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Blockchain in Enterprise Solutions: Assessing the Suitability of Blockchain for Corporate Sustainability Reporting

Information Systems Science
Master's thesis

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The aim of this master's thesis was to assess the suitability of blockchain technology as enterprise solution for corporate sustainability reporting through evaluating the technological properties and enterprise use-cases of blockchain technology and challenges in corporate sustainability reporting. Furthermore, a special focus on literature review was to demystify the properties of blockchain technology that provide its most well-known qualities. In this thesis, blockchain technology was assessed through a review of prior literature, and the current state of corporate sustainability reporting was mainly evaluated through data collected in expert interviews.

Blockchain technology has been found to have potential as an enterprise solution for a large number of corporate functions, such as supply chain management and accounting. Global corporations have publicly announced to be piloting with the technology in recent years. However, a level of technological abstraction prohibits the visibility of how the technology is concretely improving existing processes. Prior research exists on both levels, on high-level enterprise use-cases and technological deep dives, but rarely together. Corporate sustainability reporting is becoming more harmonised and standardized due to EU regulations such as the corporate sustainability reporting directive (CSRD) and EU Taxonomy. Corporations subject to the regulations are facing challenges in sourcing and managing the data required for compliant reporting. For blockchain implementations in corporate sustainability reporting, prior research is very limited and research including a more detailed technological evaluation of blockchain does not seem to exist to the knowledge of this thesis. This thesis fills a gap in the literature by providing in-depth insights into the suitability of blockchain technology for enterprise solutions, with a specific focus on sustainability reporting. Unlike previous studies that primarily address high-level concepts, this research offers a comprehensive explanation of blockchain basics, catering to readers who may not be familiar with the technology. Furthermore, given the novelty of sustainability reporting solutions, it is crucial to explore alternative options beyond traditional systems.

The main findings of this thesis validated the presumed challenges corporations face in accustoming to the new sustainability regulation and highlighted the need for efficient IT solutions to manage the vast amounts of data points and insights required for compliant reporting. While blockchain-based solutions certainly have the potential to streamline and manage the reporting process, no indications of advantages over more traditional systems built on shared databases were found. Rather, this thesis highlighted the very specific advantages and use-cases blockchain technology currently has over traditional data management solutions, which are not currently relevant in the case of corporate sustainability reporting.

As both enterprise blockchains and corporate sustainability reporting systems continue to evolve and mature, this research emphasizes the need for a fresh perspective and deeper examination of the topic. By shedding light on the challenges faced by corporations in adapting to new sustainability regulations and evaluating the potential of blockchain technology as an enterprise solution for sustainability reporting, this thesis offers valuable insights and calls for further exploration in this rapidly evolving field.

Key words: enterprise blockchain, corporate sustainability reporting, smart contracts

Pro gradu -tutkielma

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Tämän pro gradu -tutkielma tavoitteena oli arvioida lohkoketjuteknologian soveltuvuutta teknologiaratkaisuksi yritysten kestävyysraportointiin arvioimalla lohkoketjuteknologian teknologisia ominaisuuksia sekä yrityskäyttötapauksia, että yritysten kestävyysraportoinnin haasteita. Lisäksi kirjallisuuskatsaukseen keskityttiin erityisesti lohkoketjuteknologian ominaisuuksien esittelemiseen, jotka ovat sen tunnetuimpien ominaisuuksien takana. Tässä tutkielmassa lohkoketjuteknologiaa arvioitiin kirjallisuuskatsauksen avulla, ja yritysten kestävän kehityksen raportoinnin nykytilaa arvioitiin pääasiassa asiantuntijahaastatteluissa kerätyn tiedon avulla.

Lohkoketjuteknologialla on todettu olevan potentiaalia yritysratkaisuna monissa yritystoiminnoissa, kuten toimitusketjujen hallinnassa ja kirjanpidossa. Suuret globaalit yritykset ovat viime vuosina julkisesti ilmoittaneet pilotoivansa teknologiaa. Teknologinen abstraktiotaso estää kuitenkin usein suoraan näkemästä, miten lohkoketjuteknologia todellisuudessa parantaa nykyisiä prosesseja. Aiempaa tutkimusta on tehty molemmilla tasoilla, sekä korkean tason yrityskäyttötapauksista, että teknologian syvemmistä tasoista, mutta harvoin yhdessä.

Yritysten kestävän kehityksen raportointi on yhdenmukaistumassa ja standardisoitumassa EU:n säädösten, kuten yritysten kestävän kehityksen raportointia koskevan direktiivin (CSRD) ja EU taksonomian ansiosta. Säädösten piiriin kuuluvilla yrityksillä on haasteita vaatimustenmukaiseen raportointiin tarvittavien tietojen hankinnassa ja hallinnassa. Lohkoketjutoteutuksia yritysten kestävän kehityksen raportointia varten on tutkittu hyvin vähän, eikä tämän tutkielman tietämyksen mukaan näytä olevan olemassa tutkimusta, joka myös sisältäisi lohkoketjujen yksityiskohtaisemman teknologisen arvioinnin. Tämä tutkielma täyttää kirjallisuudessa olevan aukon tarjoamalla syvällistä tietoa lohkoketjuteknologian soveltuvuudesta yritysratkaisuihin keskittyen erityisesti kestävän kehityksen raportointiin. Toisin kuin aiemmissa tutkimuksissa, joissa käsitellään pääasiassa korkean tason käsitteitä, tämä tutkimus tarjoaa kattavan selityksen lohkoketjun perusteista, mikä palvelee lukijoita, jotka eivät ehkä tunne teknologiaa. Lisäksi kestävyysraportointiratkaisujen uutuuden vuoksi on tärkeää tutkia vaihtoehtoja perinteisten järjestelmien lisäksi.

Tämän tutkielman tärkeimmät tulokset vahvistivat haasteet, joita yritykset kohtaavat kestävyysraportointiprosesseissaan, ja korostivat tehokkaiden tietoteknisten ratkaisujen tarvetta, jotta voidaan tehokkaammin hallita raportointiin vaadittua määrää informaatiota. Vaikka lohkoketjupohjaisilla ratkaisuilla on varmasti potentiaalia virtaviivaistaa raportointiprosessia, ei havaittu mitään viitteitä siitä, että niillä olisi etuja verrattuna perinteisempiin jaettuihin tietokantoihin perustuviin järjestelmiin. Pikemminkin tässä tutkimuksessa nousi esiin viitteitä siitä, että lohkoketjuteknologialla ei ole tällä hetkellä perinteisiin tiedonhallintaratkaisuihin verrattuna merkittäviä etuja yritysjärjestelminä, etenkään kestävyysraportoinnin piirissä.

Avainsanat: lohkoketjut, kestävyysraportointi, älysopimukset

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1 Introduction

To move towards a more sustainable future, EU has launched its ambitious climate project called the European Green Deal with an end goal of making the continent of Europe climate-neutral by 2050 (Regulation EU 2020/852, 2020). In practice this means mobilising at least one trillion euros across sustainable investments over the next decade. In order for the investments to find the intended targets, a common and clear definition of “sustainable” is required. To facilitate this, the EU has introduced several measures including Corporate Sustainability Reporting Directive and EU Taxonomy.

Corporate Sustainability Reporting Directive (CSRD) has been proposed to improve the sustainability reporting of companies. This directive aims to strengthen the existing requirements for non-financial reporting and make these reports more comparable and reliable across the EU. Under the CSRD, companies are expected to provide detailed information about their impact on people and the planet, alongside their profit. These regulations together form an integral part of the EU's strategy to finance sustainable growth (Directive (EU) 2022/2464, 2022.)

EU taxonomy on the other hand is a classification system for economic activities defining what is sustainable. The taxonomy requires large companies in EU to disclose to what extent their economic activities are aligned by the environmental goals set by the taxonomy, coming into effect in steps starting in January 2022. (Regulation EU 2020/852, 2020.) By aligning their activities with the taxonomy guidelines, companies can become eligible for a multitude of financial benefits, thus creating an economic incentive for compliance.

EU law (Non-Financial Reporting Directive, NFRD) had already required certain large companies to provide disclosures on how they manage environmental, social and governance (ESG) challenges (Directive 2014/95/EU, 2014). The CSRD and EU Taxonomy further obligate subject companies to provide information on the proportions that their key figures like turnover align with EU level sustainability goals. Technical screening criteria is provided both regulations for each sector to assess the level of alignment of an economic activity. However, the current regulation relies on companies under the scope of NFRD to make their own assessment on whether they respect the guiding principles and meet the screening criteria. (Regulation (EU) 2020/852, 2020.)

This poses a question of trust and transparency in reporting, as greenwashing is a known phenomenon in ESG-reporting to attract investments (Uyar et al., 2020; Yu et al., 2020). The CSRD amending the NFRD has already been adopted by the EU Commission, which will require the audit of reported information (Directive (EU) 2022/2464, 2022). This will create more assurance for investors looking for ESG-investing opportunities, as well as reliability for companies looking for investments.

Blockchain has been researched and piloted as a potential solution to enhance transparency and assurance in many different use cases, among them sustainability reporting (Kouhizadeh and Sarkis, 2018). The technology provides parties involved in the blockchain real-time, immutable information and can incorporate other disruptive technologies such as the internet of things to trigger data entries through smart contracts. Prior use-cases and pilots can be found in supply chains and financial audit trails, with results implicating an efficient solution to provide reliable data and audit trails crucial in ESG-reporting. (Bakarich et al., 2020.) However, there is a lot of "hype" around the technology recognized in prior research, some with limited understanding of blockchain. (Yaga et al., 2018). Thus, further research is required on the suitability of blockchain technology as an ESG-reporting solution, with a more critical review of the technological properties that are claimed to enable efficient solutions.

The aim of this research is to investigate blockchain technology on a detailed level to evaluate how its technological properties are enabling enterprise use-cases, and whether this could be applicable to corporate sustainability reporting that is currently under major transformation due to related EU regulation. This thesis will answer the following research questions:

i. To what extent can blockchain technology serve as a viable solution for enterprise sustainability reporting?

ii. What are the perceived benefits and challenges of implementing blockchain technology for enterprise use?

iii. How do the findings from expert interviews align with or challenge the current literature on blockchain technology in sustainability reporting?

Next, in chapter two the background of corporate sustainability reporting in the EU to form understanding on the drivers of this major transformation. Following up, in chapter three technical aspects of blockchain required to understand its potential as an enterprise solution. Chapter four presents the methodology of this research, and chapter five displays interview findings. Lastly in discussion and conclusion chapters the results and findings of this thesis will be presented. This study mainly focuses on non-financial companies that must comply with the regulations, looking at the financial institutions only in the role of investors, leaving their disclosure requirements outside of this research.

To reach a conclusion, data will be mainly gathered from sustainability experts in companies that fall under the disclosure requirements. To get a more technological sense of possible blockchain implementation, blockchain specialists with experience in reporting implementations will be interviewed. Lastly, the viewpoint of investors focused on ESG will be brought in, to find out if blockchain could help them in their process of finding reliable investment opportunities. Finally, the conclusion of the thesis will evaluate what role blockchain can play in helping companies to navigate through the regulative web that is today’s corporate sustainability reporting.

2 Corporate sustainability reporting

Corporate sustainability reporting, often referred to as ESG reporting, is increasingly becoming a more formalized practice with increasing demand and pressure from stakeholders to not only report on company's sustainability practices, but to actively pursue improvement on material topics. On top of stakeholder e.g. customer, investor or supplier pressure, national government and other governing bodies as well as business associations are pushing companies to produce reliable sustainability information on the company's practices. (Herzig and Schaltegger, 2011.) It is no longer just the trending thing to do, but in the light of stakeholder pressure and regulation a must in company's annual reporting to build trust and maintain functioning relationships with stakeholders. The reporting practice has become more standardized, leading to information that is easier to quantify and compare companies with. A wide array of professional services has been born around corporate sustainability reporting, in facilitating the process as well as assessing the outcome. (Sulkowski, 2021.)

In practice a company's sustainability report consists of a dozen to a hundred pages, containing details related to its non-financial performance. These details cover environmental, social, and governance-related key figures and statements, commonly in the form of key performance indicators (KPIs), data tables and graphs, case studies or interviews with selected stakeholders. (Du et al., 2017.) The information disclosed can be qualitative or quantitative in its nature. For example, qualitative reporting can include disclosing how a company's strategy is aligned with its climate goals, while on the quantitative side a company might disclose a KPI signalling its carbon footprint. (Baumüller and Grbenic, 2021.) While sustainability disclosures have been mainly voluntary, companies have followed guidance by non-governmental organizations such as Global Reporting Initiative (GRI) and Sustainability Accounting Standards Board (SASB) to produce their sustainability reports. (Dinh et al., 2023).

More recently, through regulation, corporate sustainability reporting has become mandatory for publicly listed companies around the world. In context with this research, the focus will be solely on EU regulation mandating corporate sustainability reporting. The EU has launched a package of regulatory frameworks in an effort to harmonize and standardize corporate sustainability reporting. These regulatory frameworks include Non-Financial Reporting Directive (NFDR), EU Taxonomy, and Sustainable Finance

Disclosures Regulation (SFDR). NFDR will be superseded and complemented by Corporate Social Responsibility Directive (CSRD) in 2023. These frameworks define what information should be reported by the companies and provide sector-based guidance in their technical annexes in how to construct the information. (Ottenstein et al., 2021.)

While regulation and sanctions for non-compliance are driving the implementation of robust sustainability reporting practices, on the other side capital markets are one of the key drivers in encouraging companies to report better sustainability performance. Investors are increasingly considering both financial and non-financial information when assessing their current and potential investments. The non-financial information is noted to be a contributing factor in increasing shareholder wealth, through risk management and reputation, which in turn can lead to increased company valuation. (Dienes et al., 2016.) To help investors recognize companies with good sustainability performance, an industry has been born to provide ESG ratings for companies, scoring their sustainability performance. In accordance, confusion and scepticism related to the reliability of these ratings have emerged. Ratings agencies are deemed to construct their ratings based on self-reported data, and there are no widely accepted procedures in place in the private sector on how to process sustainability data into a singular KPI. This is one of the pain points EU is trying to address with their SFDR framework. (Walter, 2020.) Regardless, there has been research related to the impact of these rating agency scorings. A linkage between stronger stock performance and lower cost of capital has been identified for companies with financially material items on their sustainability information – meaning that their business is inherently linked with sustainability items such as emissions reduction or with enabling others in their performance. Furthermore, the opposite has been identified for companies with financially immaterial sustainability information. In the future it will be clearer whether this enhancement in performance and value is truly from sustainability-related performance, rather than just capital allocation. (Bossut et al., 2021) Nevertheless, the financial incentives for companies to report great sustainability performance are there; mainly in the forms of capital and risk management.

However, there are numerous challenges in corporate sustainability reporting despite the tightening and guiding regulation such as lack of transparency, reliability, and data gaps. It has been noted by prior research that while mandatory disclosures improve the availability of information, it does not always equate to better information quality. (Bossut et al., 2021) Furthermore, a tendency for companies to cherry-pick sustainability information to disclose has been identified. Generally, a company can focus on reporting information that is not as relevant for their business and thus they might imply a smaller impact than they are causing. (Bingler et al., 2021.) With incentives for good sustainability performance in place, there must be controls to ensure regulation will work as intended. As long as only the final report can be accessed, there will be a lack of transparency and trust to support the validity of the sustainability claims.

2.1 Development of EU non-financial reporting regulation

EU legislation supplements existing national and regional regulations for member countries. This is the case for sustainability reporting related regulation as well. As part of the European green deal, EU has launched regulatory frameworks for corporate sustainability reporting to enable consumers, investors, civil society organizations and other stakeholders to better assess the sustainability performance of companies. (Dinh et al., 2023.) To understand this regulatory landscape better, the main elements will be presented in this section. The purpose is to highlight on a more detailed level what are the data points required to comply with these regulations, as well as to show how at times data availability might prove to be a challenge for the reporting companies. As financial incentives are embedded in the system for greater sustainability performance, this creates an additional challenge in ensuring companies are disclosing the required information through transparent and trustworthy processes.

The NFRD came into effect on January 1st, 2017, and since then companies under the regulation have had to publish information related to environmental impact, social matter and treatment of employees, human rights, anti-corruption and bribery, and diversity on company boards. The NFRD has applied to large public-interest companies with average employee count exceeding five hundred for the financial year. Based on EU estimates, the NFRD has covered 11 700 companies and groups across the EU. On a more detailed note, public-interest companies have been defined to include listed companies, banks, insurance companies, and any other companies that the national authorities deem as public-interest entities. (Directive 2014/95/EU, 2014.) The disclosure can be included either in the management report as a part of the company’s annual report or published as a separate report. As a comparison, the EU has mandated International Financial Reporting Standards (IFRS) for all stock-listed companies in European stock exchanges to improve the quality of financial reporting and harmonize financial statements across the EU. However, the NFRD does not impose a specific or standardized framework for companies to employ when creating their disclosures. Thus, academics have suggested that the NFRD has been limited in its capability to promote harmonization across companies' non-financial statements. (Breijer and Orij, 2022.) Furthermore, the EU deemed the NFRD to be inadequate in scope and content in order to keep with regulative development. Regardless, since its introduction NFRD has been deemed to have improved transparency in sustainability-related disclosures of business activities and has become a core element for further initiatives related to the European green deal. (Baumüller and Grbenic, 2021.)

To improve upon the NFRD, the EU started to develop a new more comprehensive non-financial reporting directive in 2020. By April 2021, the EU Commission published their new proposal for this directive: The Corporate Sustainability Reporting Directive (CSRD). (Directive (EU) 2022/2464, 2022.) During the public consultation period, the directive was described as a major improvement in sustainability reporting by the financial services industry as well as "nothing short of revolutionary" by the Value Reporting Foundation. Generally, it was deemed that European companies are going to face significant changes in their reporting environment. (Baumüller and Grbenic, 2021.) On January 5th, 2023, the CSRD entered into force. Simultaneously, the European Financial Reporting Advisory Group (EFRAG) was tasked with creating standards for non-financial reporting, which were previously lacking. The aim was to improve the comparability of the reported information. This gave birth to the European Sustainability Reporting Standards (ESRS). Based on the draft standards published in November 2022 the first set of standards are to be adopted by mid-2023. Companies that are subject to the CSRD are required to disclose their information in accordance with these standards. (Directive (EU) 2022/2464, 2022.) To further develop the sustainability reporting requirements, the EU Taxonomy was developed to establish a common understanding on what economic activities can be classified as sustainable, with substantial contributions to EU environmental goals. Together with the CSRD, these instruments ensure that companies subject to the CSRD will disclose their environmental performance as well as the taxonomy-alignment of their economic activities. (Ottenstein et al., 2021.)

2.1.1 Corporate Sustainability Reporting Directive

As the Corporate Sustainability Reporting Directive (CSRD) is a complex and vast regulation, the aim of this section is to provide a high-level overview of the regulation in application, implementation, and contents to form a required understanding of the changing EU-level sustainability reporting requirements in the context of this research.

As stated, the CSRD considerably extends the current scope of companies that fall under the non-financial reporting directive, as well as establishes a remarkable number of new sustainability topics and KPIs that must be reported in accordance. Overall, the EU estimates that the number of companies that will have to comply with CSRD is quadruple to the number of companies currently under the NFRD, from 11,000 to 50,000. (Baumüller and Grbenic, 2021.) In brief, companies that fall under the new scope are all large and listed companies operating in the EU. All companies that meet two of the following three conditions are classified as large companies.

- €40 million in net turnover
- €20 million in assets
- 250 or more employees

In addition, companies outside of the EU that have a turnover of over €150 million in the EU must comply, adding a remarkable consideration for global companies. Furthermore, all listed companies must comply regardless of their size, although non-large, listed companies are given additional time to comply with the regulation. (Baumüller and Grbenic, 2021.)

Even though the CSRD entered into force in January 2023, companies falling under the scope of the regulation still have time to prepare, with the earliest reports due in 2025. More specifically, for companies that are currently under the NFRD, thus having at least 500 employees, the CSRD will start applying from 2024 onwards, with the first reports due in 2025. For companies that are not currently under the NFRD but fall under the scope of CSRD as a large company, the timeline is bumped back by one year, with the first reports due in 2026. For listed small and medium-sized enterprises (SMEs), the CSRD is still a bit further away, with the first reports due in 2027. (Directive (EU) 2022/2464, 2022.) Essentially, this gives the companies who might not have any processes in place relating to non-financial reporting some flexibility to comply with the CSRD, while the companies that by regulation (NFRD) should already have some of the processes in place face a tighter schedule. However, it is noted by prior research that a compliance with NFRD still requires a significant investment to transform into compliance with CSRD, as required disclosures and data points are vastly increased.

While the required disclosures differ from company to company based on their size, complexity, and nature of business, on a high-level the requirements are the same for everyone, including both qualitative and quantitative information. The basis for the reported information lies within the European Sustainability Reporting Standards (ESRS), with the first draft containing twelve standards forming a comprehensive sustainability reporting framework. In practice, the ESRS contains cross-cutting standards and topical sector-agnostic standards that affect all companies under CSRD. Additionally, sector-specific standards are currently being developed to be included in the ESRS, thus providing a more company-specific reporting framework. (Baumüller and Grbenic, 2021.)

For the standards themselves, the cross-cutting standards ESRS 1 and 2 include general level disclosures of company information in the context of sustainability. ESRS 1 requires a company to disclose information on their governance practices, strategy, management of impacts risks and opportunities as well as metrics and targets related to climate change. The other cross-cutting standard, ESRS 2, on the other hand requires companies to disclose information on the general characteristics of the company and an overview of the company's business and business model. In addition, the standard includes more specific disclosures on compliance, approximations in relation to value chain and reporting boundaries, estimation uncertainty, changes in preparation and presentation, and prior period errors. The remaining standards are all topical in their nature, with the familiar letters leading each of the three groups: Environmental, Social and Governance. ESRS E -standards set the requirements for reporting disclosures in relation to climate change, pollution, water and marine resources, biodiversity and ecosystems, and resource use and circular economy. On a concrete level, this standard could entail disclosures such as the company's carbon footprint, energy efficiency, and waste. Besides detailed disclosures and KPIs on each topic, the aim of the standard is to provide information on how the company's business model and operations are planned to align with the transition to a sustainable economy, as well as their contribution to the objectives of the European Geen Deal. Similarly, the ESRS S standards contain similar disclosure requirements for a company's social topics; information related to own workforce, workers in their value chains. the communities impacted by the company's operations as well as the end-users of the company's products or services. Disclosures might include workforce KPIs such as headcount, diversity, and occupational incidents. Lastly, the ESRS G standard contains the disclosure requirements related to a company's business conduct through strategy and approach, processes and procedures and performance. ("First Set of draft ESRS - EFRAG", 2022.)

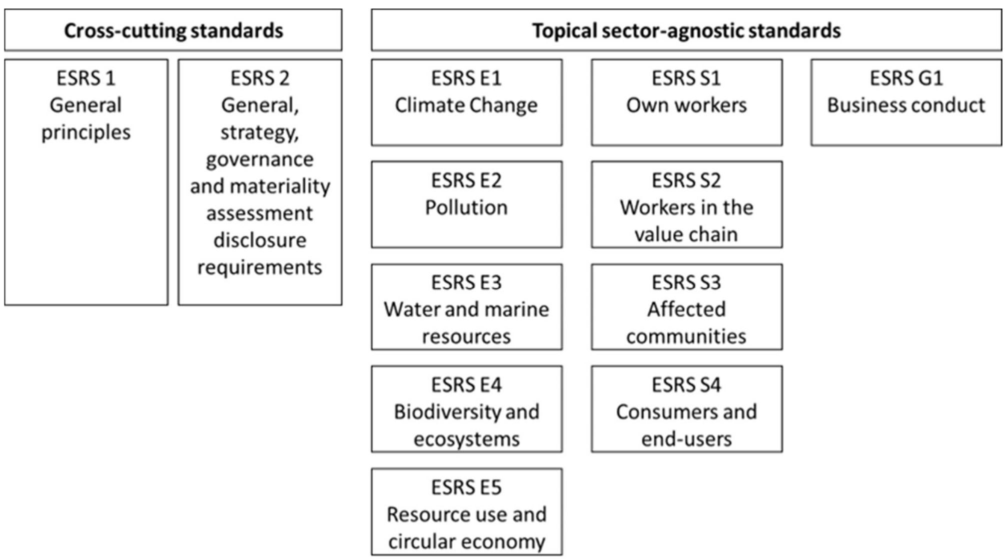

Figure 1 - First Set of draft ESRS (EFRAG, 2022)

On top of standardization of sustainability reporting through ESRS, CSRD addresses another commonly recognized issue in the trustworthiness of the reporting. With CSRD, third-party assurance will be mandatory, thus creating a new level of credibility in the reporting. This also means, that the companies under CSRD will have to have credible processes and means of sourcing the data for sustainability reporting in order to be eligible for assurance. Starting out as limited assurance requirements, there is a possibility to move into reasonable assurance requirements over time as the regulation evolves and companies become more mature in their reporting practices. (Directive (EU) 2022/2464, 2022.) Furthermore, the mandatory assurance is stressed to focus the work on evaluating the compliance of the reporting with ESRS. It is also noted that besides the auditor of the company’s financial statement, another provider can be employed to assure CSRD-reporting. (Baumüller and Grbenic, 2021.) Additionally, CSRD dictates that the report shall be published as a part of a company’s management report to improve the connection between sustainability-related and financial information. (Ottenstein et al., 2021).

Overall, CSRD is noted to be a significant step forward in corporate sustainability reporting, as comparability, completeness and reliability of sustainability reports is improved. (Baumüller and Grbenic, 2021.) Comparability is driven by the introduction of ESRS, a set of standards to form a common framework for reporting for all companies under the regulation. As CSRD introduces a more comprehensive set of reporting requirements than the previous non-financial reporting directive, companies must collect and report more data in order to comply, thus enhancing the completeness of sustainability reporting. Finally, as CSRD requires companies to have their sustainability report verified by an independent third party, stakeholder trust in the accuracy of the reported data can be increased, creating reliability for the delicate process.

However, CSRD will require European companies to invest in improving their reporting processes and structures, in order to comply with the new, more comprehensive reporting requirements. While this investment will come at a cost, the ultimate goal of the CSRD and other EU regulations is to promote sustainable decision-making by companies. (Baumüller and Grbenic, 2021.)

2.1.2 EU Taxonomy

The EU Taxonomy is inherently a classification system to deem which economic activities can be considered sustainable, a tool to evaluate the sustainability of a company’s business. It provides investors, companies, and policymakers with standardized definitions for sustainable economic activities, creating transparency for stakeholders and limiting greenwashing, ultimately helping investments to find economic activities that are truly driving the transition to a low-carbon economy. Essentially the required companies have to report the alignment of their economic activities with the taxonomy criteria as a part of their sustainability reporting. (Lucarelli et al., 2020.)

Companies that fall under CSRD are also subject to report their EU Taxonomy alignment. In addition, financial market participants that offer and distribute financial products in the

EU are subject to the regulation, in essence having to disclose to what extent their financial product includes, promotes or finances sustainable projects defined by the criteria of the EU Taxonomy. (Regulation (EU) 2020/852, 2020.) As of January 2023, all of the environmental objectives of the taxonomy which are used to evaluate the sustainability of economics activities have become mandatory to disclose against, in practice meaning that the EU Taxonomy has been fully implemented.

The EU Taxonomy is built upon six environmental objects that economic activities are evaluated against:

- Climate change mitigation
- Climate change adaptation
- Sustainable use and protection of water and marine resources
- Transition to a circular economy
- Pollution prevention and control
- The protection and restoration of biodiversity and ecosystems

In order for an economic activity to be taxonomy-aligned, firstly it needs to either substantially contribute or enable one of the six environmental objects. A substantial contribution is of course activity-based, but generally can be classified as an activity that is performed in an environmentally sustainable way. An enabling activity on the other hand can be classified as an activity that improves the environmental performance of another activity, such as manufacturing of components for renewable energy producers. Secondly, it needs to pass the Do No Significant Harm (DNSH) -criteria, which states that while substantially contributing to or enabling one of the environmental objects the economic activity cannot have a harmful impact simultaneously to any of the other objects. Next the activity has to comply with minimum safeguards, such as OECD Guidelines on Multinational Enterprises and the UN Guiding Principles on Business and Human Rights. Finally, the activity must comply with the detailed technical screening criteria developed by the EU Technical Expert Group. This criterion has definitions for sector and industry specific economic activities and their thresholds for taxonomy-eligibility. If an economic activity can hold true to all of the above, it can be considered as taxonomy aligned. (Regulation (EU) 2020/852, 2020.)

For non-financial companies, the required EU Taxonomy disclosure consists of the outcome of the alignment evaluation of their economic activities. More specifically, the disclosures must include the proportion of turnover, capital expenditure (capex) and operational expenditure (opex) aligned with the taxonomy, each separately. Turnover provides an indication of a company's current alignment with the EU Taxonomy. Capex gives investors a sense of a company's future direction. Companies that disclose their capex investments as part of a plan to be Taxonomy-aligned provide valuable information. It is recommended to complete the Taxonomy calculation separately for each environmental objective. This provides transparency and enables investors to better understand a company's sustainability performance and strategy. (Regulation (EU) 2020/852, 2020.)

As corporate sustainability reporting becomes more harmonized and standardized, it promotes the opportunity for reporting process automation. While different IT solutions for this purpose are being developed, a particularly interesting domain of new enterprise IT solutions lies within blockchain technology. In the next chapter, prior literature of blockchain technology will be presented and reviewed to form an understanding of what the technology is capable of, and where does it potentially make sense for enterprise use.

3 Blockchain

As a disruptive technology, it is noted that blockchain research is heavily influenced by opinion articles and grey literature (Chikhi et al., 2022). However, research on blockchain applications in supply chain and accounting have provided insights into the potential applications as a sustainability reporting solution that the technology has (Bakarich et al., 2020; Kokina et al., 2017; Kouhizadeh and Sarkis, 2018).

Blockchain technology has been paraded lately as a solution to almost any organizational problem. While the technology can provide powerful and efficient solutions, it is not as all-purpose as the common perception might imply. However, there are use-cases for blockchain, and its strongest properties can benefit organizations in their sustainability reporting especially in transparency, integrity, and security. (Yaga et al., 2018.)

As noted in prior research, through application of blockchain, data in its very nature can be more credible and resistant to fraud due to the data being immutable after entry (Sulkowski, 2021). It is however recognized, that blockchain itself does not solve the problem of data being invalid (Sulkowski, 2021; Wüst and Gervais, 2018; Yaga et al., 2018). Multiple researchers point out that blockchain is best applied in a situation where there is a need for promoting trust and transparency between parties, such as the relationship of regulators and entities under regulation (Sulkowski, 2021; Wüst and Gervais, 2018; Yaga et al., 2018). In the case of corporate sustainability reporting, which still often does not require third-party auditing, mistrust in reporting is common (Yu et al., 2020). The properties of blockchain seem to counter some of the challenges posed by reliable sustainability reporting, with some prior if limited research existing on the matter. Research on the application of blockchain in reporting environments such as supply chain management as well as financial accounting is more common and will be investigated as comparative research.

Chikhi et. al (2022) report that blockchain adoption can lead to an increase in traceability and transparency in overall supply chain reporting, especially through integration of smart contracts running on IoT-equipment. Through these aspects concrete benefits reported in this environment include inhibiting data counterfeiting, monitoring of carbon emissions, and fast access to immutable audit. (Chikhi et al., 2022.) In the same sense application of blockchain in accounting has been reported to reduce necessity for intermediaries, resulting in less friction in the process. In practice this means less delays and costs related to information transmission, due to continuous and transparent access to the information trail which resides in the blockchain. (Smith, 2018.)

Looking into blockchain on a high technological level, use cases in sustainability reporting, comparative research in supply chain, accounting and auditing will form a solid foundation for a critical review of the true potential of blockchain technology as a corporate sustainability reporting solution.

3.1 Blockchain technological overview

Following the definitions set on the report on blockchain by the National Institute of Standards and Technology under the United States Department of Commerce (Yaga et al., 2018), blockchain technology is based on distributed decentralized digital ledgers that a community of users can use to record transactions in that particular ledger. Once recorded, transactions become immutable. This means that no party can manipulate the recorded transaction once published. (Yaga et al., 2018.) The ledger consists of a chain of blocks, with each block having the capability of containing multiple transactions as data – thus creating a full history of recorded transactions in the chain. Copies of the full blockchain, called nodes, are distributed to all users in the community creating a network. In order to add a new block into the blockchain, it needs to be verified as a valid addition by the majority of nodes in the network, reaching "consensus" among the nodes. (Nofer et al., 2017.) In practice, through blockchain technology it is possible to create immutable data trails that require verification from all parties of the network to enter new data, without the need for a trusted third-party (Yaga et al., 2018). While attributes like persistency, auditability, immutability, efficiency, and other terms are often connected to blockchain research, it is important to understand which blockchain functionalities enable such properties.

The aim of this section is to provide an overview of the different elements of a blockchain network, from the contents of the blocks themselves to the rules that enable the forming of the chains. In addition, the goal is to look into the factors within the components of a blockchain network that promote the common qualities associated with blockchains, such as integrity, security, transparency and traceability.

3.1.1 Permissionless and permissioned blockchains

According to Yaga et al. (2018) to understand how the different components creating a blockchain work, it is important to categorize whole blockchain networks into two different categories: permissionless and permissioned. As a simple distinction where permissionless blockchain networks allow anyone to publish new blocks into the blockchain, permissioned blockchain networks have restricted this allowing only permissioned users to publish new blocks. Furthermore, Yaga et al. (2018) compare permissionless blockchain networks to the public internet, and permissioned networks to corporate intranets. Although some distinctions have been drawn between permissionless and permissioned networks compared to public and private networks respectively, as Bakarich et al. (2020) suggest in this research they are used interchangeably.

In permissionless blockchain networks, where anyone can publish blocks, network users also have the right to freely read the blockchain or write to it. As open-source software, this brings in the possibility of malicious users. Permissionless blockchain networks usually combat this by employing consensus-systems, where the users need to put in resources to publish new blocks. This can create a steep entry for possible malicious users, for example in the form of computational resources required or cryptocurrency. On top of this, these networks usually reward publishing valid-deemed blocks by the network in a form of cryptocurrency. (Yaga et al., 2018.) Typically permissionless blockchain networks can be found behind many of the popular cryptocurrencies, such as bitcoin. As all parties in the network are constantly able to observe and participate in the blockchain, near full transparency is achieved between the users. While this landscape of transparency and decentralized authority is what runs the appeal of public networks for certain blockchain applications like cryptocurrencies, it is also noted to be the reason for scarce adaption in governmental bodies or private companies. (Bakarich et al., 2020.) As prior research suggests, these entities tend to prefer “need-to-know basis” in accessibility to information (Bakarich et al., 2020; Wüst and Gervais, 2018; Yaga et al., 2018).

In a permissioned network publishing a new block requires authorization by a pre-determined authority. In this case only authorized users in the network have full read and write authorities, which effectively results in these users maintaining the blockchain. This also enables control over who can access the blockchain in any capability, creating roles of different stature within the network. In practice this can mean restricting who can read the blockchain, submit transactions or publish new blocks. (Bakarich et al., 2020.) Nevertheless, according to Yaga et al. (2018) private blockchains can have the same characteristics usually connected to public blockchains; traceability of digital assets through the blockchain and resilient distributed data storage. Consensus-systems are prevalent as well in private networks. In contrast to ones employed in public networks, methods to reach consensus in private networks do not usually require resources to the same extent. Yaga et al. (2018) recognize that commonly in order to participate in a private network, user identity must be established. Furthermore, this leads to an environment where parties participating in maintaining the blockchain share a level of trust. Required identification removes the protection of anonymity, which in turn helps to spot malicious or misbehaving users in the blockchain, possibly resulting in revoking authorization. (Yaga et al., 2018.) Thus, consensus models in private blockchains do not require as heavy consensus mechanisms to operate as public ones, since in private blockchains the user's reputation itself is at stake instead of concrete resources.

This sentiment of reputation is highlighted in an organizational environment, which is the most prevalent landscape for the usage of private blockchain. Organizations that are working together can build a permissioned blockchain network and also invite other parties participating in the business to join. All participants may record transactions on the shared ledger and new blocks can be added through a chosen consensus model, usually depending on the level of trust parties participating in the blockchain share with each other. When a private blockchain is deployed for a group of individuals or organizations, it is often called a consortium blockchain. (Yaga et al., 2018.) According to a blockchain research conducted by consulting company Deloitte, most of businesses currently employing a blockchain are using permissioned blockchains (Deloitte, 2019). As Bakarich et al. (2020) point out private blockchains are essentially trading decentralization for more control. This is quite evident, since in the world of business it is important to deny access to certain parties such as competitors and customers from business-critical information. An accompanying tendency of private blockchain in organizational environment is often the trading of anonymity for control. This promotes an environment where parties are encouraged to pursue set business purpose, while disincentivizing fraud or other actions in bad faith since they can be identified. (Yaga et al., 2018.)

3.1.2 Transactions

As introduced on a general level, blockchain consists of blocks where transactions are recorded. Transactions in this case portray interactions between parties, that are recorded. In cryptocurrency applications of blockchain, transactions in that specific currency between network users are being recorded. Cryptocurrencies are however just one example of blockchain applications; Yaga et al. (2018) note that in business-to-business environment transactions are used to tracking activities relating to assets, whether of digital or physical in nature. While the actual data within the transaction might differ from one blockchain implementation to another, the mechanism for executing transactions is usually similar despite the blockchain. A user part of the blockchain network queues for a transaction to be processed in the network. Queued transactions are stored while unconfirmed, in the order they have been submitted. When a new block is created, the waiting transactions are then issued, given the criteria and rules for transactions defined for the blockchain are fulfilled. In the case of cryptocurrencies, this could be a simple currency transfer to another user. (Monrat et al. 2019.) For other applications, the transaction could be more broadly a data transfer. Yaga et al. (2018) present two different scenarios for a broader data transfer. As a baseline, a user might simply want to add data to be stored permanently and publicly on the blockchain. A more sophisticated use-case would be incorporating the use of smart contract systems, where transactions can be employed to add data to the network and process that data according to set rules on the blockchain before storing it permanently. One of the most common applications of such smart contract systems can be found in the field of supply chain management. In this particular application, transactions in the blockchain could be used to change attributes of assets stored in the blockchain, such as shipment locations. (Queiroz et al., 2019.)

Regardless of the type of transaction in the blockchain, a key aspect in blockchain technology is to validate and authenticate the transaction. Meeting any requirement posed by the possible protocols, data format requirements or smart contracts in a blockchain implementation ensures the validity of the transaction. In terms of authentication, it is critical for determining whether the submitter of the transaction can execute the transaction. For authentication, transactions are signed by the submitter's associated private key. Verification of transactions happens through the use of associated public keys. (Monrat et al., 2019.) These keys and signatures build the foundation for encryption in blockchain, and thus lay the principles for security advantages that blockchain technology is known for.

3.1.3 Cryptography – security of a blockchain

Adapting Srivastava et al. (2019), the security aspects of blockchain can be divided into four different steps: data encryption, immutability, blocks and data verification. Data encryption refers to the cryptographic methods used in encryption, immutability the means to prevent modification of the data after being stored. Furthermore, the mechanisms behind the forming of blocks and data verification promote security on their own, discussed in more detail in this section.

Cryptography is a key part in making blockchain secure. On a basic level, encryption process is twofold: data is encrypted into ciphered text which in turn is decrypted back into readable data. One way to execute the encryption is by using symmetric algorithms, often referred to as private key encryption. In this case, the same key is used for both encryption of the data as well as decryption. (Srivastava et al., 2019.) However, blockchain implementations commonly employ asymmetric algorithms, referred to as public key encryption. In public key encryption different keys are required to encrypt and decrypt the data respectively. The key pair consists of a private and a public key. The public key is distributed in the network for all users, while the private key is kept as secret. (Srivastava et al., 2019.) Each user is given their own unique key pair in a permissionless blockchain network, where in a permissioned network this might be limited (Yaga et al., 2018). For the encryption process, a user in the network issuing a transaction can use the recipients public key to encrypt the transaction, leaving the ciphered transaction public, but only readable for the recipient in the possession of the matching private key. (Srivastava et al., 2019.) This process can be alternatively vice-versa, where the issuer of the transaction uses private key for encryption, leaving the network possessing the public key capable of decryption. This acts as a digital signature, where the issuer proves the possession of a private key. While the keys in a set pair are connected, Yaga et al. (2018) note that determining the private key based on the matching public key is not feasible, guaranteeing the cryptographic protection and thus security of the process. (Yaga et al., 2018.)

Immutability of the data might be one of the best-known attributes of blockchain. The key element behind this is a hash reference, which essentially connects the blocks into a chain. These hash references are generated through hash functions. (Srivastava et al., 2019.) When a hash function is applied to a data set, the process is called hashing. In practice, hashing calculates an output for an input of any size. In blockchain the contents of a block act as the input, which altogether through a hash function amount for the unique hash reference of a block. Yaga et al. (2018) note that when a hash function is given identical input, it will always result in the same output – making it easy to spot any changes in the input data. Even the smallest change in a block, say one bit in one of the transactions listed in the block, would result in a complete rehashing, and thus, a completely new hash reference. (Yaga et al., 2018.) One of the core functionalities of a blockchain is to include the hash reference of the previous block in the next one. This makes it easy to spot the block in the chain which has been tampered with, as tampering effects the hash references of all subsequent blocks. (Nofer et al., 2017.)

3.1.4 Block architecture and structure

As noted, the very idea of a blockchain is quite literally a connected sequence of blocks (Zheng et al., 2017). In this section there will be a closer investigation on what are the common elements within a block, as well as how do these elements connect the blocks to each other, forming a chain. A block structure is typically divided into two in prior research, with the two main elements being the block head and the block body. Within these two groupings lie more detailed information, with block header commonly consisting of information related to the properties of the block itself, while the block body is holding the information related to the transactions included in the block. (Mingxiao et al., 2017; Zheng et al., 2017.) Yaga et al. (2018) point out in their research that while many of the blockchain implementations are employing a similar set of data fields, every blockchain can decide on its own, unique data fields However, for the purpose of this research it is deemed more relevant to build an overview of an understanding of blockchain technology, and thus in the spirit of the rest of this research the most common approaches will be presented as examples.

Firstly, identifying and describing the common contents of a block header by adapting Yaga et al. (2018) supplemented by Zheng et al. (2017):

- Block number, noted to be referred to as “block height” on some implementations, signalling the number of blocks preceding the block in question.

- Block version, containing information on which rules are employed by the network in question for block validation.
- Hash value, there are various ways of determining this value, e.g., by generating the Merkle tree root, resulting in a single-value representation of all of the transaction data a block contains.
- Timestamp, the time of publishment of a block as seconds in universal time.
- The nonce value, a number that is changed by the publishing node in blockchain networks that use mining to solve the hash puzzle. It might or might not be used for additional purposes besides resolving a hash puzzle in other blockchain networks.
- Parent block has value as in the hash value of the previous block in the blockchain.

To continue adapting Zheng et al. (2017), the block body on the other hand commonly consists of the transactions happening in the blockchain. The number of transactions that can fit into a single block is defined by the size of the block as well as the size of transactions in question. Yaga et al. (2018) note very broadly that while to block body is mainly used to store transactions, there might be other data present in the block body depending on the purpose of the blockchain.

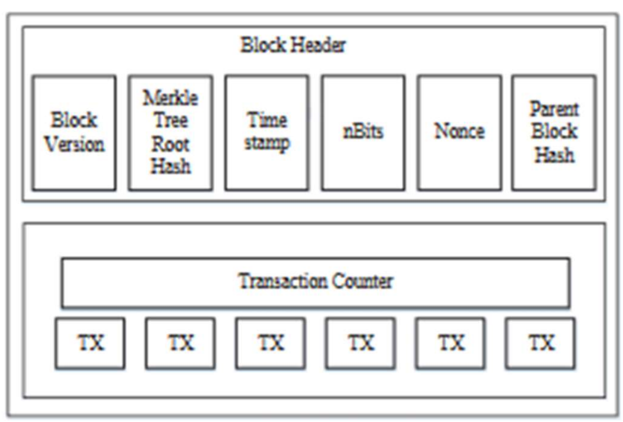

Figure 2 - Block structure (Zheng et al., 2017)

As the name suggests, in blockchain the blocks are chained together. The linking of the blocks is enabled through each block in their block header containing the hash digest of the previous block. (Kaushik et al., 2017.) As the hash is in practice is a sum of all the elements in block, including the hash of the previous block, any change in any of the blocks would results in changing the hash in every block. This is the mechanism of the blockchain that prior research notes as the enabler of easy detection and rejection of blocks which have altered data. (Yaga et al., 2018.)

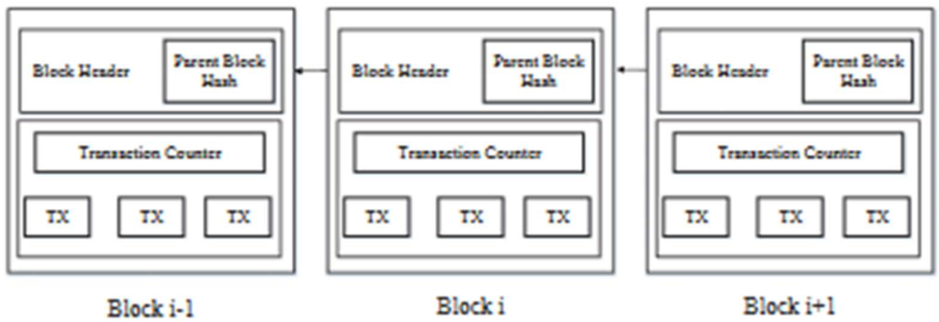

Figure 3 - Blockchain architecture (Zheng et al., 2017)

3.2 Consensus systems in blockchain technology

As consensus systems play a key role in the blockchain environment in the context of using the technology in reporting and data gathering, there will be a special focus on them compared to the other components of the blockchain in this research. Additionally, for clarity the different ways of establishing consensus in a blockchain network is going to be consistently referred to as consensus systems, connecting prior research on consensus methods, consensus algorithms and methodologies under one term.

On of the key properties of a blockchain is the system which determines the user, party, or other entity that will add, as is often called publishing, the next block in the chain. Many different systems and solutions exist for establishing the next publisher of the block, with one key characteristic being the common requirement for the output; the participants of the blockchain must unanimously agree that the block that is being published in itself is a valid addition to the existing blockchain. In addition, the network must also agree that besides the contents of the block being added, the block is acceptable in the context of the already existing blocks. The goal is the ensure a commonly validated, unambiguous order of the blocks and the transactions they contain, establishing the integrity and consistency of the data that blockchain is known to promote. (Mingxiao et al., 2017; Nofer et al., 2017; Yaga et al., 2018.)

According to Yaga et al. (2018), there are two distinct existing environments in which the blockchain and thus the chosen consensus system can operate with a foundational difference; in one it is a gruelling competition for the right to be the publishing entity where in other it is commonly predetermined to an extent. This is where permissionless and permissioned blockchain environments make on of their most distinct differences. (Yaga et al., 2018.)

In a permissionless blockchain, as touched upon earlier, anyone can publish blocks to the system. There are typically competing publishing nodes, that are trying all simultaneously to be the next publishing entity. In permissionless blockchain networks the publishing nodes are most commonly incentivized through the promise of cryptocurrency or other fees related to the transaction. In prior research financial gain is often noted as the likely main motivation for the publishing nodes to strive for the publishing position. Sometimes this can occur at the cost of the health of the network itself or at the expense of other participants of the network. This promotes the common environment in permissionless blockchain networks, where each user is generally distrusting of other participants in the network, requiring a system to keep order in the network and enabling functionality of the whole blockchain. As noted, the main role of this system is to determine the “winner” of this race, as in the publishing node that is granted the power to publish the next block. (Mingxiao et al., 2017; Yaga et al., 2018.)

On the other hand, in permissionless blockchain networks the power to publish the next node is often predetermined by the agreed upon system. The role of consensus systems here is more straightforward, as the participants are commonly trusting entities with strong identification required to participate in the network. Since there is no “race” to get to publish blocks, the consensus models are typically less demanding in computational power and thus a lot faster. (Mingxiao et al., 2017.)

In this section varying consensus systems will be defined, as well as their common use-cases reviewed and explained. Notably, in the context of the research the consensus systems currently employed in reporting and data gathering processes will be evaluated in a more distinct matter, while other consensus systems are presented to build a more whole picture on the possibilities that the blockchain technology has to offer through different implementations.

3.2.1 Initial state of a blockchain network and common principles for publishing of new blocks

How does a blockchain start? The exception to the publishing of new blocks is the very first block present in the chain, often referred to as the "genesis block". This block is not published by any user participating in the network but is rather the foundation block of the system. As Read (2022) explains the genesis block is inherently different to the other blocks in a chain because there is no block that the genesis block could link to prior to itself. Thus, the genesis block is the pre-configured block in a blockchain.

After the participants agree to the initial state of the system, the consensus system also needs to be agreed upon. As Yaga et al. (2018) note, despite which consensus system is agreed upon by the participants, each block must be valid in the context of the system and available for each participant to validate on their own. This forms the basis of any consensus system; agreed initial state and the ability for each participant to validate each following block independently. As a further note, it is a quite common situation in a blockchain that there are two valid iterations of a chain. Yaga et al. (2018) suggest that most blockchain networks deem to longer blockchain in these situations as the valid one, discarding the shorter valid chain and adopting the longer as the only valid iteration since there has been the most amount of effort directed in building the longer chain out of co-existing chains. It is considered more common with some consensus systems than others and will be expanded upon as we touch upon said consensus systems.

Adopting the definition by the National Institute of Standards and Technology under the U.S. Department of Commerce (Yaga et al. 2018), at this stage the following properties have been established in the blockchain prerequisite to the functionality of the technology:

1. The initial state of the system is agreed upon (e.g., the genesis block).
2. Users agree to the consensus model by which blocks are added to the system.
3. Every block is linked to the previous block by including the previous block header's hash digest (except for the first 'genesis' block, which has no previous block and for which the hash of the previous block header is usually set to all zeros).

4. Users can verify every block independently.

Yaga et al. (2018)

As the blockchain technology is predominantly run by software, prior research suggests that the users in the network do not have to be aware of the prerequisite properties in order to participate in the blockchain (Zheng et al., 2017).

Now that the common rules that constitute the working of a blockchain have been established, it is important to note the implications. One of the most prevalent positively deemed qualities of blockchain technology in prior research and public media pieces is that the technology does not have a need for a trusted third-party to operate, as one of the key features of a blockchain is that every participant within the network can provide verification of the system's integrity. In order to add blocks into the blockchain, all participating users and their copy of the blockchain must reach consensus on the validity of the blockchain. (Nofer et al., 2017; Yaga et al., 2018.)

For permissionless blockchains the common idea behind assigning the power to publish the next node is based on which node, as in user, can solve a computational problem the quickest. The computational resources required to solve these problems is often very resource-intensive, thus favoring the users with largest number of resources available. (Yaga et al., 2018.) As noted, for permissioned blockchains this is commonly not the case since there is a level of trust involved with the participants.

There are various consensus systems for each blockchain environment employing the properties that have been broadly described, and next they will be reviewed; what is the idea behind each consensus system, what is the most common environment they are employed in, and what practical use-cases so far have been developed around them. Firstly, the most well-known consensus systems to prior research and media will be looked into to form a cohesive understanding of the landscape. With the scope of this research in mind, the consensus systems that do not seem that prevalent in common discussion yet still have the more applicable use-cases for reporting and data gathering are to be evaluated lastly and in more detail to lay the groundwork for further assessments in the context of a corporate environment.

3.2.2 The Byzantine Generals Problem – Why consensus is critical

The very famous "Byzantine generals' problem" by Lamport et al. (1982) is raised by multitude of prior research on blockchain and its consensus systems as a foundational principle (Mingxiao et al., 2017; Zheng et al., 2017). In the problem, a group of Byzantine generals are trying to coordinate an attack on a city, but they are separated from each other and can only communicate through messengers. Some of the generals may be traitors who are trying to prevent the attack from succeeding. The generals must come to an agreement on whether to attack or retreat, but they must do so in a way that is resilient to the presence of traitors who may attempt to spread false information. Reaching consensus on whether to attack or retreat is a challenge, but as Lamport et al. (1982) note in their original presentation of the problem, it is possible through unforgeable messages, regardless of the number of generals and the number of traitors hidden among them.

As suggested by prior research such as Mingxiao et al. (2017) and Zheng et al. (2017), the Byzantine generals' problem is a very relevant one relating to the consensus systems employed in blockchain networks. In the spirit of the problem, blockchain networks do not have central entities ensuring that the participating nodes have identical ledgers. There is a need for a system to secure consistency in the nodes, to help weed out the tampered information or nodes and to establish a single source of truth across the blockchain network. This is in essence what consensus systems by design are trying to achieve. As Mingxiao et al. (2017) note, consensus systems have been under research for many years already, enabling a detailed deep dive into each system.

3.2.3 Proof of Work

Proof of work is perhaps the most well-known consensus system, mainly due to its employment in the most famous cryptocurrency, Bitcoin. Overall, the main use-case for this consensus system lies within cryptocurrencies for properties explored in this section. This consensus system is behind the common association of large amounts of computational resources, thus energy, required to operate in blockchain networks.

The foundational idea behind the proof of work (to be referred as PoW in this section from here on out) is described by Zheng et al. (2017) in simple terms. As their research suggests, the easiest way for determining who will publish the next block would be through random selection. However, this is deemed as a vulnerable selection process to malicious intent. In order for a node to prove its noble intentions as the publishing entity, it needs to invest a remarkable amount of resources usually in the form of computational power. The idea behind this is that nodes who have invested resources into the blockchain are less likely to act maliciously given the publishing power. As a return on their investment the blockchain commonly pays a reward in cryptocurrency to the publishing node. This is deemed to encourage participating nodes to act in the best interests of the health of the blockchain. (Zheng et al., 2017.) The reason why publishing nodes need to invest such vast amounts of computational power is that in order to be granted the power to publish the next block, they need to solve a related complex mathematical problem. More specifically, the required computational power of the publishing node in PoW consensus system is used to calculate a hash value for the block header of the block that is being published. (Mingxiao et al., 2017.)

In PoW, the blockchain has typically a built-in property that sets the next target value that the competing publishing nodes are trying to solve through changing the nonce value in the block header. Commonly, the hash functions that convert the information on the block header into a fixed-size output that is essentially random. (Yaga et al., 2018.) While the other information on the block header such as information about the previous block and timestamp are defined, the publishing nodes compete to get an output that matches with the current target value. A multitude of prior research notes that this process is trial and error, as the publishing nodes are essentially guessing the correct nonce value, suggesting countless numbers of possible nonce values to the hash function in order to solve the puzzle. (Mingxiao et al., 2017; Yaga et al., 2018; Zheng et al., 2017.) In essence the process described here is what creates the prerequisite condition of available resources for the nodes, as a vast amount of computational power, thus energy, is required to be granted the station of a publishing node.

Prior research notes that one of the key advantages of PoW is security (Vukolić, 2016). As PoW requires a remarkable amount of computational effort in order to publish blocks, it makes it difficult for malicious actors to try tampering with the blockchain. For a malicious actor to succeed, it would essentially need to control more than half of the computing power of the network, which results in a high enough cost for the attackers to prevent action. (Yang et al., 2019.) In addition, PoW is a prime example of decentralization. There is no central authority validating the transactions, with the blockchain participants competing to validate transactions. (Mingxiao et al., 2017.) This leads to a decentralized network, without a single entity controlling the system. Closely related, in PoW the health of the blockchain is promoted through incentivizing the "miners" by rewarding them with cryptocurrency for validating and publishing new blocks, thus further encouraging the publishers to act in the best interest of the blockchain network. (Yaga et al., 2018.)

However, PoW is not without its challenges. While PoW in its very nature is designed to promote and act as a decentralized platform, it is not completely immune to tampering. There is always a risk for centralization; in PoW solving the cryptographic puzzle can be expensive to solve and can require specialized hardware. This can prove an obstacle for individuals to effectively compete in the mining process, in worst scenarios leading to a centralization of mining power. (Yang et al., 2019.) While controlling the majority of a network's computing power is highly unlikely, it is not impossible. This has formed some security concerns regarding PoW, as in the event of an individual or a group of individuals controlling the majority of the computational power of the blockchain network, there is a possibility of manipulation. (Yang et al., 2019.)

One additional concern that prior research notes regarding PoW is the scalability. PoW can prove quite inefficient and slow for a larger network, as the complexity of the cryptographic puzzle grows. Essentially transaction throughput and confirmation are noted to be lacking, resulting in a poor user experience. (Zhou et al., 2020.) NeonVest research co-authored by Viswanathan & Shah (2018) talks of the "Scalability Trilemma in Blockchain". A key message from this research points out that the three main properties of a typical PoW blockchain, decentralization, security and scalability, are not able to all co-exist without limiting one another (NeonVest, 2019.) As a simple example, if a centralized coordinator would be added to the system to help the network reach consensus on a set of transactions more efficiently, this would theoretically lower the consumption of the system, as in computational power. However, this clashes strongly with the premise of decentralization of the blockchain network. (Zhou et al., 2020.)

Lastly, PoW is infamous for its requirement of vast amounts of computational power, resulting in high energy consumption which has raised worries on environmental impacts (Sedlmeir et al., 2020). Mining in PoW network is a business as any other, maximizing profits is a key driver. To limit the cost of computational power, the cheapest form of electricity is employed, which is often electricity produced from the highest emitting sources, such as coal. (Truby, 2018.) European central bank estimates in their article "Mining the environment – is climate risk priced into crypto-assets?" that crypto-assets do have a large carbon footprint, even the size of mid-sized countries. Bitcoin and Ethereum, two of the largest PoW-employing blockchain networks, were estimated to top the annual energy consumption of Spain from the September 2021 onwards. (Gschossmann et al., 2022.) It is to be noted, that since Ethereum has switched completely to a Proof of Stake consensus system with a significantly lower energy consumption (Ethereum, 2022).

3.2.4 Proof of Stake

Proof of Stake (to be referred as PoS from here on out) is a consensus system based consequentially on the stake that network participants have invested in that particular system. The logic behind it according to Yaga et al. (2018) is that when the users have invested resources into a system, they are more likely to promote a success of a system rather than failure. The investment is often in the form of a cryptocurrency, and once invested the cryptocurrency can no longer generally be spent. To determine the publisher of new blocks, the investment amount of each participant is evaluated, thus the amount of their stake is very closely related to whether and when each user gets to publish the next block. (Yaga et al., 2018.) PoS is noted to be an energy-saving option compared to PoW, as there are no cryptographic puzzles to be solved, thus limiting the computational power required (Zheng et al., 2017). Yaga et al. (2018) add that there are PoS networks that have eliminated the reward for block creation, with the only financial incentive coming from the transaction fees that are provided by the users.

There are different ways for a PoS network to determine how the stake of the user is evaluated to grant publishing power for the next block. One common denominator for all of these solutions is that the more stake a user has invested in a system, the more likely they are to be granted the power of publishing a new block. (Yaga et al., 2018.) In chain based PoS consensus systems, the next publisher is chosen solely based on the ratio of their invested stake in relation to the invested stakes in the network. For example, if a user were to hold stake equivalent to one percent of all the stakes invested in the network, they would have a one percent chance to be the next publisher each time. (Burmaka et al., 2021.) Another way of to determine the block publisher is a system known as coin age PoS, where the invested stake has an additional property of an age. After a set period of time, the invested stake will start to increase its likelihood of being selected for publishing, until after selection a cooldown timer will be placed on the stake. This method helps users with smaller stakes to guarantee a chance at publishing. (Mingxiao et al., 2017.) Lastly evaluated in this research is the PoS network employing a delegate system. In this version of a PoS network, the network users use their votes weighted by their stake in the system to decide upon publishing nodes. There is also an opportunity to cast your vote against the current publishing node. The voting is constant, thus forms a true challenge for publishing nodes to remain in power. By acting against the best interests of the network, the publishing node will be quickly voted out, thus incentivizing the publishing nodes to act accordingly. (Yaga et al., 2018.)

Compared to PoW, PoS has a few key advantages. Not reliant on solving complex cryptographic puzzles, it is a much more energy-efficient substitute to PoW. The Ethereum blockchain switched from PoW to PoS in September 2022, claiming 99.95% reduction in energy consumption (Ethereum, 2022). Despite the lack of cryptographic puzzles, PoS has its own way of promoting decentralization. It is still a public blockchain where anyone holding cryptocurrency can participate in, subtracting the need for computational power and specialized hardware present in PoW, further promoting accessibility and thus decentralization of the network (Mingxiao et al., 2017). In terms of scalability, PoS is a better solution compared to PoW. With no problem-solving in place, PoS networks are able to process more transactions more quickly than PoW networks, resulting in better scalability as the network grows. (Zhou et al., 2020.)

Despite the perceived improvements over PoW, prior research notes that PoS has its own disadvantages. Major centralization risks have been identified, as the network users with higher stakes commonly have more voting power in the network, possibly leading to a concentration of power. The different solutions determining the publishing nodes combat this problem each in their own way, with a common one being a built-in limit for the chance of becoming a publishing node in solutions employing probability and limiting the maximum weight of a vote to a set value in voting-based solutions. (Yaga et al., 2018.) On top of centralization risk, there are other vulnerabilities to PoS. Since there is no computational cost in creating blocks, a problem called costless simulation emerges. In essence, costless simulation means that any participant in the network can simulate any part of the blockchain at no cost. This is noted to open the door for malicious users to fabricate a competing blockchain based on the existing one. (Burmaka et al., 2021.) This in turn leads into the nothing at stake -problem, which briefly described means that the competing blockchains are able to publish conflicting blocks, thus increasing the amount of forks in the network and time for reaching consensus (Li et al., 2017). Lastly, there are some concerns regarding the initial distribution of power in a PoS network; early adopters might end up with a concentration of power, thus discouraging new participants from joining the network. Related, determining the exact value of required stake to become a publisher can prove problematic. As an example, as Ethereum switched to PoS they announced that the required stake for being eligible for publishing would be thirty coins, roughly equating to 50 000 USD at the time of the switch in September 2022. On the other side, three years prior to that the cost of thirty coins was around 3000 USD. (Ethereum, 2022.)

The most common use-cases for PoS are in cryptocurrencies, providing a more sustainable, scalable, and efficient way to reach consensus for the network compared to PoW. It is worth noting, that PoS can be applied to any situation requiring distributed consensus mechanisms, including supply chain management and various voting systems (Labazova et al., 2018.)

3.2.5 Practical Byzantine Fault Tolerance

Practical Byzantine Fault Tolerance (to be referred as PBFT) is a consensus system originally developed by Castro and Liskov (1999) to improve the existing Byzantine Fault Tolerance solutions, which it did by reducing the complexity of the algorithm from exponential to polynomial, enabling better scalability (Castro and Liskov, 1999). This consensus system has been adopted in blockchain networks as a means of reaching consensus. PBFT is generally thought to fit a permissioned blockchain, where participating nodes share a level of trust between each other. (Mingxiao et al., 2017). Like all the other consensus systems, PBFT in essence is a particular solution to the famous Byzantine Generals' Problem with a goal of reaching consensus without a centralized entity. PBFT is on a basic level a multi-round voting system between the nodes, to reach consensus on the validity of to-be published transactions.

One of the key characteristics of PBFT is that it is designed to withstand a set number of malicious participating nodes in the network. This number is 2f-1, where "f" is the number of nodes with malicious intents, implying that the consensus system is resistant to the point where the number of malicious nodes is less than one third of the number of participating nodes in the system, based on the mathematical principle of the solution for the original problem. (Castro and Liskov, 1999.) This a key sentiment behind the five-step process behind the PBFT process, described more recently by Mingxiao et al. (2017) that will be adapted in this section.

In PBFT the network consists of participating nodes, where one will serve the role of a leading node, generally based on round robin principle. This means that every node gets to be the leader in turn, and acts as the publisher of a new block. Described originally by Castro and Liskov (1999), the five-step process behind PBFT follows the next process:

1. Request: A node in the network provides a transaction request to the current leader node.

2. Pre-prepare: The leader node sends out the request with an order number to the rest of the nodes of the network, which evaluate the validity of the transaction request against the rules of the network and the historical transactions in their records.

3. Prepare: If the transaction is deemed valid, a node then sends out a prepare message to all the other nodes. If a node receives 2f+1 prepare messages, and most of the nodes accept the proposed transaction, the node will commit to the transaction.

4. Commit: All committed nodes will send out a message stating that they have committed to the transaction. When the leader node receives 2f+1 commit messages, it determines that most nodes have reached consensus in order to accept the transaction request and thus a new block containing the proposed transaction can be published.

5. Reply: Finally, all the nodes reply to the original requesting node, letting it know the outcome of its proposal.

Castro and Liskov (1999)

As noted, PBFT is best suited in a permissioned environment where malicious actors are a rare occasion. It is not designed to form a perfect system of weeding out attackers, but rather to enable a group with shared transparency and a common goal. Enterprise blockchains are commonly based on PBFT networks, or a similar version. (Labazova et al., 2018.) Common use-cases for PBFT include enterprise financial transactions, enterprise asset management, smart contracts and IoT communication. A closer look on these will be taken on the next section, where blockchain use-cases in reporting are reviewed.

A multitude of properties promote PBFT as a great consensus system for permissioned blockchains that are typically employed by enterprises. One of the key properties of PBFT is the capability of processing a large number of transactions, enabling efficient use in enterprise applications such as financial transactions or supply chain management. Related, PBFT provides relatively quick transaction finality after reaching consensus on a transaction, further promoting suitability for enterprise-use. (Labazova et al., 2018.) When it comes to security properties, PBFT is commonly employed in permissioned blockchain networks where each user is identified, and malicious actions can resolve as a removal from the network. While PBFT can detect malicious actors within the network, it is not designed for an environment where there is reason to assume a significant number of the participating nodes would act in ill manner towards the health of the blockchain network. (Mingxiao et al., 2017.) Finally, similarly to PoS, PBFT is energy-efficient compared to PoW, since performing complex computational tasks is not required.

As PBFT is mainly designed to be employed in permission blockchain networks, it is in its very nature to almost promote centralization compared to the other consensus systems. As only nodes that have identified and are approved can participate in the network, it leads to a more centralized environment by design. As one of the main properties associated with blockchain is decentralization of power, this has raised some conversation among the blockchain community. (Mingxiao et al., 2017.) Another concern regarding PBFT is its scalability. While it is able to process a vast number of transactions quickly, it is noted that the consensus system's performance might fall off as the number of nodes included in the network grows. There has been research proving that a technology called sharding, in which the blockchain networks is split into smaller networks might be an efficient solution to the scalability issue of PBFT. (Li et al., 2022.)

3.3 Smart contracts

Smart contract is defined by the United States National Institute of Standards and Technology as follows: "A collection of code and data that is deployed using cryptographically signed transactions on the blockchain network. The smart contract is executed by nodes within the blockchain network; all nodes must derive the same results for the execution, and the results of execution are recorded on the blockchain." (Yaga et al., 2018.) In other words, a smart contract is a way of executing contract terms automatically through a programmed protocol in a predefined event, such as a payment for a set action. Smart contracts to blockchain have been noted to be a major development in blockchain technology (Zheng et al., 2020.)

In essence, smart contracts are integrated within blockchains and enable users to create transactions as a means to send data to the publicly known functions of a smart contract. Due to the smart contract residing within the blockchain, it also possesses the same characteristics as all data within the blockchain; the code itself is immutable and resistant to tampering, promoting the smart contract to a position of a trusted third party. (Yaga et al., 2018.) These public functions include information storage, calculations and generally anything that can be programmed into a logic. On a more detailed note, smart contracts are digitizing contractual terms into computer logic, which are thus converted into logical flows such as if-else -statements. As a smart contract executes its function, the outcome is recorded as a transaction in the blockchain network, with same properties as any other transaction. (Zheng et al., 2020.) As in any business process automation through technology, one of the key advantages of smart contracts is the efficiency improvement over manual solutions. The unique side is the blockchain aspect; besides the business process automation, smart contracts produce transparent and attestable outcomes in data and processes, which promote trust throughout the involved parties. Related, smart contracts need to always produce the same output for the same set of input, giving them a deterministic nature. (Yaga et al., 2018.)

Consensus systems are closely connected to the execution of smart contracts. As the inputs for the smart contracts are essentially transactions, the network needs to reach consensus on the validity of the transaction before publishing it, which sends it to the smart contract. In a sense, smart contracts are participating in the blockchain network as autonomous actors with the ability of being able to receive transactions from other users, but with their behavior completely predictable for the rest of the network. (Christidis and Devetsikiotis, 2016.)

Adapting Zheng et al (2020), a typical use-case for a smart contract in a blockchain would be the relationship between a supplier and a buyer. As the parties agree on contract terms for their arrangement, this contract is converted into the lines of code in a smart contract. As the supplier delivers the products that fulfill the terms of the contract, the smart contract automatically executes. This streamlines the whole delivery process, for example payment can be automatically triggered once the terms of the contract are met. As is foundational for blockchain, the financial transaction is happening peer-to-peer – removing the need for a third party such as a bank to carry out the transaction. This can in turn lead to remarkable savings in transaction time and fees. (Zheng et al., 2020.)

It is important to note that not all blockchains support smart contracts. Blockchain implementations that support transactions such as those in Bitcoin enable the transfer of assets between mistrusting parties in a blockchain network. However, a blockchain implementation supporting smart contracts goes one step further; they allow multiple rounds of interactions to happen between distrusting parties. Christidis and Devetsikiotis (2016) present the nature of these interactions in the following manner. The first interaction between these parties participating in the blockchain is to inspect and validate the smart contract and its outcomes prior to engaging with it. Secondly, both parties can trust that the smart contract will be executed when proper, since neither controls the blockchain fully. Lastly, the parties can verify the smart contract process since all interactions need to be signed digitally. In a scenario where the outcomes of the smart chain are fully accounted for, any chance of dispute is removed since both parties have agreed and signed upon the contract. (Christidis and Devetsikiotis, 2016.)

For the blockchains that support smart contracts, it is common for the publishing node to be in charge of executing the logic within a smart contract as a new block is being published. However, there are different roles for the publishing node in different blockchains. Some blockchain implementations in turn have the publishing nodes only as validators of smart contract outcomes, rather than executers. (Yaga et al., 2018.) In permissionless blockchains, where anyone can participate in the network, there is generally a cost for issuing a transaction to a smart contract, usually in the form of a small fee in cryptocurrency. Ethereum is an example of such a blockchain. To promote correct use of the smart contracts and to combat denial of service attacks in a permissionless network, there is a limitation on the execution time each transaction to a smart contract can use. Exceeding this limit will discard the transaction. On the other hand, in permissioned blockchain networks that support smart contracts such as blockchains based on Hyperledger Fabric, the level of trust between parties is high by the nature of permissioned blockchain networks, thus the need for smart contract related is costs is not crucial. It is assumed that all parties are employing the smart contracts in the way designed, with no malicious intent. As all participants are identified and known, it is possible to sanction incorrect use of smart contracts in other ways, such as revoking access. (Zheng et al., 2020.)

As a summary, smart contracts can be deemed to have advantages over conventional contracts as well as standard business process automation information technology solutions. Adapting Zheng et al. (2020), these advantages can be roughly categorized in three main domains. Smart contracts can considerably reduce risks such as financial fraud due to the immutable nature of transactions in blockchain. Once smart contracts are recorded into the blockchain, they are essentially immune to tampering as consensus is needed for any transaction to be published in the blockchain. As such, the whole network is completely auditable and traceable, reducing the potential of malicious actors in the network. In addition to the transparent nature of transactions within the blockchain network, smart contracts can cut down administration costs as there is no need for intermediary to execute actions based on contract terms. Lastly, smart contracts can improve business process efficiency in the same way as any other information technology solution. However, the main improvement over such solutions is once again in the nature of how data is stored in blockchain. Turnaround time of these business processes can be cut down due to the lack of need for an intermediary, and the results are recorded in the blockchain, creating a transparent audit trail of events. (Zheng et al., 2020.)

3.3.1 Challenges – The Oracle Problem

> *"Too often, the words bitcoin and blockchain are confused, and it is evident that most of the papers address characteristics that strictly belong to Bitcoin, rather than to regular blockchains. Furthermore, the literature neglects that when implemented in the real world, smart contracts need oracles to operate."* (Caldarelli, 2020.)

While smart contracts are a technology with great potential, they still face challenges that limit adoption. One of the most prominent ones is called the Oracle problem, which is recognized in multitude of prior research (Caldarelli, 2020; Yaga et al., 2018). This problem is a wider consideration to blockchain technology, but especially a key challenge to recognize with smart contracts. (Yaga et al., 2018). On a general level, blockchain is deemed to function with great success when working with data that is within the blockchain. The Oracle problem describes the challenges a blockchain faces when needing to interact with real world information. While blockchain as a technology promotes data transparency and thus validity, it cannot access events in the real world on its own. Therefore "Oracles" as in the interface between the real world and the blockchain are required. (Curran, 2018.) As Caldarelli (2022) reflects, an oracle in this context can be anything that is providing the blockchain with external data. What is worth noting is that generally oracles do not have a direct input into the blockchain; instead, they gather data from the real world to be stored and then be called upon by a smart contract. In a blockchain, when a smart contract is called to execute its function that includes accessing external data, these external data deposits are then accessed to retrieve the desired information. Typical oracles in blockchain context are internet of things (IoT) censors and data platforms e.g., ERP-systems. (Caldarelli, 2020.)

To further explore the Oracle problem, it is evident that the trustworthiness of the oracles forms the basis of the problem. As some oracles can operate autonomously, e.g., retrieving public exchange rates, it is relatively easy for any participant in the system to verify the correctness of the exchange rate. In this case the trustworthiness of the oracle is not as critical, as the validity of the data can be validated by any other party. In the other end of the spectrum, a smart contract could call an oracle that handles data that is very hard or impossible to validate by an external party, such as organizational information. In these instances, the oracles need to be heavily trusted by the associated network to possess valid data. (Caldarelli, 2020.) Regarding smart contracts and blockchain, there is a clash between the idea behind oracles requiring trust and the idea of smart contracts removing the element of required trust from their execution. (Curran, 2018). The main drawback of this is characterized as "two steps back from decentralization" by Egberts (2017). Egberts notes that as the oracles are not distributed as the other elements of a blockchain, they are reintroducing a single point for possible failures. In addition, as the oracles opposite to the smart contracts calling to them are operating on data that is non-deterministic in its nature, the oracles require a level of trust. This contaminates the network designed on peer-to-peer interaction that does not require trust. Furthermore, even in the event where the oracle itself cannot be compromised; the oracle is still vulnerable to the trustworthiness of the data it is collecting. (Egberts, 2017.)

Approaching the problem from the other direction, where the data oracles store is verified and trusted, there is still the problem regarding the operations of an oracle. There is still a possibility for an oracle to malfunction on a smart contract request or be the target of tampering. Assessing this scenario from a game-theoretical standpoint points to finding that higher value smart contracts increase incentives to compromise the system. (Caldarelli, 2020.) The Oracle problem will be evaluated again with its effect on real-world blockchain applications in the next chapter.

Regardless of the Oracle problem, smart contracts as well have challenges associated with them and their implementation. Briefly, as smart contracts are essentially contracts turned into lines of code, they require a careful and precise approach to ensure they will work as intended. To elaborate, as smart contracts themselves are deployed into the blockchain, they will become immutable once published. This creates a set of challenges for the developers. As the contract needs to be understood by parties engaging in it, a smart contract needs to be translated in common language instead of complex code, which can be achieved through various tools. (Zheng et al., 2020.) In addition, while it is a challenge in itself to ensure that the deployed smart contract is programmed correctly to model the intended logic, there are additional considerations. As smart contracts are deployed to be interacted with, the developers need to consider all possible interactions to prevent contract manipulation through unexpected prompt. (Zheng et al., 2020.)

3.4 Blockchain as an enterprise solution

One of the motivations behind this thesis was to remove “technological abstraction” floating around blockchain technology. Adapting from Caldarelli (2020), blockchain technology is too often confused with Bitcoin and its characteristics. As elaborated, there are various implementations of the blockchain technology with very different mechanisms and characteristics besides the public blockchain employing Proof of Work consensus system. In this section, enterprise use-cases for blockchain will be further explored. First, the most common setups for an enterprise blockchain will be revisited, continuing to common use-cases. As the focus use-case of this thesis in sustainability reporting is approaching, special attention will be paid to use-cases and potential on reporting applications. Lastly, prevalent criticisms of blockchain implementations in enterprises will be presented.

3.4.1 Enterprise blockchains

The properties commonly associated with blockchain solutions are the same ones driving corporate interests in the technology: transparency, auditability, security, efficiency. The distributed database technology makes unauthorized modification of the recorded transactions virtually impossible, as well as records each event in the network forming a continuous trail of data. (Helebrandt et al., 2018.) Yaga et al. (2018) further note that while the technology is still relatively new, there is a lot of interest from organizations for implementation. They identify a fear of missing out on blockchain, where organizations are trying force adaptation, resulting in frustration and criticism for the technology when the use-case does not exist. They suggest a more controlled approach, where blockchain use-cases would be first identified on a general level, and then the possible adaptation would be assessed. (Yaga et al., 2018.) On a high-level, the requisite for an implementation is a need to allow mutually distrusting parties to exchange information without the need for a trusted third party; without the need to involve trust at all in the equation. (Hamida et al., 2017.)

On a high level, the main application of a blockchain solution is to act as data storage. One of the most prevalent related considerations in prior research is discussion around on how a blockchain solution can be a better alternative to traditional (centralized) databases (Rauchs et al., 2019; Wüst and Gervais, 2018; Yaga et al., 2018). On a general level, centralized databases offer better performance in terms of throughput and latency, thus providing better scalability especially against computationally demanding blockchain solutions such as PoW implementations. On the other hand, blockchain solutions enable mistrusting parties to operate without the need for a trusted third party, increasing the efficiency of execution of the system. (Yaga et al., 2018.) To further explore a suitable scenario for a blockchain solution compared to a traditional database, Wüst and Gervais (2018) present a general decision-making process that will be adapted next, where writers equal to the network participants.

In case there is a need for data being stored, a database is required. In case there is only one writer in the system, the benefits of blockchain related to multiple writers do not come into effect and thus a centralized database is a better option. In a scenario, where there are multiple writers in the system, the question of trust comes into play. If there is a trusted third party (TTP) that is always available, all write-actions can be delegated to a TTP, at the added cost in fees and increased complexity. This still is deemed as a case for a centralized database, due to the assumption of higher performance. If the TTP is not always available, a question of trust resurfaces. In a case where all writers are trusted, where the presence of malicious actors is deemed non-existent, a centralized database with shared writing access is once again displayed as the optimal solution. However, in case there resides mistrust between the writers a use-case for a blockchain solution is formed. (Wüst and Gervais, 2018.) In other words, a need to store data in a network where there are multiple mutually distrusting parties, with a lacking case for a TTP either due to availability or cost, constitutes the foundation for a successful blockchain use-case. The United States Department of Homeland Security Science & Technology Directorate presents a similar process for assessing blockchain viability, with the added steps of considering the need for immutable data and tamperproof log of all writes. (Yaga et al., 2018.) Generally, the message of prior research is as follows: blockchain technology is new and exciting, but organizations should exercise the same careful evaluation of viability as for any other technological solution.

Reiterating previous findings of the chapter with the support of Nanayakkara et al. (2021) publication “A methodology for selection of a Blockchain platform to develop an enterprise system”, the common constructs behind feasible enterprise blockchain implementations can be identified. In an organizational setting, the blockchain network is most likely to be permissioned, as there is a need to control who can participate in the network. There are various consensus systems that can enable the blockchain to run as intended. A key consideration here would be on the resource intensity of the consensus system; the more complex and computationally demanding the consensus system, the more energy it requires to run. This can lead to reduced throughput and increased latency due to the added complexity, and significant increase in energy consumption. Consensus systems that do not require solving computationally heavy cryptographic puzzles, such as Proof of Stake or Practical Byzantine Fault Tolerance or variations of either can thus lead to more efficient operation of the blockchain implementation. Related to the energy-efficiency of a blockchain implementation, Wüst and Gervais (2018) add that transparency considerations have a significant effect. If all transactions are fully transparent, efficiency is achieved at the cost of privacy. As noted, in blockchain it is common to control the transparency of the data through cryptographic means, which are also computationally expensive. (Wüst and Gervais, 2018.) Thus, organizations should consider the level of privacy required for the blockchain to function also from the energy perspective. In addition, the blockchain should support smart contracts in order to enable the organizations to build their own specific blockchain implementation. With smart contracts, it is possible for organizations to add desired logic through programming to the system, as well as establish communication capabilities with the real-world through oracles.

However, organizations do not have to start creating their blockchain implementation from scratch. Blockchain platforms provide the underlying infrastructure and tools for blockchain-based applications or systems, such as permission model, system architecture, consensus systems and smart contract programming tools. Well-known blockchain platforms include Ethereum, Hyperledger Fabric, Corda and Ripple. An organization can find a suitable blockchain platform matching their requirements to develop their blockchain-based application. (Saraf and Sabadra, 2018.) For blockchain platforms, Nanayakkara et al. add a few considerations relating to the practical implementation feasibility of the blockchain. Typically, an enterprise system has costs in two categories; initial cost and operational cost. There are naturally costs related to developing the system, and the blockchain platforms generally charge a fee based on the operations. Additionally, the support for application programming interfaces (APIs) should be considered as an enterprise system generally has to communicate with other systems as well. Therefore, the support for APIs is a critical factor for a blockchain platform to be suitable for enterprise system development. (Nanayakkara et al., 2021.)

3.4.2 Enterprise blockchain applications

Prior research has identified a multitude of use-cases for blockchain-based enterprise systems and applications, however with limited real-life implementations to date (Labazova et al., 2019). The most prevalent theoretical and to some extent implemented use-cases are found in supply chain management, real estate, finance and accounting, insurance, healthcare, digital right management, and energy (Hamida et al., 2017; Mohanta et al., 2018; Wüst and Gervais, 2018; Zheng et al., 2020). A few selected examples of blockchain-based applications from these domains will be presented in brief to build further understanding on how the technological properties of blockchain can enable different sectors to operate more effectively.

As supply chains are growing more complex, increasingly advanced information systems are required to ensure effective management. Simultaneously, the requirements from stakeholders for supply chain transparency, reliability and performance are increasing. While blockchain has potential to improve help manage more complex supply chains, the technology is still not mature in this regard and only a handful of piloting projects exist led by consortiums consisting of academia and large corporations. (PwC, 2020.) A prevalent blockchain use-case in supply chain management is the enhanced tracking of tangible assets and their origin. Creating and recording digital representations of assets has existed for a while, e.g. in the form of scanning barcodes. Blockchain can enable end-to-end tracking of these assets and their ownership throughout the supply chain, with the creation of an immutable trail of origin and ownership For example, Walmart has developed a blockchain solution together with IBM to track the origin of food items. (Sheldon, 2020.) Another company developed a blockchain solution to track the chain of custody for a conflict mineral used in consumer electronics, with the intent of providing "mine-to-manufacturer" transparency and traceability. (Sheldon, 2020.) Besides the tracking of assets and their provenance, blockchain solutions can improve the efficiency of supply chains by automating transactions and reducing the need for a trusted third party for transaction settlement. (Zheng et al., 2020).

Another domain that prior research notes as potential for blockchain-based applications is in accounting. Blockchain is noted to have a potential to develop accounting and auditing, due to being able to provide verifiable, real-time and transparent information for the accounting ecosystem. Following the logic displayed related to supply chain, the tracking of physical objects through technological solutions such as IoT-censors has the potential to automate bookkeeping processes through smart contracts and oracles. (Sheldon, 2020.) Related, the technology could transform audit and assurance practices. With surprising amount of prior research on the matter, with research topics involving the potential of real-time audits and the transformation of auditors' confirmation process. Auditors could be granted direct access to the blockchain where the bookkeeping is taking place, enabling real-time visibility and a single source of truth. In addition, some of the audit processes could be eliminated due to efficiency. Auditors need to confirm the outstanding receivable and payable balances, but as blockchain broadcasts the transactions and their details to the entire network providing verification of transfer of funds for one party to another, in theory there is no longer a need for the auditor to confirm that the transaction took place. (Brender et al., 2018.)

Insurance companies as well have started to explore opportunities enabled by blockchain solutions to improve the efficiency of their business. AXA, a French insurer has been piloting a blockchain-based application to automate claims handling processes. In this particular pilot, smart contracts on Ethereum platform were programmed to handle flight delays compensations. On a more detailed level, the smart contract was programmed to compensate passengers who had experienced flight delays that lasted over two hours. A copy of the insurance policy was recorded on the smart contract, which also accessed global air traffic data to evaluate whether the flight associated with the policy was due compensation. (Brophy, 2019.)

3.4.3 Blockchain in Sustainability Reporting

As noted, there are a multitude of potential applications of blockchain technology over various sectors. While accounting and auditing practices are very closely related to the corporate reporting process, only limited research exists. As the focus is further concentrated on corporate sustainability reporting, previous research is extremely limited and often the interpretation of the potential of blockchain is quite one-sided, focusing on the possibilities and ignoring challenges. However, to address this prior research a brief overview is given.

Bakarich et al. (2020) introduce the concept of blockchain together with sustainability reporting in their publication "The Use of Blockchains to Enhance Sustainability Reporting and Assurance". They highlight how blockchain has the potential to help companies reliably track and record their sustainability information, which is currently mainly being self-reported. Leveraging a blockchain solution could bring added transparency to the process and reported information, such as product origins, greenhouse gas emissions or conflict mineral disclosures. (Bakarich et al., 2020.) Furthermore, Liu et al. (2021) note that a lack of data verification, transparency, and consistency result in an inadequate sustainability reporting process. They propose a blockchain-based ESG reporting framework, with the goal of being able to facilitate a trustworthy ESG evaluation process for a listed company. (Liu et al., 2021.) Similarly, Jiang et al. (2022) in their paper "Blockchain-based life cycle assessment (LCA) system for ESG reporting" demonstrate such a system and its potential applications. In addition, Wu et al. (2022)

take a more technologically detailed approach in their publication “Consortium blockchain-enabled smart ESG reporting platform with token-based incentives for corporate crowdsensing”, where they propose an architecture for an ESG reporting platform through the employment of blockchain and related technologies, such as IoT-censors. To build further understanding on a practical level of a potential blockchain-based application designed for sustainability reporting, prior research will be evaluated and pieced together. As a starting point, all of these proposed solutions start out from the same viewpoint; there is a need to increase authenticity, transparency and reliability in sustainability reporting to limit occurrences, where different stakeholders face information asymmetry or greenwashed information. (Jiang et al., 2022; Liu et al., 2021; Wu et al., 2022.)

Globally, listed companies are at the forefront of facing regulations and market expectations which both demand that the companies make their collect sustainability in the first place, and secondly report it in public. Creating a sustainability report is noted to be generally a three-part process, with the preparation of the report, the generation of report, and lastly publication of the report. Furthermore, the first step involves the sourcing and preparation of raw data, while the second encompasses the actual creation of report, and the last step publicization (Liu et al., 2021.) It is noted, that a permissioned blockchain model is suited for the purpose of corporate sustainability reporting, as there is a need to limit participating users to the parties involved in the reporting process. (Wu et al., 2022.)

To address the three phases presented by Liu et al. (2021) in the context of blockchain-based application, the first phase of raw data preparation is generally proposed to be solved with IoT devices (Christidis and Devetsikiotis, 2016; Jiang et al., 2022; Liu et al., 2021; Wu et al., 2022). This technology enables real-time collection and recording of required sustainability data from sites across the supply chain. As the collected data is recorded into a blockchain, further manipulation is prevented. Incorporating smart contracts in the blockchain that are programmed to further process the input to the desired format to satisfy sustainability reporting regulation and standards. (Jiang et al., 2022.) As the input data and the contents of the smart contracts are immutable, this creates a transparent trail for data collection and processing. (Wu et al., 2022). Typical IoT devices that are employed in sustainability data gathering for emissions include meters for electricity, water, and heat. These are often supplemented by the likes of fiber optical sensors and RFID-readers to allow for proper asset tracking and allocation. (Jiang et al., 2022.) While the technology can automate a lot of the data gathering processes and thus eliminate the margin for human error, it is still challenged by the Oracle problem and related issues. These will be presented in the next section regarding challenges and criticism for enterprise blockchain solutions.

Regarding the generation of the report, logic embedded in smart contracts can automate a lot of the coordination and execution of related processes involved in sustainability report creation, in similar manner as any business process automation cases. These include enabling effective multi-party agreements and validation on the processed data, as well as the management and scheduling of related tasks for parties involved in the creation of the report. (Liu et al., 2021.) One of the key advantages of a blockchain platform in report generation that all processes will be recorded in the blockchain, thus increasingly promoting transparency in the reporting process. Stakeholders such as auditors can then be presented with a clear audit trail not only on the data, but the processes as well. In addition, this will create an added level of transparency for stakeholders such as investors who will utilize the report in their decision-making. Overall, a blockchain architecture can improve the efficiency, transparency, and security of the reporting process. However, it is noted that an architecture where blockchain is used solely for the data layer and augmented by web-based solutions in report creation might be a more feasible approach. (Wu et al., 2022.)

Lastly, blockchain can improve evaluation of the report once completed. Prior research suggests the potential of linking report assessment and grading directly into the reporting process. Evaluation criteria can be used to create smart contracts for automatic assessment and certification process, e.g., providing and transparency index for the report based on the predefined metrics related to the data collection level and then issuing a correspondent certification. (Liu et al., 2021.) Furthermore, this has the potential to build better trust on sustainability ratings, which have been under controversy due to transparency and trustworthiness (Bakarich et al., 2020). Ideally, a blockchain-based solution has the potential to create a transparent and trustworthy report on the sustainability performance of a company's entire value chain for stakeholders (Jiang et al., 2022).

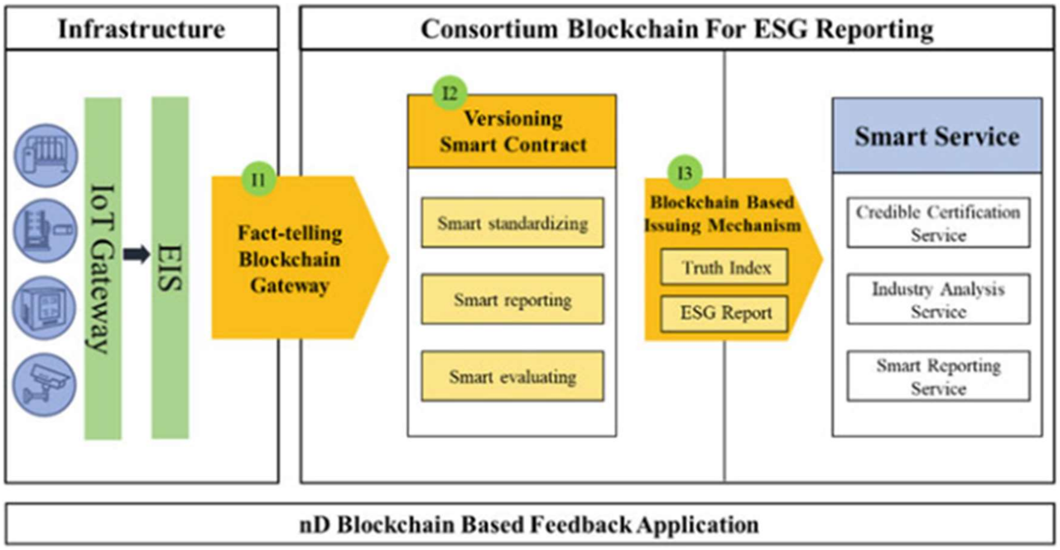

Figure 4 - Consortium blockchain architecture for ESG reporting (Liu et al. 2021)

3.4.4 Criticism

While the potential for using blockchain technology to improve current processes and systems in enterprise use, prior research demonstrates the practical implementation issues limiting current use-cases. Additionally, the very nature of enterprise blockchain solutions requires added controls to function in an organizational setting, such as controlling network participants and their transparency settings. As decentralization and transparency are built as the key purposes for a blockchain solution, this creates a conflict. Furthermore, a question is raised on the oracle problem; whether the capabilities of immutability and transparency matter within the system, as the data source can still be compromised. As Yaga et al. (2018) note, there is a very famous quote from Arthur C. Clarke “Any sufficiently advanced technology is indistinguishable from magic” that is very applicable to blockchain technology. There is a lot of excitement around the technology, which often leads to misrepresentation of the capabilities of the technology by those who do not understand it well. As is common for all new breakthroughs in technology, there is a push for trying to apply it to everything. (Yaga et al., 2018.) As an example, there is no use-case for blockchain in a scenario where data does not need to be ever stored, nor is there one in a situation where only one party is participating in the data management. While exploring the potential of the technology in business and research, identifying the suitable scenarios for blockchain implementation is essential to develop a common understanding of the technology. (Casino et al., 2019.)

The quintessential question in blockchain adoption is how it will improve the current way we store data – how is it an improvement over traditional databases, shared or not. Traditional databases are already well-established and used in enterprise applications widely. Compared to blockchain implementations, it is noted that on a general level traditional databases are way more efficient while blockchain implementations provide more transparency and trust. (Zheng et al., 2017.) One of the key challenges in blockchain is the scalability problem. The more complex the consensus system is, the more it takes resources to manage the data. It almost seems like a trade-off, where there has to be a decision made on a lighter consensus system promoting efficiency, compared to a more thorough consensus system to promote trust. Generally, this dilemma contributes to the challenges in enterprise adoption; especially in cases where the enterprise faces high transaction volumes in their data management. (Wüst and Gervais, 2018.) The attributes that make blockchain desirable prove to also create its greatest challenges. Prior research has identified these challenges, describing a "Blockchain Trilemma". The trilemma points out the three most important properties of blockchain in decentralization, security, and scalability cannot co-exist perfectly. To demonstrate this, in a scenario where a centralized coordinator is added into the blockchain system will reduce the consumption visualize of resources, as there is no need to reach consensus for the network to function. On the other hand, installing a centralized entity will erase the decentralization property of blockchain technology. (Zhou et al., 2020.) New developments in blockchain technology such as sharding and off-chain processing have been proposed to combat the efficiency problem of the blockchain, but the technologies are noted to be still in the early stages of development with very limited prior research available. (Li et al., 2022.)

As noted, blockchain implementations differ vastly from one another, from the permission model to the consensus system, from a level of transparency to the level of full cryptographic anonymity. All blockchain applications, despite their configurations, suffer from the same inherent problem, which is the Oracle problem. As the Oracle problem was presented and discussed, a focus will be brought to the real-life examples of the problem for blockchain applications. While the blockchain technology is noted to have significant potential in solving transparency challenges in supply chain management through the reliable tracking of tangible assets, there are reliability challenges in linking real products to the blockchain. As the physical products exist outside the blockchain, an oracle is required to insert data of the product to the blockchain. As oracles generally belong to the companies that are producing these products, there is a chance for a significant conflict of interest. (Caldarelli, 2020.) As the control over information resides with the producing company, it is deemed highly unlikely to involve unwanted or inconvenient data to the blockchain. For asset tracking, it is thus concluded that while the information stored in the blockchain is immutable, it does not alone constitute reliability. (Kumar et al., 2020.) On a very practical level, an IoT temperature sensor could be a part of a logistics chain to ensure a product is stored within certain temperature range through the process. The fact that the device is connected to the blockchain through a smart contract does not save it from being in danger of being tampered with; the device could be placed in a small container holding the correct temperature within the larger one it is supposed to track. This leads to the notion that the information is only as reliable as the company which provides it, and that this technology does not absolve the required level of trust that a company needs to have for its suppliers. (Wüst and Gervais, 2018.) This is a highly relevant aspect for blockchain applications in sustainability reporting as well, which is ultimately relying on the data inputs from the value chain. Suppliers have the incentive in downplaying their emissions, which would in this case be inconvenient data for the supplier, as it can be used as a part of evaluation criteria in the supplier selection process. (Chikhi et al., 2022.)

There are also very practical challenges in enterprise blockchain adoption, that are highlighted by prior research. As with all technological solutions, developing and maintaining a blockchain application is costly, as well as switching systems and training employees to the new blockchain system. Initial development costs are noted to be especially high, given the immature stage of existing applications. Limited expertise in developing such systems leads to a barrier of adoption, companies are less likely to invest in a completely new solution, where there are no available benchmarks on the market. (Y. Zhou et al., 2020.) Related, there is still a limited understanding on how the technology will be regulated in the future, increasing the associated risk in investing in blockchain applications. Key concerns in this regard relate to data privacy law and regulation, which companies are subject to. (Akram et al., 2020.) As blockchain technology matures and becomes more commonplace in enterprise applications, regulation is sure to follow (Nartey et al., 2021).

Overall, Yaga et. al (2018) provide a great approach for blockchain technology adoption in encouraging a mindset of “how could blockchain technology potentially benefit us” instead of “how can we make our problem fit into the blockchain technology paradigm”. Related to this research, there is a limited amount of prior research on blockchain in sustainability reporting, but even a smaller amount of prior research addressing this sentiment properly. To further explore this, in the next chapters experts from corporate sustainability and blockchain technology will be interviewed and the methodology of the study presented.

4 Methodology

Qualitative research methodology is described as empirical, where the researcher is collecting sensible data of the underlying phenomenon, organizing and analysing the data against hypotheses, ideas and categorical definitions. Furthermore, qualitative researcher seeks to collect understanding in great details in order to examine and answer questions such as how, what, where, when and why. (Smith, 1987.) In qualitative research, all data collection methods are noted to fall under two categories: direct one-to-one interaction with a study participant, or alternatively, a group. Additionally, interviews are noted to enable researchers to explore complex phenomena and gain insights into participants' experiences, attitudes, and perceptions. As interviews provide an opportunity for participants to elaborate on their responses and provide additional context, this can lead to a deeper understanding of the underlying phenomenon being studied and can help researches to develop more nuanced and comprehensive theories and interpretations, advantageous for qualitative research (Oun and Bach, 2014.).

In this research the aim is to evaluate the viability and potential of blockchain technology in enhancing corporate sustainability reporting through analysing the ideas and hypotheses present in prior blockchain research against the requirements posed by corporate sustainability reporting regulation. Through qualitative research methodology, collection of rich and detailed data and in-depth exploration of the complex phenomena will be facilitated. This approach will enable a more nuanced and comprehensive understanding of the potential of blockchain technology in enhancing corporate sustainability reporting, and to develop more insightful theories and interpretations. Therefore, qualitative research methodology was chosen for this research.

Furthermore, qualitative case study was chosen as the research method. Case studies can provide "…a deep holistic view of the research problem, and facilitation of describing, understanding and explaining a research problem or situation." Additionally, The United States Government Accountability Office (GAO) defines case study as follows: "a method for learning about a complex instance, based on a comprehensive understanding of that instance obtained by extensive description and analysis of that instance taken as a whole and in its context." (Baskarada, 2014.) Interestingly, case study research method has been considered as lacking in scenarios where the study phenomenon is mature and well-understood, in cases where there is no particular interest regarding the why's and how's of a phenomenon's occurrence (Darke et al., 1998).

While it has been suggested that case studies may not be the best approach for studying phenomena that are well-understood or lack interest in the underlying mechanisms, this is not the case for the research question being investigated in this project. The use of blockchain technology in enhancing corporate sustainability reporting is an emerging and evolving area of research, and there is a great deal of interest in understanding its potential and identifying the contextual factors that influence its adoption and implementation. It is also common for the case study research method in business-related research to utilize empiric data from experts in relevant professional environments (Myers, 2019). By conducting in-depth interviews with key stakeholders, such as sustainability regulation experts, blockchain technology experts, and investors, detailed data that is grounded in the experiences and perspectives of those who are intimately familiar with the phenomenon being studied can be collected. Finally, case study is noted effective in capturing complex and difficult business problems, as well as describing them in more simpler terms to increase understanding (Eriksson and Kovalainen, 2008). Aligned with this sentiment, analysing and describing the complex entities in blockchain and sustainability reporting and their relationship in a consistent manner constitutes a valid case study.

4.1 Data collection and analysis

Data was collected through conducting interviews. The main purpose of the interviews was to gather data from corporate sustainability reporting experts to validate and compare insights to those of prior literature, as well as build a foundation for further evaluation whether blockchain technology can answer some of the pain points in corporate sustainability reporting. The outcomes are presented in the discussion chapter at the end of this thesis.

The interviews were conducted as semi-structured interviews, where the interviewer has key questions prepared but is able to diverge from these questions and ask additional impromptu questions (Gill et al., 2008). Semi-structured interviews can be utilized in seeking views and insights to a focused topic, gathering institutional perspectives or background information by interviewing key informants (Hammarberg et al., 2016). Semi-structured interviews have a minimal amount of structure with a focus on open ended questions, which is noted to enable to interviewer to encourage and push the interviewee towards quality answers (Oun and Bach, 2014). Essentially, by employing semi-structured interviews maximum amount of flexibility is preserved during the interview, which can be beneficial when dealing with complex issues as well as to follow up on unexpected, interesting or novel turns the interview might take (Baskarada, 2014). While the research topic has a higher level of complexity in blockchain technology and corporate sustainability reporting regulation, the topic is clear and thus key questions were deemed to be appropriate to guide the interviews, as opposed to a completely unstructured setup. The aim was to ask open-ended questions on the relevant topics to start a natural conversation, that would enable the interviewees to state their perspective and views freely. Lastly, as the interviewed experts represented different expert groups within the study in sustainability reporting, blockchain technology, and sustainable finance, flexibility was required to cater the interviews to each expertise, while maintaining the overall focus on corporate sustainability reporting.

4.1.1 Expert interviews

The aim of this research is twofold – an overall review of blockchain technology and its properties that enable the use-case as an enterprise solution, enabling its potential as a reporting solution in corporate sustainability reporting. To the knowledge of this research, shared expertise in both domains remains quite rare. Thus, in order to bridge this gap further experts from the sustainability domain were interviewed as well as from the blockchain domain to gather insights from both and reflect them against prior literature.

EU regulation is putting increasingly strict requirements on corporations to manage their sustainability reporting practices in a transparent, trustworthy and standardized way. However, prior research is quite unified on the challenges corporations face in producing quality sustainability information. To this end, expert sustainability consultants who assist companies in sustainability reporting processes were interviewed. Consultants were chosen over in-house sustainability experts due to their broader experience in working with a variety of corporations, leading to a more comprehensive view of the current state. Additionally, to bring in the investor point of view a sustainability leader was interviewed from a bank – as the EU corporate sustainability reporting regulation is pushing companies to publish sustainability information for investors at the forefront, to promote and standardize sustainability as an investment criterion. None of the sustainability experts interviewed had a significant understanding of blockchain technology.

For blockchain technology, the challenge was increased as there is a very limited number of public experts in Finland. A blockchain technology lead from an international consulting company was interviewed to form a better understanding of the current market maturity of blockchain technology implementations in enterprise-use, as well as identify the feasibility of blockchain implementation in corporate sustainability reporting.

The interviewees were contacted through earlier relations in consulting. In the invitation, the topic of the research was disclosed with additional details on why each candidate was approached and what the expected contribution was. The key questions were sent beforehand to the interviewees. Each interview was conducted separately as a semi-structured interview. The interviews were held remotely through the service provider Zoom and recorded. After recording, the interviews were transcribed for further data analysis. The interviews were held both in Finnish and English. All Finnish interview transcripts were translated into English.

The background for the sustainability expert interviews was corporate sustainability reporting and how EU regulations set even stricter requirements for corporate sustainability information to be compliant. The aim of the data analysis was to conclude on whether notions in prior literature on the challenges of corporate sustainability reporting are relevant, and by amending the extensive literature review of blockchain technology with an expert interview, evaluate whether blockchain technology can be advantageous in this context. Specifically, the interviews were mainly employed to answer the research question: "What challenges do corporations have in sustainability reporting, especially in the face of EU regulation such as CSRD and EU Taxonomy?". Additionally, some additional insights to the blockchain technology review were sought after to answer the research question "Can blockchain technology help corporate sustainability reporting challenges?".

The interviewees were divided into three different groups based on their expertise, sustainability, finance and blockchain technology. Key questions were presented to each interviewee in semi-structured interviews, with the focus on creating conversation. The interview structure enabled unexpected answers, and additional impromptu in-depth questions. This led to an interview environment, where each expert could share their expertise in a natural way, not hindered by the interviewer's knowledge gaps.

4.1.2 Data collection

The interviewees consist of experts from professional services companies, as well as a bank. The companies in question will not be named. Personal information of the individuals who partook in the interviews will not be disclosed. To this end, the interviewees have been assigned an ID that is based on their domain of expertise. Four interviews were conducted, with an average length of 40 minutes. The interviews were held between April 2022 and October 2022.

ID	Role
S1	Expert sustainability consultant
S2	Expert sustainability consultant
F1	Head of sustainability, banking
B1	Blockchain technology expert

Table 1 – Interviewed experts

4.1.3 Research ethics

Application of ethical principles is vital in order to protect human subjects in a qualitative research study. To participate in a study, the participants must be informed to a satisfactory extent about the research and comprehend what is asked of them to form informed consent. They must also be granted the freedom of choice in participation. (Ethical Considerations in Qualitative Study, 2018.)

Each interviewee agreed to participate of their own accord and had the right to decline the invitation. All interviewees accepted the invitation in writing in an email. They were each presented with the description of the study in an email. They were also briefed in detail on the management of interview data, which is kept separately from the personal information of the interviewees. All data is stored in a secure location with no external access and kept confidential. As part of the data management plan, all interview data will be destroyed upon the completion of the research. The interviewees were made aware of the fact.

4.1.4 Data analysis

In qualitative research data analysis is noted to often be perceived as laborious and complex with lacking theoretical attention. The process is described as frustrating, in particular to novice researchers. (Azungah, 2018.) In this research, the collected data was organized thematically using the deductive approach. In the deductive approach the data is organized into predetermined themes for the coding process (Thomas, 2006). Through an extensive literature review, the aim of this research was to amend prior literature with insight from the analyzed data. In practice, the findings from the literature review are evaluated against the data analysis.

Thematic analysis was chosen as the analysis method for this research. Essentially, theming involves analyzing data according to a six-step guideline, where the first step is familiarization with the data and the second step is systematic coding of the data. In the third step, possible themes are formed based on the codes, and the relevant codes are associated with those themes. In the fourth step, the possible themes created in the third step are examined twice. First, the themes are compared to the coded data, and then they are compared to the entire dataset. In the fifth step, the confirmed themes are analyzed, and in the final sixth step, the themes are named definitively, and the analysis is written up. (Braun and Clarke, 2014.)

5 Analysis

In this section the results of the conducted interviews will be presented. The results will be further analysed and connected to prior literature in the next discussion chapter. Each of the interviewed experts were interviewed on the same theme, but with each of their expertise as a further guideline for the content. With S1 and S2, the interviews were mainly focused on corporate sustainability reporting from the perspective of the reporting companies. With F1 on the other hand, the interview grew more focused on market expectations of sustainability information and its perceived impact. Lastly, with B2 the focus of the interview was mainly on blockchain technology and its potential use-cases in enterprises. One common theme that was discussed with each expert and was prompted without asking about it specifically was the role of EU sustainability reporting regulations driving the implementation of mature corporate sustainability reporting practices.

The results will be presented in the form of summaries and quotes from the expert interviews, categorized into four identified main themes in:

- Role of corporate sustainability reporting
- Sustainability data
- Reporting transparency and reliability
- Blockchain in corporate sustainability reporting

Interviews with S1, S2 and F1 were conducted and recorded in Finnish, with the interviewer translating them into English after transcription. The interview with B1 was conducted in English and the quotes will be direct.

5.1 Role of corporate sustainability reporting

In all interviews, sustainability reporting of corporations was identified as something that is currently one of the most discussed topics in the corporate landscape.

> Regulation is the foundation for everything… and the great number of new EU corporate sustainability reporting regulation is pushing companies to further enhance their sustainability reporting processes as well as business integration. (F1)

> Corporate sustainability reporting plays a crucial role in today's corporate landscape. Sustainability reporting helps companies establish transparency, accountability, and trust with stakeholders, including investors, customers, employees, and regulatory bodies. It provides a platform to showcase progress, highlight areas of improvement, and align business strategies with global sustainability goals. (S2)

While F1 raised the point of regulation forcing the companies to act, S2 highlighted the opportunity this creates for businesses to build trust with stakeholders and showcase their strengths. Similarly, it is noted in prior research that reporting of non-financial information can lead to enhanced business opportunities and increased company valuation (Dienes et al., 2016). In the same spirit, F1 and S1 noted that while corporate sustainability reporting is still seen as more of a "compliance check" in some companies, others are actively integrating their reporting practices more deeply into their business. The role of corporate sustainability reporting as a value driver raised a lot of discussion with S1, S2 and F1 with similar notions. It is to be noted, that essentially S1 and S2 have experience in creating sustainability information that is catered to the likes of investors, such as F1. It would appear that both sides are putting an increasing focus on non-financial information – providers recognizing the value creation opportunities of strong sustainability reporting and performance, driven by investors recognizing and valuing this information and taking it into account.

> It (sustainability reporting) has transitioned from being a mere compliance requirement to a strategic tool that drives sustainable business practices. Sustainability reporting enables companies to communicate their ESG performance and demonstrate their alignment with sustainability goals. From an investor's perspective, it provides valuable insights into a company's environmental and social impact, risk management practices, and long-term viability. Investors are increasingly considering sustainability factors in their decision-making process, and robust reporting plays a crucial role in evaluating a company's sustainability performance, thereby affecting its valuation. (F1)

As noted by F1, one of the most important messages corporations can broadcast through robust sustainability reporting is their risk management and long-term viability. Climate risks are becoming increasingly relevant for all companies, as well as risks related to management of social affairs in the value chain. S2 further noted that "On risk management…companies are facing increasing reputational and operational risks in their value chain, such as ones related to human rights, climate, and corruption". Echoing this sentiment, S1 added that stakeholders are putting a greater focus on "vetting the value chains" of the companies they are involved with to manage their own risks posed by affiliation. What the interviewees were describing is essentially a positive feedback loop; companies subject to sustainability reporting are striving to develop strong and trustworthy reporting practices to avoid reputational risks and at the same time secure favourable investor relations. Investors and other stakeholders on the other hand are looking for companies with strong and reliable sustainability reporting and performance to avoid risk and look for long-term value. Furthermore, it was described by S1 on how companies in other companies' value chains are trying to position themselves through sustainability performance as a competitive edge on supplier selection, as companies need to disclose the sustainability information of their value chains as well. F1 raised a point that since value chains are nowadays global and highly complex, "…even the most mature value chain sustainability information is a sophisticated guess at best". S1 supported this notion: "…value chains are so long and complex that it is practically impossible to gather perfect sustainability information". This is recognized as well by prior research in Bakarich et al. (2020), Chikhi et al. (2022), Liu et al. (2021) and Wu and Zhang (2022).

Besides ambiguous business incentives and advantages that companies were noted to gain from good sustainability performance, there are also concrete financial incentives for companies. F1 described how the EU regulation in EU Taxonomy and CSRD create opportunities for lower cost of capital for companies with good sustainability performance. S1 provided a more general overview of the two regulations:

> The EU regulations, including the CSRD and EU Taxonomy, will significantly impact corporate sustainability reporting in the region by enhancing the quality, consistency, and comparability of information, promoting standardized reporting practices, and directing investments towards environmentally sustainable activities. These regulations also provide financial incentives by attracting investments from stakeholders who prioritize sustainable practices and ensuring access to capital for companies with strong sustainability performance. (S1)

This view matches quite well of the research that has been directed into understanding the impacts of these EU regulations, such as Ottenstein et al. (2021). The data required to report in accordance with the regulations was a focus point on all of the interviews and will be presented in a separate section. Besides the data, the interviewees identified other pain points for companies in their sustainability reporting processes. S1 noted that besides data, determining the material and the most relevant sustainability indicators to report can be challenging for companies. Furthermore, S1 reported that various reporting frameworks such as SASB, GRI and then the regulations in CSRD and EU Taxonomy can prove difficult for companies to understand and navigate. In addition, S2 noted that it is a challenge to communicate sustainability performance effectively to a diverse range of stakeholders: "…finding a balance between technical details and accessible language can be difficult for companies in their sustainability reporting". F1 called that despite some of the leading companies having successfully integrated sustainability performance into their business, "…it still remains a challenge for a lot of companies to ensure business integration… stakeholder engagement and ongoing effort is required".

Interestingly, when asked to summarize their view on the current role of sustainability reporting for corporations in a few words, S1 and S2 answered with words such as "compliance, transparency, progress, accountability, stakeholder engagement". F1 on the other hand used words such as "valuation, risk management, long-term viability". This highlighted the background of the interviewees, with F1 focusing more on the financial and business impacts of sustainability reporting and S1 and S2 highlighting themes ensuring good sustainability reporting practices.

5.2 Sustainability data

As the topic of thesis is heavily related to information systems and data with blockchain technology, it was natural for another focus point to form around sustainability data required for generating the information and reports. Data collection and management was raised by every participant as one of the key pain points for companies when generating their sustainability information.

> One of the key challenges lies within the nature of sustainability data…not all data is numerical, and even for numerical data we can talk about kilowatt hours, grams of CO2, liters of water or the number of incidents in different production lines. For some of these values, companies are heavily reliant on third party information providers such as property owners. (S1)

This challenge was echoed by S2, with a notion that is completely dependent on the industry, sector, and the nature of a company's business on what kind of sustainability information they need to disclose. While in a simple case it might be enough for an office-based company to report the energy consumption of their office building, a more complex industrial company "might have an insane number of KPIs and qualitative information to disclose in order to comply". Furthermore, S2 explained that while a simple quantitative KPI such as the electricity consumption of a building might be easily retrievable from the utilities bill, a plant's impact on the local biodiversity, as is required for disclosure by the EU Taxonomy, requires a thorough and complex assessment. Not all sustainability information is equally complex or challenging to source – it is indeed very company-specific. This was also highlighted by Jiang et al. (2022) and Liu et al. (2021) as a part of their evaluations of blockchain-enabled sustainability reporting.

Moving forward, the next step in discussing sustainability data after recognizing the variety inherently in its nature was the sourcing and management of the data.

> Each company works with the data they have. In order to be able to report anything, the requirement is that your data collection systems such as ERP-systems are running, and you are able to create the required data. Companies face challenges in collecting consistent and reliable data from various internal and external sources, including suppliers, partners, and subsidiaries. Ensuring the accuracy, completeness, and timeliness of data is essential. (F1)

In order to report, you have to have data to report thus you will need to have data collection processes in place. S2 notes that as simple as this sounds, when you add complex value chains into the equation the data sources become increasingly fragmented and hard to access. Despite not having expertise in sustainability reporting specifically, B1 raised valid concerns regarding data privacy and security while promoting data sharing among stakeholders and value chains.

> Sourcing and managing sustainability data pose significant challenges for companies. Data fragmentation across different systems, lack of standardization, and varying data formats hinder the efficient collection and integration of sustainability data. (S1)

One of the key concerns raised by S1, S2 and F1 was that as the new regulation in CSRD requires companies suddenly to report an immense number of data points and KPIs of their sustainability performance, a key issue is how will the companies be able to source all the data required. S1 notes that new processes will definitely have to be established in all companies subject to the regulation as the increase from earlier data requirements is significant. Furthermore, S2 notes that "when companies disclose anything for the public, it has to be strongly rooted in reliable data". Adding from S1, managing the volume and complexity of sustainability data can be overwhelming, thus robust data governance and data management practices are required. While the massive volume of sustainability data might be a challenge to manage, a lack of data is certainly problematic.

Despite S1, S2 and F1 having no expertise on information systems, they were unanimously raised as the critical central piece for managing sustainability data as well as reporting. Robust information systems around sustainability information were noted to be "essential to handle the volume and complexity of sustainability data". Additionally, F1 noted that "…leveraging digital solutions, such as sustainability data management platforms can streamline data collection, analysis and reporting". Despite the potential, the reality of current digital solutions tailored for sustainability reporting processes.

> I will gladly comment on this (current information systems tailored for sustainability reporting): I have not personally seen any good solutions in the market despite intently searching for one. We have large, listed companies that claim to have robust systems, but in reality, this is not the case. There is a massive amount of development required in these systems to make them viable. (S1)

> Some companies have information systems and tools that can consolidate sustainability data into a single platform…but the data is still sourced from scattered excels and no one knows where those are coming from. Additionally, the data is often still exported from the consolidated platform into various different excels for different purposes. None of the systems currently enable a comprehensive sustainability report as an export, rather just another data storage. (S2)

While sustainability data management in a system is one of the key considerations especially in larger and more complex companies, sustainability data collection is one of the true pain points identified in expert interviews with prior research such as Sheldon (2020), Liu et al. (2021) and Woo et al. (2020) displaying similar remarks.

> One of the main challenges is the lack of standardized data collection processes, making it challenging to collect consistent and comparable data across different business units or subsidiaries. Companies may face difficulties in obtaining data from external sources, such as suppliers or partners, who may have varying levels of data availability or reliability. Companies might encounter outright resistance or lack of cooperation from various stakeholders involved in the data collection process, since not all data is favorable. (S1)

> The further we move away from the reporting company in the value chain, the more data quality issues appear, such as incomplete or outdated data… which can affect the accuracy and reliability of sustainability reports. Coordinating data collection efforts across various departments or regions within the organization can be complex, requiring effective communication and collaboration. (S2)

Additionally, B1 noted that there are general challenges in all reporting that are sure to manifest in sustainability reporting as well.

> …inconsistent data formats, varying data collection practices, and lack of standardization pose challenges in aggregating and reconciling any data for any reporting purposes. Data verification, thus the accuracy and reliability of the collected data might also prove a challenge. (B1)

S1 and S2 were mainly discussing data collection in concrete terms of challenges; while it might be difficult to gather the required sustainability information for the reporting company itself, the further down the value chain the data is located to more difficult will it be to acquire and validate. S1 specifically pointed out the complexity of the "data of the supplier's supplier… if even one "fold" is enough" referencing to the complex nature of global value chains. Another point was raised on the concrete action of data collection. S2 referred to two options in man or machine. Either the data is collected and reported through manual processes, or it is automated through censors.

> Furthermore, the farther down the value chain the data collection methods are most likely to diminish remarkably in their level of sophistication if available at all. (S2)

Lastly, it was brought into discussion that separate sustainability data collection processes are horribly inefficient. B1 noted that companies must navigate the complexities of integrating sustainability data into their existing systems and processes. Essentially, instead of separately collecting sustainability data of the products and services of a company, sustainability data should be added as a data point to an already existing data collection procedure, for example related to logistics. This has been also recognized in prior research related to sustainable supply chains such as Kouhizadeh and Sarkis (2018) and Sheldon (2020).

5.3 Reporting transparency and reliability

After discussing sustainability reporting drivers and processes in the interviews, all interviews took a turn toward the trustworthiness of the reported information. Greenwashing fears are prevalent among stakeholders as noted by S1 and S2. This has led to increasing efforts in companies to verify their sustainability reporting through third party assurance services, typically offered by professional services companies. S1 points out that this does not automatically result in perfectly objective information, and this was echoed by F1.

> …the question is what data will be displayed. Of course, companies strive to portray themselves in the best possible light, such as highlighting the fact they have the lowest carbon footprint in the sector. This strengthens their story of sustainability leaders and corporate responsibility but does not automatically equate to a high level of employee satisfaction or beneficial biodiversity impact. As is with all business, selective storytelling is used to focus on the good things rather than the bad. In my experience, this is the same for sustainability information or any other corporate information and it is natural. (F1)

CSRD was mentioned by S1 and S2 to help with this issue, as the sustainability reporting output will become more standardized limiting companies' ability to manipulate which information to highlight. Another key factor from CSRD that was mentioned by S1 and S2 was the mandatory third-party assurance it brings upon the subject companies. This was deemed as a positive development, forcing companies to evaluate their sustainability information and "whether it can stand in the daylight". Before CSRD, assurance of sustainability information was not mandatory. F1 highlights that Nordic companies generally provide trustworthy information and "the market is requiring assurance even before regulation". This is credited by F1 to the stable environment of the Nordic countries, in terms of law, decision-makers and market. Furthermore, F1 highlights that Nordic companies have global value chains as well, and thus the Nordic influence of good practice can be spread among the value chain.

> Especially for companies acting in developing markets and countries through their value chain, creating transparency and reliability is a key part of corporate risk management, which enables successful business. (F1)

S1 noted that while Nordic companies are among the sustainability leaders on a global scale, there are still large corporations acting in the Nordics that do not assure their sustainability information voluntarily. There are different incentives that S1 and S2 have experienced effective for promoting transparency and reliability in corporate sustainability reporting processes.

> …it comes back to funding. There are clauses in financing options requiring specific sustainability KPIs to be met, or there can be a clause requiring assurance. This can be tied to a certain interest rate, where meeting the requirements will result in a better rate. Other great option is tying the management incentives of a company to the sustainability agenda through similar means. (S1)

Essentially, financial incentives and implications are noted to be the strongest driver for transparency, reliability and good reporting practices. In addition to third-party assurance, the experts were asked to give their thoughts on the best ways to enhance the transparency and reliability of sustainability information, especially in the face on financial incentives driving companies to focus on good sustainability performance. S1 and S2 stated that automation of the reporting processes, thus limiting manual errors and chances of manipulating the data, as well as promoting consistency in the reporting processes. While such information systems and tools were noted to be immature at the time of the interviews, the potential was acknowledged. B1 noted that as in any reporting system, if the data can be tracked it creates audit trails, which in turn can enable increasing transparency of the process. Additionally, information systems can enable real-time validation and checking of the data in question, improving the reliability of the data as long as the process is transparent. Furthermore, B1 pointed out that the centralization of data management systems can enable easier access to relevant data, which in turn can ease the verification process of the data. Similarly, S2 noted that if a company is managing its sustainability information in a coherent manner, it is remarkably easier to assure.

> If there is a financial link to the sustainability information, let’s say a stock of material in a warehouse, it creates reliability since the company wants to report the amount of stock correctly in the warehouse in their financial reporting as well. This in turn ensures that the sustainability information that is tied to the stock and is volume-based will be correct as well. In cases where the financial link is missing and the information is highly qualitative in nature, it can become a challenging process to determine the validity of the information. (S2)

In the same spirit, S1 and F1 reached similar conclusions that sustainability information that has a financial link is easier to trust, and generally has the same level of transparency as the financial information related to the item. Related, S1 that the emission factors used to quantify emissions through spent currency or used resource “are their own challenge entirely”. S1 stated that only emission factors from governing bodies and leading NGOs should be employed, and caution exercised with “less known emission factor databases”. This appears to be in line with Billio et al. (2021) research on the various emission factors and other stock sustainability information.

5.4 Blockchain in corporate sustainability reporting

The main theme of this thesis is to evaluate the potential of blockchain technology in the space of corporate sustainability reporting. When presented with information on the challenges in corporate sustainability reporting, B1 noted that at least on paper, blockchain technology seems to have answers to the typical challenges in "transparency, reliability, and accessibility" present in corporate sustainability reporting.

> It (blockchain technology) holds theoretical promise at least. The core features of blockchain, such as transparency, immutability, and decentralized data storage, have the potential to address key challenges described in sustainability reporting, including transparency, data integrity, trust, and accessibility. (B1)

Fitting with a variety of prior blockchain research, on a high-level blockchain seems to offer solutions to the challenges in sustainability reporting. To further understand blockchains' current state in enterprise use outside of literature, B1 stated the current view of blockchain technology in enterprise use.

> Not related to sustainability reporting… Enterprise use-cases for blockchain are still in the pilot stage and have appeared for example in supply chain management. The technology is still not mature for corporate use. The only companies in the world that are experimenting with technology are ones that can invest millions of dollars in projects with no guaranteed returns, such as Walmart and Coca-Cola. For companies just trying to get a digital solution for their activities, blockchain-based enterprise systems are still quite far-fetched. (B1)

While blockchain pilots have received a lot of attention in the media, it would seem based on B1's view that in truth there are not yet mature blockchain-based enterprise systems in corporate use nor in the market. B1 further echoed the sentiments raised by Yaga et al. (2018) about "blockchain hype".

> It is crucial to separate the hype from practical considerations when assessing its (blockchain) suitability for specific applications. It is important to evaluate whether it truly would be the best solution even if it would be as feasible as more traditional solutions, such as shared databases. Shared databases can offer robust data management capabilities, efficient data sharing, and simpler integration with existing systems. They can provide the qualities associated with blockchain such as transparency, data integrity, and accessibility without the complexities and resource requirements of hypothetical blockchain implementations. (B1)

B1's characterization of blockchain hype is aligned with a lot of the prior criticism blockchain technology and research has received. B1 highlights the need for critical evaluation of valid use-cases for different solutions. Furthermore, B1 notes that "the manifestation of the hype around blockchain" is observable in many ways. According to B1, it generally involves a strong belief in the universal applicability of blockchain and its power to solve all data-related challenges, while having a limited understanding of the technology. B1 notes that this development has partially been harmful to the further adoption of blockchain technology.

As a contrast, B1 was asked to evaluate the potential of blockchain technology in corporate sustainability reporting. B1 noted that as a starting point, it would be essential to conduct thorough feasibility studies, assess the specific requirements, weigh the benefits against the cost, and consider a range of technological options beyond blockchain.

It is essential to carefully evaluate the unique needs of sustainability reporting and consider a range of technological solutions. The choice should be based on factors such as data volume, frequency of updates, data privacy and security requirements, scalability, interoperability, and cost-effectiveness. (B1)

The assessment by B1 is very close to the one of Wüst and Gervais (2018) and their decision-tree for blockchain technology implementation. It would seem that for blockchain experts the use-case exists yet is very limited due to not offering significant relevant advantages over traditional shared databases.

Lastly, at the end of their respective interviews, S1, S2, and F1 were briefly presented the case of blockchain in sustainability reporting. The interviewees in question had very limited knowledge of blockchain beforehand.

> Due to my professional scepticism, I do not trust any system until I can test it. I have to test that the system fetches, calculates, and analyses information correctly… Regarding a hypothetical blockchain implementation, I would welcome it the same reservations as for any system – I would need to test it. (S1)

S2 and F1 did not have any significant remarks regarding blockchain use in sustainability reporting, but both were open to welcome any advantages an information system would bring to the space.

6 Discussion

The purpose of this thesis was to evaluate blockchain technology as a technological solution to the corporate sustainability reporting paradigm that is currently under significant transformation driven by EU regulations such as the Corporate Sustainability Reporting Directive (CSRD) and EU Taxonomy. As companies subject to these regulations face increasingly demanding disclosure requirements on their sustainability performance, the amount of data required becomes proportionally vaster and more complex to manage. Thus, as present in already established corporate reporting functions such as financial reporting, the role of information systems becomes more crucial in ensuring valid and compliant reporting practices. In this thesis, the feasibility of a blockchain implementation as a reporting system for corporate sustainability reporting was evaluated through a brief introduction of background and the requirements of CSRD and EU Taxonomy. This was followed by a comprehensive literature review of blockchain technology. to lift a veil of technological abstraction present in prior research – to put into concrete terms what technological features drive the praised properties of blockchain in enterprise use – as well as to critically evaluate whether and when a blockchain-based system might make sense. Through a qualitative case study, interviews were conducted with experts from both corporate sustainability reporting and blockchain domains to validate and amend findings from prior literature. Finally, in this section the findings from prior literature and interviews will be presented together to display correlations, clashes, and to suggest future developments. Through this structure, the research questions in "To what extent can blockchain technology serve as a viable solution for enterprise sustainability reporting?", "What are the perceived benefits and challenges of implementing blockchain technology for enterprise use?", and "How do the findings from expert interviews align with or challenge the current literature on blockchain technology in sustainability reporting?" will be approached and met.

While blockchain is mainly known for its application in cryptocurrencies, there has been a growing interest in building enterprise solutions based on blockchain technology, as noted in a vast number of prior research referenced in the literature review of blockchain technology in this thesis, notably by Yaga et al. (2018), Wüst and Gervais (2018), Casino et al. (2019), and Zheng et al. (2017). Essentially, through a combination of a fitting permission model and consensus system, which both are discussed in detail in the literature review, companies can build blockchain-based information systems where all transactions are immutable, transparent, and verifiable for all participants in the blockchain. The potential has been especially recognized particularly in supply chain management, where involving actors in a company's value chain as participants to the enterprise blockchain can create a streamlined process of information sharing between mutually distrusting parties. We examined numerous studies on blockchain-based supply chain management, ranging from critical evaluations by Chikhi et al. (2022) to implementation guidelines provided by Esmaeilian et al. (2020) and Sheldon (2020). Chikhi et al. (2022) is a great example of a critical evaluation of blockchain-based solutions, and noted tendencies among researchers to overlook the feasibility and technological properties that underpin descriptions of blockchain as "immutable", "transparent", "secure", and "reliable". Interviewing a blockchain expert (B1) highlighted that on a high-level these terms can build a seeming fit for a large number of issues, but under closer inspection, the use-cases are very limited. As noted, this aligns with prior research such as Yaga et al. (2018) and Wüst and Gervais (2018). Furthermore, aligning with Wüst and Gervais (2018), B1 presented criteria for blockchain-based use case in data volume, frequency of updates, data privacy and security requirements, scalability, interoperability, and cost-effectiveness. While several companies, such as IBM and Walmart, have piloted blockchain-based enterprise systems (Sheldon, 2020), interview with B1 revealed that these pilot projects have not yet matured into full-scale implementations. B1 cited reasons similar to those outlined by Zhou et al. (2020): the inherent risk associated with investing in new technology and the digitalization process underway in many companies. They suggested that only the largest companies might currently find it feasible to explore the potential of blockchain technology in enterprise systems.

Corporate sustainability reporting is rapidly evolving under the influence of EU regulations, a trend identified by Ottenstein et al. (2021) and Baumüller and Grbenic (2021), and confirmed by our interviewed sustainability experts, S1, S2, and F1. As these regulations impose increasingly rigorous disclosure requirements on companies, they also offer financial incentives for strong sustainability performance, such as lower capital costs. However, a key challenge highlighted by both S1 and S2 is the difficulty companies face in sourcing all the required data. This could lead to a conflict: while good sustainability performance is rewarded, companies may lack the means to fully comply with reporting requirements. Theoretically, this could tempt companies to manipulate information to reap benefits, despite insufficient data. Mandatory assurance, a part of CSRD, may mitigate this risk, but it remains a relevant consideration. In light of these stringent requirements, the role of information systems in ensuring valid and compliant reporting is becoming increasingly important. Blockchain technology, with its inherent properties of immutability, transparency, and verifiability, could potentially be harnessed for this purpose. This is particularly relevant in sustainability reporting, whereas noted by S1 and S2, the reporting process should strive to cover the whole value chain. This means that data points from each participant are required, similar to supply chain management. However, the feasibility of implementing blockchain as a reporting system for corporate sustainability must be carefully assessed. Given the complexity and high stakes of the reporting process, a thorough and cautious approach is necessary to fully understand the potential benefits and challenges of blockchain technology in this context.

Based on the literature review and the expert interviews it would seem that blockchain technology is not the most optimal solution to challenges present in corporate sustainability reporting. One question is feasibility – based on the insight gained from the interview with B1, the technology seems immature for wide enterprise adoption. Pilots do exist but have not been developed into fully fledged solutions. Modern corporate sustainability reporting that is defined by regulations such as CSRD and EU Taxonomy requires companies to collect and manage vast amounts of data which is incredibly inefficient through manual means. There is definitely a call for an information system to do the work, and similarities between supply chain management systems are raised due to having to include the whole value chain in the reporting as noted by expert interviews and prior research. It would appear to be one of the key reasons why blockchain is considered as a solution for sustainability reporting in prior research such as Wu et al. (2022) and Jiang et al. (2022), since the premise is the same as for the blockchain-based pilot projects in supply chain management.

Additionally, the literature review revealed that while blockchain technology might seem enticing, it is not the perfect solution for everything. After reviewing prior research, it was clear that most of the advantages of blockchain-based implementations were credited to the following properties: decentralization, transparency, security and reliability. Furthermore, these can all be credited to two properties of a blockchain implementation – its permission model and consensus system. Cryptocurrencies such as Bitcoin are permissionless blockchain networks employing a proof of work consensus system with no central authorities. This type of blockchain is decentralized, transparent, secure and reliable. As noted by multitude of prior research such as Yaga et al. (2018) and Wüst and Gervais (2018), this is not typically the case for enterprise blockchains. These blockchains on the other hand are permissioned blockchain networks with lighter consensus systems. Suddenly, the properties of a blockchain in immutability, transparency, and security are given up for more control. These properties also build the premise on which sustainability reporting implementations have been theorized (Bakarich et al., 2020; Jiang et al., 2022; Wu et al., 2022), confirmed by the expert interviews with S1 and S2 pointing out the transparency and reliability challenges that corporations face in their sustainability reporting. This raises the question, whether some of the prior conceptions of blockchain's suitability for corporate sustainability reporting have been based on properties familiar from blockchain implementation native to cryptocurrencies.

Essentially, there is little to no evidence to suggest that the current capabilities and properties of blockchain technology offer significant advantages over traditional shared databases in a scenario for a digital platform for corporate sustainability reporting. Moreover, blockchain nor any other technology can offer a magical solution for companies to manage their corporate sustainability reporting automatically. The added complexity brought by EU regulations will be a challenge for subject companies to adapt. As companies are learning to comply with something new, it might the best bet to employ well-known methods in assisting compliance – such as traditional shared databases. It is worth nothing that blockchain technology is rapidly evolving and a remarkable number of large companies have their own blockchain related initiative. Time will tell how these initiatives develop, and perhaps in the future there will be a blockchain implementation that is a market standard for corporate sustainability reporting platforms.

7 Conclusions

This thesis has critically evaluated the potential and feasibility of using blockchain technology for corporate sustainability reporting, but it is important to recognize the inherent limitations. The most significant one is that this research is focused primarily on the implications of blockchain technology for corporate sustainability reporting within the context of the European Union, particularly in light of recent regulations like CSRD and EU Taxonomy. The conclusions may therefore not be fully applicable to other jurisdictions with different regulatory frameworks. Furthermore, the interviews conducted as part of the research involved a limited number of experts (two sustainability professionals, one investor, and one blockchain expert). The opinions and insights of these experts were invaluable for the purposes of this study, but it must be acknowledged that the findings might have been different with a larger and more diverse sample of respondents. Moreover, while our understanding of blockchain technology is in a continuous state of evolution, the rapid emergence of new implementations, such as no-code software building platforms on top of blockchains, means that the results presented here represent a snapshot in time. Our understanding of the technology's potential and limitations could shift as the technology advances.

Considering the rapid evolution of blockchain technology and its potential impact on corporate sustainability reporting, future research could benefit from longitudinal studies that track the development of blockchain-based reporting systems over time. A continued exploration of blockchain technology's development and the implications of new variations is vital. Ongoing blockchain pilot projects from large companies such as IBM, Walmart, Coca Cola, and BMW warrant keen observation to see how their learnings could inform the use of blockchain for sustainability reporting. Another promising avenue for future research is to explore alternative technological solutions for sustainability reporting. This study hinted at the potential of shared databases; a comprehensive comparison between blockchain technology and shared databases in the context of sustainability reporting could yield interesting results. Additionally, future studies could examine in more depth the perceptions of different stakeholders (such as investors, regulators, or sustainability professionals) regarding the application of blockchain technology in corporate sustainability reporting. This could provide a more nuanced understanding of the perceived benefits and challenges of such an implementation.

Finally, more empirical studies, possibly including experiments or prototyping, could be valuable in putting theoretical considerations to practical test, further enlightening the discourse around blockchain's place in sustainability reporting.

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