and materials
3. *Re-use*: by another consumer of discarded product which is still in good condition and fulfils its original function
4. *Repair*: repair and maintenance of defective product so it can be use with its original function
5. *Refurbish*: restore an old product and bring it up to date
6. *Remanufacture*: use parts of discarded product in a new product with the same function
7. *Repurpose*: use discarded product or its parts in a new product with a different function
8. *Recycle*: process materials to obtain the same or higher quality
9. *Recover*: incineration of materials with energy recovery
10. *General*: more strategies implemented without a precise boundary

Circular economy pillars

This variable assessed which CE pillar is driving the project.

1. *preserve and enhance natural capital*, by controlling finite stocks and balancing renewable resource flows
2. *optimize resource yields, by circulating products*, components, and materials in use at the highest utility at all times in both technical and biological cycles
3. foster *systems effectiveness by revealing and designing out negative externalities*

ReSOLVE framework

This variable describes if one of more action have been taken:

Regenerate, Share, Optimize, Loop, Virtualize and/or *Exchange*.

The explanation of each action has been provided in the literature review, Section 0.

The set of variables chosen includes different frameworks to describe circular practises, since -at early stage - it was not possible to define which variable could be more useful to create a final framework combined with blockchain information.

Geographical area of interest

This variable defines the country in which the project is going to impact: countries in which is adopter or where the benefits are obtained.

Blockchain is usually applied in open-source projects, therefore among the option, it is possible to classify the project under the category "World" or "Europe".

3.2.4 Technology details section

The following section illustrates the details of the Blockchain and its application within the project.

Name of the platform

This variable describes the platform on which the projects rely.
The first main difference is whether a project relies on an existing blockchain platform, or it creates its own new platform. The collection has been conducted to give an overview of which are the most diffused blockchain in manufacturing application: further analysis is out of this discussion but can be the starting point for future research.

Uses of Blockchain

The characteristics of blockchain technologies from literature are difficult to apply directly to a project. The real use case functions of blockchain are combination of blockchain characteristics that are used to reach a unique business objective.
In other to classify our projects the literature from (Perego, 2019) and (Kouhizadeh, Zhu and Sarkis, 2020) has been taken as reference, to create different clusters.

This variable investigates the purpose for which the blockchain is used. For each project, it is possible to select one or more benefits of the blockchain among the following:

1. *Transparency*: transparency is strictly related with the key characteristic of traceability. In fact, in blockchain technology each transaction is recorded and stored securely in each node of the blockchain. This characteristic can used to control the lifecycle of a product.
2. *Openness*: Anyone can query the blockchain data information at any time. It is able to exploit this function thanks to the reliability and security given by the blockchain. In fact, data are immutable and thanks to specific protocols is possible to share encrypted data to a single entity while being transparent on the transaction with the overall network.
3. *Authentication*: information and goods can be authenticated by creating a unique code related to the information or object that is immutable over time and it will refer forever to the given object or information. The authentication process can take different names based on the nature of the authenticated entity and the methodology applied to obtain it. Some examples of authentication are tokenization of info and objects, digital twin and Non-Fungible-Tokens.
4. *Digital currencies*: the authentication mechanism can be used to create what are called digital currencies. They are often used as reward mechanism to nodes of the network, in other to keep it secured. The payments using them are fast, secure and low-cost, with real time verification without the need for intermediaries. Digital currencies can be integrated as rewards mechanisms, as mean of payment on the platforms, as financing of the project and as governance mechanism to Decentralized Communities.
5. *Smart contract*: are agreements embedded in lines of codes enabled by blockchain technology. They represent obligations to be performed by each party and the conditions for the execution of the contract

Token

This is a binary variable to describe if:

1. *0*: the project doesn't use a token
2. *1*: the project uses a token, either Security Token or Non-Fungible Token.

Cryptocurrency

This is a binary variable to describe if:

1. *0*: the project doesn't use a cryptocurrency
2. *1*: the project uses a cryptocurrency or a Utility token.

Integration with other technologies

This variable to describe if:

1. *0*: otherwise
2. If the project is developed with the support of other Industry 4.0 technologies, this variable defines the name of the technology:
   Additive manufacturing; Augmented reality; Big Data; Cloud computing; Cybernetics; Deep learning; Internet of Things; Machine learning; Neural network; Robotics.

3.2.5 Impact section

As already pointed out in the Section 0 dedicated to circular economy, there are ambiguities not only regarding the definition itself but also the indicators and the parameters to monitor the expected impacts and benefits of the projects.

The following variables have been defined from the concept that holistic evaluation was necessary to encompass the environmental, economic and social dimensions of CE.

According to (Chardine-Baumann and Botta-Genoulaz, 2014) , we have assessed the performance of each project according to their economic, environmental and social sustainability. Each dimension has been further analysed into 5 different fields, (as in the Figure 13 below).

We decided to assign a rating from 0 to 2 to each field, using the sub-fields as a check-list:

1. *0* no impact
2. *1* unintentional impact
3. *2* intentional impact

All the projects have been evaluated in terms of value proposition of the project itself and not the impact that the project is achieving in the time considered. (e.g., A new project, just announced, is classified for the potential outcome once developed.)

It is important to declare that given the novelty of all the projects and the subject itself, the information collected could be misleading.

The ratings given to each field are then summed to assign a value to three dimensions: for the purpose of this research, then projects have been compared according to these aggregated values.

Dimension	Field	Description
Economic	Reliability	*Customer service, suppliers' service, reliability of stocks, reliability of forecasts*
	Responsiveness	*Design responsiveness, purchase responsivess, source responsivess, production responsivess, delivery r., sell responsivess, return responsivess, supply chain responsivess*
	Flexibility	*Suppliers flexibility, supply flexibility, production flexibility, delivery flexibility*
	Financial Performance	*Design cost, purchase cost, source cost, production cost, delivery cost, return cost, supply chain cost*
	Quality	*Product/service quality, quality performance of suppliers, production quality*
Environmental	Env. Management	*Environmental budget, environmental certification, environmental compliance, workers implications*
	Use of resources	*Renewable energy, recycled water, inputs stemming from the recycling, recyclable outputs, recyclable wastes*
	Pollution	*Air pollution, water pollution, land pollution, other pollution*
	Dangerounsness	*Dangerous inputs, dangerous outputs, dangerous wastes*
	Natural environement	*Eco-systemic services, respect of biodiversity, land use, development of urban and rural areas*
Social	Work conditions	*Employment, work conditions, respect of social dialog, health and security, human resources development*
	Human rights	*Child and forced labor, freedom of association, discrimination*
	Societal commitment	*Involvement in local community, education, culture and technological development, job creation, healthcare, societal investment*
	Customers issues	*Marketing and information, healthcare and security, protection of private life, access to essential services*
	Business practices	*Fight against corruption, fair-trading, promotion of corporate social responsibility in the sphere of influence*

Figure 13 – Characteristics of sustainable Performance - Source (Chardine-Baumann and Botta-Genoulaz, 2014)

Economic: this dimension aims at describing the monetary and not contribution of the project. It includes the level of service offered to other actors involved, responsiveness and flexibility as well as the capability to reduce costs, while providing high quality.

Environmental: with environmental performance, we try to assess the environmental impact, defined as a modification of the environment due to human intervention. Limiting the study to projects of circular economy, negative externalities and preservation of resources should be guaranteed.
Different projects, though, focus their attention of one aspect more than another.

Social: with social responsibility, it is possible to point out the consequences of the project on the actors involved. It is distinguished into work conditions, human rights, societal commitment, customer issues, and business practices.

The scope of the research is qualitative and for some future analysis we opted for a clearer classification. The points obtained by each project along the Economic, Environmental and Social dimensions are clustered in three classes High, Medium and Low.

1. High: if the total impact along a dimension is from 10,0 to >=7,0
2. Medium: if the total impact along a dimension is from <7,0 to >= 5,0
3. Low: if the total impact along a dimension is from <5,0 and >0,0

4 Results

In this Chapter, an analysis of the population of use cases is carried out. The objective is to understand if and which are the trend of application of blockchain-enabled circular manufacturing projects.

4.1 Descriptive analysis and discussion

After an overview of all the information gathered, it has been clear that some variables were not significant to the analysis, either because not differential or not enough information were collected. Some of those have been excluded from the original methodology, while others are reported in brief to provide a starting point for future research.

All the projects and cases reported refer to existing and projects that failed have been removed from the census.
From 2013 to date (November 2021), this research has collected 55 projects and classified them according to the methodology previously described.

The following paragraphs analyse and summarize the main findings in terms of:

- Maturity of a project, their geographical distribution, and their developing strategies
- Subsectors of application within the manufacturing industry
- CE strategies and pillars supported
- Process impacted and innovation introduced
- Usefulness of blockchain: to highlight which characteristics of BC are exploited
- Impact on sustainability dimensions

The descriptive analysis of the database provides a static picture of the sample from different perspectives, and it is followed by a more dynamic overview of the interaction between two or more variables.
The discussion reflects around qualitative trends as well as challenges and barriers in the implementation of the blockchain technology in the manufacturing industry once combined with circular economy objectives.

The 55 projects analysed have been described and classified through the five sections of variables listed in the previous chapter: General Section, Development Section, Scope section, Technology Details Section and Impact Section. The results for all variables are summarized in tables at the beginning of each subsection, in terms of:

> *results obtained*: how many details we have been able to gather for the projects
> *comment and results*: brief description of the result, when not significant, or reference to the chart in which a better explanation is provided.

(e.g., Website: 55; Annex; it means that we have been able to collect the information about the website of all 55 projects and in the Annex, it is possible to find the list of them).

The list of *Project Names* is reported here (Figure 14).

Projects

1	**BHP**	29	**Agoratechlab**
2	**Walmart**	30	**ChemChain**
3	**Carrefour food blockchain**	31	**TRICK**
4	**GreenTrack**	32	**HEREWEAR**
5	**GSBN**	33	**PestNu**
6	**Pharma Ledger**	34	**EFPF**
7	**Responsible Sourcing Blockchain Network**	35	**Textilechain**
8	**Atomyze**	36	**FoodChain**
9	**Circularise**	37	**4C**
10	**Trafigura**	38	**KleanIndustries**
11	**Flexidao**	39	**BYD**
12	**Plastick bank**	40	**TE-FOOD**
13	**Bext360**	41	**CONNECTING FOOD**
14	**Volvo**	42	**GOODSId**
15	**CircularChain**	43	**FOOTBRIDGE**
16	**Covestro**	44	**JOONE**
17	**Cycle4Value**	45	**CIRCULAR TREE**
18	**CERA 4in1**	46	**SEVA**
19	**U.S. Air Force defense security data**	47	**MINESPIDER**
20	**Provenance Project**	48	**FEELERA**
21	**Rapid Precision Parts Production**	49	**GENUINE WAY**
22	**BlockWEEE**	50	**MANGROVIA**
23	**Vestiga Blockchain**	51	**TREECYCLE**
24	**DiLLaS**	52	**MFG**
25	**Circular Crowd Production Platform**	53	**REFORK**
26	**Ptwist**	54	**FETCH**
27	**REFLOW**	55	**Veritree**
28	**Empower**		

Figure 14 – List of Projects

4.1.1 General section

This section provides an overview of the projects with variables as:
Project Name, Born Year, Sub-sector and Website.

	Variable	Results obtained	Comment
General section	Name	55/55	Figure 15 - List of Projects
	Born year	55/55	Chart 7 - Born Year
	Subsector	55/55	Chart 8 - Manufacturing Subsectors
	Website	55/55	Annex

Table 2 – General section results

The list of *Project names* has been reported in the Figure 14, while in the Chapter 7 - Annex is possible to find their complete description and the relative *Website*.

Born year variable provides an information about the number of projects that started during a defined period of time.

Since the dataset collected is limited, we analysed the number of projects aggregating by coupling the years for readability (Chart 7). The trend related to project of Blockchain and Circular economy in the manufacturing field is still evident: the projects are at their early stages. While is possible that all the projects born before 2016 have failed, its highly improbable, so we can say with a certain confidence that the diffusion is growing significantly.

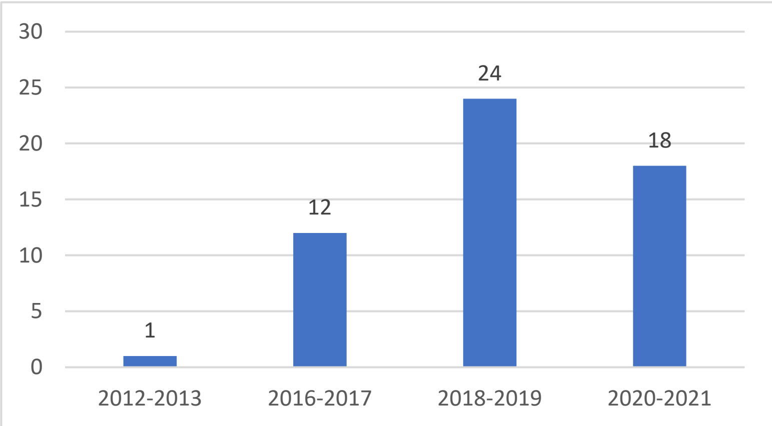

Chart 7 – Born Year

After a relevant number of projects developed and announced in the year 2018-2019, it is possible to notice a slowing down in the trend: the reason is probably due to the Covid-19 pandemic that slowed down the development of projects already underway and postponed announcements of new platforms. To verify if this is true, it will be necessary to wait for projects launched in the next months.

The sector considered in this discussion is Manufacturing: the variable *Sub-Sector* returns an information about the sub-sectors in which the projects are applied. (Chart 8)

It was necessary to add a category called "General" to include projects that support and implement circular approaches in more than one manufacturing subsector, an example is represented by the research project REFLOW which offers a new approach to circular economy in urban areas. The project tries to co-create and test regenerative solutions at business, governance, and citizen levels to create a resilient circular economy.
This project is designed to support citizens and governments as well as businesses, such as manufacturers who want to future-proof their industries by supporting social, environmental and economic transformation. (Cordis, 2019)

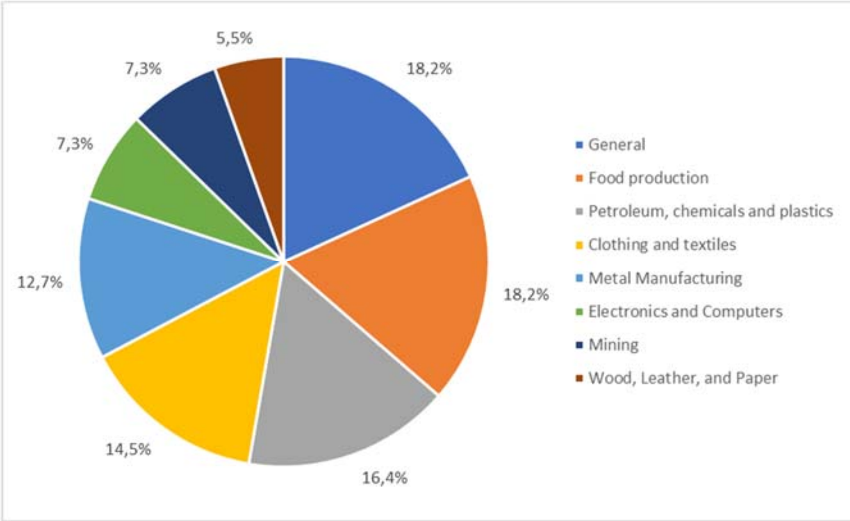

Chart 8 – Manufacturing subsectors

The same can be said regarding Circularise, which facilitates a shift to a circular economy by digitalising and tracing materials across complex supply chains on a public blockchain without risking confidentiality. This project involves and supports many other organizations which belong to different manufacturing subsector, such as Porsche (automotive industry) or Domo (chemicals).

The category "General", the most representative, includes companies representing service or technologies providers for manufacturing sector. The implementation of blockchain has more benefits when implemented in large scale projects due to its intrinsic characteristics and a support from services providers is often necessary: to promote more integrated collaboration and trust among partners, blockchain has the potential to facilitate the sharing of transparent and trustworthy information. It is necessary that everyone within the ecosystem uses the same protocol and infrastructure, otherwise the economic and non-economic returns will not justify the cost of replacing the existing structure.

The second most populated sub sector is the "Food Production" one: the reasons are related to the barriers that can be overcome by blockchain. In this category indeed it is possible to find projects from big supermarket companies, as Walmart and Carrefour, implementing blockchain to track food from producers to consumers.
In case of an outbreak of food-borne disease, traceability and immediate recalling of products can not only save lives but also discard only products from the affected farms, so in this way blockchain enables to overcome both trust and safety issues.

Another project worth mentioning is CircularChain, the circular economy blockchain, which is a concrete solution to promote material reuse and recycling: through traceability and trust they are able to guarantee correct waste management, for example transforming organic waste into soil amendments.

In the list, we found interesting projects related to "Petroleum, Chemicals and Plastics": they use blockchain platform to secure the transactions and to allow transparency, traceability and rapid scalability while their aim is to collect plastics and other polluting materials, creating closed-loop supply chain.

Finally, there is evidence about a movement in this direction within the "Clothing and Textiles" industry: to mention one, FootBridge uses B2B blockchain network to perform an in-depth Life Cycle Assessment, to measure the environmental footprint and identify possible improvement.

4.1.2 Development section

The developing section is comprehensive of seven variables: Developing Stage, Developing companies, Employees' Company, Connection Between parties, Implementation scale, Nationality and introduced innovation.
They have been necessary to try to understand the state of the art of each project.

	Variable	Results obtained	Comment
Developing section	Developing Stage	55/55	Chart 9 - Developing stage
	Developing Companies	55/55	Annex
	Ecosystem: N° Employees in the companies	46/55	11 (0-10); 20 (11-50); 6 (51-200); 1 (201-1000); 8 (>10.000)
	Project/Company Nationality	55/55	Annex
	Connection between parties	55/55	Chart 10 - Connection between parties
	Implementation scale	55/55	Chart 11 - Implementation scale
	Introduced innovation	55/55	Chart 12 - Introduced innovation

Table 3 – Development section results

Analysing the *developing stage*, we can notice a equal number of project being in "Operative" and in "Pilot stage"(43,6%). These data are promising, since it means that the projects have been actually implemented either small or large scale. (Chart 9)

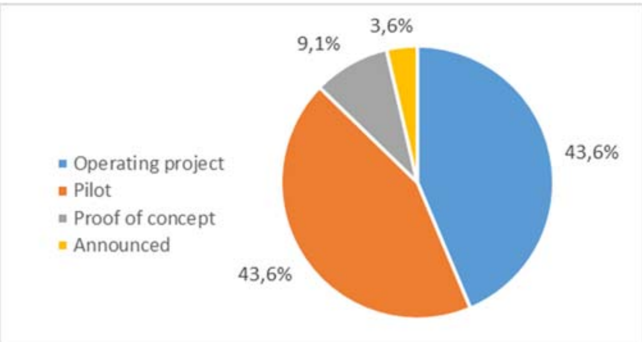

Chart 9 – Developing stage

As already mentioned, the Covid-19 pandemic could be the cause of slowing down of launch of new projects. To verify that, it will be necessary to check how projects in "Announcement" or "Proof of concept" stages will be performing in next months.

Another interesting aspect from this section is the *Connection Between Parties* (Chart 10). Blockchain-enabled projects are usually large and involving different actors: this variable highlights how the projects connect together different actors along the same supply chain. To describe this situation, it is used the concept of Vertical digital Integration, meaning that the companies upstream or downstream the supply chain connect together as a single ecosystem on the blockchain.

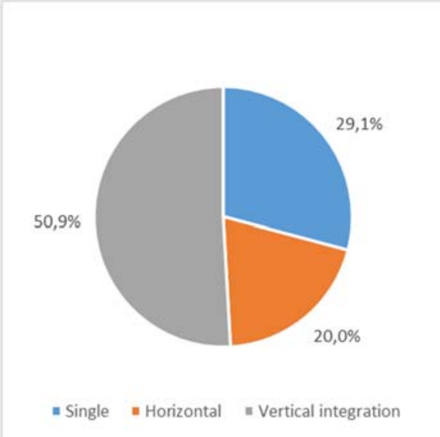

Chart 10 – Connection between parties

To explain this concept, BlockWEEE provides a great example: they create a network, supported by a rewarding system, to track waste of electric and electronic equipment (WEEE) in a circular economy perspective. Through blockchain, they developed a solution in which it is possible to create smart contracts between producers, client and final user, to track the state of the equipment installed.

For what concern the *Implementation scale*, Chart 11 more than 60% of projects are implemented at "Meso level", information which convey a concept similar to "vertical integration" described before: circular strategies are adopted within a network of industries, to foster closing the loop activities.

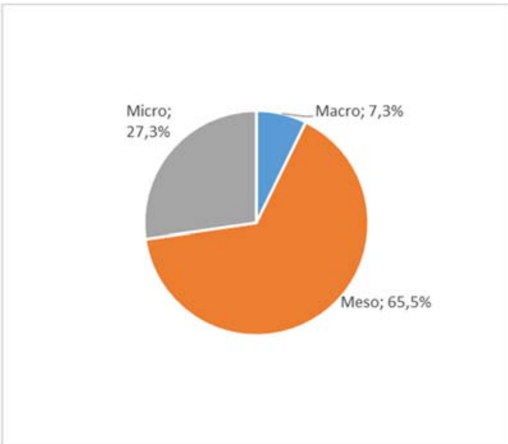

Chart 11 – Implementation scale

For implementation at "Macro level", CERA4in1 represents a explicatory example: this project is still at "Pilot stage", but the aim is to become the first universal and comprehensive certification scheme to control and validate production, processing and traceable transport of all mineral resources.

In the same line of reasoning, it is possible to discuss about the *Introduced innovation*. In the vast majority of projects (74%) the innovation brought in the process by the blockchain is associated with “Tracking & Supply chain management”. (Chart 12)

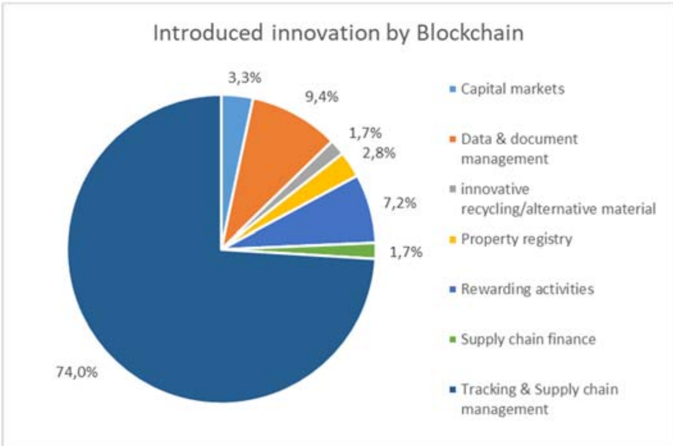

Chart 12 – Introduced innovation

Only a couple of projects have innovation within “Data & Document Management”, such as Veritree: they leverage on blockchain solutions to allow planting organizations to gather ground level data, manage their projects more effectively, and deliver sponsors a world-class experience.

In this section we included also a variable related to *Number of employees*, which gave an idea of the overall dimension of the project, and another variable to indicate the *Nationality* of the project or the company developing it. Since the sources used included different European funding initiatives, this variable can be misleading of the actual situation.

4.1.3 Scope section

The scope section is where data about circular economy have been collected.

	Variable	Results obtained	Comment
Scope section	Intentionality	55/55	56,4% Direct; 43,6% Indirect
	Strategies	80/55	Chart 13 - The 9Rs' framework
	CE Pillars	80/55	Chart 14 - Circular pillars
	ReSOLVE	150/55	Chart 15 - ReSOLVE
	Area of interest	55/55	Chart 16 - Area of interest

Table 4 - Scope section results

The variable *Intentionality* defines a project "direct" in case it applies intentionally one or more circular strategies (9 Rs), to differentiate that project from others that apply blockchain to manufacturing processes and improve those in a sustainable direction. This is a key variable to categorize the projects based on the relation with other variables in next sections. In this first analysis, we can notice that the 56,4% of the projects is directly involved in circular manufacturing.

For each project, it was possible to select a maximum of three circular strategies between the framework of the 9 Rs, if more than three where applied the project fell under the category "General".

All the projects have been classified under at least one circular strategy, also if the project wasn't directly applying the strategy. As it is possible to see from the descriptive analysis of the results (Chart 13) the most common strategy is "Reduce" implemented by 41,25% of the projects. This has been explained later, but the reasoning is related to more opportunities within this area of action. In fact, Blockchain simplifies supply chain and creates a more efficient, transparent, and trustworthy system, able to reduce the waste burden globally. (IBM)

The second strategy with more incidence is "Recycle" with 21,25%: Agora Tech Lab tries to value waste while supporting cities and packaging manufacturers or other waste disposal organisation in creating a cradle-to-cradle resource economy. Once again, the blockchain is used to compensate consumers for appropriately recycling their waste (e.g., packaging).

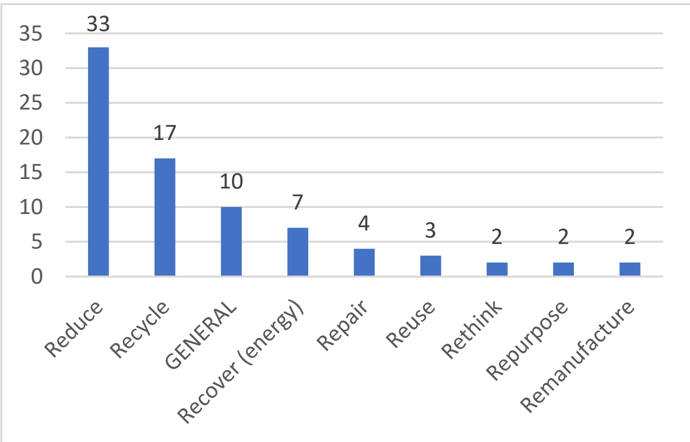

Chart 13 – The 9R's Framework

The *Circular economy pillars* (Chart 14) are a less strict categorization compared to the 9R's.

The first pillar "Preserve and enhance natural capital" was selected when the focus of the projects was on the upstream part of the value chain, connected to designing the whole system in order to use new materials and technology which can help in preserving nature (e.g., renewable energy, recycled products).

The second pillar "Circulating products longer and at their highest utility", - shortened as "Cycling longer" - instead, focus on products in their usage phase already on the market and on how those could be designed to be re used, repaired or remanufactured, so that they don't become waste.

The last one, "Design out negative externalities", takes in consideration that after cycling within the system some products may become actual waste. The improvement here is on the last part of the supply chain, to avoid polluting or incorrect disposal of materials.

The purpose of Circular Economy is to design products and processes in the respect of all three pillars, but in practice some projects (58% of our sample as in Chart 14) started with the improvement on a single part of the supply chain. The results show how the most diffused application of blockchain is in the upstream process of preservation of natural resources, where the technology is used to track back provenance of products guaranteeing their sustainability.

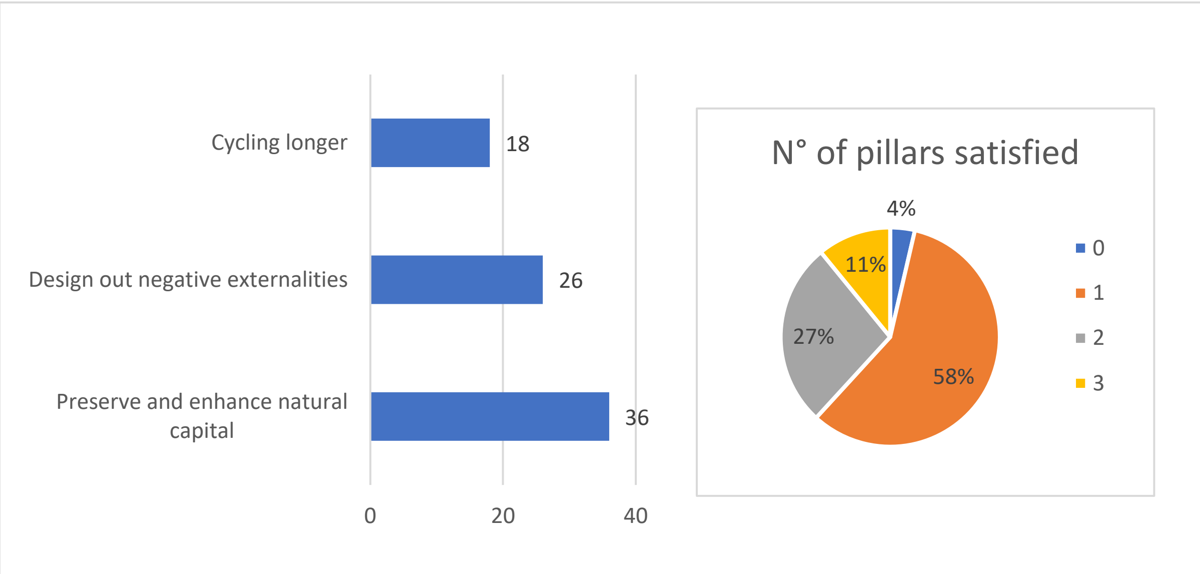

Chart 14 – Circular economy pillars (A. Count; B. Number of pillars satisfied)

There are also some projects working to implement blockchain to improve all along the three pillars, such as Circular Crowd Production Platform and Covestro.
Circular Crowd Production Platform aims at creating a net of SME in other to reduce the impact of producing building in a rapid urban growth environment: the project provides a pathway to systemic change, creating a blockchain-based system of suppliers to optimize materials usage, recycling of materials, while reducing wastes and CO_2 emissions.

Covestro is instead trying to design plastic products which can last longer, through treating the wastes of a resource, not to be discarded, but reinserted in the manufacturing process. This company represents an innovative material supplier for Porsche: the idea is to manage trust by creating a virtual "digital twin" in blockchain for each batch of material, carrying all relevant information. Transparency can guarantee the quality and sustainability of material composition as well as support in closing the loop.

In the Chart 15, the occurrences of the different circular actions undertaken in the projects have been reported, classified according to the *ReSOLVE model*.

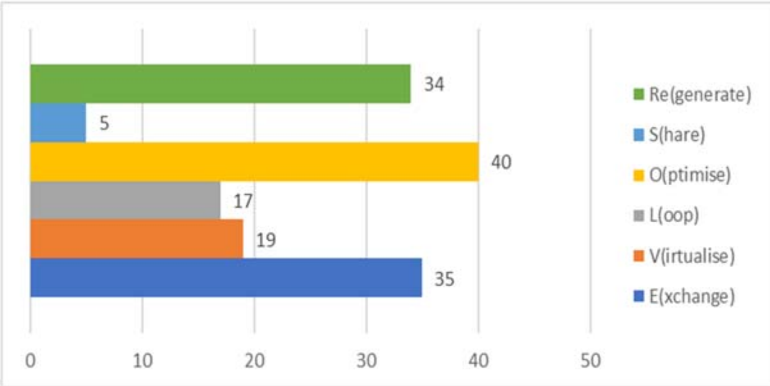

Chart 15 – ReSOLVE framework

Each project could apply one or more actions: e.g., Plastic Bank is classified as "Regenerate" since the project aims at stopping ocean plastic, creating a recycling ecosystem, reducing the need for virgin plastic materials; and "Loop" since they reprocess materials from reintroduction into the manufacturing supply chain.

While the *Nationality* of the project or of the company was a non-relevant variable, the results from *Area of interest* show how most of the project point to a geographically wider area, resulting in the 65% of the projects trying to impact worldwide. (Chart 16)

This result is not surprising, once connecting the purpose of the projects with the bigger purpose of the Agenda 2030, to reach the 17 goals in all nations and every sector: blockchain's characteristic of openness (and possibility to be replicated) becomes an enabler to the object.

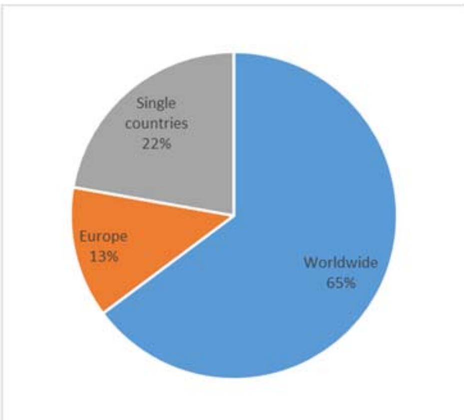

Chart 16 – Area of interest of projects

ChemChain project is funded by European commission, but it supports the creation of an open-source global blockchain platform to transfer information on hazardous chemicals along

the value chain.
Other projects though, despite the fact they are implemented in one single country, they have the potential to be replicated and become international.

4.1.4 Technology details section

Data under this section have been collected to analyse the projects under the blockchain perspective.

	Variable	Results obtained	Comment
Technology details section	Platform Name	55/55	Hyperledger Fabric (41%); Ethereum (27%)
	Uses of Blockchain	130/55	Chart 17 and 18 - Uses of Blockchain
	Token	55/55	36,4% of projects use token
	Cryptocurrency	55/55	34,5% of projects use cryptocurrency
	Other technologies	21/55	Chart 19 - Integration with other technologies

Table 5 – Technology details section

The variable *Uses of Blockchain* represents the core of the research: it describes the main reasons blockchain is being applied into the project. The variable comprehends five categories of blockchain features and for each project it was possible to select one or more of these.
The most used blockchain features in the projects are reported in a ranking of occurrences in Chart 17.

"Transparency", a broader concept of traceability, is overall the most diffused *Use of blockchain* within the projects selected: 45 out of 55 exploit the trait to enable CE strategies

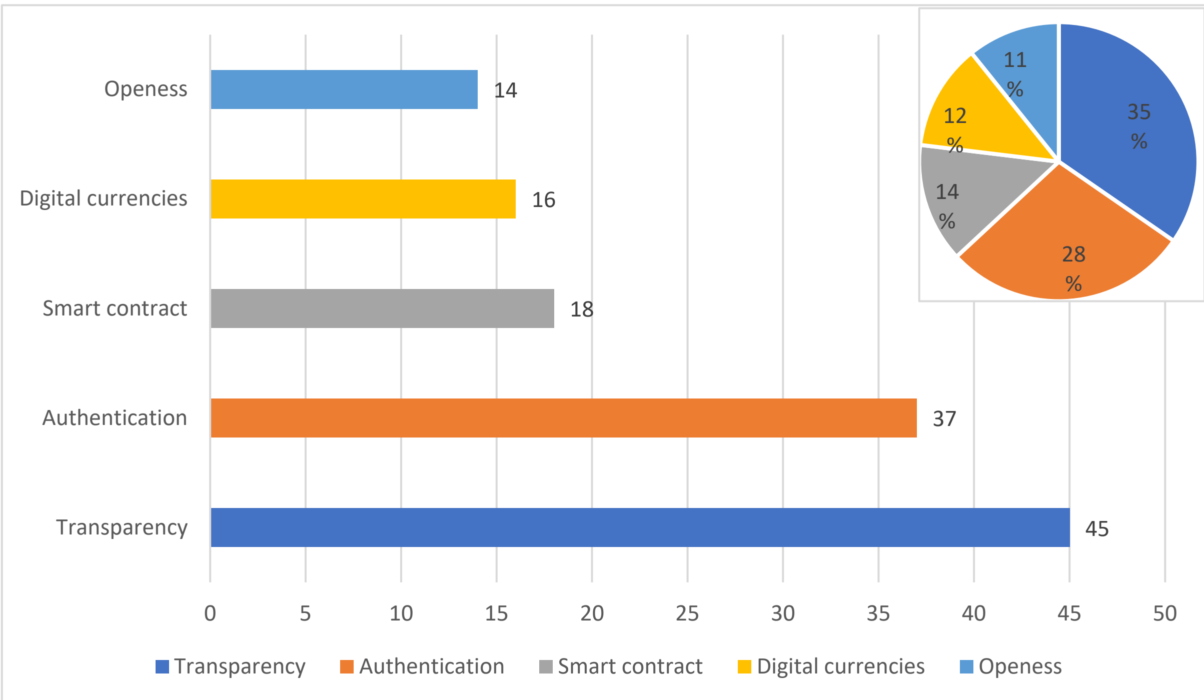

Chart 17 – Uses of blockchain (single)

within their project. This result finds confirmation with the literature.
“Transparency”, through the tracking of each movement, exchange or change in the tracked good, can guarantee the commitment of the suppliers and provide trust in the client. Correct information along the whole supply chain represents a driver for the circular economy to become feasible both economically and environmentally. For example, if we consider recycling processes false information about substances is not only costly but also potentially dangerous.
In the real manufacturing cases, the application of “Transparency” occurs in the form of *real time data, reduce recall time, reduce uncertainty, visibility on wastes, trace and control each production step*.
“Authentication” is another relevant characteristic, in the form of digitalization of information and goods, through the creation of digital twins and NFTs. This technique, enabled by cryptographic signatures, permits the receiver of a digital file to be sure that no one single bit of the file has been changed, creating what can be imagined as a “digital object”. Examples of authenticator providers for files and NFT platform are (Swiss Blockchain Consortium) and (Opensea). In projects analysed by our research that uses “Authentication”, the creation of “digital objects” is present and is applied to materials and information.
In the real manufacturing cases, the application of “Authentication” occurs in the form of *guaranteed quality standard, sharing of digital products and reduce counterfeit products.*
“Smart contract” facilitates and automates the exchange of goods removing a third-party actor. The use of smart contract appears, as further highlighted in Chart 17, in projects that integrate different businesses and large-scale projects. An example of intensive use of smart contract is (Fetch.ai) a project that aims to facilitate the development and management of smart contract for businesses.
In the real manufacturing cases, the application of “Smart contract” occurs in the form of *remove third party actors, KPI based automatic purchase and contract digitalization.*
“Digital currencies”, exchanged directly on the blockchain, are a perfect integration of smart contracts, as a form of payment, to execute an exchange. In the projects selected they are often used as financing tool, working like stocks in the financial market or like engagement tool to leverage on shareholders’ behaviours.
The application of “Digital currencies” appeared in the projects as: *engagements tools*, *native platform payments*, *efficiency of transactions, governance tools and financing tools*.
For what regards “Openness”, it points to a system where data are shared among participants but with cryptographic security. Among the analysed projects, the application of “Openness” has been found in the forms of *sharing of data and documents and reducing the bullwhip effect*.

The definition of this variable is developed from adapting the key characteristics of Blockchain to the manufacturing strategies: for this reason, despite the relevance of understanding the occurrences of each single result, it emerged that the projects adopted blockchain to exploit

two or more features in combination, as shown in Chart 18.
"Transparency and authentication" result to be more adaptable to the manufacturing purposes. To facilitate our discussion, we use an illustrative example: TextileChain.

Blockchain is applied to textile industry to certify ethic and social responsibility: the information related to each product are digitalized and immediately available to all the actors within the supply chain (authenticated by the network) and are standardized and accessible. "Transparency" is used to gain consumers' trust, while showing how production processes have followed circular processes, reducing resources and wastes.

On the other hand, "Digital currencies and Smart contracts" are often used in a combined way: the manufacturing industry is actually transitioning towards more circular practices, and the implementation of blockchain can contribute economically to the feasibility and sustainability of the project itself.

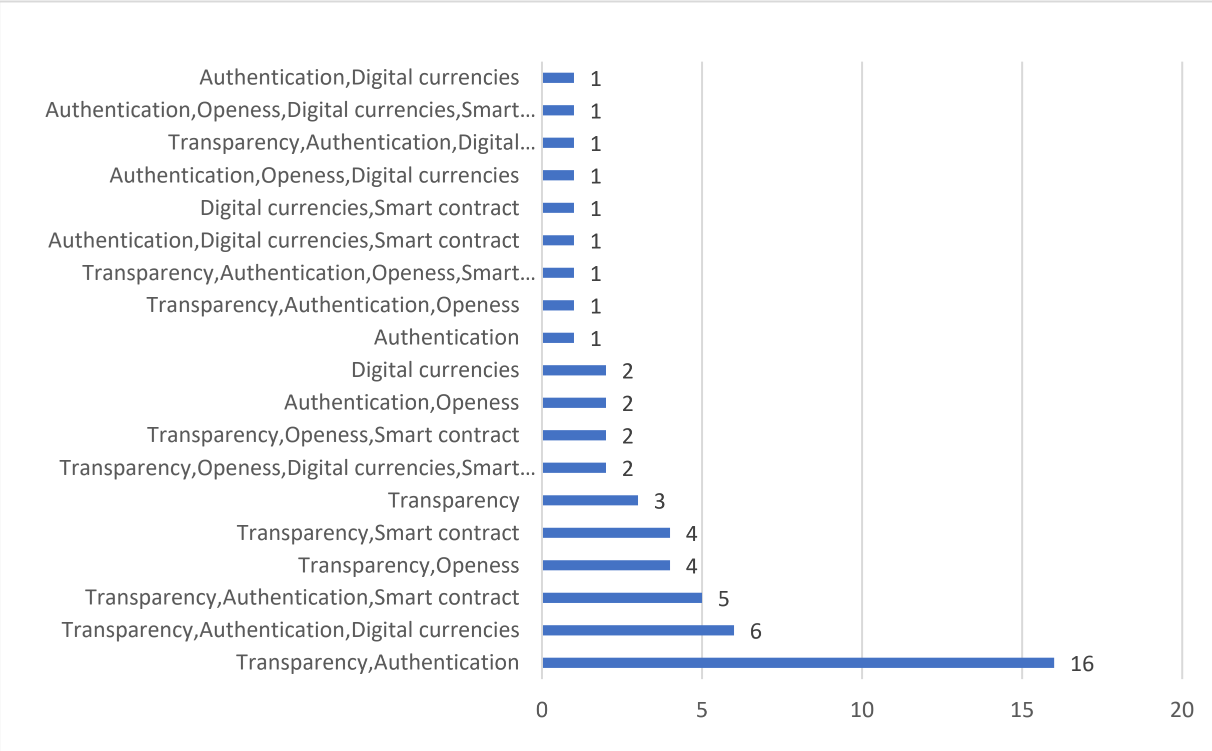

Chart 18 – Uses of blockchain (combination)

As specified at the beginning of this chapter, the blockchain technology is a tool particularly important as integrator of different realities and different technologies. Thanks to the features of security (due to immutability) and transparency in sharing of data, it can be used in combination with other I4.0 technologies to foster circular manufacturing.
The last variable of the Technology details section takes into account this aspect and reports an indication of how many projects are integrating I4.0 technologies in their development.
Only 21 out of 55 projects apply blockchain technology in combination with another Industry 4.0 technology: among those, "Internet of Things (IoT)" is the most predominant (Chart 19).

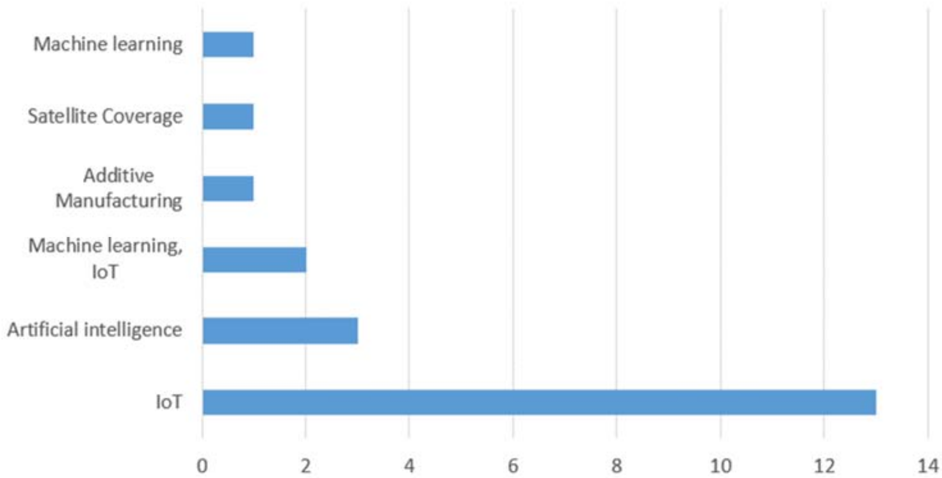

Chart 19 - Integration with other technologies

The reason relays in the characteristics of the technologies.
Internet of Things (IoT) refers to a system of interrelated, internet-connected objects that are able to collect and transfer data over a wireless network without human intervention. The manufacturing industry is exploiting those features in order to collect data about production of their products (in terms of materials and process) and to prevent failures in processes. (Christidis and Devetsikiotis, 2016). The blockchain enters in the picture promising to make the interconnected communication more secure and less consuming.
Within our sample, Walmart with IBM uses IoT-enabled blockchain to store the temperatures, position, arrival times, and status of shipping containers as they move. Immutable blockchain transactions help ensure that all parties can trust the data.

It is important to declare that this variable aims only to indicate how many projects use two or more technologies in a combined way, without including those projects which may use blockchain and another Industry 4.0 technology in two different extents.

4.1.5 Impact

The last section of our research envisages providing an overview of environmental, economic, and social impact of the projects. This section was introduced since meaningful discussion of the possible contribution from blockchain to the circular economy with regards to the three dimensions of sustainable development is lacking. (Böckel, Nuzum and Weissbrod, 2021)

To do so we followed the approach of (Chardine-Baumann and Botta-Genoulaz, 2014), dividing each dimension in 5 sub dimensions. For each sub-dimension we gave point ranging in a scale from 0 to 2: 0 in case the initiatives don't impact that sub-dimension, 1 if the impact achieved is only a positive externality or 2 if the impact is achieved intentionally by the project. The main three dimensions result from the sum of the different sub-dimensions inside it.

With the support of some projects, the following paragraph aims at explaining how the framework has been used. (Table 6)

Project Name	**Economic**	**Environmental**	**Social**
GreenTrack	**4**	**8**	**8**
PestNu	**8**	**10**	**2**

Table 6 – Examples on Impact

Both projects are highly focused on their environmental performance, in fact Pestnu works on how blockchain and other digital technologies can reduce pesticides and fertilisers use, therefore impacting all the subfields (environmental management, use of resources, pollution, dangerousness and natural environment), while GreenTrack is a blockchain platform, which provides the customers end-to-end visibility of forest to fashion, guaranteeing the application of more conscious extraction and closed loop processes.

Regarding social responsibility instead, the project based on GreenTrack declares to be more involved in fair trading and to care about customers issues (providing transparent and authentic information); on the other hand, Pestnu implements different strategies focused on improving responsiveness of the system as well as quality of the service provided, to improve the economic results of the company.

The approach, despite being qualitative, gave a good classification of the impact in the triple bottom line of each project.
The considerations begin from the establishment that Blockchain protocol, as well as other investment in digitalisation, provides opportunities to achieve sustainable economic growth while preserving the environment and being socially responsible. (Upadhyay et al., 2021)

Table 7 summarises the results of the analysis in terms of average points: the following explanation provides an understanding of the impacts, but for further discussion the focus is on economic contribution, environmental performance, and social responsibility only.

Table 7 is needed to clarify the collection results.
The three factors with highest ratings are *Reliability*, *Use of resources* and *Quality*.

Main dimensions	**Sub-Dimensions**				
1: Economic	1.1 Reliability	1.2: Responsiveness	1.3: Flexibility	1.4: Financial Performance	1.5: Quality
6,62	1,67	1,38	1,05	1,05	1,45
2: Environmental	2.1: Environmental Management	2.2: Use of Resources	2.3: Pollution	2.4: Dangerousness	2.5: Natural Environment
5,96	1,36	1,62	1,13	0,95	0,91
3: Social	3.1: Work Conditions	3.2: Human Rights	3.3: Societal Commitment	4.4: Customer Issues	5.5: Business Practices
3,69	0,55	0,53	0,85	1,02	0,75

Table 7 – Impact section results

These results are in line with the notions from literature review: in fact, integration of blockchain technologies in circular manufacturing leads implicitly to the above-mentioned benefits.
Tracking systems, immutability of transactions and smart contracts, intrinsic to the blockchain, can lead to improvement in many sub-fields of *Reliability*, such as reliability of stocks and forecast.
Moreover, traceability is a driver for high Q*uality* standards since it enables – combined with transparency – to guarantee production quality and quality performance of suppliers along the whole supply chain. (Chakrabarti et al., 2019)

It was mentioned that Reduce is the most diffused circular strategy adopted. This is confirmed from the points given to *Use of resources*, in which it was evaluated how the initiatives are working on resources reduction and efficiency of their supply chain. Once the blockchain is able to solve the lack of information and eliminate the asymmetry among partners, it enables these actors to balance their need and reduce the "bullwhip effect" (e.g., in inventory management).

The two least affected aspects are W*ork conditions* and H*uman rights*: it is an appropriate consideration to make that most of the projects describe and focus their statement on environmental performance and economic sustainability, without explaining how they tackle social issues. This cannot imply that their social duties are disregarded.

Figure 15 presents the aggregated results, with the focus on the three dimensions: Environmental, Economic and Social sustainability.

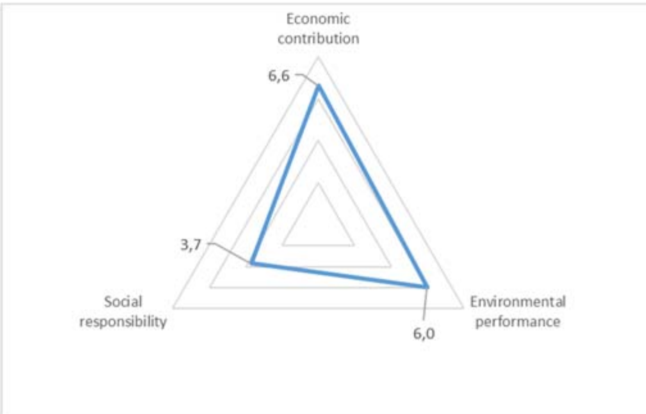

Figure 15 – Impact results on the Triple Bottom Line

About environmental sustainability, the first element to mention is the possibility to trace products from "cradle to gate", in order to reduce carbon footprint and unsustainable practices. Blockchain makes sure green pledges are not just greenwashed, since it guarantees transparent and immutable date. (World Manufacturing Forum, 2021)
Then, rewarding programs can increase people motivation to participate in recycling programs: the exchange of rewards (tokens) is faster and permanently recorded, encouraging

and leading to more environmental sustainability.
When blockchain is used to analyse and monitor energy consumption or quality and safety of products (e.g., food), it helps reducing pollution and dangerousness of materials. (Chardine-Baumann and Botta-Genoulaz, 2014)

(Saberi et al., 2019) speculates that blockchain in supply chains will more effectively manage economic and environmental sustainability rather than social sustainability. It is more complex to highlight the social benefits achieved in the supply chains that use blockchain, which doesn't mean that those benefits don't exist.
A correct blockchain-enabled supply chain helps in guaranteeing human rights, detecting unethical behaviour or health and safety issues in the workplace. (Varriale et al., 2020)

4.1.6 Descriptive analysis considerations

Summarizing the consideration from the first descriptive analysis:

- Projects analysed are "new". 42/55 have been founded in the last 3 years.
- There are two main categories of projects: on one side manufacturers directly integrating circular manufacturing strategies in their processes and on the other technology providers that try to help manufacturing companies to integrate new digital and circular strategies.
- Overall, 56,4% of projects are "Directly" implementing circular strategies.
- The projects tend to be wide in scope. Three variables detect this trend: integration among different industries at almost 80%, "Meso level" or "Macro level" of *Implementation scale* together at 72,8% and *Area of interest* for 65% of project being "Worldwide".
- 49,8% of the projects analysed is operating, others are in earlier stages.
- "Transparency" - often enabled by tracking with IoT technology - is the most used application.
- From a qualitative value driver analysis about the projects, the "Economic" dimension is the most relevant.

4.2 Analysis of variables interaction

From now on, the analysis is focused on the interaction between two or more variables. The aim is to understand other qualitative characteristics of the projects selected. Finally, the results combined help to create a framework to describe the state of the art of blockchain-enabled projects in circular manufacturing.
The implementation of the Circular Economy within the projects has been translated into different frameworks: the *9R's*, *ReSOLVE* or the *CE Pillars*. Among the different frameworks, the most significant one has been further discussed.

In the image below (Figure 16) an overview of the results obtained until now, and the future research steps are summarized.

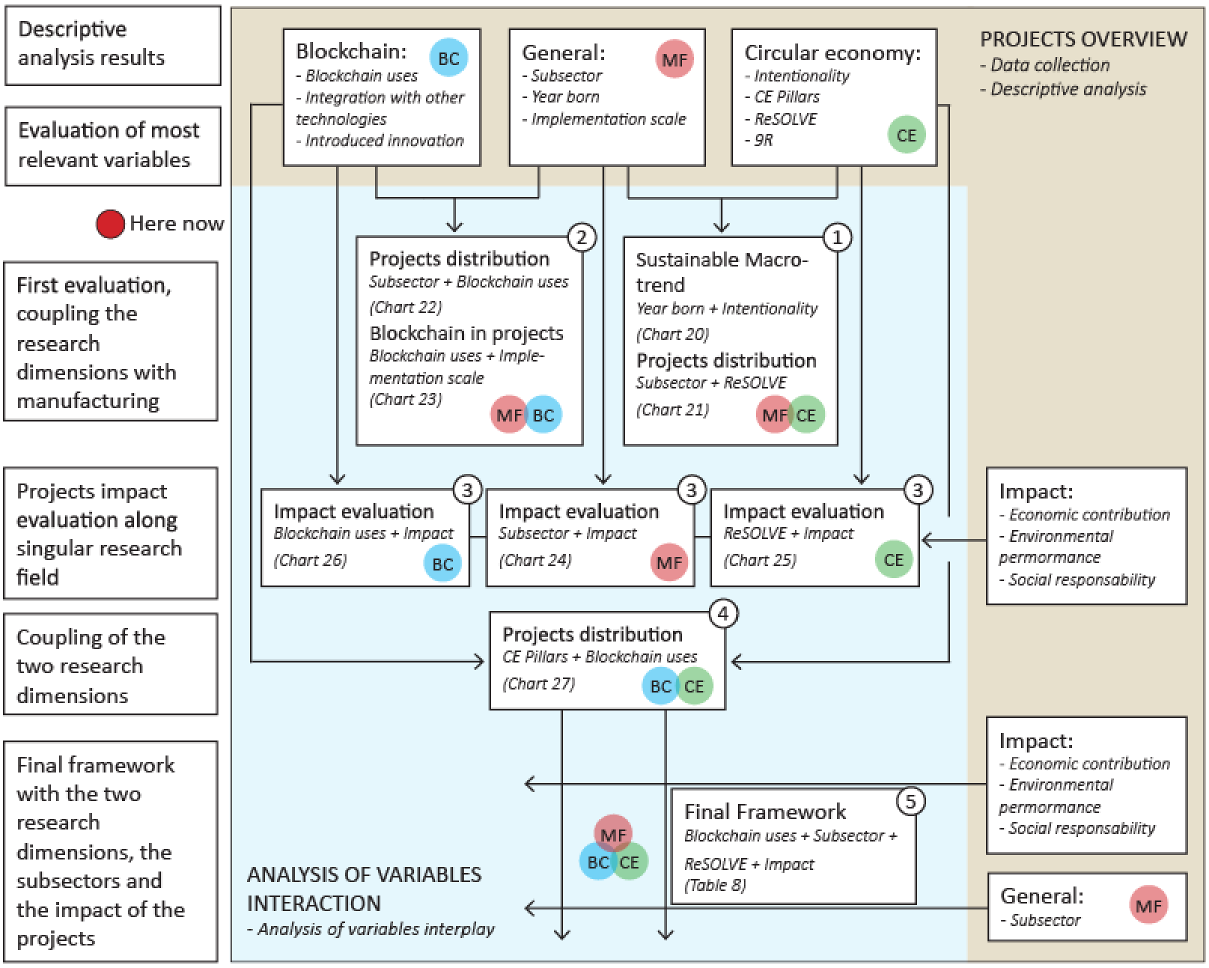

Figure 16 – Description of future analysis

Manufacturing and Circular Economy interaction

The first interesting element to analyse is the result coming from the intersection of the variables *Born Year* and *Intentionality* that shows a direct or indirect application of circular strategies in the project. In the last years there is an inversion on number of projects directly implementing circular economy strategies compared to the past years. (Chart 20)

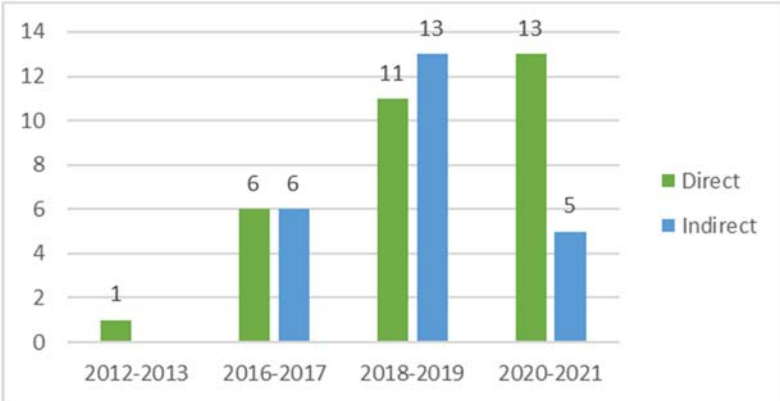

Chart 20 – Born Year and Intentionality

Being our sample size non statistically relevant, to confirm this trend is necessary to refer to external sources and highlight that the number of financing activities to support those type of initiatives has increased overall (e.g., European Commission Horizon 2020).

Chart 21 and Chart 22 summarize the dispersion of the initiatives according to their *Subsector* and the *ReSOLVE framework*, and then according to their *Subsector* and *Uses of Blockchain*.

As seen in the descriptive analysis, Section 4.1.1, the manufacturing industries in which the majority of initiatives was found are the "Food production", "Petroleum, chemical and plastic" and "Clothing and Textiles". "General" subsector comprehends a number of projects aimed at improving the manufacturing sector along their supply chain without being focused on just one subsector.

For what regards this last category, along the *ReSOLVE framework* we can notice a high presence of projects aimed at "Optimize". This is in line with the nature of the projects that try to improve the overall manufacturing supply chain. Some examples are Mangrovia, Circular Tree and Vestigia Blockchain. They are process optimizers and don't focus on a single manufacturing subsector.
Vestigia blockchain uses blockchain to create a scalable platform adaptable to any company, though their experience is in industrial sectors, health, and agri-food. The platform is based on smart contracts to control production and automate the decision process, saving costs and errors: this project supports other companies implementing circular economy, through the reduction of wastes and operational risks without changing product or technology.

For what regards the “Food production” the projects found are categorized under three main circular actions: “Regenerate”, “Optimize” and “Exchange”. This categorization contains projects as Walmart that is changing its technology to foster efficiency and it now uses IBM Food Trust to trace some of their products all along the supply chain. The time needed to trace a product is optimized to few seconds, from 2/3 days, while the product, transportation and environmental impact is now traced and kept under management.

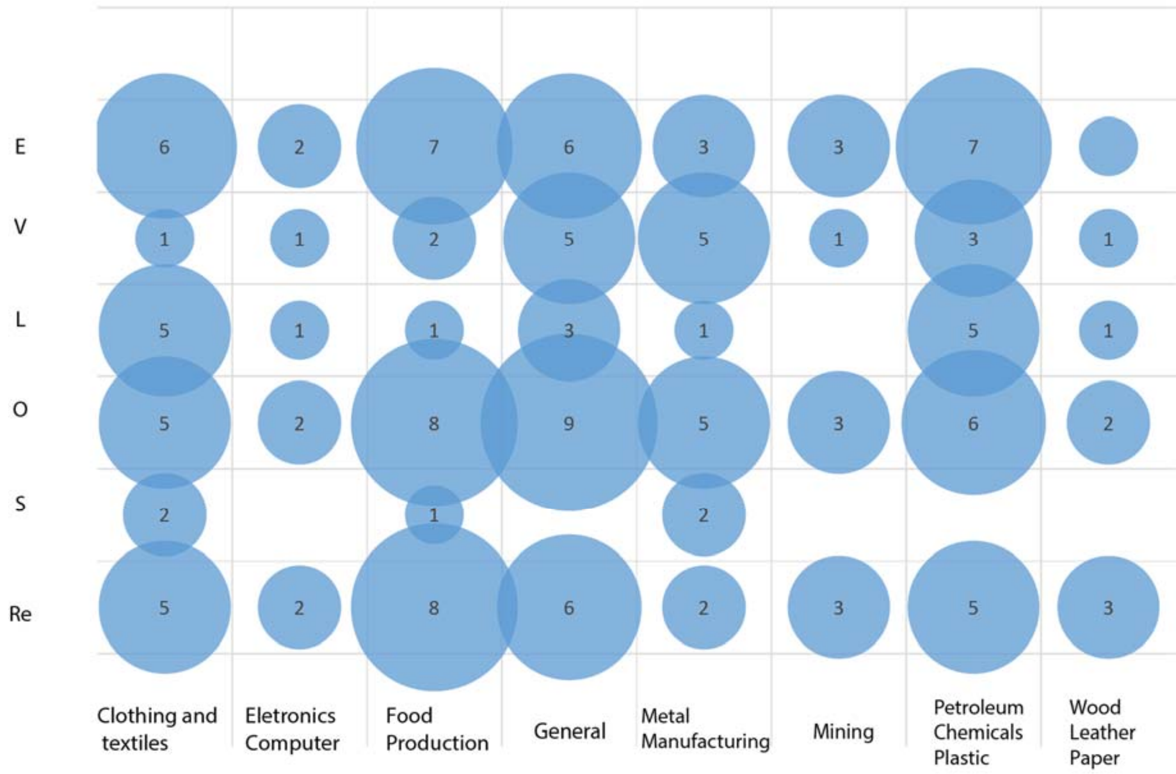

Chart 21 – Subsectors and ReSOLVE framework

A second example, categorized under Re (Regenerate) and O (Optimize), is ConnectingFood. This project tries to optimize the food production supply chain of third-party food manufacturers and uses the technologies installed to certify for the environmental sustainability of the products (Regenerate).

The third category by density of projects is “Petroleum, Chemicals and Plastic” where the practices implemented by projects are well balanced between all the circular strategies of ReSOLVE model but “Share”.

An example that implements all (Re,O,L,V,E) strategies is Covestro. Their objective is to use alternative raw materials and renewable energy (Re), to introduce innovative recycling technologies in order to optimize the recycled materials while using them again (O, E, L), and joining a global cross industry circular strategy by exchanging authenticated information and digital twin of plastic for car manufacturers.

The subsector of “Clothing and textiles”, fourth by number of projects selected, is well distributed between “Regenerate”, “Optimize”, “Loop” and “Exchange”. Representative

projects under this category are Footbridge and Herewear. The latter is categorized under all of the principal circular strategies of the subsector (Re,O,L,E).
Herewear, a project under financing by the European Union Horizon 2020, innovates the clothing industry through empowering local, circular and bio-based textiles. They introduce new material solutions, processed with sustainable technologies, and create a network of micro factories. Blockchain, providing full transparency and verification of the sources, is used for the creation of a digital twin: it is implemented in order to support both use phase and end-of-life processing (repair, re-use or recycle).

Manufacturing and Blockchain interaction

The following Chart 22 shows the dispersion of features of blockchain-enabled projects according to different "Subsectors".
From the selected projects, the most used blockchain features are transparency and authentication, followed by the other three features with similar results. Those features are used among the different subsector in different ways. Some of them are analysed.
"Food Production" highlights the clearest use of the technology by transparency and authentication features. The use of the two combined is for the food industry a way to: easily recall products through transparency of the goods movement, valorise the product by certifying the provenance and manufacturing process by authentication of goods and immutability of the blockchain (Batwa and Norrman, 2020). An example is presented by Provenance Project. Its aim is to give proof of provenance to the products of a food producer brand and to trace the items in order to help understanding their social and environmental impact.

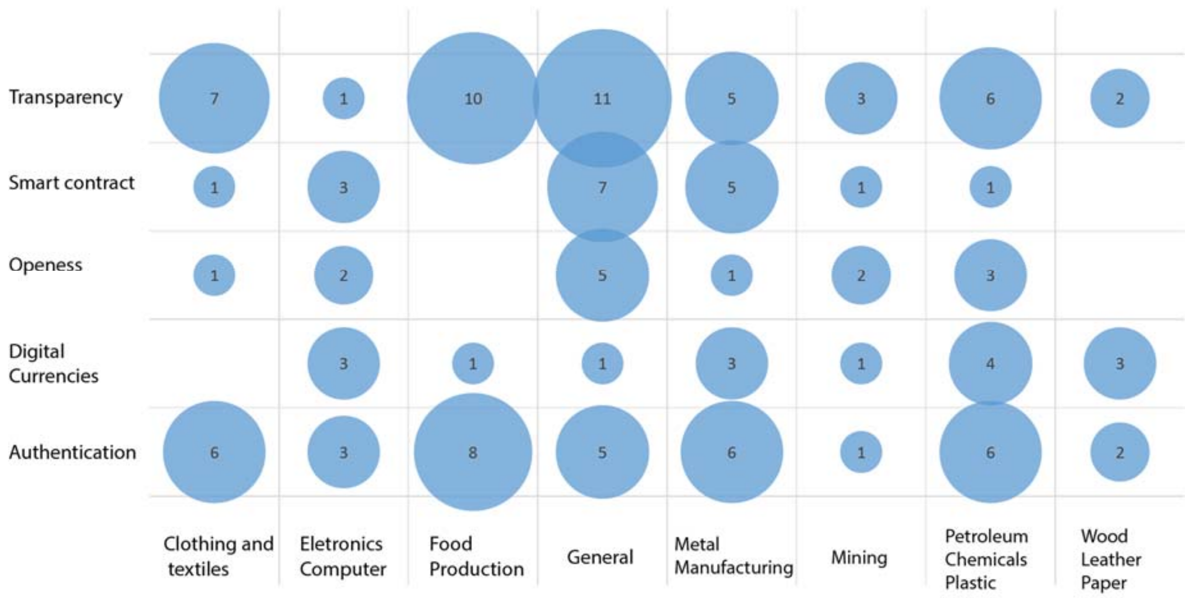

Chart 22 – Subsector and Uses of Blockchain

The results for “Clothing and textiles” are similar to the one of “Food Production”. In fact, the blockchain functions most applied for the “Clothing and Textiles” industry are “Transparency” and “Authentication” especially when the blockchain is implemented at supply chain level.

Those attributes allow for real-time information visibility from a trusted source of data (Batwa and Norrman, 2020).

“General subsector” projects rely as well on transparency and authentication, that are the most versatile, but they introduce an intensive use of smart contracts. The application of “Smart contracts” is strictly connected with the nature of the category that comprehend projects that implement circular approach in more than one manufacturing subsector, often in support of supply chain management. In fact, “Smart contracts” are highly employed to optimize the processes and automate exchange of products and goods without a third party (Upadhyay et al., 2021). An example is represented by Mangrovia, a blockchain solutions platform, which integrates smart contracts resident and active on a blockchain to guarantee greater security and certain enforceability, enabling consistent operational efficiency and automation.

“Metal manufacturing” relies as well on the use of “Smart contract and authentication”. Inside this category, a good representation is Smart MFG. Their proposal is a platform where sharing of 3D metal part piece for manufacturing is possible through the tokenization of the prototypes and the smart contracts to manage copyright management and royalties for the producer.

Another way to analyse the intersection between Manufacturing and Blockchain is through Chart 23. Given the majority of projects implementing circular strategies at “Meso level” (Section 4.1.2, Chart 11 – Implementation scale), which means that the project is developed within a network of firms or along a supply chain, Chart 23 highlights the relative importance of *Uses of Blockchain* according to the *Implementation scale*.

Understanding what happens at “Micro level”, none of the projects in our sample is exploiting the benefits of blockchain deriving from “Openness”. This result is explicable by the fact that, blockchain as a distributed ledger accessible, requires computational power to be accessible to anyone, and when the blockchain is implemented in the contest of a single company this may not be necessary.

On the contrary, at both “Meso” and “Macro level”, “Openness” becomes more relevant. At “Macro level” in fact, when circular strategies are used to create new regulations among nations, Openness of blockchain enables different actors to access all the information, in a secure way. With the support of “Transparency” - being sure the document is signed originally from the source and has gone through a clear and available path- “Openness” gives the blockchain the proprieties to help in regulating international scale projects. Many scientific papers analyse the uses of blockchain for the governments where the aim is to use blockchain as regulatory framework between nations to validate national certificates (e.g., vaccinations, professional qualifications, biometric Identity).

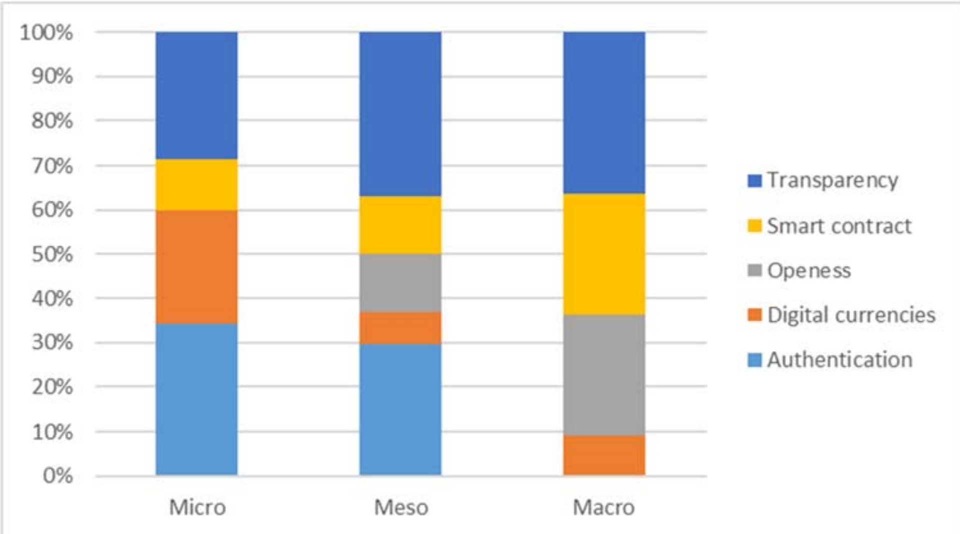

Chart 23 – Uses of Blockchain and Implementation Scale

Triple bottom line Impact

In the Section 4.1.5, the discussion revolved around the environmental, economic and social impact of the projects. Using those results, the purpose is to understand whether there are some differences according to the three main topics of this paper: Manufacturing, Circular economy and Blockchain. In the this context we used *Subsector* (Chart 24), the *Uses of Blockchain* (Chart 26) and the *ReSOLVE strategy* (Chart 25).

Due to the limited size of the sample, the considerations reported are only the ones confirmed by the literature.

The first chart presents how impacts along the triple bottom line changes according to the Subsectors: from Chart 24, it is possible to draw some meaningful considerations, which means that the effect of applying blockchain to circular projects varies in different subsectors.

In the “Food Production” industry, blockchain can help in the three dimensions. Under an economic point of view, blockchain empowers the food industry by reducing transaction costs and intermediaries. (Forbes, 2021)
More value comes from information symmetry between customers, producers, and suppliers: this value is translated in economic contribution and improved working conditions for the producers, and in quality and interest in customer issues. (Deloitte, 2019)

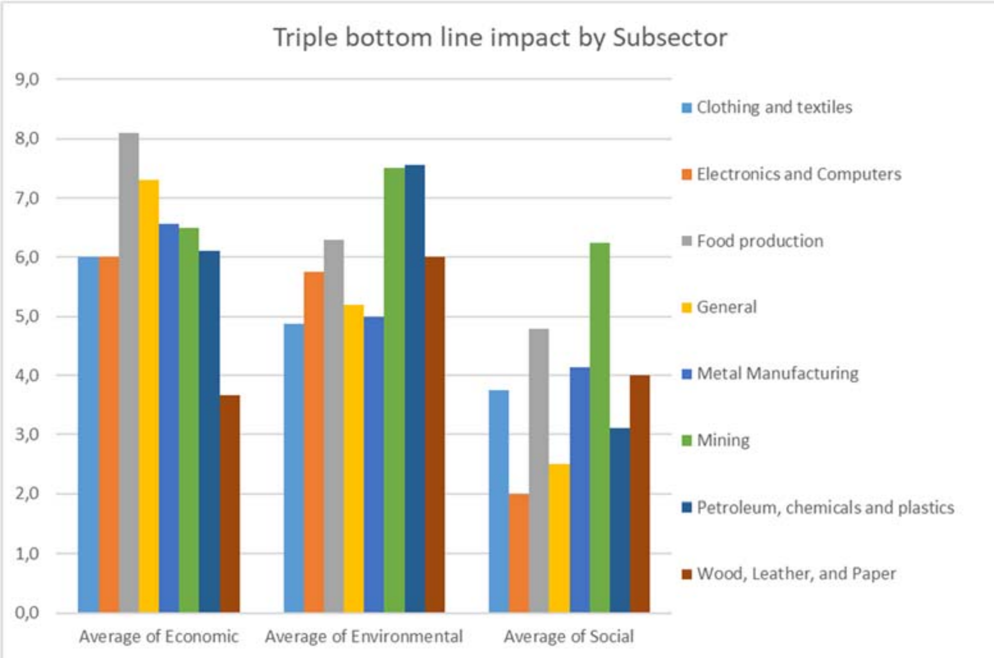

Chart 24 – Triple bottom line impact by Subsector

From a supply chain perspective, blockchain helps to ensure efficient and trusted transactions while simultaneously enhancing traceability and recall capability, aiding food safety and the rapid identification of potential food fraud, counterfeits and other forms of illicit trade (Rejeb et al., 2020).

For other industries, such as the “Petroleum, Chemical and Plastics”, more interest is attributed to the environmental impact. While those materials have an important share in our economy, they can have serious negative effects on the environment and human health. (European Union - Plastic strategy, 2020), so alongside with profitability of the recycling business, blockchain is implemented to boost and incentivize the recycling process.
It was mentioned that it is more complex to highlight the social benefits achieved in the supply chains that use blockchain, but in some industries, as the “Mining” one, it is strongly declared how transparency is used to guarantee better working condition and business practices of workers.
There is in fact the need for some subsectors more than others, like the last two discussed, to devise means of incorporating the circular economy pillars into activities, to ensure that the environmental degradation and lower social responsibility commonly associated to those

sectors are duly considered and minimised in the process. (Ogunmakinde, Sher and Egbelakin, 2021)

The Impact dimensions analysed according to the ReSOLVE model do not provide any meaningful result. (Chart 25)

In Chart 26, we can see how blockchain is not a good classifier for the impact of a project, this result is reasonable due to the fact the blockchain does not define the project, but instead it is utilized as a tool.
In fact, the different *Uses of blockchain* are not differential in their impact on the Environmental dimension or the Social one (Chart 26): about the Economic contribution of blockchain, it is possible to notice how projects in our sample adopt "Digital Currencies" as a way to create an ecosystem and to influence greener behaviours of consumers rather than increasing the economic impact of the projects.

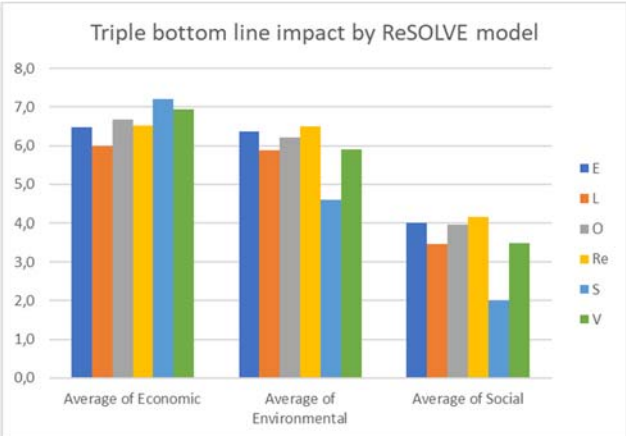

Chart 25 – Triple Bottom line impact by ReSOLVE

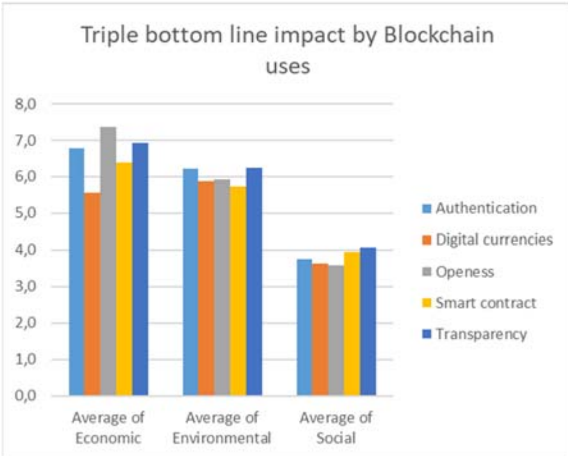

Chart 26 – Triple Bottom line impact by Uses of Blockchain

Within the literature, Cryptocurrencies are designed to be used as an alternative to real currencies that, among other things, could capture and monetize currently unrealized economic value and sometimes they are used in a speculative way: the divergence from our result can be - in part – ascribable to the circular nature of the projects in the sample, in which the economic value is used to achieve the environmental objective.

Now, that the relations between the subsector, blockchain, circular strategies and triple bottom line have been analysed, we have a clearer picture on the projects collected.

The aim of our study is to describe blockchain technology's current contribution to the circular economy in the Manufacturing industry: fixed the variable of manufacturing – since all projects belong to this industrial sector – the projects have been interpreted according to the blockchain's feature and the circular economy dimension through the Circular Economy pillars.

Blockchain and Circular Economy interaction

The projects disposed along circular economy pillars (Chart 27**Error! Reference source not found.**) confirms what appeared in the (Chart 13 – The 9R's Framework) where the concentration is higher upstream of the supply chain and downstream. Projects selected often implement blockchain technologies to connect the upstream and downstream part, but the presence of projects directly involved in "Cycling longer" practices is less relevant. A reason behind lower projects in the middle of the value chain is related to newness of subjects and therefore less regulations of practices as sharing or remanufacturing.

Although not studied within this discussion, Blockchain has the potential to benefit remanufacturing: blockchain can bring transparency and avoid the risk of counterfeit products, to guarantee the security and reliability of knowledge sharing (Li et al., 2021). Under a circular economy perspective, remanufacturing has a vital role in promoting practises of making used products as good or better than new, while saving materials and reducing impact on environment. Blockchain can boost these benefits while reinventing Remanufacturing.

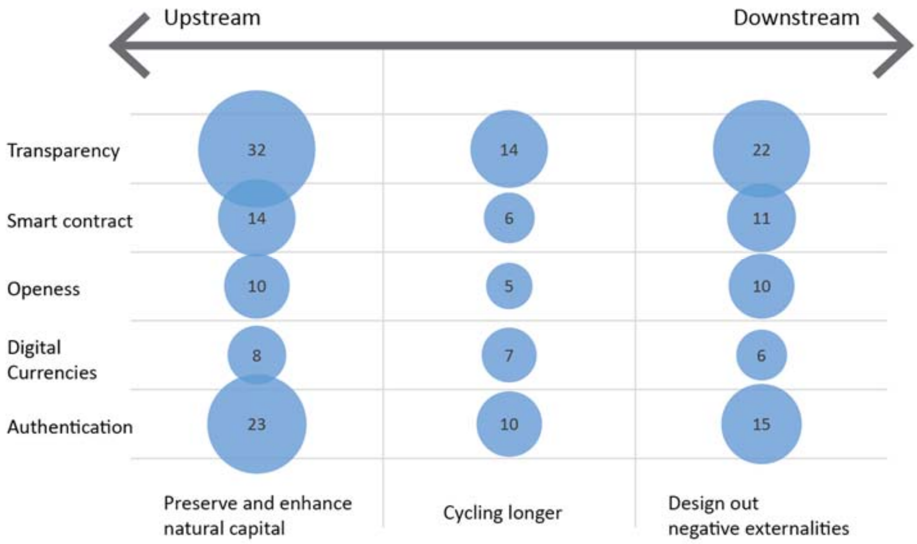

Chart 27 – Distribution of Projects according to Uses of Blockchain and CE pillars

For what concern sharing as a circular strategy, smart contracts can activate payments options as soon as a relevant KPI is meet reducing the uncertainty in the sharing process. Through authentication processes (Tokenization and NFTs) it introduces the concept of sharing of digital objects (E.g., The sharing the patents of a product).

In the database the projects have been classified giving them from zero up to three of the CE Pillars. During the descriptive analysis [Section 4.1.3] we described the characteristics of Circular Crowd Production Platform as an example of project categorized under all the three CE Pillars: now an overview of the blockchain perspective is given.

The Circular Crowd Production Platform project, as already specified aim at bringing together SME in the building sector around Berlin and integrate them in a unique platform. The platforms' aim is to fully manage the supply chain being open about information on wastes, energy consumption and innovation of building materials. The *Uses of blockchain* that the platform needs more are: "Transparency", "Authentication" and "Openness". In fact data sensibility to protect competitive advantage is a primary objective for the future success of the project. Data - in a platform of both vertical and horizontal integration like Circular Crowd Production Platform - need to be shared in a secure way and only with trusted nodes, this is achieved with "Openness". Another objective that Circular Crowd Production Platform wants to reach is reduction of wastes and energy used to produce materials and the blockchain feature that most can help is "Transparency", to both reduce overproduction and to maximize the use of recycled materials. Because the platform's aim is to share also innovative building systems the authentication by *Protecting and Monetizing Critical Intellectual Property* [Section 2.2.3] becomes an important feature that the project could implement.

The same analysis represented in Chart 27 has been performed combining the variable *Uses of Blockchain* with the variables *ReSOLVE* and *The 9Rs' framework*. Both graphs convey similar messages, thus those charts have not been reported in this work.

In the intersections between *Uses of Blockchain* and *CE Pillars*, some qualitative trends need to be highlighted.

- The high presence of "Transparency" and "Authentication" along the use of blockchain is relevant for all the intersection between the CE Pillars.
- As percentage of the project under each of the three pillars, "Digital currencies" are more relevant in the intersection with "Cycling longer". In fact, *Cryptocurrency* variable, indicating the use of a proprietary cryptocurrency inside a project, is used more frequently in the pillar "Cycling longer". The use of cryptocurrencies appears often as a reward mechanism to try to influence the stakeholders' behaviour. [Plasticbank, Ptwist]

Final framework

To conclude the analysis, the framework built is intended to give a final overview of the projects, answering the research question:

(RQ) *How can blockchain attributes enhance the sustainable performance of circular manufacturing?*

Table 8 summarizes the findings along the three fields of research reporting the common characteristics.
It gives, for each *Subsector*: a generalized example of project, the most diffused and relevant *Uses of Blockchain* and the most diffused and relevant Circular Economy actions (*ReSOLVE*) adopted. Uses of Blockchain and Circular Economy actions are listed in decrescent order of occurrences within the sample.
In addition, for each subsector it has been summarised how sustainability dimensions – environmental, economic and social - are impacted.

The main findings analysed in detail during the discussion are reported here with a qualitative approach: it useful to remind how the results are partial are referred mainly to the sample under consideration.
Nevertheless, blockchain can benefit circular economy practices across industries, but an important tension to consider is that blockchain is not a one-size-fits-all solution (Kouhizadeh, Zhu and Sarkis, 2020), since applications tend to vary.

The common benefits across the selected initiatives include blockchain delivering transparent and secure transactions and may regenerate resources, reduce intermediary costs, optimise efficiency of processes and responsiveness. Projects selected aim at improving the environmental performances, reducing negative externalities, while at the same time is clear how the economic contribution is a major concern to guarantee involvement and survival of projects.

	Most relevant *Uses of Blockchain*	Most relevant CE actions applied (*ReSOLVE*)	*Impact* over the three sustainability dimensions		
Sub-sector: Description of an example initiative [N = 55 projects]	**Out of 5:**	**Out of 6:**	**Eco:**	**Env:**	**Soc:**
Clothing and textiles: Creation of digital twins to certificate their standards and be able to recognise them at end of life. Track all the process and the transportation from the production to the customer. [N = 8]	Transparency Authentication	Exchange Regenerate Loop Optimise	M	L	L
Electronics, Computers: Creation of digital twins for electronic wastes to track them and optimize the recycling materials. Track the whole lifecycle for electric batteries. [N = 4]	Authentication Digital currencies Smart contract	Exchange Regenerate Optimise	M	M	L
Food production: Creation of digital twin to guarantee product authenticity. Track all the process and the transportation from the production to the customer. Collected data to show impact of production and product, certify provenance, time to market, reduce recall time. [N = 10]	Transparency Authentication	Regenerate Optimise Exchange	H	M	M
General: Facilitate the interaction between suppliers by activating purchases and sales by interacting with data coming from sensors and KPIs. [N = 10]	Transparency Smart contract Authentication Openness	Optimise Regenerate Virtualise Exchange	M	M	L
Metal Manufacturing: Create a platform where 3D manufacturing modelling can be shared and manages by the platform itself by the use of smart contracts. Create a platform for manufacturing pieces and build a marketplace to exchange them. [N = 7]	Authentication Transparency Smart contract	Virtualise Optimise	M	M	L
Mining: Built a universal material certificate that contains information about material, quality and sustainability standard. [N = 4]	Transparency Openness	Exchange Regenerate Optimise	M	H	M
Petroleum, chemicals and plastics: Try to associate a currency value to the recycling materials. Reward people to recycle. Exchange freely new molecules, discovery, and share all confidential information, in a trusted way. [N = 9]	Transparency Authentication Digital currencies	Exchange Optimise Loop Regenerate	M	H	L
Wood, Leather, and Paper: Try to associate a currency value to the recycling materials or to the planted trees. Reward people to behaviour. [N = 3]	Digital currencies Authentication	Regenerate Optimise	L	M	L

Table 8 - A panoramic view of projects applying Blockchain to enable circularity in the manufacturing industry

5 Conclusion

The concept of circular economy has gained momentum among businesses, policymaker, and researchers, since through a set of strategies, it contributes to sustainable development in a more efficient and productive way.

The application of circular strategies in the Manufacturing industry is becoming inevitable: decoupling growth from virgin resources consumption, delivering value to underused or second-used materials, products, and components together with appropriate disposal of end-of-life resources are only some of the actions that manufacturers should implement. (Kristoffersen et al., 2020b)

To facilitate the shift towards the implementation of more circular strategies within the Manufacturing industry, the digital technologies represent a valid enabler: accurate collection of data and measurement, as well as self-adjustment impact on the excessive resource use.
Virtualization reduces wastes in the design phase, maximising resources efficiency. Tracking of information along the whole supply chain drives towards to more compliance to sustainable normative, reducing risk of counterfeit products as well as greenwashing activities.

Among the other digital technologies, research on blockchain is developing rapidly in different fields. It is particularly relevant to understand whether and to which extant blockchain implementation in Circular Manufacturing industry is able to enhance environmental sustainability and social responsibility, alongside the economic growth.

The research work is based on 55 projects, gathered from online repository of initiatives on circular manufacturing or blockchain, as CORDIS, EU-Blockchain, B-Hub or CoinMarketCap.

Regarding the actual state of the projects selected, more than 80% are either Operating projects or Pilot and it is possible to identify a nascent trend of projects born with the intentional aim of promoting and adopting the circular economy.

From the results obtained, it is possible to understand that the most impacted process in Circular Manufacturing is the Supply Chain, in which the innovation introduced consists in "Tracking and Supply Chain Management" (74% of the sample), which collects activities related to product management and traceability from producers to final consumers. This result emerged from many projects in our sample, despite the different Subsector to which they belong, and in the literature.
The most populated Subsectors are: "Food Production", "Petroleum, Chemical and Plastics" and "Clothing and Textiles". To those categories, it was necessary to add a "General" one, to include projects implementing circular approaches to more than one manufacturing subsectors.

Within these sectors, circular strategies are implemented at “Meso level”, within a network of industries, often connected between each other in a vertical relation of supplier-client.

From a deeper analysis on how Circular Economy has been applied, both the ReSOLVE framework and the three Circular Economy pillars represent the same situation: projects try to implement the upstream process of preservation of natural resources or the downstream of designing out negative externalities. The central part of the supply chain, which can be improved by circulating the products longer or by actions as loop or share, reported less case studies, in our sample as well as in the literature.

Coherently with the innovation introduced, the Blockchain is adopted most frequently for its: “Transparency and Authentication” features. Blockchain represents the main technology for building transparent digital supply chains, enabling greater transparency of products and creating trust among actors.

Thinking about the Blockchain as an enabler of Circular Economy, “Transparency” is exploited to trace products origins and to verify the sustainability of the process. On the other hand, “Authentication”, as digitalization of information, is used in the form of digital twins and NFTs. The potential to tokenise natural resources attributes to the resources more value, incentivising greener behaviours of customers. (Kouhizadeh, Zhu and Sarkis, 2020) and (World Manufacturing Forum, 2021)

These two features are also used combined with “Smart Contracts” and “Digital Currencies”. Although in the literature, many potential applications are described, within our samples it was possible to found two main uses: “Smart contracts” as a way to guarantee best practices and fair prices and “Digital Currencies” as a rewarding method to promote circular activities, as recycling.

Different projects impacted on environmental performance in various way, tracing and reducing negative externalities. In the attempt to contribute to the scarce research on the implications of blockchain applications in the circular economy regarding sustainability (Böckel, Nuzum and Weissbrod, 2021), the projects presented a significant economic contribution: companies rely on the need to achieve economic profitability, to guarantee the success and motivation of all actors involved. (Ghisellini, Cialani and Ulgiati, 2016)

The results of the analysis are combined together in a framework, to merge the findings within the research gap identified: real cases of Blockchain application in Circular Manufacturing.
Summarizing, Blockchain can benefit circular economy practices across Circular Manufacturing in different ways according to the different subsectors, but the common benefits include transparent and secure transactions and the potential to verify regeneration of resources, reduce intermediary costs, optimise efficiency of processes and responsiveness. Achieving those results may lead to significant improvement on environmental performances, while guaranteeing economic contribution

The contribution of the presented work supports the creation of a bridge between Circular Economy and Blockchain, in the Manufacturing industry, through exploring the current discussion of academics about the subjects and building common understanding. The analysis of the projects contributed to the research, allowing to explore the current successful application.

This thesis created a framework, to further investigate projects in the future. From a practical point of view the thesis leave a tool (Table 8) to easily understand the nature and scope of other projects according to their manufacturing subsector. Moreover it enables to compare projects outside of the presented work, in terms of their sustainability implications.

Some limitations of this research work can be highlighted.
This thesis based its discussion on 55 projects, therefore not a statistically significant number. The selection of initiatives has been done starting from the above-mentioned databases: the results provided are either referred to the sample under study, or -when generalized- are supported by the literature.

The framework is created by the authors and the classification of some variables can be affected by subjectivity. The choice of variables is strongly connected to the Manufacturing industry; therefore, the proposed framework may not be applicable to other contexts.

Despite the theoretical potential benefits of Blockchain in Circular Manufacturing, applications in operating projects are still limited, due to various barriers: complexity of integration, lack of awareness and trust are the most common ones.
Promising results about the future of the Blockchain are linked to the increase above 517% of the global demand for blockchain engineers, with a significant shortage of experts and professionals. In fact, in order to implement blockchain and new technologies enhancing circular manufacturing systems, new skills and competences are needed.

To conclude the work two main future directions of research are suggested.
The state of the art shows how blockchain-enabled projects work in different ways along the supply chain, mainly upstream, sourcing of renewable materials, and downstream, on a more responsible collection and disposal of end-of-use products.
The research could benefit from investigating on how blockchain can bring benefits to Circular Manufacturing, also in the usage phase, extending product lifecycle (remanufacturing, refurbish, reuse..)
While investigating the implications of blockchain applications in the circular economy regarding sustainability (Böckel, Nuzum and Weissbrod, 2021), it was clear how projects applying Circular Strategies were improving the environmental performance and that Blockchain can manage and guarantee a significant economic contribution. To achieve a more complete understanding, it is interesting to study how blockchain can make a profound impact to sustainable social responsibility.

6 References

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6.1 Sitography

https://ellenmacarthurfoundation.org/

https://cordis.europa.eu/en

https://b-hub.eu/

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https://coinmarketcap.com/

https://www.blockchain4innovation.it/

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https://www2.deloitte.com/it/it.html

7 Annex

This additional chapter provides a schematic overview of each of the projects used for the analysis in the thesis. The one reported below is an empty example which can be used for future research purposes.

Project name						0
[website](#)						
Brief description of the project						
Born Year						
Subsector						
Developing Stage						
Nationality						
Developing Companies						
N° Employees						
Implementation scale						
Connection between parties						
Introduced innovation						
Intentionality						
9Rs						
Circular Economy Pillars						
ReSOLVE						
Area of interest						
Platform Name						
Platform type						
Usefulness of BC						
Token						
Crypto currrency						
Other technologies						
Economic						
Environmental						
Social						

BHP — 1

https://www.bhp.com/

BHP provides materials for essential infrastructure. The purpose is to bring people and resources together to build a better world, through a strategy to deliver long-term value and returns through the cycle.

Born Year	2019	
Subsector	Mining	
Developing Stage	Operating project	
Nationality	Australia	
Developing Companies	BHP	
N° Employees	>10000	
Implementation scale	Meso (Industry network)	
Connection between parties	Single	
Introduced innovation	Tracking & Supply chain management	
Intentionality	Indirect	
9Rs	Reduce	
Circular Economy Pillars	Preserve and enhance natural capital	Design out negative externalities
ReSOLVE	Re,O,E	
Area of interest	Worldwide	
Platform Name	Hyperledger Fabric	
Platform type	Permissioned	
Usefulness of BC	Transparency,Openess,Digital currencies,Smart contract	
Token		
Crypto currrency	1	
Other technologies		
Economic	3	
Environmental	7	
Social	7	

Walmart — 2

https://www.ibm.com/it-it/blockchain/solutions/food-trust

Walmart thought that blockchain technology might be a good fit for the decentralized food supply ecosystem: transparency and traceability in the food system could help save lives by allowing companies to act faster and protect the livelihoods of farmers by only discarding produce from the affected farms,

Born Year	2017
Subsector	Food production
Developing Stage	Pilot
Nationality	United States
Developing Companies	IBM
N° Employees	>10000
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Indirect
9Rs	Reduce
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	Re,O,E
Area of interest	Worldwide
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Transparency
Token	
Crypto currrency	
Other technologies	IoT
Economic	9
Environmental	7
Social	9

Carrefour food blockchain 3

https://www.carrefour.com/en/group/food-transition/food-blockchain

Carrefour is European pioneer of the food blockade: blockchain applied to food sector can be used to store information about the product: its origin, where it was farmed or how it was produced. It guarantees consumers complete transparency on the circuit followed by the products.

Born Year	2018
Subsector	Food production
Developing Stage	Pilot
Nationality	France
Developing Companies	Carrefour
N° Employees	>10000
Implementation scale	Meso (Industry network)
Connection between parties	Horizontal
Introduced innovation	Tracking & Supply chain management
Intentionality	Indirect
9Rs	Reduce Repurpose
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	Re,O,E
Area of interest	Europe
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Transparency,Authentication
Token	
Crypto currrency	
Other technologies	
Economic	8
Environmental	6
Social	4

GreenTrack 4

https://www.greentrack.com/

The platform provides end to end visibility of forest to fashion, on which Birla Cellulose leads sustainable wood sourcing practices and Sappi guarantees that materials are made from woodfibre-based renewable resources.

Born Year	2020
Subsector	Clothing and textiles
Developing Stage	Operating project
Nationality	India
Developing Companies	Birla Cellulose, Sappi
N° Employees	>10000
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Recycle Reduce
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	Re,O,E
Area of interest	Worldwide
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Transparency,Smart contract
Token	
Crypto currrency	
Other technologies	
Economic	4
Environmental	8
Social	8

GSBN — 5

https://www.gsbn.trade/

GSBN is a trade data utility platform powered by blockchain that enables supply chain participants to work collaboratively to accelerate the digital transformation of the industry.

Born Year	2018
Subsector	General
Developing Stage	Proof of concept
Nationality	England
Developing Companies	Oracle
N° Employees	1 to 10
Implementation scale	Macro (New regulations adopted by countries)
Connection between parties	Horizontal
Introduced innovation	Tracking & Supply chain management
Intentionality	Indirect
9Rs	Reduce
Circular Economy Pillars	Design out negative externalities
ReSOLVE	Re,V
Area of interest	Worldwide
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Transparency,Smart contract
Token	
Crypto currrency	
Other technologies	
Economic	9
Environmental	2
Social	0

Pharma Ledger — 6

https://pharmaledger.eu/

The goal of this project is to provide a widely trusted platform that will support the design and adoption of blockchain-enabled healthcare solutions while accelerating delivery of innovation that will benefit the entire ecosystem, including the manufacturers.

Born Year	2020
Subsector	Petroleum, chemicals and plastics
Developing Stage	Pilot
Nationality	United States
Developing Companies	Innovative Medicines Initiative, Novartis, European Union
N° Employees	11 to 50
Implementation scale	Meso (Industry network)
Connection between parties	Horizontal
Introduced innovation	Tracking & Supply chain management
Intentionality	Indirect
9Rs	Reduce
Circular Economy Pillars	Preserve and enhance natural capital; Design out negative externalities
ReSOLVE	E
Area of interest	Worldwide
Platform Name	Ethereum, Sovrin, Hyperledger Fabric, Corda, DAML, Quorum
Platform type	Permissionless
Usefulness of BC	Authentication,Openess
Token	
Crypto currrency	
Other technologies	IoT
Economic	6
Environmental	4
Social	3

Responsible Sourcing Blockchain Network — 7

https://www.rcsglobal.com/

RCS Global Group use a unique methodology to assess and map exact battery metal supply chains. Resulting in transparency and traceability, they assesses suppliers and sub-suppliers and advise on how to improve their responsible sourcing, responsible mining and ESG performance.

Born Year	2019	
Subsector	Mining	
Developing Stage	Operating project	
Nationality	Worldwide	
Developing Companies	Global group	
N° Employees	0	
Implementation scale	Meso (Industry network)	
Connection between parties	Horizontal	
Introduced innovation	Tracking & Supply chain management	
Intentionality	Direct	
9Rs	GENERAL	
Circular Economy Pillars	Preserve and enhance natural capital	Design out negative externalities
ReSOLVE	Re,O,L,E	
Area of interest	Worldwide	
Platform Name	Hyperledger Fabric	
Platform type	Permissioned	
Usefulness of BC	Transparency,Openess,Smart contract	
Token		
Crypto currrency		
Other technologies	IoT	
Economic	9	
Environmental	8	
Social	7	

Atomyze — 8

https://www.atomyze.ch/

Tozenization of the physical world, enabling commodities to be traded in a simple and secure way, and bring new access, increased liquidity, optimized efficiency, and improved transparency to the industry, within a seamless eco-system.

Born Year	2021
Subsector	Metal Manufacturing
Developing Stage	Pilot
Nationality	Switzerland
Developing Companies	Nornickel
N° Employees	11 to 50
Implementation scale	Meso (Industry network)
Connection between parties	Single
Introduced innovation	Supply chain finance
Intentionality	Indirect
9Rs	Reduce
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	V,E
Area of interest	Worldwide
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Transparency,Authentication,Smart contract
Token	1
Crypto currrency	
Other technologies	
Economic	7
Environmental	8
Social	5

Circularise — 9

https://www.circularise.com/

Circularise facilitates a shift to a circular economy by digitising and tracing materials across complex supply chains on a public blockchain without risking confidentiality.

Born Year	2016		
Subsector	General		
Developing Stage	Operating project		
Nationality	Netherlands		
Developing Companies	Circularise, Covestro, Domo		
N° Employees	11 to 50		
Implementation scale	Meso (Industry network)		
Connection between parties	Vertical integration		
Introduced innovation	Tracking & Supply chain management		
Intentionality	Direct		
9Rs	GENERAL		
Circular Economy Pillars	Preserve and enhance natural capital	Cycling longer	Design out negative externalities
ReSOLVE	Re,O,L,E		
Area of interest	Worldwide		
Platform Name	Ethereum		
Platform type	Permissionless		
Usefulness of BC	Transparency,Smart contract		
Token	1		
Crypto currrency			
Other technologies	0		
Economic	2		
Environmental	6		
Social	3		

Trafigura — 10

https://www.trafigura.com/

Trafigura is a commodity trader, in deal with Circlor, to provide CO2 emission tracking for its nickel and cobalt trading division. Both metals are used in electric vehicle (EV) batteries. Moreover Trafigura is working on responsible sourcing initiative.

Born Year	2017	
Subsector	Metal Manufacturing	
Developing Stage	Operating project	
Nationality	Singapore	
Developing Companies	Trafigura	
N° Employees	>10000	
Implementation scale	Meso (Industry network)	
Connection between parties	Vertical integration	
Introduced innovation	Tracking & Supply chain management	
Intentionality	Direct	
9Rs	Reduce	
Circular Economy Pillars	Preserve and enhance natural capital	Design out negative externalities
ReSOLVE	Re,O	
Area of interest	Worldwide	
Platform Name	Hyperledger Fabric	
Platform type	Permissioned	
Usefulness of BC	Transparency,Authentication,Smart contract	
Token		
Crypto currrency		
Other technologies	0	
Economic	6	
Environmental	9	
Social	5	

Flexidao — 11

https://www.flexidao.com/

FlexiDAO's software helps companies reach net zero emissions by tracing where their electricity comes from and its true CO_2, every hour of the day.

Born Year	2017
Subsector	Electronics and Computers
Developing Stage	Pilot
Nationality	Spain
Developing Companies	Flexidao
N° Employees	11 to 50
Implementation scale	Micro (Single product)
Connection between parties	Single
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Recover (energy)
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	Re,O,E
Area of interest	Worldwide
Platform Name	
Platform type	
Usefulness of BC	Transparency,Authentication,Smart contract
Token	
Crypto currrency	
Other technologies	
Economic	6
Environmental	7
Social	2

Plastick bank — 12

https://plasticbank.com/about/

Plastic Bank is "turning plastic into gold", by revolutionizing the world’s recycling systems to create a regenerative, inclusive, and circular plastic economy.

Born Year	2013
Subsector	Petroleum, chemicals and plastics
Developing Stage	Operating project
Nationality	Canada
Developing Companies	Plastick bank
N° Employees	51 to 200
Implementation scale	Micro (Single product)
Connection between parties	Horizontal
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Recycle
Circular Economy Pillars	Cycling longer; Design out negative externalities
ReSOLVE	Re
Area of interest	Worldwide
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Transparency,Authentication,Digital currencies,Smart contract
Token	
Crypto currrency	1
Other technologies	
Economic	7
Environmental	7
Social	7

Bext360 — 13

https://www.bext360.com/

Deployed in emerging economies worldwide, Bext360 technology facilitates greater transparency, business intelligence, and provides a sustainability metric.

Born Year	2019
Subsector	Food production
Developing Stage	Pilot
Nationality	United States
Developing Companies	Bext360
N° Employees	11 to 50
Implementation scale	Micro (Single product)
Connection between parties	Single
Introduced innovation	Tracking & Supply chain management
Intentionality	Indirect
9Rs	Reduce
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	Re,O
Area of interest	Worldwide
Platform Name	Stellar
Platform type	Permissioned
Usefulness of BC	Transparency,Authentication,Digital currencies
Token	1
Crypto currrency	1
Other technologies	cial intelligence
Economic	10
Environmental	6
Social	7

Volvo — 14

https://www.media.volvocars.com/global/en-gb/media/pressreleases/260242/volvo-cars-to-implement-blockchain-traceability-of-cobalt-used-in-electric-car-batteries

Volvo is partnering with Circulor to commit to an ethical and more circular supply chain of raw materials and to implement blockchain traceability of cobalt used in electric car batteries.

Born Year	2019		
Subsector	Metal Manufacturing		
Developing Stage	Pilot		
Nationality	Worldwide		
Developing Companies	Volvo, Circulor		
N° Employees	>10000		
Implementation scale	Micro (Single product)		
Connection between parties	Horizontal		
Introduced innovation	Tracking & Supply chain management		
Intentionality	Indirect		
9Rs	Reduce		
Circular Economy Pillars	Preserve and enhance natural capital	Cycling longer	Design out negative externalities
ReSOLVE	Re,O,L		
Area of interest	China		
Platform Name	Hyperledger Fabric		
Platform type	Permissioned		
Usefulness of BC	Transparency,Authentication,Smart contract		
Token			
Crypto currrency			
Other technologies	IoT		
Economic	5		
Environmental	7		
Social	7		

CircularChain 15

https://www.suez.com/en/who-we-are/innovating-for-the-future/circularchain-the-circular-economy-blockchain

CircularChain, the circular economy blockchain designed by SUEZ, meets the growing need for transparency and trust with regard to the health and environmental quality of secondary raw materials. It is a concrete solution that promotes material reuse and recycling.

Born Year	2021
Subsector	Food production
Developing Stage	Proof of concept
Nationality	France
Developing Companies	Suez
N° Employees	>10000
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Recycle
Circular Economy Pillars	Cycling longer; Design out negative externalities
ReSOLVE	Re,S,O
Area of interest	Europe
Platform Name	
Platform type	
Usefulness of BC	Transparency,Authentication
Token	
Crypto currrency	
Other technologies	
Economic	7
Environmental	8
Social	3

Covestro 16

www.covestro.com

trying to design plastic products which can last longer, through treating the wastes of a resource, not to be discarded, but reinserted in the manufacturing process. The idea is to manage trust by creating a virtual "digital twin" in blockchain for each batch of material, carrying all relevant information.

Born Year	2020
Subsector	Petroleum, chemicals and plastics
Developing Stage	Operating project
Nationality	Worldwide
Developing Companies	Covestro, Circularize
N° Employees	>10000
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	innovative recycling/alternative material
Intentionality	Direct
9Rs	Rethink; Reuse; Remanufacture
Circular Economy Pillars	Preserve and enhance natural capital; Cycling longer; Design out negative externalities
ReSOLVE	Re,O,L,V,E
Area of interest	Worldwide
Platform Name	Ethereum
Platform type	Permissionless
Usefulness of BC	Transparency
Token	
Crypto currrency	
Other technologies	
Economic	8
Environmental	6
Social	3

Cycle4Value — 17

https://www.cycle4value.at/

Bike Manufacturers with FTI Mobility tested a model of trasparent rewarding to promote cyclism. Blockchain is used as a rewarding system as well as a way to trace CO2 savings.

Born Year	2020
Subsector	Metal Manufacturing
Developing Stage	Pilot
Nationality	Austria
Developing Companies	Bike Citizens
N° Employees	11 to 50
Implementation scale	Micro (Single product)
Connection between parties	Single
Introduced innovation	Rewarding activities
Intentionality	Direct
9Rs	Recover (ε Reduce
Circular Economy Pillars	
ReSOLVE	O,V
Area of interest	Austria
Platform Name	Ardor
Platform type	Permissioned
Usefulness of BC	Authentication,Digital currencies
Token	1
Crypto currrency	1
Other technologies	chine learning
Economic	5
Environmental	4
Social	4

CERA 4in1 — 18

https://www.cera4in1.org/

CERA 4in1 aim's is to become the first universal and comprehensive certification scheme to control and validate production, processing and traceable transport of all mineral resources.

Born Year	2017		
Subsector	Mining		
Developing Stage	Pilot		
Nationality	Europe		
Developing Companies	CERA 4in1		
N° Employees	11 to 50		
Implementation scale	Macro (New regulations adopted by countries)		
Connection between parties	Horizontal		
Introduced innovation	Data & document management		
Intentionality	Direct		
9Rs	Reduce		
Circular Economy Pillars	Preserve and enhance natural capital	Cycling longer	Design out negative externalities
ReSOLVE	Re,O,L,V,E		
Area of interest	Worldwide		
Platform Name	VeChain		
Platform type	Permissioned		
Usefulness of BC	Transparency,Openess		
Token	1		
Crypto currrency			
Other technologies			
Economic	5		
Environmental	8		
Social	8		

U.S. Air Force defense security data — 19

https://constellationnetwork.io/

U.S. Air Force defense signed a contract with constellation network and Xage to secure data. They provided a best solution to keep data securely even within a system failure or a cyber attack while reducing the overall resources necessary to keep secured a big amount of data.

Born Year	2019
Subsector	Electronics and Computers
Developing Stage	Operating project
Nationality	United States
Developing Companies	Kinnami Software
N° Employees	11 to 50
Implementation scale	Meso (Industry network)
Connection between parties	Single
Introduced innovation	Data & document management
Intentionality	Indirect
9Rs	Reduce
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	
Area of interest	USA
Platform Name	Hypergraph
Platform type	Permissionless
Usefulness of BC	Authentication,Openess,Digital currencies
Token	
Crypto currrency	1
Other technologies	IoT
Economic	7
Environmental	4
Social	2

Provenance Project — 20

https://www.provenance.org/

Provenance is the software solution for sustainability communications with proof: its mission is to enable people understanding impacts of goods and services in terms of natural resources depletion and worsening of enviornmental or social impact.

Born Year	2017
Subsector	Food production
Developing Stage	Operating project
Nationality	United States
Developing Companies	Provenance
N° Employees	11 to 50
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Reduce Recycle
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	E
Area of interest	Worldwide
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Transparency,Authentication
Token	
Crypto currrency	
Other technologies	IoT
Economic	7
Environmental	8
Social	6

Rapid Precision Parts Production — 21

https://syncfab.com/parts-manufacturing/

Syncfab is a the industry pioneer building blockchain technology for digital transformation: the blockchain-based platform facilitates interactions between buyers and manufacturers with smart contracts to streamline production processes and tokens to provide incentives for participants. Material savings and sharing of information through provinding accessibility of parts and prototypes to thousands of manufacturers.

Born Year	2018
Subsector	Metal Manufacturing
Developing Stage	Operating project
Nationality	United States
Developing Companies	synclab
N° Employees	11 to 50
Implementation scale	Meso (Industry network)
Connection between parties	Single
Introduced innovation	Tracking & Supply chain management
Intentionality	Indirect
9Rs	Reduce, Recycle, Repurpose
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	S,O
Area of interest	USA, Canada
Platform Name	Ethereum
Platform type	Permissioned
Usefulness of BC	Transparency,Authentication
Token	1
Crypto currrency	1
Other technologies	IoT
Economic	9
Environmental	2
Social	3

BlockWEEE — 22

https://erion.it/it/news/erion-a-ecomondo-il-progetto-blockweee/

They create a system, supported by a rewarding system, to track waste of electric and electronic equipment (WEEE) in a circular economy perspective. Through blockchain, they developed a solution in which it is possible to create smart contracts between producers, client and final user, to track the state of the equipment installed.

Born Year	2020
Subsector	Electronics and Computers
Developing Stage	Proof of concept
Nationality	Europe
Developing Companies	EIT Climate-KIC
N° Employees	51 to 200
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Recycle, Repair
Circular Economy Pillars	Cycling longer, Design out negative externalities
ReSOLVE	O,L,V,E
Area of interest	Worldwide
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Authentication,Openess,Digital currencies,Smart contract
Token	
Crypto currrency	1
Other technologies	IoT
Economic	9
Environmental	5
Social	2

Vestigia Blockchain — 23

https://www.vestigia.io/en

Vestigia uses blockchain to create a scalable platform adaptable to any company, though their experience is in industrial sectors, health and agri-food. The platform is based on smart contracts to control production and automate the decision process, saving costs and errors: this project supports other companies implementing circular economy, through the reduction of wastes and operational risks.

Born Year	2017
Subsector	General
Developing Stage	Operating project
Nationality	Spain
Developing Companies	VESTIGA foundation
N° Employees	1 to 10
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Indirect
9Rs	Reduce
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	O
Area of interest	Worldwide
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Transparency,Authentication,Smart contract
Token	
Crypto currrency	
Other technologies	IoT
Economic	8
Environmental	4
Social	2

DiLLaS — 24

https://www.eitdigital.eu/fileadmin/files/2019/factsheets/digital-industry/Dillas_Factsheet.pdf

Dillas is an IoT and Blockchain solution that offers a new and unique view on shipment events data for logistics companies and their partners. Moreover, it allows stakeholders involved to intervene if something goes wrong, and thus limit the damage before it's too late.

Born Year	2019
Subsector	General
Developing Stage	Operating project
Nationality	Netherlands
Developing Companies	InnoTractor
N° Employees	11 to 50
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Indirect
9Rs	Reduce
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	O,L,V,E
Area of interest	Europe
Platform Name	
Platform type	
Usefulness of BC	Transparency,Authentication,Openess,Smart contract
Token	
Crypto currrency	
Other technologies	IoT
Economic	9
Environmental	4
Social	2

Circular Crowd Production Platform — 25

https://www.nu.tu-berlin.de/menue/forschung/laufende_projekte/circular_crowd_production_platform/

Circular Crowd Production Platform aims at creating a net of SME in other to reduce the impact of producing building in a rapid urban growth environment: the project provides a pathway to systemic change, creating a blockchain-based system of suppliers to optimize materials usage, recycling of materials, while reducing wastes and CO2 emissions.

Born Year	2021
Subsector	General
Developing Stage	Announced
Nationality	Germany
Developing Companies	Nachhaltige Unternehmensentwicklung
N° Employees	0
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	GENERAL
Circular Economy Pillars	Preserve and enhance natural capital; Cycling longer; Design out negative externalities
ReSOLVE	O,V,E
Area of interest	Worldwide
Platform Name	
Platform type	
Usefulness of BC	Transparency,Authentication,Openess
Token	
Crypto currrency	
Other technologies	
Economic	7
Environmental	8
Social	4

Ptwist — 26

https://cordis.europa.eu/project/id/780121

PTwist aims to design, deploy, and validate an open platform which will twist plastic reuse practices, by boosting citizens awareness, circular economy practices, and sustainable innovation inline with the new plastics economy vision.

Born Year	2018
Subsector	Petroleum, chemicals and plastics
Developing Stage	Pilot
Nationality	Greece
Developing Companies	ARISTOTELIO PANEPISTIMIO THESSALONIKIS
N° Employees	0
Implementation scale	Micro (Single product)
Connection between parties	Single
Introduced innovation	Rewarding activities
Intentionality	Direct
9Rs	Recycle
Circular Economy Pillars	Cycling longer
ReSOLVE	O,L,E
Area of interest	Europe
Platform Name	Ethereum
Platform type	Permissionless
Usefulness of BC	Digital currencies
Token	
Crypto currrency	1
Other technologies	
Economic	3
Environmental	7
Social	1

REFLOW — 27

https://reflowproject.eu/

The REFLOW project aims to develop circular and regenerative cities through enabling active citizen involvement and systematic change to re-think the current approach to materialze flow in cities.

Born Year	2019
Subsector	General
Developing Stage	Proof of concept
Nationality	Europe
Developing Companies	Reflow
N° Employees	1 to 10
Implementation scale	Macro (New regulations adopted by countries)
Connection between parties	Single
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Rethink GENERAL
Circular Economy Pillars	Preserve and enhance natural capital; Cycling longer; Design out negative externalities
ReSOLVE	Re,O,V,E
Area of interest	Europe
Platform Name	
Platform type	
Usefulness of BC	Transparency,Openess,Smart contract
Token	
Crypto currrency	
Other technologies	
Economic	7
Environmental	7
Social	4

Empower — 28

https://Empower.eco

Empower generates value out of plastic waste – enabling collectors, recyclers, brands and consumers to make a real impact on the environment.

Born Year	2020
Subsector	Petroleum, chemicals and plastics
Developing Stage	Operating project
Nationality	Norway
Developing Companies	Empower
N° Employees	51 to 200
Implementation scale	Micro (Single product)
Connection between parties	Single
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Recycle
Circular Economy Pillars	Cycling longer
ReSOLVE	Re,O,L,E
Area of interest	Worldwide
Platform Name	Ethereum
Platform type	Permissioned
Usefulness of BC	Transparency,Authentication,Digital currencies
Token	1
Crypto currrency	1
Other technologies	
Economic	4
Environmental	8
Social	3

Agoratechlab 29

https://www.agoratechlab.com/

Agora Tech Lab tries to value waste while supporting cities and packaging manufacturers or other waste disposal organisation in creating a cradle-to-cradle resource economy.

Born Year	2019
Subsector	Petroleum, chemicals and plastics
Developing Stage	Pilot
Nationality	Netherlands
Developing Companies	Agora Tech Lab
N° Employees	1 to 10
Implementation scale	Micro (Single product)
Connection between parties	Single
Introduced innovation	Rewarding activities
Intentionality	Direct
9Rs	Recycle, Recover (energy)
Circular Economy Pillars	Cycling longer
ReSOLVE	O,L,E
Area of interest	Europe
Platform Name	Holochain
Platform type	Permissionless
Usefulness of BC	Transparency,Authentication
Token	1
Crypto currrency	1
Other technologies	
Economic	4
Environmental	8
Social	3

ChemChain 30

https://chemcha.in/

ChemChain is the revolutionary blockchain platform to transfer information on chemicals in products along the value chain, from chemical manufacturers to consumers, recyclers and waste operators

Born Year	2019
Subsector	Petroleum, chemicals and plastics
Developing Stage	Pilot
Nationality	Netherlands
Developing Companies	Chemchain
N° Employees	1 to 10
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Recycle, Reuse
Circular Economy Pillars	Cycling longer, Design out negative externalities
ReSOLVE	Re,L,E
Area of interest	Worldwide
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Transparency,Openess
Token	
Crypto currrency	
Other technologies	
Economic	9
Environmental	8
Social	2

TRICK — 31

https://cordis.europa.eu/project/id/958352

TRICK will provide a complete, SME affordable and standardised platform to support the adoption of sustainable and circular approaches: it will enable enterprises to collect product data and to access to the necessary services on a dedicated marketplace, open to third party solutions.

Born Year	2020
Subsector	Clothing and textiles
Developing Stage	Pilot
Nationality	Europe
Developing Companies	Piacenza SPA, European Union
N° Employees	0
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	GENERAL
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	S,O,L,E
Area of interest	Worldwide
Platform Name	
Platform type	
Usefulness of BC	Transparency,Openess
Token	
Crypto currrency	
Other technologies	
Economic	8
Environmental	5
Social	2

HEREWEAR — 32

https://herewear.eu/

Herewear, a project under financing by the European Union Horizon 2020, innovates the clothing industry through empowering local, circular and bio-based textiles. They introduce new material solutions, processed with sustainable technologies, and create a network of microfactories.

Born Year	2020
Subsector	Clothing and textiles
Developing Stage	Pilot
Nationality	Belgium
Developing Companies	CENTRE SCIENTIFI
N° Employees	0
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Repair Remanufacture Recycle
Circular Economy Pillars	Preserve and enhance natural capital, Cycling longer
ReSOLVE	Re,O,L,E
Area of interest	Worldwide
Platform Name	
Platform type	
Usefulness of BC	Transparency,Authentication
Token	1
Crypto currrency	
Other technologies	
Economic	6
Environmental	8
Social	6

PestNu — 33

https://cordis.europa.eu/project/id/101037128

PestNu targets the field -testing and demonstration of digital and space based technologies (DST) and agro-ecological and organic practices (AOP) under a systemic approach to reduce the pesticides and fertilisers use, and loss of nutrients.

Born Year	2020	
Subsector	Petroleum, chemicals and plastics	
Developing Stage	Pilot	
Nationality	Europe	
Developing Companies	ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS	
N° Employees	0	
Implementation scale	Meso (Industry network)	
Connection between parties	Vertical integration	
Introduced innovation	Data & document management	
Intentionality	Indirect	
9Rs	GENERAL	
Circular Economy Pillars		Design out negative externalities
ReSOLVE	Re,O,L,E	
Area of interest	Worldwide	
Platform Name		
Platform type		
Usefulness of BC	Authentication,Openess	
Token		
Crypto currrency		
Other technologies	AI	
Economic	8	
Environmental	10	
Social	2	

EFPF — 34

https://cordis.europa.eu/project/id/825075

EFPF is a smart factory ecosystem and a digital platform that interlinks different stakeholders of the digital manufacturing domain. It enable users to utilise innovative functionalities, experiment with disruptive approaches and develop custom solutions to maximise connectivity, interoperability and efficiency across the supply chains.

Born Year	2020	
Subsector	General	
Developing Stage	Pilot	
Nationality	Europe	
Developing Companies	INSTITUTO TECNOLOGICO METALMECANICO, MUEBLE, MADERA, EMBALAJE Y AFINES-AIDIMME	
N° Employees	0	
Implementation scale	Meso (Industry network)	
Connection between parties	Vertical integration	
Introduced innovation	Tracking & Supply chain management	
Intentionality	Indirect	
9Rs	Reduce	
Circular Economy Pillars		Design out negative externalities
ReSOLVE	O,L,E	
Area of interest	Worldwide	
Platform Name		
Platform type		
Usefulness of BC	Transparency,Openess	
Token		
Crypto currrency		
Other technologies	IoT	
Economic	7	
Environmental	3	
Social	1	

Textilechain — 35

https://textile-chain.it/

Textilechain is a project with the purpose of tracking the textile and fashion industry, to support Made in Italy around the world. They use blockchain to help partners in communicating and to simplify costs and monitor quality.

Born Year	2020
Subsector	Clothing and textiles
Developing Stage	Operating project
Nationality	Italy
Developing Companies	Textilechain
N° Employees	1 to 10
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Indirect
9Rs	Recycle Reduce
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	Re,E
Area of interest	Worldwide
Platform Name	Ethereum
Platform type	Permissionless
Usefulness of BC	Transparency,Authentication
Token	
Crypto currrency	
Other technologies	IoT
Economic	7
Environmental	3
Social	4

FoodChain — 36

https://food-chain.it/

Foodchain provides blockchain technology to trace and digitally authenticate food products, enabling a transparent, safe and reliable supply chain ecosystem. The solution is addressed to producers, MMR, public administration, logistics and transport.

Born Year	2019
Subsector	Food production
Developing Stage	Operating project
Nationality	Italy
Developing Companies	Foodchain
N° Employees	1 to 10
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Indirect
9Rs	Reduce
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	Re,O,L,E
Area of interest	Italy
Platform Name	Ethereum
Platform type	Permissionless
Usefulness of BC	Transparency,Authentication
Token	
Crypto currrency	
Other technologies	IoT
Economic	7
Environmental	6
Social	7

4C — 37

https://4c.cst.cam.ac.uk/

The Cambridge Centre for Carbon Credits (4C) is creating a trusted decentralized marketplace where purchasers of carbon credits can confidently and directly fund trusted nature-based projects that ties together corporate funders to conservationists via automated and transparent global oracles.

Born Year	2021	
Subsector	General	
Developing Stage	Announced	
Nationality	England	
Developing Companies	Cambridge University	
N° Employees	0	
Implementation scale	Meso (Industry network)	
Connection between parties	Horizontal	
Introduced innovation	Tracking & Supply chain management	
Intentionality	Direct	
9Rs	GENERAL	
Circular Economy Pillars		Design out negative externalities
ReSOLVE		
Area of interest	Worldwide	
Platform Name	Tezos	
Platform type	Permissionless	
Usefulness of BC	Transparency,Authentication,Digital currencies	
Token	1	
Crypto currrency	1	
Other technologies	ellite Coverage	
Economic	8	
Environmental	6	
Social	2	

KleanIndustries — 38

https://kleanindustries.com/waste-processing-innovations/kleanloop-blockchain-dapp/

Klean Industries is an environmentally conscious industrial solutions company focused on providing clean energy and recovered resources to various industrial manufacturing sectors.

Born Year	2019		
Subsector	Petroleum, chemicals and plastics		
Developing Stage	Proof of concept		
Nationality	Vancouver		
Developing Companies	KleanIndustries		
N° Employees	11 to 50		
Implementation scale	Meso (Industry network)		
Connection between parties	Horizontal		
Introduced innovation	Tracking & Supply chain management		
Intentionality	Direct		
9Rs	Recycle		
Circular Economy Pillars		Cycling longer	Design out negative externalities
ReSOLVE	O,V,E		
Area of interest	USA		
Platform Name			
Platform type			
Usefulness of BC	Transparency,Authentication,Digital currencies		
Token	1		
Crypto currrency	1		
Other technologies	AI		
Economic	6		
Environmental	10		
Social	4		

BYD — 39

https://store.hbr.org/product/byd-blockchain-enabled-green-ecosystem/W20638

BYD is a chinese company which launched a Blockchain-enabled green ecosystem that delivered new value to customers by issuing carbon points to users who had made efforts to reduce their daily carbon emissions. Users could spend carbon points at partner merchants and get rewards.

Born Year	2019
Subsector	Electronics and Computers
Developing Stage	Pilot
Nationality	China
Developing Companies	BYD
N° Employees	201 to 1000
Implementation scale	Micro (Single product)
Connection between parties	Single
Introduced innovation	Rewarding activities
Intentionality	Indirect
9Rs	Recover (energy)
Circular Economy Pillars	Cycling longer; Design out negative externalities
ReSOLVE	Re,O,E
Area of interest	China
Platform Name	VeChain
Platform type	Permissionless
Usefulness of BC	Digital currencies,Smart contract
Token	1
Crypto currrency	1
Other technologies	
Economic	2
Environmental	7
Social	2

TE-FOOD — 40

https://te-food.com/

TE-FOOD enables to present product information as a rich experience to differentiate your brands, and to prove the quality of your products. Transparency and immediate recalling of products are their way to improve circularity, through reduction of wastes.

Born Year	2016
Subsector	Food production
Developing Stage	Pilot
Nationality	Germany
Developing Companies	Te-FOOD
N° Employees	11 to 50
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	GENERAL
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	Re,L,E
Area of interest	Germany
Platform Name	TE-FOOD
Platform type	Permissioned
Usefulness of BC	Transparency,Authentication
Token	
Crypto currrency	
Other technologies	
Economic	9
Environmental	6
Social	5

CONNECTING FOOD 41

https://connecting-food.com/en/

Connecting Food offers digital transparency solutions which create value for agri-food players and restore consumer confidence in food. It uses QR code as a digital twin of the products, to regain cosumers' trust, while checking real circular commitment of producers.

Born Year	2020
Subsector	Food production
Developing Stage	Pilot
Nationality	France
Developing Companies	Connecting Food
N° Employees	11 to 50
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	GENERAL
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	Re,O,E
Area of interest	France
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Transparency
Token	
Crypto currrency	
Other technologies	
Economic	9
Environmental	3
Social	1

GOODSId 42

https://www.goodsid.io/en

The GoodsID solution stands on a block-chain protocol, used for proving, certifying value, managing and benefiting from security and power given to owners. It fosters not only resale, but also renting, sharing or donating of products.

Born Year	2017
Subsector	Clothing and textiles
Developing Stage	Operating project
Nationality	France
Developing Companies	GOOD Id
N° Employees	51 to 200
Implementation scale	Micro (Single product)
Connection between parties	Single
Introduced innovation	Property registry
Intentionality	Indirect
9Rs	Repair Reduce
Circular Economy Pillars	
ReSOLVE	Re,L,E
Area of interest	Worldwide
Platform Name	
Platform type	
Usefulness of BC	Authentication
Token	1
Crypto currrency	
Other technologies	
Economic	5
Environmental	1
Social	4

FOOTBRIDGE 43

https://footbridge-impact.com/

FOOTBRIDGE trace garment from end to end and calculate the footprint, by making the right eco-design decisions and by having a real control of your supply chain, while strengthening the producer-consumer link to close the loop.

Born Year	2019
Subsector	Clothing and textiles
Developing Stage	Operating project
Nationality	France
Developing Companies	FOOTBRIDGE
N° Employees	51 to 200
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Reduce
Circular Economy Pillars	Design out negative externalities
ReSOLVE	Re,O,E
Area of interest	Worldwide
Platform Name	Tomochain
Platform type	Permissionless
Usefulness of BC	Transparency,Authentication
Token	
Crypto currrency	
Other technologies	
Economic	7
Environmental	5
Social	1

JOONE 44

https://joone.co.uk/pages/factories

Their commitment is connected with safe materials, from well-managed and controlled sources: defining high standards for traceability, quality and control as a way to promote engagement.

Born Year	2019
Subsector	Clothing and textiles
Developing Stage	Operating project
Nationality	France
Developing Companies	JOONE
N° Employees	11 to 50
Implementation scale	Micro (Single product)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Indirect
9Rs	Reduce
Circular Economy Pillars	Design out negative externalities
ReSOLVE	Re,L,E
Area of interest	France
Platform Name	Tomochain
Platform type	Permissionless
Usefulness of BC	Transparency,Authentication
Token	
Crypto currrency	
Other technologies	
Economic	7
Environmental	4
Social	1

CIRCULAR TREE 45

https://www.circulartree.com/

Their goal is to provide solutions for supply chains to become more responsible and sustainable e.g., measuring carbon footrpint, certifying raw material extraction.

Born Year	2018
Subsector	General
Developing Stage	Operating project
Nationality	Germany
Developing Companies	CircularTree
N° Employees	1 to 10
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Reduce GENERAL
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	Re,O,E
Area of interest	Worldwide
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Transparency,Authentication
Token	
Crypto currrency	
Other technologies	
Economic	8
Environmental	10
Social	4

SEVA 46

http://seva.green/

Seva is a way to increase awareness about end-of-life and looping of clothing. This solution offers smart after use solution, which connects donors, carriers and new users.

Born Year	2021
Subsector	Clothing and textiles
Developing Stage	Operating project
Nationality	Romania
Developing Companies	SEVA Green
N° Employees	0
Implementation scale	Micro (Single product)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Reuse Recycle Repair
Circular Economy Pillars	Cycling longer
ReSOLVE	Re,L,E
Area of interest	Romania
Platform Name	Elrond
Platform type	Permissionless
Usefulness of BC	Transparency,Authentication
Token	
Crypto currrency	
Other technologies	
Economic	4
Environmental	5
Social	4

MINESPIDER 47

https://www.minespider.com/downstream-manufacturers-brands

Minespider is a blockchain-based platform for responsible mineral sourcing: show raw material provenance, capture sustainability, legal and compliance data, and communicate responsibility efforts, analyze & manage suppliers, resonate with conscious consumers.

Born Year	2018
Subsector	Mining
Developing Stage	Operating project
Nationality	Germany
Developing Companies	MINESPIDER
N° Employees	11 to 50
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Indirect
9Rs	Recycle; Reduce
Circular Economy Pillars	Design out negative externalities
ReSOLVE	Re,O,E
Area of interest	Worldwide
Platform Name	Hyperledger Fabric
Platform type	Permissioned
Usefulness of BC	Transparency,Authentication
Token	1
Crypto currrency	1
Other technologies	
Economic	9
Environmental	7
Social	3

FEELERA 48

https://feelera.eu/

The web platform for tracking the supply chains and the processes that generate value: through calculation of indicators, their aim is to achieve different SDGs, as (5) gender equality, (7) affordable and clean energy and (12) responsible consumptio and production.

Born Year	2020
Subsector	Food production
Developing Stage	Pilot
Nationality	Italy
Developing Companies	FEELERA
N° Employees	1 to 10
Implementation scale	Meso (Industry network)
Connection between parties	Vertical integration
Introduced innovation	Tracking & Supply chain management
Intentionality	Direct
9Rs	Reduce; Recycle; Recover (energy)
Circular Economy Pillars	Preserve and enhance natural capital; Design out negative externalities
ReSOLVE	Re,L,E
Area of interest	Italy
Platform Name	Ethereum
Platform type	Permissionless
Usefulness of BC	Transparency,Authentication
Token	
Crypto currrency	
Other technologies	
Economic	7
Environmental	6
Social	3

GENUINE WAY 49

https://genuineway.io/it/

Genuine Way is a tech service provider specializing in the development and distribution of blockchain-integrated solutions for manufacturers of consumer goods in the food, fashion, cosmetics & pharma industries: their mission is to promote conscious consumption all around the world.

Born Year	2018	
Subsector	Food production	
Developing Stage	Operating project	
Nationality	Swizerland	
Developing Companies	GenuineWAY	
N° Employees	11 to 50	
Implementation scale	Meso (Industry network)	
Connection between parties	Vertical integration	
Introduced innovation	Tracking & Supply chain management	
Intentionality	Indirect	
9Rs	Reduce	
Circular Economy Pillars	Preserve and enhance natural capital	Design out negative externalities
ReSOLVE	Re,O	
Area of interest	Europe	
Platform Name	Ethereum	
Platform type	Permissionless	
Usefulness of BC	Transparency,Authentication	
Token	1	
Crypto currrency		
Other technologies		
Economic	8	
Environmental	7	
Social	3	

MANGROVIA 50

https://mangrovia.solutions/

Mangrovia is a software house providing consulting, development and support services for blockchain solutions, offering security, transparency and efficiency. Within the supply chain, their aim it to eliminate wastes embedded within business processes.

Born Year	2017	
Subsector	General	
Developing Stage	Operating project	
Nationality	Italy	
Developing Companies	MANGROVIA	
N° Employees	11 to 50	
Implementation scale	Meso (Industry network)	
Connection between parties	Vertical integration	
Introduced innovation	Tracking & Supply chain management	
Intentionality	Indirect	
9Rs	Reduce	
Circular Economy Pillars	Preserve and enhance natural capital	Design out negative externalities
ReSOLVE	Re,O,V,E	
Area of interest	Europe	
Platform Name	Hyperledger Fabric	
Platform type	Permissioned	
Usefulness of BC	Transparency,Smart contract	
Token	1	
Crypto currrency		
Other technologies	Machine learning, IoT	
Economic	8	
Environmental	2	
Social	3	

TREECYCLE — 51

https://treecycle.ch/en/#tree-calculator-en

Blockchain technology enables them to create secure, transparent and innovative digital assets (tokens) that can be safely stored or traded throughout the world at a fraction of the cost of traditional banking systems. Their TREE token is collateralized by a physical tree.

Born Year	2018
Subsector	Wood, Leather, and Paper
Developing Stage	Pilot
Nationality	Swizerland
Developing Companies	TREECYCLE
N° Employees	1 to 10
Implementation scale	Micro (Single product)
Connection between parties	Single
Introduced innovation	Capital markets
Intentionality	Direct
9Rs	Recover (Reduce
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	Re
Area of interest	Worldwide
Platform Name	Ardor
Platform type	Permissioned
Usefulness of BC	Transparency,Authentication,Digital currencies
Token	1
Crypto currrency	1
Other technologies	
Economic	4
Environmental	8
Social	5

MFG — 52

https://smartmfg.io/

Smart MFG promotes new technologies and applications for use within the Industrial Manufacturing industry. Introducing tokens within the supply chain, they virtualize products and guarantee truth about products.

Born Year	2017
Subsector	Metal Manufacturing
Developing Stage	Pilot
Nationality	USA
Developing Companies	smartMFG
N° Employees	1 to 10
Implementation scale	Meso (Industry network)
Connection between parties	Horizontal
Introduced innovation	Property registry
Intentionality	Indirect
9Rs	Reduce
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	S,V,E
Area of interest	Worldwide
Platform Name	Ethereum
Platform type	Permissionless
Usefulness of BC	Authentication,Digital currencies,Smart contract
Token	1
Crypto currrency	1
Other technologies	Additive Manufacturing
Economic	5
Environmental	3
Social	1

REFORK — 53

https://refork.com/

REFORK uses tokeneconomy to promote and distrubite its products, which leave no microplastics or any chemical or toxic traces.

Born Year	2019
Subsector	Wood, Leather, and Paper
Developing Stage	Operating project
Nationality	Czech Republic
Developing Companies	REFORK
N° Employees	11 to 50
Implementation scale	Micro (Single product)
Connection between parties	Single
Introduced innovation	Rewarding activities
Intentionality	Direct
9Rs	Recycle Reduce
Circular Economy Pillars	Preserve and enhance natural capital; Cycling longer
ReSOLVE	Re,O,L
Area of interest	Worldwide
Platform Name	Ethereum
Platform type	Permissionless
Usefulness of BC	Digital currencies
Token	
Crypto currrency	1
Other technologies	
Economic	2
Environmental	2
Social	1

FETCH — 54

https://fetch.ai/

FETCH has the potential to revolutionize industries, improving efficiency through optimization of existing systems. In the context of supply chain, AI and blockchain can llow business to analyze future patterns, enabling them to navigate disruptions months in advance and preempt changes in customer buying patterns.

Born Year	2017
Subsector	Metal Manufacturing
Developing Stage	Pilot
Nationality	England
Developing Companies	FETCH
N° Employees	51 to 200
Implementation scale	Macro (New regulations adopted by countries)
Connection between parties	Horizontal
Introduced innovation	Data & document management
Intentionality	Indirect
9Rs	Reduce
Circular Economy Pillars	Preserve and enhance natural capital
ReSOLVE	O,V,E
Area of interest	Worldwide
Platform Name	Ethereum
Platform type	Permissionless
Usefulness of BC	Transparency,Openess,Digital currencies,Smart contract
Token	1
Crypto currrency	1
Other technologies	Machine learning, IoT
Economic	9
Environmental	2
Social	4

Veritree 55

https://veritree.com/#about-veritree

Leveraging on blockchain solution, the project allows planting organizations to gather ground level data, manage their projects more effectively, and deliver sponsors a world-class experience.

Born Year	2019			
Subsector	Wood, Leather, and Paper			
Developing Stage	Pilot			
Nationality	Canada			
Developing Companies	Veritree			
N° Employees	11 to 50			
Implementation scale	Micro (Single product)			
Connection between parties	Single			
Introduced innovation	Data & document management			
Intentionality	Direct			
9Rs	Recover (ε Reduce			
Circular Economy Pillars	Preserve and enhance natural capital			
ReSOLVE	Re,O,V,E	O	V	E
Area of interest	Worldwide			
Platform Name	Cardano			
Platform type	Permissionless			
Usefulness of BC	Transparency,Authentication,Digital currencies			
Token	1			
Crypto currrency	1			
Other technologies				
Economic	5			
Environmental	8			
Social	6			