Master in Digital Communication Leadership

Co-funded by the Erasmus+ Programme of the European Union

# BLOCKCHAIN TECHNOLOGY FOR MONITORING AND REPORTING OF CARBON EMISSION TRADING.

***A case study on its possible implementation in the Danish energy industry.***

MASTER THESIS

to obtain the Erasmus Mundus Joint Master Degree

in Digital Communication Leadership (DCLead)

of

Faculty of Cultural and Social Sciences

Paris Lodron University of Salzburg

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Salzburg, 31st of July, 2020

**Disclaimer**

This research document has been prepared to look at the possibilities of how blockchain can be implemented in a specific case study of monitoring and reporting of carbon emission trading in the Danish energy industry. The document represents only the views of the author at the time the study was carried out and not necessarily those of the European Commission, EU ETS, Ethereum, Hyperledger Fabric, CLI and Energy Blockchain Labs.

**Executive Summary**

The main objective of the research is to look at how blockchain can be used for monitoring and tracking CO2 emission trading in the energy industry with a focus on the European Union Emission Trading System (EU ETS) framework. Guided by the network, stakeholder and network theory, the researcher was able to gather the relevant data necessary to address the research questions, interpret findings and analyse. Applying both empirical data from semi-structured expert interviews and literature reviews, three outcomes are presented. The first is on the current conditions and challenges of monitoring and reporting CO2 emissions. Second is putting into consideration if blockchain is the right fit to solve these challenges and how. Third stage looks at the factors that might affect the implementation of such a system.

The use of blockchain to address the issue of climate change is increasingly a discourse among countries, industries, and stakeholders. Already, industries and climates initiatives view the technology as a potential solution for combating climate change (UNFCCC, 2017; Willers, 2018). The EU Regulation (EU) 2015/757 is also positive that implementing innovative technologies can accelerate climate actions and reduce CO2 (European Commission, 2015). For a long time, the EU has been combating the issue of climate action in industries through sustainability programs. One of such programs is the EU monitoring reporting and verification (MRV) program under the EU ETS. However, systems have some key challenges and areas for improvement which makes it ineffective.

The first stage of the study findings reveals that the monitoring and reporting of CO2 emissions is a mandatory requirement by law for all energy operators under the EU ETS program. However, most energy operators are non-compliant to the program in reality. This creates gaps and issues of non-compliance in the current system. Other challenges the study found out are the lack of transparency, lack of standardization in CO2 accounting and the issue of double counting.

The second stage of the research was guided by the cases studied and requirement engineering (RE) to explore these identified challenges and if blockchain is the right fit to address them. Most importantly how can blockchain fix the said challenges. This stage of the research addressed the main research question: how can blockchain be used for monitoring and reporting of CO2 emission trading in the energy industry. Through

elucidation of the study analysis, the research developed a private-permissioned Hyperledger blockchain otherwise referred to as a Process Flow Networked (PFN) to address the identified challenges. Particularly, the smart contract of the blockchain was highlighted as a key feature. This is because of its ability to automate, be immutable and digitally enforce negotiations without a middleman. These characteristics are unique in solving the issue of compliance, transparency, standardization, and double counting identified.

Furthermore, through the result validation in a post-expert interview, the research found out that the verification step in the process of monitoring and reporting CO2 may not be ‘fully’ replaced by blockchain because the technology is still evolving and not yet mature. Human effort will be required in the verification stage of the process. As such, the study encourages further work on this. The implementation of the proposed blockchain comes with challenges which the third stage of the research addressed.

The third stage presents technological constraints and a high level of stakeholder’s collaboration as major factors that might affect the implementation of the proposed system. Also the system requires a high level integration with other technologies such as the Internet of Things (IoT) and machine learning.

Therefore the study also encourages future research in these areas. This is because blockchain is continually evolving its technology capabilities. As such, it remains a topic of interest in research and development for addressing climate change. This research explores how blockchain, with its smart contract and distributed ledger technology (DLT) can be used to address a critical global issue: climate change. Such a study is a good contribution for creating sustainable practices to solve the global climate issue. Not just the energy industry but other sectors: maritime, aviation, shipping e.t.c can learn from the research findings.

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**Acronyms**

AER: Annual Emission Report
AI: Artificial Intelligence
AR: Account Representative
CO2: Carbon Dioxide
DLT Distributed Ledger Technology

DoC Document of Compliance

ETR: Emission Transaction Registry

ERP: Enterprise Resource Planning

EU ETS: European Union Emission Trading System

EUAs: European Unit Allowances

EU TL: European Union Transaction Log

GHG: Greenhouse Gas

LRF: Linear Reduction Factor

ICT: Information Communication Technology

IoT: Internet of Things

MRV: Monitoring Reporting Verification

MWh: Megawatts per hour

PBFT: Practical Byzantine Fault Tolerance

P2P: Peer to Peer

PFN: Process Flow Network

PoS: Proof of Stake

PoW: Proof of Work

RE: Requirement Engineering

SDGs: Sustainable Development goals

TCO2: Tonne per Carbon Dioxide

TTP: Trusted Third Party

**Organisations**

CLI: Climate Ledger Initiative

EEA: European Environmental Agency

EU: European Union

GIZ: Gesellschaft für Internationale Zusammenarbeit

IBM: International Business Machines Corporation

IEA: International Energy Agency

IISD: International Institute for Sustainable Development

MIEN: Ministry for Environment and Natural Resources

NGO: Non-Government Organization

UNDP: United Nations Development Programme

UNFCCC: United Nations Framework Convention on Climate Change

## 1. Introduction

Information Communication and Technology (ICT) has a unique potential to enable industries to move towards a low-carbon economy which is central for creating a global positive impact. According to Ericsson research, ICT solutions can lower carbon emissions global by up to 15 percent by 2030 (Malmodin and Bergmark, 2015). Already in Europe, the European Union (EU) has started implementing ICT solutions to reduce carbon emissions in industries and create a sustainable impact. One of such actions is the implementation of the European Union Emission Trading System (EU ETS) in pursuant to Directive 2003/87/EC (Danish Business Authority, 2019) for the energy, for high polluting industries: with shipping, aviation (Coren, 2019 ), and energy topping the list (European Commission, 2019). The energy industry alone accounts for over 1000 million tonnes of CO2 (EEA, 2019), and all types of energy production accounting for 72% of global GHG emissions (World Resources Institute, 2017).

Launched on the first of January 2005, the EU ETS was set up to help the EU and regulators improve its administration strategy to reduce CO2 emissions. The program operates in the 28 EU countries including Denmark and covers around 45% of the EU's GHG emissions (European Union, 2016). Since its launch, periodic targets have been set to lower CO2 emissions in the EU. Recently, an energy target of a 40 % CO2 reduction is set to be achieved by 2030 (IEA, 2020). To achieve this target, the EU mandates all energy operators under the EU jurisdiction to work with the EU ETS program (European Commission, 2015). Despite the implementation of the program as an incentive to reduce emissions in the energy sector, it has failed to yield substantial reductions in emissions. Between 2013 to 2018, CO2 emissions from industrial installations decreased by only 0.3% (IEA, 2020). Although, the year 2020 has seen a tremendous decrease in GHG levels amid the sharp reduction of industrial activities. This is as a result of COVID-19 health crisis. According to IEA reports (2020), the ongoing crisis could enable the EU to meet its targets. Nonetheless, it should not lead to complacency.

The failure in the EU ETS contributes to the EU not being on track towards achieving its emissions reduction targets. It will require a significant system transformation in the current policies and regulations (IEA, 2020), to enable the EU achieve its 2030 CO2 emission reduction targets. The EU Regulation (EU) 2015/757 is positive that the implementation of new innovative technologies can accelerate climate actions and reduce

CO2 (European Commission, 2015). In this digital era of ICT, there exist different technologies that can work to combat the climate crisis. As more industries find innovative ways to mitigate the impact of CO2 on climate change, the idea of optimizing blockchain technology has been at the forefront of many conversations (Kyler, 2018.) The United Nations Framework Convention on Climate Change (UNFCCC) is exploring the use of blockchain technology for improving the monitoring and reporting of GHG emission reduction and avoidance of double counting (UNFCCC, 2017). Additionally, research studies are already developing blockchain distributed ledger technology (DLT), for carbon tokenization: tradable permits that provide an holder the right to emit one ton of carbon dioxide (CFI Education, 2020). An example of such blockchain application is the monitoring reporting and verification (MRV) system developed by Climate Ledger Initiative (CLI) ( CLI, 2019).

Blockchain as a form of DLT is distributed across and managed by a peer-to-peer network, and not driven by a centralized authority. Instead, its data is maintained by a database replication and computational trust (Ray, 2018). There has also been a growing number of sustainable and climate action projects that view blockchain as a disruptive solution towards solving climate action. “Blockchain could contribute to greater stakeholder involvement, transparency and engagement and help bring trust and further innovative solutions in the fight against climate change, leading to enhanced climate actions” (UNFCCC, 2017). Other digital technologies have also been viewed as a potential tool against climate change. However, blockchain is seen as a main technological solution that provides the benefit of transparency, trust and cost effectiveness, which is beneficial to different stakeholders (UNFCCC, 2017).

As such, it can be adopted for monitoring and reporting carbon impacts through its adaptation in the EU ETS. This is because its traceability and transparent nature will ensure that emission trading can be monitored and reported transparently thereby eliminating any data gaps. A working example of such a blockchain for trading carbon assets is the blockchain innovation by IBM and Energy Blockchain Labs in China (UNFCCC, 2017). Therefore the study focus arises from the benefits of applying blockchain for monitoring and reporting CO2 emissions and positive feedback on emerging numbers of research. With the problem of the rise of CO2 emissions, blockchain as an innovative technology can potentially address these challenges. The research study will focus on blockchain for monitoring and reporting CO2 emission trading in the energy.

Through case study analysis, literatures and theories of network, stakeholder and market structure, the study aims to close the research gap by elucidating on how blockchain can be implemented for monitoring and reporting CO2 emissions trading in the energy industry. To address the research focus, there will be three main stages. First, the researcher will look at the current conditions and challenges of monitoring and reporting CO2 emissions trading. Next, the study will look at how blockchain can be used to address the said challenges to meet industry needs. Lastly, it will look at the factors that might affect the implementation of blockchain for CO2 emission trading and provide recommendations on how it can be mitigated.

**Energy industry sustainability programs**

The term "sustainability" has been defined in many ways. However, the most quoted definition is coined from the Brundtland report. The report defined sustainable development as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations Brundtland Commission,1987). Sustainability is the foundation for the present leading global framework for international cooperation, according to the 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs) (IISD, n.d). A key sustainability program the EU has embarked on to achieve its climate and energy targets is the EU ETS. Ever since the EU ETS implementation, reducing carbon in the energy trading activities has become a prime concern for energy operators and its stakeholders. According to European Union (2015), the EU ETS is a "cap and trade" system. It caps the total volume of GHG emissions from installations. After the 'Kyoto Protocol' to the UNFCCC became consensual in 1997, legal binding for GHG reduction targets were set (European Union, 2015).

The EU ETS became mandatory for all energy operators under the EU and policy instruments were necessary to meet the Kyoto commitments. While EU ETS has the potential to cover many economic sectors, the program is focused on emissions which can be measured, and reported to a high degree of accuracy (European Commission, 2015). Even though the EU ETS is the largest carbon trading market in the world (European Union, 2016), the program seems like a failure. This is because it is not delivering the CO2 cuts required by science ( Friends of the Earth Europe, n.d), which is below 2°C (Milman, 2013). With a focus on the EU ETS framework, the study will look at the current challenges of the program when it comes to monitoring and reporting of $CO_2$ emission trading and how blockchain can address these challenges.

## 1.1 Problem and background

"Science tells us that the global current path faces at least 3° Celsius of global warming by the end of the century. The climate emergency is a race we are losing, but a race we can win" (Guterres, 2019). $CO_2$ emissions are a major contributor to climate change, accounting for 80% of all man-made EU GHG emissions and influenced by factors such as climate conditions, (e.g. cold /long winter or hot summer), economic growth, population size, transport and industrial activities ( Eurostat, 2020). A 50% increase of global $CO_2$ emissions have also been recorded since 1990 (UNDP, n.d.). As a result of the climate rise, the Paris Agreement was adopted in December 2015 and entered into force in November 2016 (European Union, 2020a). The Paris Agreement is an agreement within the UNFCCC on the mitigation of GHG emissions, adaptation, and climate finance (Paris Agreement, 2015).

The agreement's objective is to minimize the risk and impact of climate change by limiting the temperature to 1.5°C and holding 2°C (UNFCCC, 2015). The UNFCCC is an international body and intergovernmental body working to achieve the stability of GHG concentration in the atmosphere at a level that would prevent dangerous interference with the climate system (European Union, 2020b). The United Nations also created the Sustainable Development Goal (SDG) 13: climate action, with a focus on creating a positive impact on climate related issues. (United Nations, 2018). All these actions are put in place to enable the EU meet its target roadmap until 2050 towards a low-carbon economy (Agora Energiewende 2019).

The year before COVID-19 health crisis (2019), a clear drop in solid fossil fuels which generated high amounts of $CO_2$ emissions was observed in many EU countries. The reason for the drop was due to the substantially increased price of Emission Unit Allowances ( EUAs), in 2019 compared to 2018 (> 25 € / t $CO_2$) (Eurostat, 2020). EUAs are tradable units under the EU ETS to emit one tonne of $CO_2$. It became less economically profitable for energy operators to use solid fossil fuels because they emit more $CO_2$ per MWh (MegaWatts/hour) electricity produced than other fuel e.g natural gas (Eurostat, 2020). Designed to decrease annually from the year 2013, the purpose of the raising the prices of EUAs is to reduce the number of units available to businesses under the EU ETS by 1.74% per year (European Union, 2015.) The EU does this through enforcing a mandatory monitoring reporting and verification ( EU MRV) scheme for energy operators. Every year, energy operators need to hand in an annual emission report AER which is the key document providing the amount of emitted GHG in a given year. The AER then needs to be verified by an independent accredited verifier. The verification of emission reports and accreditation of verifiers must be in line with the EU Accreditation and Verification regulation: Regulation (EU) No 600/2012 (European Union, 2012). The essence of this in the MRV system is to guarantee that one tonne CO2 equivalent emitted is equivalent to one tonne reported for all carbon market participants including energy operators. This principle popularly referred to as “a tonne must be a tonne” (European Union, 2015).

The objective of the MRV program is to ensure that operators meet their obligation to give-up sufficient allowances in line with their emissions. To set emission reduction goals for energy operators, a certain amount of data is required. This is called the “baseline emission data” (Tabau, 2008), which must be defined to determine the required amount of effort to reduce emissions. However, the challenge is that such data are readily unavailable or difficult to collect therefore making its validity questionable. This is an outstanding problem of the EU ETS monitoring and reporting program because there exist no standard measurement and protocols, and many data measures are only estimates which lead to confusion (King, 2018).

The implementation of the EU MRV has experienced other challenges which makes it an inefficient system. The issue of double-counting is another challenge. Double counting means recording the same thing twice. Since there exist no standard protocols in monitoring and reporting the activities of carbon trading under EU ETS, multiple allowances are recorded into the system and claimed as one single entity (Schneider, Kollmuss and Lazarus, 2014). The system also lacks transparency as self reporting is often practiced with no independent emission verification which leads to ‘CO2 report cheating’ and corruption within the carbon market (Bohm, 2013). Without a trustworthy system for monitoring and reporting, sustainable strategies for reducing CO2 emissions will have only a limited impact. As such, there is a crucial need to look into innovative solutions that can monitor and report activities of CO2 emission trading. Innovation and technology deployment are critical in the areas of these underperformance.
Previous study by Perino and Wilner (2016) suggested improving the efficiency of EU ETS

by introducing new stabilizing allowances supplies in the carbon market. Peter and Frank (2011) suggested introducing a carbon floor price to guarantee minimum price of allowances, while Khamila et al (2017) focused on improving management and increasing abatement investment in the ETS using blockchain. Also, the study of Tabirao (2018) suggested the possibility to use blockchain for monitoring reporting and verification of CO2 in the shipping industry. However, there is very limited study on monitoring and reporting CO2 emission trading under the EU ETS program in the energy industry.

Guided by the knowledge of network, stakeholder and market structure theories, the study aims to elucidate on the possibilities of how blockchain can be implemented for monitoring and reporting CO2 emissions for the Danish energy industry. As such, the researcher will first look at current conditions and challenges of implementing the monitoring and reporting of CO2 emission trading. Next blockchain will be accessed if it is the right fit to address these challenges and how can this be done. To address the research problem, it is pertinent to formulate research questions which will serve as a guideline throughout the study. As such, some questions have been formulated below.

## 1.2 Research questions

Main question

How can a blockchain be used for monitoring and reporting CO2 emission trading in the Danish energy industry?

Sub-questions

- What are the current conditions and challenges of monitoring and reporting CO2 emission trading in the energy industry?
- What are the factors that might affect the implementation of blockchain for monitoring and reporting CO2 emission trading in the energy carbon market?

*Terminologies used in the research question*

i)*Monitoring*: The term monitoring as used in the main question above, refers to a regular observation and documentation of activities.

ii)Reporting: refers to a gathered set of information which will be used for making informed decisions in order to improve a process.

iii) *Emission trading*: this is a market-based approach to control pollution by providing economic incentives for reducing the emissions of pollutants.

From the questions formulated above, it is paramount to first investigate the current conditions, needs and challenges of the energy industry to address the problem of the study. The first sub-question looks at the industry's perspective on the current mandatory EU ETS framework and its implementations. After mapping out the current implementation, challenges, and areas of improvements, the researcher will see if blockchain is the right fit and how the technology can address these challenges. To address the second sub-question, the researcher will first provide a blockchain conceptual model that is guided by the technology capabilities to fit the industry's needs. Next, the researcher will look at the possible factors that might affect the implementation of blockchain for carbon trading and provide recommendations. These recommendations are geared towards influencing the possibilities of implementing blockchain for carbon trading in the energy industry.

## 1.3 Research objectives

At the end of the study, the researcher aims to:

1. Investigate the conditions and challenges of the current EU ETS framework for monitoring and reporting of CO2 emissions trading in the energy carbon market.
2. Create a blockchain monitoring and reporting blockchain model designed for the energy Danish industry. This model will present the level of collaboration among the stakeholders in the industry and their relationships. It will also present document workflows and the capabilities of the smart contract in blockchain.
3. Identify the factors that might affect the possible implementation of the proposed blockchain and provide recommendations.

## 1.4 Relevance

Blockchain as an evolving technology has become a popular topic for research and development nowadays. However, the last two years, 92% of the 26,000 blockchain-based projects have been recorded as unsuccessful (Trujillo et al., 2017 and Graham, 2018). This is why it is paramount for this study to investigate the current challenges of the industry and if blockchain technology as an enabler of climate change can address these challenges and how. The study recognises that technology has a great potential of rendering current technology and middlemen obsolete. This will lead to a restructuring of market and business models in the different industries (Roiena, n.d.), because it has the tendency to create a new mechanism with a new set of rules.

Furthermore, there are other attributes that set the technology apart such as its decentralisation attribute. This attribute of blockchain has the power to reform the entire carbon trading market structure. Infact, from a centralized to a decentralized structure has been a prime developmental pattern and is continuously evolving in the creating, establishing and enforcing rules (Davidson et al., 2016). Nowadays, blockchain is becoming a technology for creating decentralized market structures through cryptocurrency and smart contract application. This attribute of blockchain makes it possible for anyone in the network to write, join, validate transactions following a predefined set of rules within the system. Moving from centralization to decentralization can be traced back to history. The internet is also another example of a decentralized knowledge sharing platform (Benkler, 2006).

From a technological perspective, blockchain is perceived to be disruptive, still evolving and in its early phase of adoption. Blockchain as an innovation can 'form a new techno-economic paradigm' setting off a new era (Davidson et al., 2016). Perez (2015) also described this new era as the green global age, where digitalization contributes to green infrastructures, changing environmentally issues to solutions. This will go a long way in affecting not just the environmentally aspects but the social and economic aspects of society: industries outside the energy industry, and government policies. However, in order to achieve this shift in paradigm, industry, infrastructures and authorities need to be available and willing to work together (Perez, 2015). On a global scale, green research and development is now a major subject of discussion for addressing climate action mitigations through adopting digitized solutions such as DLT solutions as blockchain. Organisations such as UNFCCC and Climate Ledger Initiative (CLI) are already driving climatic actions with the use of blockchain and DLT (UNFCCC, 2017) (CLI, 2020). A use case example is IBM teaming up with Energy Blockchain Labs for trading carbon assets (UNFCCC, 2017) .

Other use cases exploring the use of blockchain for carbon trading, crediting and market include Climate Coin (2018) and Poseidon (2018). Infact, the subject matter of the usage of blockchain and DLT technology for climate mitigation can take different directions and focus not just carbon trading. However, for this paper, the focus is to apply it for monitoring and reporting CO2 emissions trading. As such, it is pertinent to identify what type of blockchain can help the energy industry understand the type of challenges it is facing, the stakeholders and their level of collaboration. This information will help define a blockchain consensus that fits the industry and stakeholder needs. Consensus is a fault-tolerant mechanism used in computer and blockchain systems to achieve the necessary agreement on a single data value within a network of distributed processes or multi-agent systems (Rosic, 2018).

The energy industry is currently undergoing a double transformation: one that involves energy transition from fossil fuel to renewable energy and digitalisation which is changing its value chain (Peter et al. 2019). On a national level, already some Danish energy companies are considering blockchain applications. According to the head of digitalisation at Ørsted: a danish energy company, “we are looking at blockchain, it is still a new area” (Engerati, 2019). Other industries such as shipping, transport, and logistics companies can also learn how blockchain can be applied to monitor their emissions from the study findings. It is also important for this study to look at the policies that can support the implementation of the technology and where the power is to influence such implementation. The mapping out of both the industrial and technologically enablements will suggest the kind of market structure that can be established to facilitate the use of the technology.

Using a case study approach: Danish energy industry, the research will focus on how blockchain can be used for monitoring and reporting CO2 emissions trading. The goal of Denmark's total GHG emissions is to be 38-39% below emissions in the United Nations (UN) baseline year of 1990 (Danish Energy Agency, 2019). In the absence of any new initiatives to help reduce emissions, this projection will increase (Danish Energy Agency, 2019). This topic is not just a concern for Denmark but for the whole continent. For a long time, the U.N has advocated clean energy consumption – one that includes a global commitment to carbon reductions while promoting growth that is both socially inclusive and environmentally sustainable (UNDP, 2017). This research aims to explore how blockchain can create a positive impact for carbon trading. Several research has shown that carbon emissions from the energy industry as well as other industries is a global issue. This issue has also been on political discourses and development agendas. As such, it is important to carry forward this research related to an innovative technology as blockchain. This work will be targeted at enabling the monitoring and reporting of carbon emissions trading in order to keep up with the pace of global phenomenon and discussions whilst influencing policies and regulations.

## 1.5 Scopes and Delimitation

In order to reach the research objective and answer the research questions, it is important to define some research scopes and delimitations of the research objectives as highlighted ( section 1.3). These scopes have been broken down according to the objectives of the study.

**Objective 1:**

The research is not from a worldwide perspective but on a national level (Denmark) and in the order of how it can be used. Therefore, the research will not address conditions, challenges outside the scope of the EU ETS framework. The Danish energy industry operates under this framework.

**Objective 2:**

The blockchain conceptual model that will be presented will be limited to only monitoring and reporting of CO2 emission trading for the Danish energy industry. The model will only include the identification of stakeholders, and their relationship within the network, high level agreements and processes, document workflows and an overview of the smart contract capabilities. As such, the research will not cover a full proof of concept model in specific details such as prototyping and testing. This means that it will not create complete blockchain architecture layers such as data storage abstraction, identity service providers, consensus, smart contract, API and interoperability levels within the network.

***Objective 3:***

This objective will focus on identifying the factors that might affect the implementation of blockchain for CO2 trading in the energy carbon market. This objective will also look at the social, economical and environmental (i.e the sustainability pillars) implications of the implementation of blockchain technology for carbon trading and what type of market structure will enable its implementation. The proposed blockchain will not include any other factor not listed in objective 1 and objective 2 and 3. Some out of scope research propositions include cost benefit analysis, carbon pricing structure, system of market and motive of self-Interest on traders in the carbon market.

## 1.5 Summary

A summary of the research chapters is discussed below:

*Chapter 1:* gives the introduction of the research that covers the background of research, research problem, research questions, objectives, relevance and the scopes and delimitations of the study.

*Chapter 2:* introduces the methodology of the research design and approach. It presents the methods and scientific approaches used during this project. This will describe the whole process of achieving and understanding the research objectives, theoretical framework, results, analysis, and conclusions.

*Chapter 3:* introduces the theoretical background. The theories for the study include stakeholder theory, network theory and market structure theory. This will also introduce an overarching theoretical framework for the study which will be used to formulate the conceptual framework for the research.

*Chapter 4:* describes the conceptual framework which is built on the foundation of the theoretical background of the study, literature and case studies.

Chapter 5: is the first part of the literature review that focuses on the energy industry's perspective, and the EU ETS sustainability programs. This chapter also includes the pillars of sustainability and the UN SDG 13 and 17.

*Chapter 6:* is the second part of the literature review that focuses on blockchain technology. It gives an overview of the blockchain's smart contract, consensus, the usage of the blockchain, types of blockchain and their differences.

*Chapter 7:* presents three cases: a pilot case in Mexico, a case study in China and Danish case study of the research work. The goal of this chapter is to look at the feasibility of implementing blockchain for CO2 trading. What already worked? and what will not work?

*Chapter 8:* presents the data collection and interpretation of the research findings.

*Chapter 9:* is the analysis of the result gathered in the research. This describes in detail the three-core objectives of the research. This addresses the current procedures and challenges of the monitoring and reporting of CO2 trading, creates a blockchain conceptual framework, and looks at factors that will affect its implementation and how they can be addressed.

Chapter 10: This presents the findings of the study, implications, limitations and recommendations. This chapter takes a step back to look at the entirety of study.

*Chapter 11:* presents the conclusion of the study. This includes the research milestones, possible pitfalls in implementing the proposed system, the actors that can influence implementation and beneficiaries, general study limitation and relevance of its implementation.

## 2. Methodology

According to SAGE research methods (2012), in order for the researcher to ensure a transparent and obvious correlation between the approach and the method such that it makes sense within a particular paradigm, it is imperative to have a solid methodology. Given the nature of the research focus, the methodology that is used in the study is qualitative. The researcher applied grounded theory, case study and requirement engineering (RE). The reason for using qualitative methodology is because it enabled the researcher to explore and dig deeper into understanding how blockchain as a technology can be used for monitoring and reporting CO2 emission trading from the context of social interactions, systems and processes.

The methodology focuses on “words and depth” which are useful factors for arriving at a research outcome (Tiley, 2017). Qualitative methodology being explorative in nature seeks to “unearth opinions to form new concepts and theories” (Tiley, 2017). Such strength to provide complex textual descriptions of how people experience the given research issue into unlocking new findings fits the description of the research objectives (section 1.3). Hence the reason why qualitative methodology was used for the study. The researcher recognises that the methodology is subjective in nature and may lead to induced bias in the data interpretation and analysis of the study. This is why a triangular method of data collection was adopted in the study: through semi-structured expert interviews, literature and case study. The methodology section is divided into two broad sections: methodological approach (section 2.1) and data collection approach (section 2.2). Section 2.1 explains the specific procedures and techniques the researcher used in identifying, processing and analysing information used to answer the research question. Section 2.2 describes the process used in gathering information used to answer research questions and evaluate research outcomes.

### 2.1 Methodological approach

#### 2.1.1 Grounded theory : an inductive approach

Glaser and Strauss (1967), founders of grounded theory, introduced the theory in order to legitimize qualitative research. Grounded theory is the discovery of emerging patterns in data (Glaser and Strauss, 1967: Holton, 2017). According to Charmaz, (2001), it can also be used to modify existing theory, expand on or uncover differences from what is already known. The study applied the Grounded theory using inductive reasoning. By induction, the study starts with a range of individual cases and extrapolate patterns from them to form a concept category (Charmaz, 2006, p. 188). Another author defined inductive reasoning as a systematic set of "procedures for analyzing qualitative data that can produce reliable and valid findings" (Thomas, 2006). Grounded theory using inductive reasoning starts with the open exploration and systematic analysis of data that leads to developing a theory grounded in data (Thornberg and Charmaz, 2013, p. 153).

For this reason, the Grounded theory using an inductive approach was chosen as the most appropriate method for the study because it avoids making any prior assumptions and adopts a more neural view of opinions. The researcher was able to investigate both individual and social phenomena such as organisational and institutional changes and practices, identify transformations and problem-solving processes in social groups. Furthermore, the theory was applied to enable the researcher to evolve existing knowledge about the study focus to expand on or uncover differences from what is already known. The Grounded theory offers a specific approach for handling the analytic phases of inquiry, whilst integrating data collection and analysis to form new findings. These reasons align with the objectives of the research as described in (section 1.3 of the study). By applying grounded theory inductively, the researcher was able to i) condense the data from the study into a summary format; ii) establish clear links between the research objectives and the study findings from the data collected; and iii)develop new findings from underlying evidence in the data collected.

The study began with a broad query (qualitative analysis) about the EU ETS framework, its conditions and challenges of monitoring and reporting CO2 emission trading with a focus on Danish case study. Also a qualitative analysis of blockchain technology was made, and case studies that have applied for blockchain emission trading were analysed. By collecting relevant information about the topic, the interview questions were formulated for the semi-structured expert interview. This method (interview questions) enabled the researcher to collect primary data to support the literature and theories of the study. After collecting the primary data, the interview responses were then transcribed using Descript software application (see interview summary and transcript in appendices 2, 3 and 4). Next, the grounded theory was inductively applied following three steps: i) developing codes, ii) thematic analysis: identifying themes, patterns and relationships and iii) summarizing the data. The data gathered was coded in two different stages using open and axial coding. Coding is the categorization of data, by defining the data that is being analysed (Gibbs, 2007). A code can be a word or a short phrase that represents a theme of idea(s). Open coding is the initial organization of raw data to make meaning out of it (SAGE, 2017), while axial coding is the construction of linkages between data collected (SAGE, 2017). The three steps are explained in detail below.

i) The researcher proceeded with the first step: open coding, where data was segmented into expressions and described in single words to short sequences of words. A wide range of raw data from the 13 semi-structured expert interviews (more details about interview in 2.2.1) were assigned preliminary codes after organising the data into a clean excel sheet. Next, the researcher applied the axial coding process where the codes were broken down into core themes as it addresses the research questions. At this stage, codes were then categorized into concepts as it relates to each other using thematic analysis which is the second step.

ii) Thematic analysis: Thematic analysis can be defined as analysing qualitative data that share a focus on identifying themes (patterns of meaning) in qualitative data (Braun and Clarke, 2006). Additionally, analytical and critical thinking were applied in the identification of themes, patterns and relationships from the data gathered. The researcher scanned the data for words and phrases most commonly used by the experts, references, occurrences and phrases used with unusual emotions (confidence, anticipation etc). Next, the researcher interconnected and linked the categories of codes into a final category.

iii) Summarize the data: After categorizing the data, a total of nine categories emerged. The theme generated and categorization of the codes were based on the i)relationships between the codes, ii) frequencies of the codes, iii) underlying meaning across the code, iv) and its relevance to address research questions. The final nine categories that emerged are: 1) the current processes of the EU ETS; 2) technology application; 3) education and awareness; 4) blockchain benefits; 5) needs improvement for EU and blockchain; 6) politics; 7) challenges of EU ETS; 8) sustainability; 9) market system. These were the final categories used for conceptualizing the data analysis to form meaning. A link to data coding can be found here and appendices 4.

Also noteworthy quotations from semi-structured expert interviews were noted in italics and quotation marks the data analysis to highlight major themes within the findings and possible contradictions. Through the process of constant comparison of the data, commonalities and dissimilarities among the categories of information became clearer to analyze data from the underlying evidence gathered.

The researcher recognizes the limitations of using the grounded theory approach because it has the tendency to be data subjective, leading to difficulties in establishing reliability and validity of information. This is why the researcher adopted a triangular method of data gathering: combining qualitative literature review and pilot case studies for data analysis. Also, a post-expert interview was conducted with three experts to validate the blockchain conceptual model proposed in the study. This adds credibility and validity to the study findings.

### 2.1.2 Case study: a qualitative approach

Qualitative case study is an approach to research that uses explorative means to facilitate understanding of a subject matter within its context, by consulting different data sources. Since the focus of the study is both technology and industry specific, the nature of its specificity makes it case study appropriate. A case study was considered for the study because the researcher seeks to answer the research question on 'how': how can blockchain be used for monitoring and reporting CO2 emission trading in the energy carbon trading. According to Yin (2003), a case study design should be considered when the focus of the study is to answer the how and why questions, when behaviors of those in the study cannot be manipulated or boundaries are not clear between phenomenon and context. Therefore, it was important for the study to use case study.

The Danish energy industry was considered a good case because a country with one of the world's leading cities of blockchain innovation according to (Ministry of Foreign Affairs Denmark, 2019). Also, as described in (section1.4), some energy companies are already considering the use of the technology (Engerati, 2019). The EU Regulation (EU) 2015/757 also supports innovative technologies that can accelerate climate actions (European Commission, 2015) as (described in section 1). To conclude, the Danish energy industry does not have such a system in place. These points make it an interesting case to study.

First, the researcher looked at the current conditions and challenges in order to propose a blockchain conceptual model that will fit the industry needs and preferences. Under this case study, the Danish emission trading system was reviewed in the context of its current conditions, implementation, and role of its different stakeholders. As such it is a descriptive case study. A descriptive case study describes a "phenomenon and the real-life context in which it occurred" (Yin, 2003). The researcher recognizes that limiting the study to a case study may restrict the results from being applied in a general context. Hence, the reason why it is not just the Danish emission trading was reviewed but the EU ETS framework. This allows the result findings to be replicated to a wider population (e.g the Member States of the EU).

2.1.2.1 Pilot case study

Pilot cases are important aspects of the study. A pilot study case is a small-scale test of the methods and procedures to be adopted on a larger scale (Porta, 2008). The researcher chose to study a pilot case because there are readily available or a very limited number of already working cases that focus on blockchain for monitoring and reporting CO2 emission trading. Studying pilot cases helped the researcher in the formulation of the research question as well as understanding the subject matter. Furthermore, it helped the researcher ascertain the feasibility of the proposed blockchain model for the study: what will work and what will not work? To enable the researcher to answer the main question of the study, it was imperative for the researcher to understand how carbon trading can be done with blockchain using the pilot cases as a foundation to address the question.

The two cases chosen for the study was because they do not only just capture the specific application of blockchain for carbon trading, they also address the main research question. The first case: Climate Ledger Initiative (CLI) pilot case is specifically designed for the monitoring, reporting and verification (MRV) of carbon emissions. However, the difference between the pilot study and the research focus is the Danish context and the fact that this study provided a conceptual model on how the proposed system will work. The proposed system is not only the MRV process but for carbon trading as well. The CLI pilot cases lacked this information. The second case: Energy Blockchain Labs, is the world's first blockchain-based system for carbon asset trading, based in China which is already implemented. By studying an already working system, the researcher was able to gather insights on how blockchain can be furtherly applied for carbon trading in the case study context. The case studies also provided valuable information for not only the researcher but for other researchers in the future. The researcher understands that reviewing cases does not guarantee the success of the study. Nonetheless, case studies “increases the likelihood of success” for a research (Hundley and Teijilin, 2002).

### 2.1.3 Requirement engineering (RE)

RE is the process of generating requirements knowledge from the user's inputs regarding a new product or innovation capabilities (Aviv, et al. 2018). For this study, knowledge gathered for proposing a blockchain model are from cases studied, literature and expert interviews. RE was adopted for the study to ascertain the capabilities of the proposed blockchain model. There are four main processes required to fulfil the RE development. These are: i) feasibility study, ii) elicitation and analysis, iii) requirement specification and documentation and iv) requirement validation and testing (Elgabry, 2016). More details about RE are explained in the conceptual framework of the study ( section 4.2).

The goal of applying RE to the study is to make the approach to solving the study problem clear and complete. Also, to ensure the proposed blockchain model is correct, reasonable and effective. The study recognises the limitations of applying this methodology such as difficulty in meeting with all relevant stakeholders and resistance to change. However, two out of three main stakeholders in the monitoring and reporting of $CO_2$ emissions were interviewed: energy operators, and authorised Verifiers. Information from these stakeholders increases the study’s validity and reliability. The RE process will be applied and described in more details in Chapter 4 (conceptual framework) of the study.

## 2.2 Data collection method

### 2.2. 1 Semi-structured expert interviews:

In order to gather insight into the possibilities of implementing blockchain for monitoring and reporting of carbon trading in the energy industry, a semi-structured expert interview was adopted. Saunders et al. (2007) defined the qualitative method as a technique that uses and/or generates non-numerical data for the research result and data analysis. Semi-structured expert interviews were adopted for the study because it is a way of gathering first-hand knowledge from expert’s experience which cannot be statistically looked up from literature. Also to enable the researcher to control the direction of the interviews. Furthermore, the use of interviews as a tool is useful for gathering and validating reliable data that are relevant to the research questions and objectives (Saunders et al, 2007). This type of qualitative data collection involves asking participants a series of predetermined but open-ended questions. It involves describing, interpreting, contextualizing and gaining in-depth insights into specific concepts or phenomena (SAGE, 2008). That way, the methodology enables the researcher to formulate the research focus and scopes, in order to address the research question and create a more scientific analysis of the literature reviews and validations. The table 1.0 below presents the list of interviewees, the role in the company and industry description. Due to privacy concerns, this will be the only shared information about the participants details.

| # | Tags | Code | Interviewees and roles | # of interviews | Industry |
|---|---|---|---|---|---|
| 1 | Interviewee 1 | A | Senior Lead Originator | 1 | Danish energy company - Ørsted |
| 2 | Interviewee 2 | B | Senior Public Affairs Advisor | 1 | Danish energy company - Ørsted |
| 3 | Interviewee 3 | C | Digitization and Strategy | 1 | Danish energy company - Ørsted |
| 4 | Interviewee 4 | D | Co-creation Architect in research and development on blockchain (IBM) | 2 | Technology company that have successfully implemented blockchain and pilot-testing for carbon trading |
| 5 | Interviewee 5 | E | Blockchain and Crypto currency consultant | 1 | Technology company working with cryptocurrency and blockchain |
| 6 | Interviewee 6 | F | Principal Auditor & EU ETS Verifier | 2 | An International accredited registrar that deals with EU MRV auditing and verification |
| 7 | Interviewee 7 | G | Program Director at CLI | 2 | Climate initiative working with DLT, Blockchain, machine learning and IoT |

| | | | | | |
|---|---|---|---|---|---|
| 8 | Interviewee 8 | H | Sustainability Advisor | 1 | Sustainability strategy consultancy for climate change, carbon and energy |
| 9 | Interviewee 9 | I | Vice President market development at Xpansiv | 1 | Technology company working with carbon and blockchain |
| 10 | Interviewee 10 | J | Head of North America Market at Xpansiv (focused on blockchain and carbon trading) | 1 | Technology company working with carbon and blockchain |
| 11 | Interviewee 11 | K | Business Manager working with blockchain | 1 | Software company |
| 12 | Interviewee 12 | L | Co-founder of a technology startup working with blockchain | 1 | Software company |
| 13 | Interviewee 13 | M | Senior Policy Advisor at Danish Energy Agency | 1 | Danish Energy Agency |

Table 1: Summary of the interviewers details, their respective industries and roles.

From the table 1 above, the study interviewed a total of 13 experts from the energy industry, climate initiatives and policies, technology and the EU ETS auditing field. The selection of the interviewee is based on purposive sampling in order to identify the needs of the energy industry, and understand how blockchain can be implemented to meet these needs. From the table, experts: A, B,and C were chosen for the study because the research question is focused on the Danish energy industry and these experts are working in Danish energy industry as at the time of this study. Their roles as Senior Lead Originator, Senior Policy Advisor and Digital and Strategy Consultant are also relevant for the study. The first’s role is focused on anchoring carbon trading activities, and facilitating access for the company’s carbon market. While the second job role is focused on policies and regulations surrounding the energy industry which is relevant for the study. The Digital and Strategy expert was selected because the expert is involved in anchoring digital and strategy affairs of the company. As such, will be involved in the decision making process of implementing a new technology or process in the company. Therefore, their inputs are relevant for addressing the two sub questions of the study: current conditions of the industry and factors that might affect implementing blockchain for the industry carbon trading. Also, the energy company: Ørsted, was chosen specifically for the study because it is currently transitioning from fossil fuel to renewable energy. As such its business model is focused on adopting sustainable ways to reduce carbon emissions which fits the description of the study focus and the research main question. Furthermore, the company has also shown interest to use blockchain technology as described in section 1.4 (Engerati, 2019).

The interviewees D and E were particularly eligible for the study because of their expertise in blockchain technology use cases. The former: C, has over 10+ years of experience leading use cases projects on applying blockchain for carbon projects in the field of research and development at IBM. IBM already implemented working systems of blockchain for different carbon projects, which one of its projects will be studied in further details in the case study section 7.1. Interviewee E was particularly eligible to also help answer the main research question on how blockchain can be applied for carbon trading due to his years of experience working with blockchain on several projects.

It was important to interview a Principal Auditor and Verifier of the EU ETS for the study to help address the first sub-question of the study. This is focused on the current conditions and challenges of monitoring and reporting CO2 emission trading in the energy industry. Given that one of the stakeholders of the EU ETS is a Verifier, it was pertinent for the researcher to understand its current conditions and challenges directly from an important stakeholder. The Program Director (G) was eligible for the study to understand the feasibility of how blockchain can be used for carbon emission trading which is the main research question of the study. (G) works at one of the case studies that will be reviewed in the research (CLI in section 7.1). As such will have information on how blockchain can be applied for monitoring and reporting emission trading and factors that might affect the implementation of the system. Both focus addresses the main research question and sub-question two of the research.

Sustainability Advisor (H) was selected for the interview due to the sustainability theme in the research which addresses the social, economic and environmental implications of using blockchain. Particularly, the expert (H), helped address the main question and second sub-question of the study from a sustainability viewpoint. Both the Vice President and Head of North America market (I & J) are decision makers in a company that is already using blockchain for carbon trading. As such their inputs were useful to address the main research questions as well as subquestions. Similarly, the Business Manager and Co founder (K & J) were also eligible for the similar purpose as interviewee I & J. The Senior Policy Advisor (K) was particularly eligible for the study to help address the second subquestion in the Danish energy industry context. As the Senior Policy Advisor in the Danish Energy Agency, it was important for the research to have information about the policies and regulations surrounding the energy industry in the Danish context which is central for the study. The results from the interviews are presented in the results in Chapter 8 (interpretation of results) and supporting transcription of these interviews presented in the appendices 4 below.

It was pertinent for the researcher to interview the main stakeholders of the EU ETS: Verifiers and the Energy operator, though, only one Verifier company and one energy operator company were interviewed. The researcher is aware that the result may be subjective as it relates to these interviewed companies. Therefore, the researcher used a triangulation method, which considers two or more data sources for gathering data. This is to ensure a data dependability of the research. Triangulation method combined data collected through interviews and qualitative literature and case study analysis. This was followed by comparing and combining the results. That way, the researcher was able to have an increased level of knowledge to address the research question and strengthen the research's standpoint from different aspects.

The other sources reviewed are the EU ETS policies, sustainability programs and its methodologies, and the case studies used for the research. The goal of the analysis was to identify the missing gaps which were then included in the interview design in order to address them. Some examples of the interview questions formulated include: i) Do you have a standard tool to monitor and report the energy emissions from installations? If yes, what is it and how does it work? If no, why not?; ii) how does the company monitor and report its suppliers emissions, to ensure they are accurately disclosing the right carbon emissions?, iii) what is the collaboration with other stakeholders in Europe or the world like when it comes to carbon trading?; iv) Is the company considering blockchain for carbon trading to reduce its emissions and why?, v) between the four types of blockchain networks — public blockchains, private blockchains, consortium blockchains and hybrid blockchains, which will be better for monitoring and tracking carbon trading and why? A full details of interview questions can be found here and appendices 4 below.

Interviews were both online and personal meetings and answers were recorded using iPhone audio recorder, Skype recorder, Quicktime recording feature and manual note taking. All the interviewees were recorded with ethical consent. A confidential agreement was also undertaken between the researcher and the energy company interviewed. To ensure validity of the interview questions, they were first reviewed by the research supervisor and 'external audit' i.e. peer review, after its design. This was followed by pilot-testing the questions by three interviewees in the technology company and energy industry to aid the design of the research method. The researcher employed a blend of closed and open-ended questions based on four main phrases: blockchain, monitoring, reporting and carbon trading, which are central to answering the research questions. Open-ended questions were incorporated in the design to encourage elucidated answers in the whole research process. A maximum of one-hour was scheduled in order to minimize fatigue for both the researcher and experts. The interview started with a presentation of the researcher about the topic, then the researcher asked the interviewees to give an introduction about themselves. Prior to the scheduled interview, the researcher already prepared the topic for discussion and sent a research overview to interviewees informing them about the research topic and scope.

After collecting interview data, it was interpreted, analysed and a blockchain conceptual model that shows the process flow and network relationship for monitoring and reporting CO2 trading for the Danish energy industry was developed. The researcher went further to validate the proposed conceptual model by interviewing three experts in a post-expert interview. These are the Program Director (G) at CLI: the study pilot case, Co-Architect at IBM (D), and EU ETS Verifier (F). They were specifically selected for validating the research analysis due to their experience working with the blockchain and the EU ETS program. As such, these experts were consulted twice and feedback given was included in the study's validation ( section 9.2.1.4).

### 2.2.2 Qualitative study of long-term CO2 trading plans of the EU ETS

This involved investigating the concept behind the framework of the EU ETS and how that would go in line with the belief of long term sustainability. The EU ETS handbook which contains the mandatory EU ETS and EU MRV sustainability programs for carbon trading was reviewed. Specifically the analysis includes literature about the EU ETS implementation process, stakeholders and their roles, pillars of sustainability and SDG 13: climate action and 17: partnership for goals. These aspects were particularly important for the researcher to understand the current conditions and challenges of the EU ETS, the social context: i.e sustainability, and its implications when it comes to the application of blockchain for monitoring and reporting CO2 emission trading.

### 2.2.3 Qualitative and analytical study of blockchain technology

The study also reviewed the fundamentals of blockchain in detail. This helped the researcher to understand the core parts of the technology and its suitability for the study focus, and how it can be implemented for monitoring and reporting carbon trading. The qualitative analysis of the smart contract, consensus mechanism, types of blockchain and their network types and choosing the appropriate blockchain were analysed. Also, blockchain convergence with other technologies was presented to ascertain how blockchain can be combined to maximize its potential. The qualitative analysis of blockchain was particularly important for the study to help the researcher have an increased knowledge of the overall understanding of the technology. Understanding how the technology works is pertinent for the researcher to be able to determine if its the right fit for the industry needs and challenges and how it can be implemented.

## 2.3 Summary

To address the research problem from a critical standpoint, the methodological approach adopted in this study took two directions: first is the combination of the grounded theory and case study methodology. While the second direction is the RE. Both directions take the form of an empirical approach of data gathering. Data gathering involved a triangulation method of semi-structured expert interviews, literature and case studies. The study was guided by the theories of network, stakeholder, and market structure in the interview questions formulation, interpretation and findings. Next, a blockchain conceptual model for monitoring and reporting CO2 emission trading was developed. The model was further validated by three experts in a post-expert interview to increase the validity and reliability of the study. To summarize the research design and approach, the research is descriptive in nature with the grounded theory inductively applied to explore new concepts and findings. The methodologies were combined in a new way to elucidate on how blockchain can be used for monitoring and reporting CO2 emission, and provide tangible value-added steps towards a comprehensive system.

## 3. Theoretical framework

Monitoring and reporting $CO_2$ emission trading in the energy 'carbon market' is connected and coordinated through the 'power and governance' of authorities and 'stakeholders' relationships. These concepts are central to this study. Therefore, the theoretical basis of this study will be on i) network theory which is focused on the concept of power relationships within a network and its social implications; ii) stakeholders theory which shows the communication and relationships of the different stakeholders within a system; iii) market structure which is the degree of competition within the market for a product. The concept of 'power and relationships' will be explained by network theory, while stakeholders relationship will be explained by stakeholders theory and 'carbon market' by market structure theory.

'Power and governance', as used in the study is relational (Dahl, 1957), which exists in coordination and the ability of an actor to command that coordination. While stakeholders refer to participants within a system sharing a common goal. While, 'carbon market' is a collection of various transactions through which volumes of GHG emission reductions are traded. The theories of network, stakeholder and market structure are applied to the study to understand and explain the existing knowledge on the subject matter within the "limits of critical bounding assumptions" (Gabriel, 2008: Kivunja, 2018).

Chapter 3 has two parts. The first part introduces theories of network, stakeholder and market structure. The second part looks at an overarching summary that connects and shows the relationship between the three theories.

## 3.1 Network theory

### 3.1.1 Network theory of power

Traditional modes of governance are often oblivious of changes in power relationships resulting from the emergence of new technologies, practices, and relationships in markets. However, taking into account these changes are essential for constructing governance in a market, industry, or company. In order to analyze these new power relationships, Manuel Castells's conception of network power (Castells, 2000, 2011) and networked society (2004) will be studied. Castells (2000), conceptualized networked power as the dominant form of power exerted within modern networked societies. The scope of this study does not cover arguments for or against this conceptualization of societal powers that structure modern societies. Instead, it reflects on the general implications of network theory in a wider societal context. Castell (2000, 2011) forms of network power are viewed as they directly relate to new powers that emerge within networks. Concerning digital domains and blockchain to be specific, power must be conceptualized as fluid, as different actors perform different governance roles within different contexts (Zwitter and Hazenberg, 2020). Since identities and roles are no longer central to the exertion of power in social coordination, new forms of power have taken their place, thus requiring a new form of governance (Zwitter and Hazenberg, 2020). According to Castell (2011), these forms of power are four types as it relates to network: i) networking power, ii) network power, iii) networked power and iv) network-making power.

i) Networking power: is the power that actors and organizations have that form the fundamentals of the network. This power refers to the ability to include and exclude others, and thereby controls the makeup of the network Castell (2011); ii) Network power: This is the power that results from the standards required to coordinate interactions. This primarily concerns the imposition of rules within a network Castell (2011); iii) Networked power is the power that actors have over one another within a network. This power imitates traditional conceptions of power but the way in which it is exerted differs per network, as the forms and processes of networked power are specific to each network Castell (2011); iv) Network-making power: This refers to the power of an actor has to constitute or re-program a network according to its values and specific interests. This can take the form of a powerful actor following strategic alliances between dominant actors of various networks (Castells, 2011).

### 3.1.2 Network society

The concept of the network society described the interpretation of the social implications of globalisation and the role of digital communication technologies in society (Castells, 2004). A network society is one “whose social structure is made up of networks powered by micro-electronics-based information and communications technologies.” Network societies are shaped by network effects which is described as a phenomenon where a product or service gains additional value as more people use it. Additionally, influences such as religion, culture, politics, organizations, and social status all shape the network society (Castells, 2004). Historically, there have always been social networks: the key factor that distinguishes the network society in the past and now is the use of ICTs. ICT helps to create and sustain far-flung networks in which new kinds of social relationships are created (Castells, 2004). According to Castell (2004), three processes led to the creation of new social structure in the late 20th century: i) the restructuring of industrial economies to accommodate an open market approach, ii) the freedom-oriented cultural movements of the late 1960s and early 1970s, including the civil rights movement, the feminist movement and the environmental movement; iii) the revolution in information and communication technologies. The importance of this economic restructuring is that it promoted conditions for emergence of the open market development paradigm (Castells, 2004).

## 3.2 Stakeholder theory

Stakeholders refer to any group or individuals capable of influencing a system or processes’ and/or final results (Li et al, 2012). The stakeholder theory is a “view of capitalism that stresses the interconnected relationships between a business and its customers, suppliers, employees, investors, communities and others who have a stake in the organization” (Freeman, 2018). The theory suggests that value should be created for all stakeholders, not just shareholders by a firm/organisation. In other words, the goal of stakeholder management is to create methods for managing the various groups and relationships that lead to the strategic outcome. Furthermore, Freeman (2018), described the idea of managing stakeholders with an argument that managers must formulate and implement processes that satisfies all the groups that have a stake in the business.

According to Margaret and Geoffrey (2016), the composition of the stakeholder community changes over time with regards to the dynamic project environment. As such stakeholder relationships, and issue interdependencies changes as well. In order to cope with such dynamics, there is a necessity for continuous monitoring and updating the processes required for the entire stakeholder relationships (Magaret and Geoffrey, 2016). To conclude, "great companies endure because they manage to get stakeholder interests aligned in the same direction" (Freeman, 2018).

### 3.3 Market structure

In neo classical economics, markets are classified according to the structure of the industry serving the market (Fischer, 1997). There are four major taxonomies of market structures as defined by Richard (2019). These are: i) *Perfect competition*: this is a market system characterized by many different buyers and sellers (Richards, 2019). For such a market with many market players, it is impossible for any one participant to alter the prevailing price in the market i.e many sellers of a standard product; ii) Monopoly competition: This is the exact opposite of a perfect market. In this market structure, only one producer exists of a particular good or service, and generally no reasonable substitute (Richards, 2019). In such a market system, the monopolist is able to charge whatever price they wish due to the absence of competition; iii) Oligopoly competition: This involves a few sellers of a standardized or differentiated product (Fischer, 1997; Richards, 2019). This is similar in many ways to a monopoly. However, the main difference is that rather than having only one producer of a product, there are a handful of producers that dominate the majority of the production (Richards, 2019); iv) Monopolistic competition: This is a market structure with many sellers of differentiated products. This system combines the element of market system of monopoly and perfect competition (Richards, 2019).

For this study, it is imperative for the researcher to understand the market economics in which the case study operates in. This is especially relevant for the data interpretation and analysis of the research findings.

### 3.4 Critical analysis: notable relationships between theories

To answer the main research question, Castell's ( 2000, 2004, 2011) theory of network was chosen. This is because it will provide understanding about the relationships and standards needed to coordinate interactions during monitoring and reporting of carbon trading. In order to ascertain how blockchain can be used for monitoring and reporting of CO2 emissions, the relational power within the network plays a major role. This is because power has the ability to fundamentally influence humans and their social relationships which applies to business transactions.

A notion that somehow an “unregulated market has failed to produce social outcomes in accordance with the public interest is often the justification for the emergence of regulations” (Agarwal, 2017). Simultaneously, the nature of governance towards organizations and how businesses are being transacted is also changing. Policies and regulations are slowly moving from a top-down approach towards a more horizontal mode of governance, shaping the way businesses operate. Like in the case of monitoring and reporting CO2 emission trading in the EU, the introduction of the EU ETS, with underlying regulations operates as a form of incentive for businesses. Instead of fines like carbon taxes, the EU encourages Member States to be more climate conscious through rewarding them with carbon allowances.

On the other hand, the advancements of digital technology are increasingly shaping the activities of organizations and how they transact businesses, which creates a networked society capable of influencing individuals and societies. As such, there is a need for effective governance to protect the basic interests and needs of these stakeholders interacting with digital technologies. Stakeholders also need to be accountable for complying to regulations set down within the market. Generally stakeholders are connected by many different kinds of social interactions ( Pryke, 2004). This study will focus on the communication pattern and stakeholder’s relationship when it comes to information exchange. The processes involved in monitoring and reporting carbon trading are interrelated, (more details in Chapter 5), meaning the presence or absence of an incident within the network of stakeholders could trigger an issue and affect the relationship within the network.

Such interdependencies influence the ability of institutions to deal with market power. This is because interdependencies could give institutions a more competitive advantage as when they cooperate as opposed to when they compete. Cooperation, in this context, is based on the ability to communicate between networks. Competition, in this context, is based on the ability to outperform others, either within a market or a network.

While Castell (2011) network theory is a key theory to address the research focus, the coordination of interactions among stakeholders in the monitoring and reporting of CO2 emission trading is not without a market structure. Network power theory also has a link to stakeholder and market structure because organizations are moving away from business as usual, incorporating digital technologies which forms a world of digitally interconnected stakeholders. This changes power controls and how stakeholders transact within a market.

### 3.5 Summary

To answer the main research question for the study, Castell's (2011) theory of network power will help the researcher understand the standards needed to coordinate interactions and how digital technologies can form a networked society, influencing business as usual. Stakeholder theory will provide an understanding of how the current conditions of the monitoring and reporting CO2 emission trading works from the stakeholders perspective. Both theories (network and stakeholder) address objective 1 and objective 2 (section of the study). The knowledge of the market structure theory will help the researcher understand the underlying implications of the factors that may affect the implementation of blockchain and how they could be mitigated. This addresses objective 3 of the research.

The goal of combining these theoretical approaches is not only to show the relationships between them and the underlying implications, but to connect the researcher to existing knowledge and add to research findings. Although the researcher recognises that there are other alternative theories which challenges the study's perspective such as transaction cost, theory of innovation, cost-benefit theory as examples. The chosen theoretical framework better explains and challenges the existing knowledge within the scope of the study whilst helping the researcher achieve the research objective of the study. The theoretical background will be the main supporting theories for the conceptual framework of the study in Chapter 4 and research findings (Chapter 11).

## 4. Research conceptual framework

The research is guided by the theories of network power, stakeholder and market structure in Chapter 3 (theoretical framework). This is supported by the case studies and literature reviews (Chapter 5 & 6) of the study. Maxwell (2004) argued that the function of the theory in a conceptual framework is a source of information and guide for the research design for redefining the research goals and questions. Also, in choosing appropriate methods and the identification of the validity of analysis and conclusion, including its threats. Miles & Huberman (1994) also defined conceptual framework as the system of concepts, assumptions, expectations, beliefs, and theories designed to support the study. The use of a conceptual framework is relevant because it provides an overall picture of the research design and approach. This is helpful for the researcher to organise and connect different concepts, theories and ideas. Figure 1 below presents the models and processes that are used for the creation of the framework.

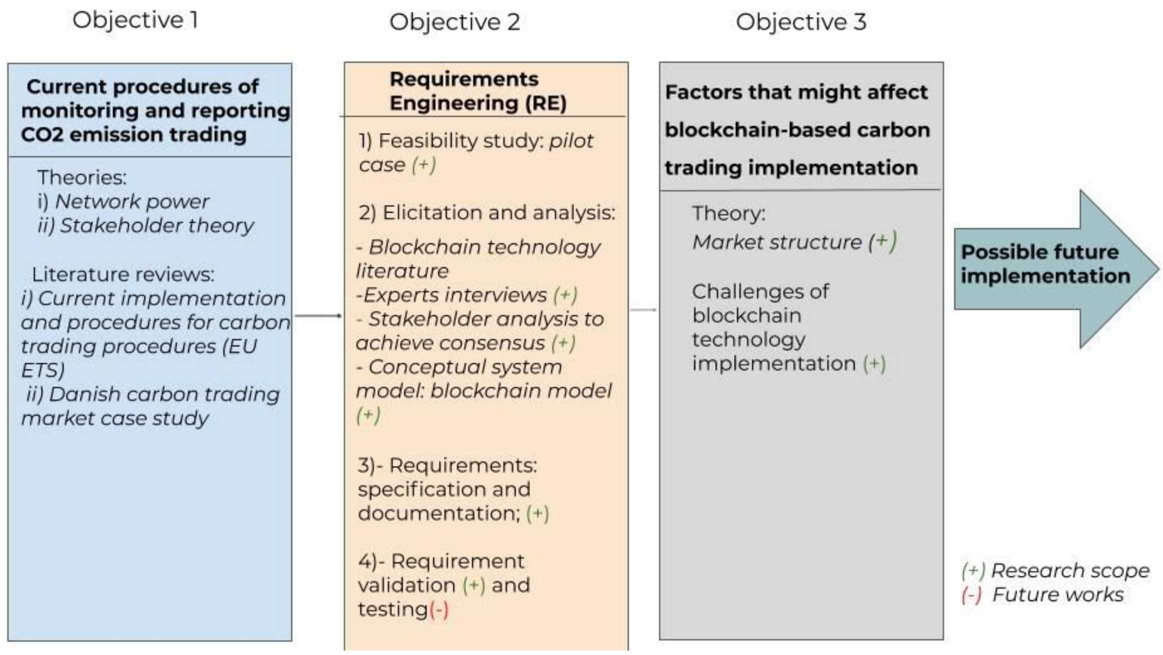


Figure 1: Research conceptual framework

To answer the research question, the study is divided into three broad parts as seen in the figure 1 above. Figure 1 describes the three stages linked to the research objectives to be able to arrive at the research outcome. They are also arranged in a sequential manner. This means that the research outcome from the first stage will contribute to the next stage, and the second stage will contribute to the third stage. Each stage has specific outcomes and is mainly built on the theories of network power, stakeholder and market structure. The first stage is the current conditions and challenges of monitoring and reporting of CO2 emission trading. The second stage is the RE stage for implementation of blockchain for monitoring and reporting CO2 emission trading in the energy industry. While the last stage presents the factors that might affect the implementation process and how it can be addressed. The research outcome and scope did not consider the creation or presentation of a working prototype of blockchain for monitoring and reporting of CO2 trading due to time constraints and other limiting factors explained under the limitation of the study (Chapter 11).

4.1 Stage 1: Current conditions and challenges

The process of monitoring and reporting CO2 emission trading is based on the stakeholder theories and the theories of network power by Castell (Castells, 2000, 2011). Firstly, network theory will enable the researcher to understand how the current procedure of $CO_2$ emission trading works, including the relationship and interdependencies of the different stakeholders within the carbon energy market and industry. The stakeholder theory will help the researcher have a better understanding investigating the responsibilities and obligations of each party in the monitoring and reporting process of $CO_2$ emission trading. Furthermore, literature reviews on the EU ETS process of monitoring and reporting $CO_2$ emission trading are being looked at to understand the current conditions and challenges of the system. This stage also looks at the Danish energy emission trading system (case study) which will be reviewed in Chapter 7 of the study. The result from this stage will represent the first research outcome which addresses objective 1 of the study. This result will then be the basis for designing the proposed blockchain system which leads to the result of the second stage of the conceptual framework.

### 4.2 Stage 2: Requirements engineering (RE)

RE is the second stage of the research framework. According to Sajjad (2010), it is a process of stakeholders "identification of their needs, purpose and consequence of system development." Finding what to build is the most critical thing in system development (Nuseibeh and Easterbrook, 2000). As described in figure 1, there are four main stages in RE: i) feasibility study; ii) requirement elicitation and analysis; iii) requirement specification and documentation; iv) requirement validation and testing (Elgabry, 2017). This research will only cover the first three stages due to time constraints. The fourth stage is partly covered by validating the proposed blockchain conceptual model which will be presented in the analysis chapter (section 9.2.4). Under RE, the first stage: feasibility study is represented by the case studies in (Chapter 7 of the study). This will be combined with the second stage which is elicitation and analysis and present blockchain study's literature (Chapter 6). Additionally, data from expert interviews, and conceptual modelling of blockchain for monitoring and reporting $CO_2$ emission trading will be presented.

The third part of RE presents the requirement specification. It is important to note that there are different types of requirement specifications for building a software as blockchain. However, the study will focus on the functional requirement specification. This is because functional requirements are based on documents of the operations and activities that a system must have to be able to perform (Younas et al, 2019). As stated in the research scope (1.5), the objective of the research is not to create a working prototype but show how blockchain can be operational for monitoring and reporting CO2 emission trading.

Part of the fourth stage which is requirement validation presents a post-expert interview response with industry experts (as described in section 2.2.1). The RE process will be guided by six main questions that are important to address objective 2. These are: i) who are the stakeholders involved? ii) what kind of power/relationships exist between them?; iii) what are the obligations of these stakeholders? iv) what is the document workflow?; v) what is the relevant data to look at in the system?; and; vi) what kind of blockchain will best fit the industry's needs and preference?

### 4.3 Third stage: Factors that might affect blockchain implementation

The third stage will be achieved after the first and the second stage results and analysis is already done. This stage will contribute to the critical understanding and identifying the factors that could affect the possible implementation of blockchain for monitoring and reporting CO2 trading. Since the research scope does not cover a working prototype, the research is only limited to looking at the factors that might affect blockchain implementation for monitoring and reporting CO2 trading. This section is guided by the market structure theory. The third stage addresses objective 3 of the research.

## 5. Energy industry

Chapter 5 discusses the EU ETS sustainability tools and programs targeted towards monitoring and reporting CO2 emissions and reductions: EU Union Registry and EU monitoring and reporting program, with its stakeholders. The chapter also presents the power relationships within the system and pillars of sustainability which are central to the study. The chapter concludes with the challenges of the EU ETS framework which is central to address sub-question one of the research (section 1.2) and a critical analysis of literature.

### 5.1 The EU ETS framework

Energy is a fundamental pillar for human social wellbeing, economic, and other key aspects of human endeavour. As such, its production and consumption is high. Energy activities especially in the industrial sector is a major contributor to the rise of CO2 emissions globally ( European Commission, 2019). To tackle the rise of $CO_2$ emissions in the EU, a carbon trading system otherwise known as the EU ETS was introduced.

Established in January 2005, the EU ETS is a cornerstone of the EU's policy to address climate change, and its key tool for reducing GHG in a cost effective manner (European Union, 2015). It is the world's first major and biggest carbon market, accounting for over three quarters of international carbon trading (European Union, 2016). The EU ETS is in four phases; phase 1: 2005 - 2007; phase 2: 2008 - 2012; phase 3: 2013-2020; phase 4: 2021 - 2030 (Europe Commission, 2018). Operating in all EU countries, the system limits emissions from more than 11,000 heavy energy-using installations and airlines operating in Europe  and covers around 45% of EUs GHG emissions (European Union, 2015).

Introduced as a form of incentive for energy operators to cut their emissions, the EU ETS adopts a "cap and trade" principle (European Union, 2016). A cap is set on the total amount of certain GHG that can be emitted by installations covered by the system, which is then reduced overtime so that the total emissions fall. To reduce emissions caps for companies over time and set a level of ambition for the EU ETS, the EU adopts a mechanism called the linear reduction factor (LRF) (Glowack, 2020). The use of the LRF consists in the rule that from 2014 and each subsequent year, the total quantity of allowances based on Directive 2003/87/EC decreases linearly by 1.74% of the amount of allowances in 2010 (Glowack, 2020) (as described in section 1.1). However, the EU ETS propose to increase the LRF to 2.2% from the fourth phase 2021 onwards: in line with the EU's 2030 climate target of 40% reductions (Jong, 2016).

Within the cap system, companies receive or buy emission allowances which can be traded, and can also buy limited amounts of international credits from emission-saving projects around the world (European Union, 2016). Annually, companies must surrender enough allowances to cover for its emissions. If a company reduces its emissions under the cap setting, it can keep spare allowances to cover for its future needs or sell to another company that is short of allowances. The process of selling these emission allowances is known as 'trading'. According to Pan et al. (2018), trading can be defined as a market mechanism employed to promote emission reduction of GHG such as carbon dioxide ($CO_2$).

5.1.1 EU ETS: Union Registry implementation process

Due to the complexity of the cap and trade system and to meticulously account for emission allowances issued within the EU, a Union Registry was established. The EU ETS Union Registry, which is technically operated by the European Commission, was established in pursuant to Directive 2003/87/EC (Danish Business Authority, n.d). The Union Registry is an electronic accounting system used for monitoring and reporting EU allowances under the EU ETS (European Union, 2015). The Registry records the accounts of the Member States as well as legal companies that own allowances and eligible international credits e.g Certified emission Reductions (CERs) and Emission Reduction Units (ERUs). It contains a transactional log called the European Union Transaction Log (EUTL) (European Union, 2015).

The EUTL "automatically checks, records, and authorises all transactions that take place between accounts in the Union registry" (European Union, 2015). This verification is to ensure that transfers of allowances from one account to another is consistent under EU ETS rules. The type of transactions recorded in the EU TL include the creation of allowances, free allocation, auctioning, transfers, surrendering and deletion of accounts. The Union registry keeps and maintains track of only the ownership of allowances, and Assigned Amount Units (AAUs) which are held in electronic accounts of the registry (European Union, 2015). The figure 2 below shows how the Union Registry works.

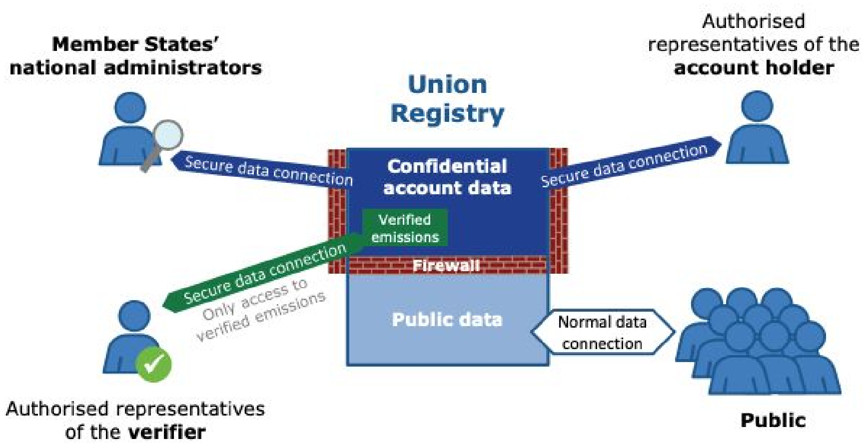


Figure 2: The Union Registry and its stakeholders. Source: European Union (2015).

Figure 2 above presents some of the processes that take place within the Union Registry of the EU ETS. From the diagram, there are four stakeholders. These are the Member States' national administrators; ii)authorised representatives of the account holder; iii) authorised representatives of the verifier; and the iv) public. They are involved in daily transactions of the Union registry. The roles of the stakeholder will be discussed in details below. However, all data stored in the registry are confidential and transferred through secured firewalls. The main purpose of the registry is to keep an account of the companies covered by the EU ETS Directive (European Union, 2015) . Each EU Member State manages its own separate section of the EU ETS registry.

### 5.1.2 Stakeholders and their roles

As mentioned above, the four main stakeholders involved in the transaction of the EU ETS are: i) the Member States' national administrators; ii) authorised representatives of the account holder; iii) authorised representatives of the verifier; and the iv) public.
i) Member States' national administrators: They are responsible for checking all data submitted to ensure no fraudulent activities occur (European Union, 2015); ii) Authorised representatives of an account holder (energy operator): these are entities that have legal rights to access and change its confidential account data such as reported emissions or perform transactions through a secure connection (European Union, 2015); iii) authorised representatives of a verifier: They are typically appointed by an operator, and only have limited access to the data of that operator's installation(s) to verify reported emissions submitted by operators (European Union, 2015); iv) public: After the operators have fulfilled their annual compliance obligation, the verified emissions and the amount of surrendered allowances are made public through the EU Transaction Log (EUTL) public website (European Union, 2015).

Other stakeholders are the i) *EU Member States*: These are the 31 countries of the European Economic Areas that operate under the EU ETS jurisdiction. Their major role is the annual auctioning of new EUAs to ensure stable supply of allowance so it does not run out (European Union, 2015). ii) *European National Regulatory Authorities (NRAs)*: an independent body that ensures each European country meets its targets for energy markets and implements all EU regulatory policy (European Union, 2015).

## 5.2 Monitoring and reporting of CO2 emissions under the EU ETS

Since the establishment of the EU ETS, monitoring and reporting the sustainability impact of the energy industry in terms of its emissions has been a major topic in policy implementation on a global scale. As stipulated under Directive 2003/87/EC, the monitoring, reporting and verification (MVR) of GHG emissions must be robust, transparent, consistent and accurate for the EU ETS to operate effectively (European Commission, 2018).

The Directive considers two parameters that are needed for the energy operators to comply with: i) the annual submissions of an approved monitoring plan for monitoring and reporting emissions, which is then verified by an authorised verifier (European Commission, 2018); ii) The annual reconciliation of allowances and verified emissions (European Commission, 2018). The essence of the MRV system is to guarantee that 'one tonne CO2 equivalent emitted is equivalent to one tonne reported. This principle popularly referred to as "a tonne must be a tonne" (European Union, 2015). Energy operators are responsible for preparing an emission monitoring plan and annual emission report, while an independent verifier checks the reported emissions of operators within the system. After fulfilling these obligations, only then will an energy operator be issued allowances in the form of EUAs. The goal is to enable companies to meet their obligations and give-up sufficient allowances in line with their emissions (European Commission, 2018). To ensure that stakeholders work together towards achieving the goal of the EU ETS, mandated regulations and Directives have been set. The next section discusses these mandates and Directives below.

### 5.3 Power and governance: relationship between regulations and energy industry

In the EU, policies and regulations have a great impact on the implementation processes of the EU ETS program. The study identifies nine of these policies and are presented below.

1) Regulation (EU) No 525/2013 of the European Parliament states that Member States should ensure that energy operators of certain specified activities hold a GHG emissions permit and that they monitor and report their emissions of GHG specified in relation to those activities (European Commission, 2018);
2) Regulation (EU) No 525/2013 of the European Parliament stipulates that system for monitoring and reporting emissions and allowance removals should be updated accordingly (European Commission, 2018);
3) Data and methods reported for activities and installations under Directive 2003/87/EC/article 37 shall be made for the purpose of preparing national GHG

inventories and to ensure consistency of the reported GHG emissions (European Commission, 2018);

4) Council Decision 93/389/EEC of 24 June 1993: monitoring mechanism of CO2 and other GHG emissions shall continue to be evaluated towards meeting commitments in respect of these emissions. This mechanism will assist Member States in determining the total quantity of allowances to allocate (European Commission, 2003);

5) Regulation (EU) 2019/331 sets out rules on free allocation of emission allowances for the EU ETS phase 4 between 2021 and 2030 (European Union, 2019;

6) In accordance with Regulation (EU) 2018/1999 of the European Parliament, the EU Commission is committed to implementing policies that promote research, innovation and digitalisation towards a sustainable low-carbon economy (European Commission, 2018);

7) Directive 2003/87/EC of the European parliament will continue to promote policies and measures through multi-stakeholder partnerships, including scheme for GHG emission allowance trading, for the reduction of GHG (European Commission, 2003);

8) Member States should lay down rules on penalties applicable to infringements of Directive 2003/87/EC and ensure that they are implemented (European Commission, 2018).

9) Regulation (EU) 2018/1999: Member States shall make available to the public comprehensive information concerning methodologies used for calculating CO2 emissions.

## 5.4 Sustainability for climate action

There is no one single definition of sustainability as previous studies have defined the term in different ways. However, the most widely accepted definition is that of "meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations Brundtland Commission,1987). Sustainability development is the foundation for the present leading global framework for international cooperation, according to the 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs) (IISD, n.d). These foundations are made up of three pillars namely the social, economic and environmental pillars of sustainability. They are often referred to as "corporate pillars of sustainability." (Thwink.org, 2014).

All three pillars are essential because if any one pillar is weak then the system as a whole becomes unsustainable. The SDGs on the other hand, are global goals which were adopted by the United Nations Member States in 2015 as a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030 (United Nations, 2018). There are 17 SDGs in total, but this study will be focused on two: Climate action: SDG 13 and partnership for the goals: SDG 17 because of its centrality to the study focus. Both the pillars of sustainability and the SDGs: 13 and 17 are discussed in further details below.

### 5.4.1 Pillars of sustainability

There are three pillars of sustainability. These are environmental, social and economic pillars. 1) The environmental pillar has been identified as the world's biggest challenge to achieve. It is the "ability of the environment to support a defined level of environmental quality and natural resource extraction rates indefinitely" (Thwink.org, 2014); 2) Social pillar: deals with the ability of a social system, such as a country, or organization to function at a defined level of social well being and harmony indefinitely (Thwink.org, 2014); 3) economic pillar is the ability of an "economy to support a defined level of economic production indefinitely" (Morone and Clark, 2020). The U.N is focused mostly on the economic pillar, because economic growth is what most of its members want most. This creates a void in achieving the entirety of the pillars (Thwink.org, 2014).

### 5.4.2 Sustainable development goals (SDGs)

For this study, the key SDGs that will be focused on are SDG 13: climate action and SDG 17: partnerships and goals. This is because they both reflect on the focus of the study. When it comes to SDG 13, it is focused on taking urgent actions to combat climate change and its impacts (United Nations, 2018). This is directly linked to the study as its focus is centered on how blockchain technology could address monitoring and reporting CO2 emissions trading. This has an impact on climate change.

The study also reflects upon how important it is for multi-stakeholder partnership to achieve the common goal of reducing CO2 emissions in the energy sector. This is what SDG 17: partnership for goals is focused on. SDG 17 refers to a need for different stakeholders, including cross sectors and cross country to collaborate and share knowledge, expertise, technology and financial resources in order to achieve the Sustainable Development Goals (Pierce, 2018). It calls for countries to align policies, and visions for improving equitable trade and coordinated investments initiatives to promote sustainable development across borders (United Nations, 2018). Some authors argue that it is the most important SDG because “without significant progress on SDG 17, achieving other SDGs will be a near impossible task” (Pierce, 2018).

## 5.5 Challenges of EU ETS

The implementation process monitoring and reporting CO2 emission trading is not without challenges. Six challenges have been identified according to some researchers.These are the lack of standardization, double-counting, transparency, too many middlemen, high cost and overallocation of carbon allowances. More details are discussed below.

1) Lack of standardization: there exist over 200 methodologies for calculating CO2 emissions (IETA (2013). As such, the system currently lacks a standard data measurement, and many measures are only estimates which contribute to overallocation of emission data (King, 2018);
2) Double-counting: this means entering a record or transaction twice as a single entity. The lack of internationally agreed rules between trading parties is a reason for double-counting (Schneider et al. 2014);
3)Transparency: According to Bohm (2013), self reporting is often practiced within the EU ETS with no independent emission verification. Such practice leads to ‘*CO2 cheating*’ and corruption within the carbon market (Bohm, 2013) ;
4) Too many middlemen: carbon trading involves a number of intermediaries (e.g consultants, carbon brokers and project developers, policy makers etc), which gives a hint about its complex nature and unnecessary high cost (Bohm, 2013);
5 High cost: Too many middlemen and complex mechanisms leads to the high cost which is a challenge for trading carbon (World Bank, 2011). This puts some organisations off to participate in sustainability programs because it is either complicated or expensive;
6) Overallocation of carbon allowances: Over-allocation of allowances is caused by economic crisis and industry lobbying ( FutureLearn, 2018). In 2018, allowance price tripled to 25 Eur due to this challenge (Florian, 2018).

## 5.6 Critical analysis of literature: Why does the EU ETS look like what it looks like?

From the literature reviewed, the  EU ETS is a “cap and trade” (as described in section 5.1) that caps the total volume of GHG emissions from installations and aircraft operators responsible for around 50% of EU GHG emissions (European Commission, 2015). By allowing trading of emission allowances, emissions from installations and operators stays within a set cap while least-cost measures are taken to reduce emissions. The formation of the EU ETS emanated from the need of the EU to meet its commitments under the Kyoto Protocol (as described in Chapter 1).

In its pathway towards a low-carbon competitive economy, the EU has set a GHG reduction target for its Member States (European Commission, 2015). The MRV sustainability program is part of the tool the EU is using to create trust and transparency in the monitoring and reporting of emission trading systems for its Member States. Therefore, one can argue that it is an essential tool for compliance and transparency of the EU ETS. This is due to the enforcement backing it up and the reporting mechanism to ensure that one tonne CO2 equivalent emitted is equivalent to one tonne reported. As such, it provides a mechanism for both carbon market participants and authorities to keep track and monitor emissions from industrial activities. This can be viewed as the first stage in the EU ETS program.

On the other hand, the Union Registry can be viewed as a tool used in the second stage of the EU ETS program. This is because both tools: MRV and the Union Registry work side by side. According to the European Commission (2015), an annual reconciliation of allowances, verified GHG emissions and compliance status: that shows individual operators have surrendered enough allowances to cover verified emissions of previous years, must be submitted every year. Once the emission report is verified and has been reconciled, energy operators are issued allowances for the next trading cycle. While on the other hand as (described in 5.1.1), the Union Registry is an electronic accounting system for accounting EU allowances issued under the EU ETS and international credits (European Commission, 2015).

It is questionable that despite the EU ETS being a mandatory program, companies still practice “self reporting” which leads to ‘CO2 cheating’ and corruption which Bohm (2013), pointed out as a challenge of the system. Apparently, the act of self reporting leads to non-transparency and compliance which defeats two key factors for implementing the EU ETS program in the first place. Little wonder why the EU ETS has failed to yield substantial reductions in emissions. The IEA (2020) report as described in Chapter 1 of the study, stated that between 2013 to 2018, CO2 emissions from industrial installations decreased by only 0.3%. Another report suggested that the EU ETS is falling to deliver the

$CO_2$ cuts required by science ( Friends of the Earth Europe, n.d). The required cut by science is below 2°C ( Milman, 2013).

Clearly the system is defective, but there seems to be a light at the end of the tunnel. The EU Regulation (EU) 2015/757 supports the implementation of new innovative technologies that can accelerate climate actions and reduce $CO_2$ (European Commission, 2015) as described in (Chapter 1). Therefore there exists the possibility of fixing the system's said challenges through innovative technologies that will bring transparency to the system and ensure compliance.

## 5.7 Summary

Chapter 5 presents the energy industry and its sustainability programs. This includes the EU ETS framework and the EU MRV for the monitoring and reporting of $CO_2$ emission trading. These sustainability programs became adopted in the industry to drive the agenda of reducing carbon emissions. As such it was important for the researcher to look at the concept of sustainability, its pillars and the SDGs 13; climate action and SDG 17: partnership and goals which is central to answer the sub question 2 of the research question. Stakeholders and their roles in the EU ETS implementation process was also presented. Furthermore, the power and governance structure of the industry was also presented showing who controls what and the stipulated obligations for the stakeholders in the energy sector under the EU ETS.

The chapter also identifies six challenges of the program: lack of standardization, double counting, transparency, too many middlemen, high cost and overallocation of carbon allowances ( section 5.5). A critical analysis of the literature was also reviewed (in section 5.5) to analyse in depth the reason for the EU ETS program and why it is perceived as an ineffective system in its monitoring and reporting process. What the main challenges of the program are and what technological possibilities are there to address these challenges.

## 6. Blockchain technology

Chapter 6 discusses the fundamentals of blockchain technology such as its characteristics. The section also introduces smart contracts, consensus and the public and private networks of blockchain with examples. Types of blockchain: Ethereum and Hyperledger is also presented. Furtherly, an analysis of choosing the right blockchain is presented with a flowchart showing it the technology is the right fit for the case study. Lastly, blockchain convergence with other technologies is presented and its implementation challenges.

### 6.1 Blockchain fundamentals

Blockchain is a distributed ledger technology (DLT) that transmits and stores data packages called blocks through a digital chain wherein the blocks are connected to each other (World Bank, 2017). Blockchain technology was first described in 2009 in a cryptography blog by an unknown entity with the pseudonym “Satoshi Nakamoto” (Nakamoto, 2008). As its name suggests, blockchain gets built up by blocks of data gradually being ‘chained’ together. The blockchain network basically manages a decentralized database, but it is logically centralized by nature (Buterin, 2014) (Hua and Sun, 2019). In other words, no one controls them and there is no infrastructural central point of failure, but operates with one commonly agreed state and the system behaves like a single computer. After the first application of blockchain, some key characteristics have been identified about the technology. The table 2 summarizes these characters in more detail. The table was adapted from a combination of literatures as described below.

| Key characteristics | Description |
|---|---|
| Decentralization | No central authority required to approve transactions and set rules – the blockchain based workflow is decentralized. |
| Security | The database is an immutable record. Posts to the ledgers cannot be revised or tampered with – not even by the operators of the database |
| Trust | Distributed nature of the network requires computer servers to reach a consensus, which allows for transactions to occur between unknown network participants. |
| Transparency | An automatic feature which is a key part of the blockchain network, reducing any need for checks and balances. |
| Public sharing | Servers/entities/nodes, maintain the entries (blocks), and every node sees the transaction data in the blocks when created. |
| Automation | The software that enables blockchain-based operations prevents the entry of conflicting or double transactions into the dataset. Transactions occur automatically. |
| Immutable | Blockchain is a tamper proof architecture and designed to be realistically unchangeable. |

Table 2: Key characteristics of blockchain and its description.
Sources: Hreinsson and Blöndal, (2018), Tian, (2018), Buterin (2014), Seebacher and Schüritz, (2017), MIEN and GIZ (2019).

From the table 2 above, the decentralized nature of blockchain contributes to creating a private, reliable and universal environment for its participants within the network. While some authors explicitly mention the concept of security of blockchain technology, others described it indirectly as trust, which is in relation to establishing transparency through a publicly shared network. The data shared on the network which are automated and immutable, are publicly viewed by the network participants and transactions are ongoing throughout the P2P network, building data integrity within the network.

## 6.2 Smart contracts

Smart contracts is an agreement on blockchain between two or more parties in the form of a computer code. They are simply computer protocols intended to digitally facilitate, verify, or enforce the negotiation or performance of a contract without intermediaries (Rosic, 2018). Due to the permissioned nature of the consensus mechanism, only the members of the network can access the smart contracts that run in the blockchain network, which controls and triggers an automatic action when a certain predefined conditions are met. These smart contracts are automatically protected from tampering because they are stored in the shared database within a network in an underlying consensus among the participants of that network (Buterin, 2017). Specifically, the smart contract feature, and distributed ledger capabilities are distinguishing features that can be used for monitoring and reporting of Greenhouse Gas (GHG) emissions (Öker and Adıgüzel, 2016). By setting predefined standards and rules within the smart contract, the cost of reaching an agreement, formalizing and enforcing standardized rules in traditional contracts are eliminated (Shermin, 2017). This way the role of intermediaries is eliminated. In essence, a smart contract verifies whether or not participants of a transaction comply with the rules pre-established in the agreement. Accordingly, the transaction can be validated or rejected and have a closed life cycle within the system. However, as intelligent as it sounds, smart contracts may fail to foresee unexpected eventualities within the institutions, by means of human errors or subversive actors (Shermin, 2017). In such cases, smart contracts might need to be overridden by supermajority consensus (Shermin, 2017).

## 6.3 Consensus mechanism

To address the challenge of blockchain distributed computing from fault and malicious attack the consensus mechanism was developed. A consensus is a fault-tolerant mechanism in blockchain that facilitates an agreement on a single data value within a network of distributed processes or multi-agent systems (Rosic, 2018). To achieve consensus, an agreement is generated among the network participants wherein participants need to validate before a transaction can be considered valid. Consensus fault tolerant, attack resistant and collusion tolerant nature are major reasons why its mechanism is important in the decentralization functionality of the blockchain technology (Buterin, 2017). There are three main types of consensus mechanism namely the Proof-of-Work (PoW) , Proof-of-Stake (PoS) and the Practical Byzantine Fault Tolerance (PBFT).

i) *PoW:* is a “method that prompts users to repeatedly run hashing algorithms or other client puzzles, to validate electronic transactions through mining'' (Voshmgir & Kalinov, 2017). Mining uses a high amount of power consumption to solve mathematical puzzles and mine a block (Tabirao, 2018). Examples of blockchain that use the PoW are Bitcoin and Ethereum.

ii)*PoS*: To achieve this consensus mechanism, users need to prove ownership of a certain amount of currency or a stake before it can join the blockchain network, generate a block, and validate transactions (Voshmgir & Kalinov, 2017). In other words, it operates via a virtual mining mechanism as opposed to the hardware mining in the PoW consensus.

iii) PBFT: PBFT node operates by acting maliciously against the common goal of reaching an agreement (Cachin & Vukolic, 2017). In other words, the majority (or a minimum specific number) of nodes have to approve a transaction for the transaction to be completed for security reasons. E.g of blockchain that use this is the Hyperledger.

### 6.4 Types of blockchain network

According to Buterin(2015), there are three main types of blockchain. These are the private, public and consortium blockchain.

*i)Public:* : a type of blockchain in which anyone in the world can read and see transactions if it is valid or not. They are permissionless - meaning they do not require any permission to access its network. These kinds of blockchain are fully decentralized (Buldas, et.al., 2014); ii) *Private:* a type of blockchain that requires permission to access its network. In other words, they are permissioned blockchains. Permissions are central to the created network and reading permissions may be public or restricted (Tabirao, 2018); *iii) Consortium:* this is a hybrid type of blockchain that operates under the leadership of a group of member companies instead of a single entity. Consortium blockchain requires a “consensus process and is controlled by a pre-selected set of nodes“ (Tabirao, 2018). Buterin (2015) later categorized the types of blockchain into two: private and public, arguing that the idea that there is  “one true way” to be blockchaining either publicly or privately.

### 6.5 Ethereum and Hyperledger fabric

Etherum is the first real decentralised (distributed) computing platform that enables the execution of smart contracts (Ethereum, 2020) and was first discovered in 2014 (Buterin and Griffith, 2017). Etherum, which is an open source code, facilitates smart contracts using a “Proof of Work" (PoW) consensus mechanism. In the past years, there have been conversations of switching Ethereum blockchain fully from PoW to PoS consensus, which is expected to be fully implemented by 2020 (Baker, 2018). This implies that switching from a PoW to PoS will fundamentally lower power consumption, since it operates virtually.

On the other hand, Hyperledger fabric was developed due to the fact that existing blockchains suffer from a fundamental flaw of not being fully scalable (Hreinsson and Blöndal, 2018). Hyperledger is an open-source project founded in 2015 with the primary aim of its implementation for global business transactions.  Hyperledger is built on a modular architecture that allows for adjustments and implementation of further functions, which makes it flexible. Its consensus mechanism is called the Practical Byzantine Fault-Tolerance (PBFT).  The major similarity of the Hyperledger and Ethereum is that they can both be used to power smart contract applications. However, they share a number of differences when it comes to mode of operation, governance, consensus type, and currency. The table 3 below presents the differences between Hyperledger and Ethereum. The source of the five elements in the table 3 are listed below. These elements were selected as the most relevant for the study because they encapsulate the main characteristics that distinguish the two blockchains in a detailed but comprehensive manner which is further incorporated in the Chapter 9 (data analysis section) of this study.

| # | Elements | Ethereum | Hyperledger |
|---|---|---|---|
| 1 | Mode of operation | -Permissionless, public<br>- Permissioned, public | Hyperledger-Permissioned, private |
| 2 | Centralized regulation (Governance) | Ethereum developers | Open governance model based on Linux model |
| 3 | Consensus | POW, POS, | PBFT |

| | | | |
|---|---|---|---|
| | type | | |
| 4 | Run smart contracts | ✓ | ✓ |
| 5 | Native currency | ✓ (ether) | N/A |

Table 3: Comparisons between Hyperledger and Ethereum. Sources: Makhdoom, I., Abolhasan, M, and Ni, W.,(2018); Friebe (2017).

In summarizing table 3 above, the only similarity Ethereum and Hyperledger share is that they can both power smart contracts. While Ethereuem could either be permissionless or permissioned network depending on the type of set-up, Hyperledger is always permissioned and private. Ethereum governance mode is run by its developers while Hyperledger is run on an open governance mode once a party is part of the network. When it comes to their consensus mechanism, Ethereum could use the PoW and PoS which runs on smart contracts, while Hypeledger uses PBFT which also runs on smart contracts . While Hyperledger has no currency, the Ethereuem uses ether currency.

6.6 Choosing the appropriate blockchain for carbon trading

When it comes to choosing the right blockchain for an industry or environment, there are two fundamental criteria as described by Kravchenko (2016) that should be taken into account. These are: *1)level of anonymity of validators*: if their identity should be known or not; and, 2) *level of trust in validators*: in which predefined rules are set and in the event of violation, an inevitable punishment for misbehavior within the network is issued.

Wüst and Gervais (2017) also supported these two criterias of Kravchenko (2016), adding that blockchain is not necessary if there exist no database requirement, or if there is only one writer, and Trusted Third Party (TTP) is always online. TTP is a trusted individual or entity who facilitates interactions between two parties. In the case of a permissioned blockchain, a TTP issues a certificate of authority to verify the writer (participant) identity within the network. A permissionless blockchain does not need a TTP as the network is free for anyone to join.

For this study, since the energy industry is governed by regulations and directives, it is important to also take into account the governance and authority especially related to climate policies. As such, the researcher took a step further to review other features to consider when choosing the appropriate blockchain for specifically monitoring and reporting CO2 trading which will meet the needs of the energy industry.

Lo et al. (2017) developed a Suitability Evaluation Framework for choosing either blockchain or a conventional database. The framework was constructed as a result of a research conducted for the Australian government for implementing a proof-of-concept blockchain system (Staples et al. 2017). It was subsequently used for evaluating supply chain, electronic health records, identity and stock market (Lo et al. 2017), and has become popular. The Suitability Evaluation Framework consists of flowcharts, including yes/no questions as shown in Figure 3 below.

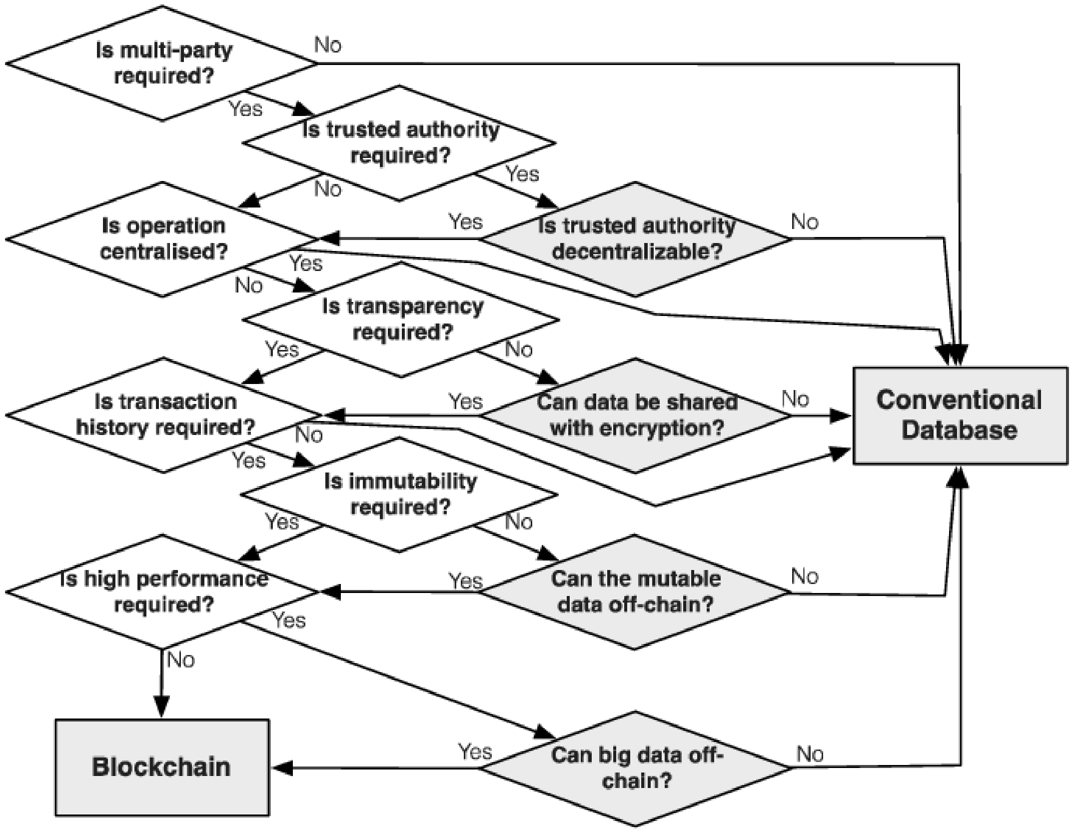


Figure 3: Suitability Evaluation Framework for choosing blockchain or a conventional database. Source: Lo et al. (2017).

From figure 3, the four features that distinguish this from other frameworks when choosing blockchain include a trusted authority, operation centralisation, transaction history, and high performance requirement. Trusted authority is a regulatory body that governs the operation of the system. If an operation must be centralised or decentralised determines whether blockchain should  be used. Transaction history also plays a key role. While Lo et al. (2017) suggested that blockchain should be adopted only if high performance is not required: performance requirement, it could also be because blockchain is still emerging. As such, its scalability in terms of speed is still being researched and developed (Burlakov, 2019). Off-chain as used in the diagram refers to transactions within a database network whose value is moved outside of the network and becomes invisible to the nodes on the network.

### 6.7 Blockchain convergence with other technologies (IoT, and machine learning)

The topic of combining blockchain with other technologies has been a topic of interest for both research and industry. "The combination of blockchain with machine learning and IoT unlocks new, more accurate ways to measure, report and verify climate outcomes at lower transaction costs"(CLI, 2019). IBM (2016) described blockchain as a game changer for the Internet of Things (IoT). "IoT describes the connection of devices — any devices — to the internet using embedded software and sensors to communicate, collect and exchange data with one another" (Ernest and Young, 2016). Through smart contracts in blockchain decentralized networks, devices will be able to function securely and autonomously by creating agreements that are only executed upon completion of specific requirements (Pauw, 2018).

Apart from IoT convergence with blockchain, machine learning is another technology that gives a boost to the technological ecosystem. Machine learning can be described as software that changes when it learns from new information. As a software "it is self-adaptive and does not necessarily add new rules manually in the system" (Intersog, 2017). Blockchain can benefit from machine learning's ability to accelerate the analysis of big amounts of data. Combining these two technologies have the potential to create a totally new paradigm (Intersog, 2017).

### 6.8 Key challenges of blockchain implementation

Despite the perceived potentials of blockchain to improve $CO_2$ emission reduction, its implementation still "lurks at every turn" (Burlakov, 2019). Referencing Deloitte (2018), Burlakov (2019) and (MIEN and GIZ, 2019) literature, five key challenges were identified for the implementation of blockchain technology. These challenges are: lack of awareness, regulation and governance, scalability, cost and efficiency, and security and privacy.

1) Lack of awareness: This is a principal challenge for potential adopters and implementers of the technology which raises the question of if the technology is indeed the right path to their businesses (Burlakov, 2019);

2) Regulation and governance: This ties into the first issue: awareness. The technology has to also be understood by the regulatory body and has to align with their goals and targets to assess its impact for its different stakeholders Deloitte (2018). Already, some governmental bodies around the world are exploring the need to regulate the technology once they figure out what it is Burlakov (2019);

3) Scalability: Running a large volume of transactions via blockchain at high speeds is one of the greatest challenges with blockchain facing its developers today (Burlakov, 2019).

4) Cost and efficiency*:* Since the technology is still under research and development, making it more sustainable and less expensive is still in the process. Example of an efficiency issue is the emergence of a POS consensus mechanism in the Ethereum blockchain. POS was introduced to solve the high consumption of electricity that POW consumes during its mining process (Deloitte, 2018).

5) Security and privacy: Blockchain security is still questionable due to its historical record of being hacked (Burlakov, 2019). There are also the issues with anonymity level the networks peers are willing to share (Deloitte, 2018).

## 6.9 Critical analysis of blockchain technology

From the literature reviewed, blockchain technology (as described in section 6.1), is a DLT that transmits and stores data packages called blocks, through a digital chain that connects the blocks to each other (World Bank, 2017). What sets the technology apart is due to its fundamental characteristics such as transparency, immutability, decentralisation, trust, sharing capabilities, and automation. While some authors have argued that its security is questionable due to the record of hacking the technology in the past (Burlakov, 2019), the technology offers immutable recording keep of information that cannot be easily tampered (Buterin, 2014; Tian, 2018).

It can be argued that its smart contract feature makes the technology unique. This is because it has the ability to digitally facilitate, verify and enforce negotiations or performance without a middleman (Rosic, 2018). However, there seem to be some actions that a smart contract cannot digitally perform despite its intelligence. Unexpected eventualities by means of human errors or non-conforming actions as set by the rules of the blockchain network cannot be solved by a smart contract (Shermin, 2017). In such a case, smart contracts need to be overridden by a supermajority consensus. This says to a large extent the limitation blockchain has when it comes to credibility of information stored within the network.

The credibility of information stored in the blockchain is an important aspect of the technology to be fully maximized. The study therefore identifies this as a challenge of the technology. However, some research suggested that combining blockchain with other technologies such as IoT and machine learning will help blockchain maximize its full potential (IBM; 2016; Intersog, 2017; Paw, 2018; CLI, 2019). “Combining blockchain with machine learning and IoT unlocks new, more accurate ways to measure, report and verify climate outcomes at lower transaction costs” (CLI, 2019). Although this research focus is not on tackling the credibility of information stored within a blockchain, the study encourages future work on how this can be achieved by combining the said technologies with blockchain as described in study future work (section 10.4).

## 6.10 Summary

Blockchain technology is a topic for research and development in the past years
and understanding the technology fundamentals is necessary to boost the benefits of its implementation. As a distributed ledger technology that has the potential to remove the ‘middleman’, its smart contract which is immutable and transparent has driven so much attention towards the technology. Different industries and the authorities are considering the technology for solving different industrial needs due to its characteristics of transparency, decentralization, trust, immutability and security which have also contributed to how popular the technology has become nowadays.

When it comes to blockchain’s application, the question of whether it should be a public or private network comes to play, and these decisions may vary depending on the access restriction preferences: permissioned versus permissionless. Choosing the type of blockchain: public vs private also brings trade offs when it comes to the implementation of blockchain.

Its implementation is also with challenges. The challenges of awareness, regulation, scalability cost and security are some of the identified problems associated with its implementation and adoption in different industries including climate initiatives. Technologies like machine learning and IoT have also been associated with maximizing the potentials of blockchain in terms of greater efficiency. However, it will still take some years to fully explore its full potential since it is still an emerging technology.

**7. Case study**

This chapter presents three cases for the study. One is a pilot test case while the other is a working case: an already implemented case. Both are studied to access the feasibility of the research solution that will be proposed. As presented in the methodology (2.1.2), pilot cases are "dress rehearsals" of full survey operations which are implemented to determine whether problems exist that need to be addressed before a full scale production ( Lavrakas, 2008). In other words, it is a preliminary study on a small scale conducted to evaluate feasibility, duration, cost, possible events for the purpose of improvement upon study design before launching full scale.

The goal of having a feasibility study is to examine the practicability of using blockchain for monitoring and reporting CO2 emission trading. It is not enough to get data from experts and literature review, but also to ascertain if the proposed solution is doable and narrow down the possibilities. Already, there are digital trading initiatives linked to blockchain technologies as presented in the appendices 1.0 below. But there is a very limited number focused on monitoring and reporting using blockchain. However, this study will focus on Climate Ledger Initiative (CLI) and Energy Blockchain Labs.

The first organization: CLI was chosen for the study because its pilot case is specifically designed for the monitoring, reporting and verification (MRV) of carbon emission trading in Mexico. The second case study: Energy Blockchain Labs was selected for the study because it is not just a pilot study but the world's first blockchain-based system for carbon trading. By studying an already working system, the researcher is able to dive deeper in understanding how blockchain can be applied for carbon emission trading for the study case. The third case is the Danish emission trading system. It is important to understand how blockchain can be applied in the study's case: the Danish carbon trading system in this case. The three cases are presented in detail below.

## 7.1 Climate Ledger Initiative (CLI)

Climate Ledger Initiative's (CLI) mission is to "accelerate climate action in line with the Paris Climate Agreement and the Sustainable Development Goals (SDGs) through blockchain based innovation for climate change mitigation, adaptation, and finance" (CLI, 2018). Founded in 2016, the initiative addresses climate change with technologies such as blockchain, DLT, Internet of Things (IoT), Artificial Intelligence (AI), and the use of remote sensing (CLI website, 2020). A pilot study of blockchain for monitoring and reporting Mexico's CO2 emission trading was done in 2018 (MIEN and GIZ , 2019). This was carried out to solve mainly the issue of double-counting, non-transparency of allowances auctioning, and high cost and fraudulent activities within the system (MIEN and GIZ , 2019). The pilot phase is set to begin in 2020, and run for three years before transitioning to a fully operational system. The breakdown into phases is to enable the stakeholder understand how the system will work overtime.

***How does it work?***

After carrying out the suitability evaluation, an hybrid approach based on Ethereum was proposed which will utilize the business approach of crypto exchanges of private or dedicated tokens to gain access to the network. Only the owner of the private key can change the entry of the ledger (MIEN and GIZ , 2019). It will combine both in centralized and decentralized features. What this means is that the allocation of allowances, acknowledgement of offset units and registry account management would be managed on the centralized database. While the generation and distribution of tokens will happen on a permissioned blockchain layer.

That way, the governing layer can ensure that the "amount of allowances, offset units and emission units correspond to the total amount of tokens generated on the blockchain layer (MIEN and GIZ, 2019). In a case where allowances are outside the boundaries of the ETS, respective units have to be effectively marked as "booked-out" on the Transaction Layer, and the token needs to be withdrawn from the registry platform" (MIEN and GIZ, 2019). Also a hybrid model will enable gradual and subsequent enhancement of the blockchain layer by the respective development of its underlying smart contract (rules setting, fixation of token specifications, etc.). While the majority of ETS activities will take place on the centralized transaction layer, disintermediation may not be achieved at this point. This is because, even with blockchain, the middleman is still required to ensure proper functioning of the account system as well as to maintain flexibility as it relates to ETS events like allocation of allowances etc. (MIEN and GIZ , 2019).

***Leveraging blockchain technology***

Four aspects of blockchain are being leveraged for blockchain application in the proposed system. These are: database, multiple writers, trustworthiness, and disintermediation.

1) Database: The database capacity of the technology to records serialized carbon units: e.g.allowances, offset units, etc.) is a suitable fit for emission trading (MIEN and GIZ , 2019); 2) Multiple writers: Blockchain feature of immutability and transparency will play a big role in keeping track of all transactions by the different registry participants (MIEN and GIZ , 2019); 3) Trustworthiness: Blockchain integrated into the registry will enable common rules to be set up through smart contracts in such a way that users can rely on the accuracy of the database's content without having to trust its direct counterpart (MIEN and GIZ , 2019); 4) Disintermediation: For emissions transaction registry, the intermediary runs the registry on a technical level. Using blockchain instead can provide technical means of transferring allowances and offsetting credits between different accounts (MIEN and GIZ , 2019).

7.2 Energy Blockchain Labs

Energy-Blockchain Labs Inc., is a Beijing-based collaborative initiative on energy and environment blockchain applications (Andoni et al, 2019). Founded in 2016, and in partnership with IBM blockchain technology, they created the "world's first blockchain-based green asset management platform on the open source Hyperledger Fabric" (EnerCom, 2017). It operates a system that allows high-emission organizations to monitor their carbon emissions and meet quotas by buying carbon allowance/credits from low emitters ( IBM, 2018). The goal is to reduce the costs of China's national carbon market by 30% (Andoni et al, 2019), and create an efficient way for businesses to meet government-mandated carbon emissions reduction quotas (IBM, 2018). Since China is responsible for approximately one-quarter of the world's emissions (Ritchie and Roser, 2017), their government established Carbon Emission Reduction (CER) quotas, which allocate CO2 emissions limits to enterprises and individuals which have prompted growing trade in carbon assets/carbon offsets (EnerCom, 2017). The proof of concept was completed in 2016 and a beta version of the blockchain carbon asset platform was released in May 2017 (EnerCom, 2017).

*How does it work?*

Carbon asset development ledger based on IBM Blockchain technology records and quantifies the environmental impact of participants' energy production and consumption activities (IBM, 2018). This way, participants can easily track their carbon footprint and better understand when to buy or sell in the carbon asset market. Additionally, regulators can easily monitor progress against quotas to ensure that carbon reduction goals are met by participants (IBM, 2018). According to IBM reports, developing carbon assets alone is a complicated process and takes about 10 months with multiple parties involved. However, the introduction of blockchain, serves as a data bridge between China's green economy and all the stakeholders: emission enterprises, governments carbon asset exchanges, verifiers and certification bodies etc (Cao, n.d; IBM, 2018).

*Leveraging of blockchain technology*

Four characteristics of blockchain are being leveraged in its application. These are smart contracts, immutability, transparency and collaboration.

1) Smart contract: Over 200 carbon asset methodologies have been compiled into blockchain smart contracts for calculation of quotas for enterprises that need to reduce emissions (IBM, 2018);

2) Collaboration: The smart contract feature also enables digital collaboration across participating parties within the network (IBM, 2018);

3) Immutability: The DLT of blockchain increases the credibility of China's carbon market. This is because it can trace the history of data shared on the network and makes information secure and untampered (EnerCom, 2017). The immutable nature also makes it easier and less expensive for regulatory authorities to audit and oversee the carbon market.

4).Transparency: This feature also enables stakeholders within the network to address regulatory requirements in a very transparent manner and monitor progress of the stakeholders compliance in visible and real time (EnerCom, 2017).

### 7.3 Element and scope: CLI vs Energy Blockchain Labs

This section presents a summary of the two pilot case studies in scope and elements. The sources of the elements in the table 4 below is based on the literature by Makhdoom, Abolhasan and Ni (2018), and Friebe (2017). These elements were selected as the most relevant for the study because they cover the main characteristics that distinguish the two studies as it is relevant to the research.

| # | Elements | CLI | Energy Blockchain Labs |
|---|---|---|---|
| 1 | Pilot test | 2019 | 2016 |
| 3 | Carbon project base | North America- Mexico | Asia - China |
| 4 | Mode of operation | Permissioned, private | Permissioned, private |
| 5 | Type of Blockchain | Ethereum | Hyperledger Fabric |
| 6 | Centralized regulation (Governance) | Yes | Yes |
| 7 | Consensus type | POW or POS | PBFT |
| 9 | Run smart contracts | Yes | Yes |

Table 4: Comparisons between CLI and Energy Blockchain Labs Carbon trading schemes. .
Element sources: Makhdoom, I., Abolhasan, M, and Ni, W., (2018). Friebe (2017).

From the table 4 above, CLI and Energy Blockchain Labs carbon trading schemes share some differences as well as similarities. While they are both permissioned and private, and run on smart contracts, the latter’s hybrid approach is based on Ethereum while the former is based on Hyperledger Fabric. This means that their consensus mechanism is different because Ethereum uses PoS or PoW while Hyperledger Fabric uses the PBFT consensus mechanism. When it comes to governance both systems are monitored by a central authority. The researcher was unable to get any specific information on how the governance works around carbon trading for Energy Blockchain Labs in China. However, a report showed that the China government sets emissions allowances and emission caps (Timperley, 2018).

### 7.4 Case study: Danish energy carbon trading market

Denmark has made a commitment to reduce the emission of CO2 and other GHGs through a number of national and international agreements. One of such agreements include Denmark's Climate Act target to reduce GHG emissions by 70 % by 2030 (compared to the 1990 level) and reach net zero emissions by 2050 (State of Green, 2018). In 2000, a legislation on the Danish CO2 quotas (the CO2 Quota Act) was passed by the Folketing - the Danish Parliament in 1999 (State of Green, 2018), which required Denmark to make core changes in its energy legislation towards achieving its energy targets. This introduced the Danish Union Registry for carbon trading. However, it became enforced in January 2001 (State of Green, 2018).

#### 7.4.1 Danish carbon emission trading: implementation process

The Union Registry is a joint registry for all national allowance registries in the EU ETS. Energy operators in Denmark are mandated to set up an account in the Union Registry (Danish Business Authority, 2019). In Denmark, the Danish Business Authority manages all Danish accounts in the EU ETS Registry (Danish Business Authority, n.d). To trade allowances, energy operators are required to have an account in the Danish emission Trading Registry (Danish Business Authority, 2019) which is connected to the EU ETS Registry for all participating Member States. Every holder of an account in the registry may then trade with Emission Reduction Units- ERUs, or Carbon Credits- e.g. CERs, AAUs and RMUs (Danish Business Authority, n.d). However, long-term Certified Emission Reductions (lCER) or temporary Certified Emission Reductions (tCER) - types of carbon credits trading, are not accepted by the Danish emission registry (Danish Business Authority, 2019).

Through the EU ETS, energy operators are annually required to submit allowances equalling their emissions. Only accounts that have been added by an account representative (AR) can be part of a transaction. The account entered by the AR will be added to a specific list of accounts called “trusted accounts” (Danish Business Authority, n.d). In some exceptional cases, trading accounts where transactions to other accounts can be carried out only with the approval of an additional authorized representative (AAR). The AR also has the legal rights to add an account to the list of trusted accounts, but this must be approved by another authorized representative (AR) or by an additional authorized representative (AAR) (Danish Business Authority, n.d). After the account becomes approved for transacting carbon credits, the account experiences a delay of 168 hours 97 days, for security reasons before it can be added to the trusted account list (Danish Business Authority, n.d).

Once the delay is over, the account becomes added to the trusted list, and active. This is only when allowances can be distributed using active accounts among the participating operators, while the remaining are auctioned off. There exist no limit to the volume of transactions, but energy operators are not allowed to transfer more emission allowances than held in their account. (Danish Business Authority, 2019). To trade allowances, account holders are free to enter into their own agreement concerning price; allowance/credit volume to be traded, transaction date etc with the party they wish to trade with.

All financial transactions related to the sale of emission allowance/credits take place outside the registries and do not have to be notified to the Danish Business Authority (Danish Business Authority, n.d). Following this context, the registration of ownership of emission allowance or credit is the core purpose of the registries. An account holder have the following option to trading credits: i) trade with another account holder, ii) trade through carbon exchange market; iii) trade through a broker/intermediary who also has an account in the EU ETS registry or a national emission trading registry (Danish Business Authority, n.d).

### 7.4.2 Stakeholders in the Danish emission trading registry

There are five main stakeholders. These are the EU Commission, Danish Business Authority, authorised representatives of the account holder, authorised representatives of the verifier; and the public.

1) EU Commission: The Commission manages, controls and updates the EU ETS registries of its Member States registries linked to it, including Danish emission registry

(European Union, 2015). It also sets the allowance cap for each Member State;

2) Danish Business Authority: This is an organisation in Denmark, that handles all the affairs of businesses operating in Denmark. In the case of emission trading, they manage the Danish emission registry and are responsible for ensuring data submitted contains no fraudulent activities (European Union, 2015) and that transactions are properly documented according;

3) Authorised representatives of an account holder: these are entities approved by the energy operators that have legal rights to access and change confidential account data such e.g reported emissions or perform transactions through a secure connection (European Union, 2015). On an annual basis, the operator must submit an emission report which is verified by an accredited verifier;

4) Authorised representatives of a verifier: They are typically appointed by an energy operator, and only have limited access to the data of that operator's installation(s) to verify the reported emissions (European Union, 2015). The verifier account cannot contain allowance units and cannot perform transactions, but is used solely to verify GHG emissions related to operator holding accounts ( Danish Business Authority, 2019);

5) Public: These are members of the general public. CO2 emission reported as well as the Union Registry with common data elements to track the issue, holding, transfer and cancellation shall be made accessible for the public and confidentiality as appropriate according to Directive (EU) 2018/410/ article 25 (European Commission, 2018).

*Other stakeholders*

Other stakeholders such as the energy suppliers and subcontractors, other industries/traders under the EU ETS program (maritime) and partners: non governmental organisations (NGOs) are also part of the system. This is because they play a major role in the CO2 emissions transactions with the energy operators. For example, subcontractors such as a steel manufacturing company that produces wind turbines for an energy company plays a role in affecting its emissions. Also ship vessels responsible for transporting these turbines to installation sites is another example.

### 7.4.3 Type of data stored in the Danish trading union registry

According to the Danish Business Authority, (2019), there are five types of data stored within the registry. These are:

1) National implementation measures: This is a list of installations covered in the ETS Directive in each EU country. It also contains any free allocation to each of those installations in the third phase (2013-2020); 2) Accounts of companies with allowances;
3) Transfer of allowances: these are transactions performed by account holder; 4) Annual verified CO2 emissions from operator’s installations; 5) The annual reconciliation of allowances and verified emissions: there must be enough allowances to cover company's verified emissions that must be surrendered (European Commission, 2015). After the Danish Business Authority has checked the emission report data submitted, the operators are mandated to surrender the requisite number of allowances to cover their emissions by end of April every year ( Danish, Business Authority, 2019).

Other data such as financial information related to the sale of credit allowance are stored outside of the Union Registry ( Florian, 2018) (Danish Business Authority, 2019).

## 7.5 Summary

The case study chapter presented three cases. The first case presented is based in Mexico and coordinated by CLI and the Ministry for the Environment and Natural Resources, Mexico (MIEN). The study proposed a hybrid emission trading system which will run on Ethereum on a private network with two layers connected to the blockchain. The first layer will be centralized and controlled by the Mexican government. While the second layer will be decentralized and will contain activities such as generation and distribution of tokens on dedicated administrative wallets.
The second project is based in China and by Energy Blockchain Labs in partnership with IBM technology. A blockchain based carbon asset trading system that allows high-emission organizations to monitor their carbon emissions and meet quotas is a working system in China. The government also monitors and tracks individual and companies emissions through the system.
The third case is the case of the Danish emission trading system which does not use blockchain for carbon trading as at the time of this study. With an emission registry, it monitors and reports the activities of carbon trading in the Danish energy sector. Additionally, the sole purpose of the registry is to keep record of account ownership within the registry. As such the registry does not store financial transactions details. The next chapter of the study (Chapter 8) presents the data collected from the semis-structured expert interviews and its interpretation.

## 8. Data Interpretation

Chapter 8 presents all the data gathered for the purpose of this study. This includes literature, expert interviews, pilot case studies and theories. Primarily, the literature works help in framing the important scope of the research. Some of these details are validated through the post-expert interviews. As mentioned in the (section 2.2.1) of the study, semi-structured expert interviews were adopted for the study to gather first-hand knowledge which cannot be statistically looked up. Also, for the researcher to be able to control the directions of the interviews. Simultaneously, the empirical data collected through qualitative methods also contributes to new ideas and suggestions for the implementation of blockchain monitoring and reporting of carbon emission trading in the energy industry.

After code the data gathered in the study, nine main areas were identified to help the researcher answer the main research questions and sub-questions of the study. As described in the methodology (section 2.2.1), through applying the grounded methodology, these categories emerged based on: 1) relationships between the codes, 2) frequencies of the codes, 3) underlying meaning across the code, 4) and its relevance to address research questions. The nine categories are 1i) current conditions and process of the EU ETS; 2) technology application; 3) blockchain benefits; 4) needs improvement; 5) politics; 6) challenges of the EU ETS; 7) sustainability; 8)Market system; and 9) education and awareness. After coding and applying themes to the data, the main data emerged and were interpreted.

From the interpreted data, multi- experts from the interview, literature and pilot tests agreed that the current EU ETS system needs to be more robust to cater for the challenges of the system, particularly transparency, compliance, double counting and standardization. These were pertinent challenges identified from most data sources reviewed. Most of the experts viewed blockchain as technology that could address the said problem, but it needs to be politically decided from the top level (government) to implement such a technology.

It was also gathered from multiple data sources that the concept of sustainability and competition could also influence the implementation of blockchain for carbon trading if a good business case is presented. Such a system can give competitive advantages for its participants according to the data gathered Also, implementing such a system will also require hevel level of collaboration and partnership from multi-stakeholders as well as educating them on the technical legacy of the system. These data findings are recognisable from pilot test reviewed and practical shows how feasible the proposed solution can be when it comes to its implementation.

The digital collaboration capacity of blockchain is a factor being leveraged on by Energy Labs (section 7.2) for carbon trading in China. While CLI will be pilot testing the emission trading system within a three year span to give enough room for its stakeholders to learn about the technology (section 7.1). This is the importance of having a pilot case study for the research in order to review the feasibility of the thesis solution and narrow down possibilities with best practices. A summary of the data interpreted is presented in the (appendices 2.0) and  the data coding analysis in (appendices 4) A link to the data interpreted can also be found here.

Chapter 8 has three main steps. The first step is the approach and design used for interpreting in the data. Step 2 summarizes the nine categorizations of data which the researcher considers the most relevant for answering the research question. Under this section, two or more codes were combined to conceptualize the data. In step 3, the researcher labelled the categories and presented the experts responses and secondary data (literature review, pilot case study and theories). Using the grounded theory approach (as described in section 2.2.1 of the study), this section presents the new knowledge derived from the data collection from the perspective of the participants of the study and shows how they are linked with the literature, theories and pilot cases reviewed in the study.

8.1 Step 1: Approach and design for data interpretation

As described in (section 2.2.1) of study, semi-structured expert interviews were adopted for the data collection of the study. The theories used for the study, literature review and external sources (e.g Ørsted energy company sustainability report 2019 and other company's whitepapers) were also consulted in the formulation of the interview questions. The researcher also considered the feasibility to answer the questions within the time frame of the research and practical constraints: access to experts etc, when developing the research questions. A background research on each individual expert was carried out and questions were formulated and asked according to their area of expertise to address the research question ( see section 2.2.1 for more detail). Some examples of the questions formulated include: 1) How does the energy operator monitor/track/record emissions suppliers, to ensure they are accurately disclosing the right carbon emissions?; 2) What is the collaboration with other stakeholders in Europe when it comes to carbon trading? Is the company considering blockchain for carbon trading to reduce its emissions and why?; 3) Between the four types of blockchain networks — public blockchains, private blockchains, consortium blockchains and hybrid blockchains, which will be better for monitoring and reporting carbon trading and why?

A total of 13 experts from the energy field, blockchain, Danish energy Agency, and climate action initiatives were interviewed. As already explained in table 1.0 (section 2.2.1), the experts were selected for the study based on identifying the needs of the energy industry, as well as understanding how blockchain can be applied to meet these needs. The 13 experts interviewed for the study includes: 1) three experts from the energy industry: Senior Lead Originator (A), Senior Public Advisor (B), Digital and strategist Consultant (C); 2) Two from blockchain industry: Co-creation Architect in research and development on blockchain (IBM) (D) and Blockchain and Cryptocurrency Consultant (E); 3) Principal Auditor & EU ETS Verifier (F); 4) A Program Director at a Climate initiative working with blockchain (company is also a pilot case study: CLI); 5) A Sustainability expert (H); 6) Two managers at a technology company working with blockchain: I and J; 7) Two managers at a software company working with blockchain K and L; and 8) Senior Policy Advisor at Danish Energy Agency (M).

The categorization of the codes and the generation of the themes for the data were based on the i)relationships between the codes, ii) frequencies of the codes, iii) underlying meaning across the code, iv) and its relevance to address research questions. A total of nine categories were identified in this stage which cuts across the conceptual framework (as described in Chapter 4) to address the research question. The process of categorization was necessary to help the researcher define what data to be interpreted and analysed. It also served as a way to organise the data in a more structured way during the data interpretation and analysis of the study.

A summary of the interview can be found in the appendices 2.0 of the study below. More details about the coding process and categorization from the raw transcribed data, as well as the interview questions can be found in the appendices 4.0. The summary of nine categories are presented in the next section.

8.2 Step 2: Summary of data categorization

1) Current process of the EU ETS: The data under this categorize presents two main themes: business as usual, monitoring and the EU ETS methodology. The knowledge shared by the experts that corresponds to the current EU ETS process and the business processes to fulfill the EU ETS were labelled under this category;
2) Technology application: The data under this category represents three themes: blockchain technology, its monitoring and reporting capabilities and other technologies that are connected to blockchain;
3) Blockchain benefits: Ths category presents five themes as identified by the participants of the study: accountability, trust, transparency, immutability and identity;
4) Needs improvement: This categorize presents the knowledge shared by the participants which responds to the phases of the EU ETS and the areas for work upon for a better system;
5) Politics: This category presents regulations and policies surrounding the framework and implementation process of the EU ETS;
6) Challenges of the EU ETS: This section presents challenges such as double counting and standardization, overallocation of allowances, as shared by the participants of the study;
7) Sustainability: This section includes two main sub themes: pillars of sustainability - environmental , social and economic impact, and UN SDGs 13: climate action and 17: Partnership for goals and SDG;
8) Market System: This section presents data as it relates to the theories used in the study. The theories include network, stakeholders, and market structure were the themes

labelled under this category. The category presents data shared by the participants in relation to the carbon market system and its cost implications, as well as stakeholders management and their relationship within the network;

9) Education and awareness: This category presents the awareness theme. The information grouped under this category is in relation to knowledge and perception of the EU ETS and the use of blockchain technology.

### 8.3 Step 3: What do experts and secondary data say?

*1) Current conditions and processes of the EU ETS*

When discussing the current procedures of the EU ETS, interviewees were particularly concerned about the business processes, monitoring and reporting and the methodology surrounding the system. The current procedures of the EU ETS were mainly discussed with five interviewees: Senior Lead Originator at a renewable energy company (A), Principal Auditor & EU ETS Verifier (F), Project Director at a Climate focused company working with Blockchain and Carbon trading ( G), and Sustainability Advisor (H). Senior Lead Originator (A) mentioned that the current EU ETS is currently undergoing some changes to launch its fourth phases (2021 - 2030). Both Sustainability Advisor (H) and Senior Lead Originator (A) agreed that the current EU ETS is not robust enough. Both experts (A and H) commented that the new system to be launched has to be a more robust and better system to encourage participation, as a lot of companies are not motivated to participate in the current EU ETS due to the complexity of the system. (A) further expressed that most companies are waiting for the launch of the next phase (2021 - 2030) to participate in the EU ETS which is currently under negotiations. (A's) viewpoint backs up the findings from the literature (section 5.1) about the fourth phase 4 (2021 - 2030) of the EU ETS. He expressed his doubt about politicians and authorities implementation of a better system, but described a 'light at the end of a tunnel situation' when he said " …. *we need to see where this will end*." Methodology plays a key part in the implementation of the EU ETS as expressed by Sustainability Advisor (H).

In contrast, Principal Auditor and Verifier of the EU ETS (F) stated that the "... *EU ETS is pretty robust as verification alone at installation level involves a lot of processes for a complete GHG submission"*. In the EU, the current methodology for the verification of carbon emission is manually done according to (F). (F) stated that most companies prepare their data on some form of excel sheets which is a traditional process of verifying activity data from installations and emission related activities. After the data has been registered, Verifiers use the "… *excel calculator based on ISO 6976 to calculate calorific values, density, relative density and to check for any missing gaps in data"*. In (F)'s opinion, " … *it's not high tech, but it's pretty smart*." The emissions after being verified from emission sites are then used for the EU ETS compliance and annual submission of GHGs.

Relating to this point, (H) expressed that if the methodology for monitoring reporting and verifying (MRV) of CO2 is not done properly, CO2 emissions could be overstated or understated carbon emission, putting the process at risk to achieve sustainability. To avoid the issue of over registering or under registering as pointed out by (H), (A) suggested that only one register should be launched in the new phase (2021- 2030), for monitoring all projects that are registered. According to the findings from the literature reviewed there is more than one register for entering transactions of carbon trading. The first register is nationally operated and controlled by the EU Commission for all Member States under the EU ETS jurisdiction: Union Register (European Union, 2015). The second register is state owned and controlled by that Member State. For the study case, the Danish Business Authority manages all Danish accounts in the EU ETS Registry ( Danish Business Authority, 2019). The Program Director at CLI (G) commented that the government is in charge of assigning quotas and allowances within the EU for its Member States. This statement backed up the literature in (section 5.2) which highlights the EU Commission as the issuer of allowances for its members.

Other information shared by experts that could be relevant for the study are that of the Digitalization and Strategy expert (C) at the energy company. (C) suggested that though the methods and procedure of carbon trading is viewed as complex, it all comes down to making a good business case and legislation backing it up. (H) strongly opined that carbon trading emission should be the last resort for a company. Instead, businesses should start from reducing their carbon internal footprints.

*2) Technology application*

Regarding blockchain possibilities for monitoring and reporting CO2 emission trading, the Vice President at the technology company(I), mentioned that it is important to define the problem first. According to (I), after the problem is defined, then blockchain can be accessed if it is the best solution or not. (I) particularly stated that if blockchain is to be used for "... *just trading, it's not, particularly better or worse than anything else that's already up there*." Both (I) and the digitalisation expert (C) agree that the technology is as good as any other database or accounting ledger and does not bring any additional value. In (C) opinion, any other protocol can be used for carbon trading. However, a major reason why blockchain may be adopted for monitoring and reporting carbon emission trading is its immutability capabilities according to (I).

One the contrary, Senior Lead Originator (A), Blockchain Consultant (E) and Sustainability Advisor (H) all agreed that the technology is advantageous in terms of its traceable capabilities. Stressing the importance of financial accounting and ability to trace information back its history, (I) mentioned that blockchain is a good fit for monitoring and reporting CO2 emission trading. (A) stated that CO2 emission allowances tracked through blockchain cannot be used two times since blockchain has an efficient way of monitoring things with its stamp feature, hence making it secure to trade with the technology. Blockchain consultant (E), also stated that the tokenization ability of blockchain - replacing a sensitive data element with a non-sensitive equivalent, which can be tracked back through its network is an advantage of blockchain for carbon trading. (H) pointed out that the technology can be furtherly used for other climate initiatives such as tracking and tracing green investments acquired from carbon trading and offsetting projects. The three experts confirmed a fundamental characteristic of blockchain reviewed in (section 6.1), which is its immutability nature. According to the literature, blockchain can store immutable records and posts to the DLT ledger cannot be revised or easily tampered. (I), furtherly stated that the use of blockchain for monitoring and reporting of CO2 emission trading is only a part of the puzzle as there are many other aspects to trading C02: data collection, verification etc.

When it comes to the type of blockchain for monitoring and reporting CO2 emission trading, Co-creation Architect in research and development at IBM (D) recommended a private blockchain. This is because it is a closed system and access is restricted to only the network members within the chain, he mentioned. In opposition, Blockchain Consultant (E) suggested a public blockchain is better for carbon trading because it achieves more network effects. Although (D) initially suggested that Ethereum blockchain would have been preferred due to its public networking capabilities, thus creating more network effect within the network.

This aligns with Castells (2000) theory of network effect (section 3.1), which viewed new power emerging from networks that have tendencies to create a network effect and gain value as more people join the network. However, (D), countered the initial suggestion of Ethereum due to high consumption of electricity during consensus mining, hence Hyperledger fits better from an ecological point of view. The literature (section 6.5) described Ethereum's PoW mining process as energy-consuming while Hyperledger's PBFT consensus mining consumes less electricity compared to POW. Program Director (G) agrees with both (D) and (E) but with a different approach. (G) suggested a hybrid type of blockchain with a centralised and decentralised layer. .

According to (G), the hybrid approach will be a bit of a compromise having a decentralized layer of blockchain which is accessible to the approved participants in the network and centralized layer which will only be accessible by the registry and controlled by the authorities. In (G's) opinion, it is a better approach because business as usual has to change and stakeholders will need time to learn how the technology works before switching fully to a new system. Another compromise (G) described is that the users of the decentralized network will have a high self responsibility since the decentralised system does not have "... *something like a hotline in case something is wrong or missing within the system. It is gone for good*." (G)'s suggestion backs up the pilot case reviewed in the study for having a hybrid approach for monitoring and reporting CO2 trading arguing that it will enable gradual and subsequent enhancement of blockchain layer overtime.

The technology's implementation for CO2 trading will involve many stages, added the Co-founder at the Software company (L). According to (section 6.6) five features of the technology when choosing the appropriate blockchain for CO2 trading are i) level of anonymity of validators; ii) level of trust in validators; iii) TTP; iv) transaction history; and v) high performance requirement. Amidst the opinions of the experts, Senior Policy Advisor (B) at the energy company mentioned that the company is looking into different ways of using digital tools to reduce its CO2 consumption, which could involve a combination of two or more technologies. When it comes to the convergence of the technologies, (D) and (G) agreed that combining blockchain with other technologies like IOT can create an impact in automating the process of data entry, making data more trusted.

In (G's) opinion, the use of blockchain to analyse a mass data generated by IoT gives credibility to the data and and data can furtherly be associated to specific accounts from the source it was generated. (B) and (G) and (I) further suggested machine learning as a useful technology for data analyses before entering it into a blockchain ledger. (I) mentioned that it could be used to clean the data before it is entered into blockchain, thus having an effect on the overall outcome of CO2 trading. The literature (section 6.7) suggested that the convergence of blockchain with other IoT and machine learning give new ways of accurately measuring reporting and verifying climate outcomes. Senior Policy Advisor (B) at the energy company declared his confidence in blockchain being relevant to report and verify the company's climate outcomes in 2032, due to its traceability and documentation features as noted in section (6.1) of the study.

*3) Education and awareness*

Raising awareness and educating stakeholders of how blockchain works is a common factor most interview respondents pointed out. Co-creation Architect (D) and Blockchain Consultant (E) stressed the need to educate businesses and regulators about the technicalities of the technology. As a precondition to work with the company, suppliers and subcontractors will have to learn how to maintain standardizations and robust reporting according to Senior Policy Advisor (B) at the Energy Company. Co-creation Architect (D) also expressed a notion around semantics, which are understood differently, thus the importance of standardizing blockchain language. However, (D) stated a concern about the slow pace of standardization, as technology evolves ten times faster than the speed of standardization processes. This backs up the literature in section that the technology is still evolving and not fully scaled (section 6.8). Program Director (G), expressed the need to improve the user experience of the technology and that it may take a while to convince policy makers to adapt to a new system or discontinue an already working system even though it may be inefficient. Changing mindsets is a challenge, stated (G) and suggested pilot testing the technology first before fully adoption. This suggestion is inline with the pilot case CLI reviewed in (section 7.1), which stated a three year pilot test is necessary for the implementation of the Emission Trading system in Mexico for stakeholders full adoption.

*4) Blockchain benefits*

When it comes to the benefits blockchain offers, ten of the experts expressed five main features of the technology; trust, accountability, transparency, immutability and identity. Trust had the highest number of concurrence with six experts: Senior Lead Originator (A), Senior Policy Advisor (B), Co Creator at IBM (D), Program Director (G), and Co-founder of

Software Company (L), pointing it out as an essential quality. (D) particularly stressed trust as the primary benefit of using blockchain for carbon trading, while (G) second the motion stating the technology fits a system where there are big trust issues. (G) furtherly approves the technology as a tool to create trust within the network, moving human reliability and reducing errors. Blockchain gives credibility in (A)'s opinion while (L) expressed that the technology can be trusted. The convergence of blockchain with a technology like the IoT makes the network more trusted said (D). (A) further expressed the energy's company's approval to support a carbon trading monitoring and reporting system that uses blockchain. According to (A), it is a trustworthy system, which gives additionality in carbon projects. To conclude on the point around trust, the literature (section 6.1) confirmed trust as a fundamental feature of the blockchain which gives data integrity. While discussing the accountability benefits raised by the experts, (B) from the energy company mentioned that accountability was the reason the company adopted blockchain for a previous project. According to (B), the project was in order to secure accountability. (B) furtherly expressed that accountability is relevant for the company's supply chain in terms of tracing things backwards.

When it comes to transparency, both Blockchain Consultant (E) and Cofounder (L), stated that the technology is a transparent system. Sustainability Advisor (H), added that using the technology for blockchain creates transparency around carbon accounting. (J) also concurred stating transparency as beneficial to the carbon market. According to (J), transparency makes people feel more comfortable, that way they are likely to transact. The literature (section 6.1) stated transparency as an fundamental feature of the technology that reduces any need for checks and balances. In (I) opinion, transparency is the reason the company adopted blockchain for its customers, so that they can make informed decisions. For immutability, (L) mentioned that blockchain could serve as a competitive advantage because it can show a track record of activities. Immutability is also important for financial accounting and monitoring according to (I). Furthermore, (D) mentioned that the keeping record of history makes it difficult to manipulate data stored with the technology as you can trace back to history according to (L).

To buttress these points, bothe literature (section 5.1) and pilot case study (Energy Blockchain Labs: 7.2), stated immutability and transparency as key features for leveraging blockchain for carbon trading. However, (I) stated that due to data privacy concerns, it is important to be selective of the type of data to enter on the blockchain network. Only one expert, Co-Creation Architect at IBM (D), mentioned identity as an important feature of the technology. (D) expressed optimism in the blockchain identity capabilities, stating that its an evolving technology and could be used to identify humans in the future.

*5) Needs Improvement: EU ETS carbon trading and blockchain technology*

When it comes to needs improvements two themes were identified. These are: i) improvements in EU ETS carbon trading; ii) improvement in blockchain. A total of five experts gave opinions on the need for improving the EU ETS current system and blockchain application for monitoring and reporting CO2 emission trading. However, only one expert suggested that the EU ETS current system works fine. The Digitalization expert (C) argued that the current carbon trading works fine and it's only challenge is that there is no free market for carbon trading because it has to be regulated. (C) furtherly expressed that it will become crucial for businesses to carbon trade in the future. In contrast, the Senior Lead Originator (A) stated that due to challenges such as double counting and complexity, the system needs improvement. According to (A) from the energy company, the company is not currently involved in any large scale carbon trading projects because it is not a working system and the framework has to be renewed and made more robust and trustworthy. Senior Policy Advisor (B) at the energy company furtherly mentioned that the company is only involved in small scale carbon trading and offsetting projects. According to (B), "... *we're buying forest credits from some verified supplier that we trust will actually result in actual carbon reductions*". (A), argued that a many companies are not doing CO2 trading because they are waiting for a new system EU ETS phase 4: 2021 - 2030, as mentioned in the literature (section 5.1). There is an ongoing discussion in the EU to create a more robust system for the next phase, stated A. Both ( A) and (B) emphasized on the need for the new framework to be policy driven in order for significant changes to be made in reducing CO2.

When it comes to blockchain, Blockchain Consultant (E) stated that it will take another two years or 18 months to fully develop the technology. Blockchain is still emerging as stated in (section 6.8) and "has to evolve as humans evolve," said the Co-creation Architect (D). Having a better performance is also a feature that will attract the technology to a massive adoption. (D) further buttressed this point by comparing blockchain to the internet in its early days, how it evolved from technology experts to 'everyday people.' The literature (section 6.8) goes with the points raised in the literature about the five challenges of blockchain implementation. These are awareness, governance, scalability, cost and security.

*6) Politics*

Policies and regulations play a major role in the execution of an effective EU ETS as agreed by five respondents. Sustainability Advisor (H) stated that the system is quite politicized which is a big challenge. (H) furtherly added that big corporations that emit large amounts of CO2 are influential in the decision making around CO2 trading because they have huge carbon liabilities. This corresponds with Castell's theory of power (2011) which suggested network-making power of stakeholders having the ability to reprogram a network according to its values and specific interests. Co- creation Architect at IBM (E) suggested that blockchain implementation for monitoring and reporting CO2 emissions need to be strongly blacked up by regulators. Sustainability Advisor (H) added that to achieve the Paris agreement (as stated in section 1.1 of the study), a policy driven energy transition is necessary. The Paris Agreement is an agreement within the UNFCCC on the mitigation of GHG emissions, adaptation, and climate finance. (H) suggested that policies do not necessarily have to be mandates such as taxes, but could be subsidies or financial incentives, as it is a good tool that could drive carbon abatement. Following the same line of argument, legislation should be the main target to avoid issues like double-counting according to Senior Lead Originator's (A). For an efficient system, the authorities need to set up rules for companies to buy a limited amount of allowances certificates according to (C). Opposing the influence policies have on companies towards climate action, (A) at the energy company argued that the energy company committed to reduce CO2 within its supply chain for the sake of its supply chain and not due to regulations. According to (A), "... *it's the right thing to do, ...we hope it can give us a competitive advantage to be on the forefront of this development*". There is no need for specific regulations to be put in place, although politically imposed standards could influence suppliers to easily report their emissions, added (A).

This standpoint corresponds with Castells (2000, 2011) network power in (section 3.1.1) of the study), which is primarily concerned with the imposition of rules within a network and standards required to coordinate interactions. When it comes to connecting blockchain to monitoring and reporting carbon trading, according to (C), it comes down to regulations. Program Director (G), also added that a centralised register controlled by the government is more manageable and straightforward than having a decentralized carbon registry system. In (A)'s opinion, for blockchain to work effectively for carbon trading, it has to be politically mandated by law to use the technology, or companies will not be able to get carbon allowances. However, (A) pointed out that some companies in locations/countries with no renewable focus may face challenges complying to such policies. The authorities can nonetheless keep track of whether or not a country is meeting up with its CO2 obligations and targets through the Climate Action Tracker (CAT) - an independent website for evaluating the different policies the country level, added (H).

*7) Challenges of the EU ETS*

Three respondents: Senor Lead Originator (A) , Senior Policy Advisor (B), and Senior Policy Advisor at the Danish Energy Agency (M), pointed out double-counting as a major challenge with the EU ETS framework. (A) broke the problem of double counting - which is a process where carbon credits are registered more than once, into two parts. The first involves registering carbon credits more than once in a register, while the other aspect is where carbon trading does not provide additionality which is expected. This has been the cause of some criticism according to (A). Both (B) and (M) agreed that blockchain seem to be relevant to solve the challenges of double counting. Furthermore, the literature reviewed in the study also identified two additional challenges with the framework. These are lack of standardization, and carbon allowance overallocation. Lack of standardization in CO2 data computation causes overallocation of emission data as a result of unreadily availability of accurate emission data. This makes data validity questionable. The last challenge is the over-allocation of carbon allowance in the EU ETS caused by industry lobbying and economic crisis according to the literature studied.

*8) Sustainability*

Two themes were identified under the sustainability category. These are the pillars of sustainability - environmental, social, economic impact and the United Nations' SDGs 17 - partnership for goals. For the first theme, a total of four respondents, stressed the importance of sustainability in businesses. When it comes to the environmental impact on the use of blockchain for carbon trading, three experts gave their opinions on the subject matter. Co-Creation Architect at IBM (D) was optimised that blockchain can help organisations initiate actions to reduce C02 emissions and save the environment as seen in some IBM use cases worked on. The Program Director (G) stresses the need to consider energy consumption when choosing a suitable blockchain for carbon trading. As the literature reviewed, Hyperledger was identified as a better fit compared to Ethereum because of Ethereum's high power consumption during its POW consensus mining. This corresponds with the literature study (section 6.5).

Senior Policy Advisor at the energy company (B), stated that it is increasingly relevant for the company's consumers to buy green certificates to make sure their energy consumption is matched by green generation. Other ways the energy company is practicing sustainability environmentally, is through the purchase of forest credits which results in carbon reductions according to (B). However, a major challenge expressed when it comes to the environment is the difficulty in finding technologies that produce the company's wind turbines, with no emissions or finding technologies for ships that transport the turbines without using fossil fuels. (B) went further to express the shared plans of the company when it comes to reducing CO2 emissions. These plans include completely phasing out coal trading by 2032, and working with its suppliers to reduce emissions as much as possible. (B) stated that there is no concrete roadmap yet on how to get there, commitments have been made and will be worked on within the next 12 to 20 years. The carbon footprints that cannot be reduced will be offset through trading schemes or compensation schemes, (B) added. The literature (section 5.4.1) identified these pillars of sustainability; social, environment and economic, string that their impact is necessary in achieving CO2 emission reduction globally.

On social impact, both Program Director (G) and the Sustainability Advisor (H), pointed out that blockchain for monitoring and reporting carbon trading has an effect on the social wellbeing of the society In (G)'s opinion, the replacement of the middleman with technology will cause people to lose their jobs. This leads to economic implications: economic pillar of sustainability. According to the (section 5.4.1), a country is economically stable when it is able to support a defined level of economic production indefinitely. Unemployment is the direct opposite to achieving this. On the contrary, (H) stated that investing in carbon trading or offsetting projects equals investing in a community, making it more resilient. According to (H), "... *you are not only creating carbon credits, which is your main objective, but you're also sort of creating a positive impact in that community.*" The literature (section 5.4.1) identified the social pillar as the ability for a community to function and sustain itself indefinitely which aligns with (H)'s point of view. From an economic point of view, creating employment through carbon trading brings a sort of economic activity into the community, according to (H). This also fulfills the United Nations SDG 1: no poverty, because that community becomes less poor, (H) added.

On SDG 17: partnership for goals, six experts agreed that cooperation between the partners/stakeholders is key in making the blockchain for carbon trading effective. They further gave some suggestions on how the next EU ETS phase would work better with strategic partnership among stakeholders. Senior Lead Originator (A), mentioned that companies will have to work together to develop such a system. Senior Policy Advisor at the Danish Energy Agency (M), added that if "EU leaders can agree to a higher climate target in the EU, then the EU ETS could be strengthened." When it comes to communication and exchange of information over the blockchain network, the Co-creator at IBM (D), stressed the need for all participants to be able to read and write over the network. Program Director (G), pointed out that working together with blockchain can create a competitive advantage for the stakeholders involved. This suggestion was furtherly compared with the adoption of the internet, stating that because of the internet connectivity feature, it became convenient for a group of companies to work together rather than owning separate systems. Such strategic alliance aligns with Castell theory of network-making power (section 3.1.1) and the Oligopoly market structure described in (section 3.3) which involves a few sellers of a standardized or differentiated product. However, a problem of such a system as identified by (D) is that some companies have trust issues, as such, fear losing their data to spys over a shared network. This presents a challenge for companies to work together. Blockchain Consultant (E) and Vice President market development (I) agreed with this notion, stating that there has to be willingness of companies to want to communicate with each other. (I) explicitly stated that wherever there is human, there are always challenges in the aspect of agreeing with each other.

*9) Market system*

Under the market system category, four themes were identified that directly have an effect on the structure of the carbon market. These are competition, network effect, stakeholders and cost. The themes identified have a direct relationship with the theoretical framework (Chapter 3) of the study. When it comes to competition, Program Director (G), Sustainability Advisor (H) and Business Manager (K), agreed that competition is essential for the acceleration of blockchain usage for monitoring and reporting CO2 emission trading. In (G's) opinion, the use of blockchain has potential to increase competition between businesses,but can only be proven correct by practical outcome. (G) furtherly stated that " …. *if one competitor sees that it's a working system, then they would probably follow up*." Sustainability Advisor (H) added that such a phenomenon is already happening where companies have asked to do peer events in order to know the level of

$CO_2$ reduction ambitions and targets from competitors. In (H's) words, " *my client's competitor has set carbon neutral commitment by 2025, my client too wants to be carbon neutral in 2020 to be ahead*." As such, competition is driving more action than it would, since businesses are making commitments, (H) added.

According to (H), competition will not only have an effect on the energy industry but other industries, like Microsoft for example, who are already making bold commitments to go carbon positive and trade their carbon historical emissions. (H) stated that "*If you want to be a market leader, you want to do more or do it earlier*." Therefore it could create a positive impact and be used as a market tool to reduce carbon emissions in the industry. Business Manager (K) stated that it could serve as a competitive advantage for companies who use blockchain for monitoring and reporting due to its immutability nature. Companies will be able to show a track record that they practice what they preach. The literature (section 3.3) described four types of competition that exist within a market. These are perfect competition, monopoly competition, oligopoly competition, and monopolistic competition. While a perfect competition is described as an unrealistic competition to achieve within a market because only one participant cannot alter the prevailing price in the market, monopoly deals with one seller dominating the market. Oligopoly is described as a group of sellers/producers who dominate the market with differentiated standardized products. Monopolistic competition is having many sellers with differentiated products selling in a market. However, (H) stressed the importance of creating a free market: with no competition restrictions or impositions from the government and allowing it to run on its own.

When it comes to the network effect that blockchain could have on the carbon market, Sustainability Advisor (H) argued that the case of Microsoft making bold commitments creates a network society phenomenon. The literature (section 3.1.2) described the impact of network society by Castells (2004) in which social structures of the society are shaped by digital communications technologies, thereby creating new social structures.
The effect of network also comes into play in the description shared by Blockchain Consultant (E) when it was mentioned that the use of a public blockchain is a better approach because a public network achieves greater network effect. Network effect as described in (section 3.1.2) is a phenomenon where a product or service gains additional value as more entities use it.

Other industries that could benefit from blockchain for carbon trading are the consumer and food industry, according to Business Manager (K). (K) gave Unilever company as an example stating that as the single largest consumer company, they are currently into carbon offsetting, planting trees in different parts of the world. (K) expressed enthusiasm in the possibilities of the company's interest to use a system as a blockchain for monitoring and reporting their carbon emission trading. That way surveillance of their many subcontractors, and their carbon trading transactions could be monitored, the expert added. For the food industry, (K) mentioned that the industry is responsible for about one-third of CO2 in Denmark and blockchain could potentially help cut their emissions.

Two experts particularly touched upon stakeholder's management. Blockchain Consultant (E) emphasized the importance of educating all the stakeholders involved in the network on how the system will work. According to (E), " *the decision maker, energy sustainability officer, CeO or the CTO, the regulators, from a top down basically need to make sure that they have knowledge of the technology and how it works at least at basic level*". On the contrary, the Vice president of market development (I) stated that stakeholders do not really want to know about the technology, they need to know that it works. The stakeholder theory described in the (section 3.3), suggested value creation for all stakeholders. The literature stated that the goal of stakeholder management is to create a method for managing various groups and relationships that leads to strategic outcome(s).

The last theme under the market system deals with cost. The three experts that shared their opinions around this theme touched upon how blockchain have an impact on transaction costs for energy companies. Program Director (H) was of the opinion that the transaction cost to participate in the EU ETS carbon trading is relatively expensive for low emitters of CO2. As such, it only makes sense for big emitters to participate in the EU ETS from an economic point of view. (H) stated that replacing intermediaries with blockchain will lower transaction cost and faster process results, but only for high CO2 emitters. Blockchain Consultant (E) viewed the reduction of the transaction costs as an incentive to use the technology for monitoring and reporting CO2 emission trading. (E) added that replacing intermediaries removes the reliability of human operators who are prone to making errors. The Vice President (I) also agreed with (E) about reduced transaction costs, especially the enormous paperworks being issued for contracts will get reduced. This aligns with the smart contract feature of blockchain as described in the literature ( section 6.2). Smart contracts are computer protocols intended to digitally facilitate, verify, or enforce the negotiation of a contract without intermediaries.

## 9. Data Analysis

Chapter 9 is the data analysis for the entire study. The chapter is divided into three broad parts: part 1, 2 and 3. Following the data interpretation (chapter 8), part 1 presents the current conditions and challenges of the energy industry identified. Using the conceptual framework (section 4.1), the network and stakeholder theories were used to help analyze the power relationship and stakeholders of the current system for monitoring and reporting $CO_2$ emission trading. Part 2 explains the technology perspective of blockchain implementation for monitoring and reporting carbon emission trading in the energy industry. Here, the requirement engineering process (section 4.2 of the study) was applied in the breakdown of the analysis. Part 3 presents the factors that might affect its implementation and how they can be mitigated. Here the market structure theory (section 4.3 of the study) was adopted. The research analysis presented in this chapter is not only that of the researcher but has been validated by experts in the industry in a post-expert interview after data analysis (see section 2.2.1 for details) and seen to be a concept that is feasible for monitoring and reporting $CO_2$ trading in the energy industry.

### 9.1 Part 1: Networked system of stakeholders: governance and power relationships

This section presents two parts: i) the current conditions; and, ii) challenges of monitoring and reporting $CO_2$ trading in the energy industry. The first part explains the conditions and shows the power relationships between the stakeholders within the network and the implications of these relationships. By applying the knowledge of the network and stakeholder theories ( section 3.1 and 3.2 of the study), the research was able to understand the governance and relationship between stakeholders and how this affects a wider social context. This understanding was useful for providing recommendations to address the current challenges of the current system which is the second part of this section.

### 9.1.1 Current conditions and procedures

The researcher mapped out the EU ETS mandatory program following the interview and its policy implementation. The reason for choosing the EU ETS framework for the study is because it is globally recognised for the implementation of carbon trading monitoring and reporting (European Commission, 2015). Also, it focuses specifically on CO2 specific emissions in the energy industry. Since the study is focused on the Danish market which is under the EU, it is in alignment with the EU ETS framework and "... *perhaps the best known example of a system that can facilitate trading of carbon credits and allowances*," according to the Senior Lead Originator at the energy company. The figure 4 below presents the main steps involved in the EU carbon monitoring and reporting of CO2 emission trading and the stakeholders involved in the process. The process model below was validated by the Program Director at CLI in a post-expert interview and feedback is documented in (section 9.2.4 under validation section of the study).

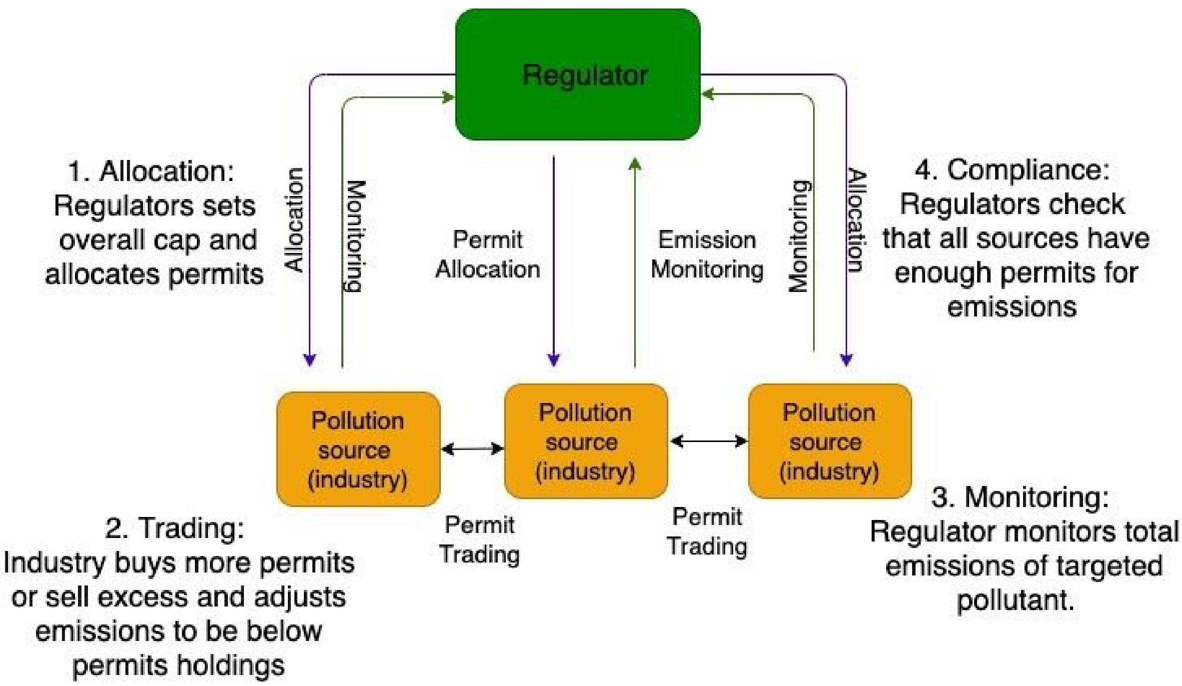


Figure 4: Current conditions of the EU ETS carbon trading program.

Source: Researcher's own work; adapted from: European Union (2015) and Duflo et al.(2010).

Figure 4 shows governmental oversight, which is the most relevant pillar of the ETS operations. The diagram is a representation of the researcher's understanding of what the current conditions of the EU ETS looks like. This is also part of the research findings which originated as a result of the researchers qualitative reviews of the EU ETS handbook, literatures, and the data interpreted in Chapter 8. The Regulator can be classified into two, the EU Commission and the Danish Business Authorities. For the purpose of this diagram, they were both emerged but these regulatory categories can be separate entities performing specific roles which will be further discussed in the stakeholder section (9.2.1.) below. The current market is highly backed up by regulators, hence the diagram. The regulators set the standards, and procedures of how the process should be carried out. They also verify compliance. However, they do not fix carbon emissions amounts for each energy operator. In other words, they set the cap and ensure that companies trade within that cap. Each energy operator is responsible for setting emissions and baseline targets for carbon emissions. The power of the regulator to mandate and 'control' the system is the type of power Castell (2011) referred to as " network power" (section 3.1). The regulators have the power to impose mandated rules and standards required to coordinate interactions and communicate within the EU ETS framework.

Other factors such as the amount of allocated allowances decreases over time are not illustrated in the diagram above but will be referred to below (section 9.2.3). For this research which will demonstrate the linkage of the carbon trading system with blockchain, the diagram is a simplified version of the research purpose and is sufficient for illustrative purposes only. In figure 4, the regulator has the overview of all the processes: allocation, trading, monitoring and compliance. The figure also presents four main areas especially important to fulfill the successful implementation of a carbon trading scheme in the EU. These are setting caps and allocation of permits, trading, monitoring, and compliance.

I) *Setting the cap and permits allocation*: This involves fixing a baseline target for aggregate emissions for the energy industry in order to produce reasonable prices and emission reductions. For the allocation of permits, the regulator distributes permits to the energy industry, to build support for the trading scheme. In some cases, permits are freely distributed in relation to baseline emissions under Regulation (EU) 2019/331 (section 5.3).
2) *Trading*: The trading of European Union Allowance (EUAs) is a fundamental part of the EU ETS. By using the cap and trade mechanism as described in (section 5.1), the system incentivizes companies to reduce their carbon emissions. Energy operators buy EUAs in order to later surrender them for the right to emit carbon or other GHGs. If they reduce

their emissions, they can sell the resulting surplus of EUAs and financially profit from reducing their environmental footprint.

3) *Monitoring of transactions*: The regulator ensures that the quantity of emissions from each industrial plant and/installations are continuously monitored. The Union Registry is also a functional part of the EU ETS where all transactions of European Union Allowances (EUAs) are stored. This remains a central database controlled by the Commission. It keeps track of ownership of Member States' EUAs within the system (European Commission, 2015).

4) *Compliance*: The regulatory framework also sets an atmosphere for the industry to comply with required standards set by the EU. The energy operator is required to comply with the monitoring plan and emission report. By law, the operator is also required to surrender its EUAs by the end of a compliance cycle, which is then rencolliced with its emission report already submitted. Once confirmed that the emission reported equals EUAs surrendered, a Document of Compliance (DoC) is then released, as an evidence of the company's compliance to regulation (European Union, 2015).

### 9.1.2 Current challenges of monitoring and reporting

***3) Lack of transparency and data reliability in CO2 allowances accounting***

Data reliability and the lack of a non-transparent process within the EU ETS is another condition identified. Some of the energy operators practice 'voluntary' self reporting of their CO2 emissions, while others are currently not participating in the EU ETS according to one of the experts (section 8.3). This is because they are waiting for the fourth phase of the EU ETS in 2021. The practice of self reporting or non-compliance opens the door to carbon cheating and corruption within the market. When it comes to data reliability in the verification of CO2 emissions, the EU ETS Verifier interviewed stated that the current process is manually done following the ISO 6976 calculator to check for missing data gaps. This process is a subject to overallocation or under allocation of emission data as a result of human errors and makes its validity questionable. Transparency and data reliability plays a key part in the implementation of the program and the fourth phase of the EU ETS (2021- 2030) should take these into account in the new program implementation.

Applying blockchain for monitoring and reporting CO2 emission trading leaves data transparent. The technology digitizes transactions by saving each of the transactions exchanged in a series of cryptographic blocks which is immutable and provides data transparency as described in (section 6.1 of the study). This process will not only bring transparency to the system but build trust, cooperation and communication between the stakeholders of the blockchain network. As such, a new form of network governance is established as a result of the technology, a modernized network society according to Castells (2004)( section 3.2). However, modern network society is not only formed by technology but cultural, political and economic factors also play a major role in the networked society. Another prudent solution for data reliability will be the application of a more advanced technology such as big data technologies. These are software-utilities that are developed to analyse, proces and extract data and information from a complex and large data set. From the data interpreted (section 8.3)  machine learning softwares like artificial intelligence and IoT sensors could also be used to improve data reliability by analysing and cleaning data before entering it into a blockchain ledger. This will have an impact in the overlap monitoring and reporting process of CO2 emission trading.

***2) Issue of double counting***

The Union Registry is a central database operated by the EU Commission that keeps track of the ownership of all EUAs in the system (European Commission, 2015). According to the (section 5.1.1), trading transactions between account holders occur outside the registry and the Union registry is only responsible for recording ownership of EUAs. In other words, the Union Registry does not register the price of EUAs or financial information related to transactions in the system. Also, exchange of international allowances outside the EU is not currently practiced, according to the Senior Lead Originator from the interview. Therefore it is not seen as an issue that needs to be solved in this case study. Since transaction records are not stored within the register, counting a transaction more than once is bound to occur.

The lack of financial information related to transactions creates the problem of double counting. From the data interpretation, multiple respondents from the interview, literature and case studies also pointed out the risk of double counting CO2 allowances already offset due to poor monitoring systems. This is a condition where multiple entities claim ownership of one single allowance's credit. When more than one allowance's credit becomes registered in more than one place, it does not provide additionality to the EU ETS program. The problem of additionality: as identified by one of the experts, is a current problem of the EU ETS, which has led to its criticism. Carbon trading is heavily criticized due to the level of environmental integrity when it comes to impact. According to the

Senior Lead Originator at the energy company, non-additionality issues have created discouragement of energy operators to participate in the EU ETS program since it does not justify a claim that trading CO2 allowances actually reduces emissions.

To solve the issue of double counting, one of the study experts suggested that it is better to have one standard registry for the allocation of allowances and not multiple registries. Additionally, through the application of blockchain technology, the issue of monitoring transactions and double counting can be mitigated. From the data interpreted (section 8.3), blockchain as a DLT can offer transparency and access control for monitoring and reporting data transactions entered into the technology, while managing corresponding adjustments within the system. Its immutability nature makes it difficult for information stored in the ledger to be altered or changed, creating room for accountability in the monitoring process. Similar to accounting, for monitoring of transactions to be successful, each accounting party should log transactions into one registry. This way all activities of the transaction can be monitored and easily tracked. Also the current system does not keep record of financial transactions related to the sale of EUAs. This takes place outside the registries as revealed in the data interpreted. For the technology to be applicable to the aspects of monitoring and reporting EUAs, the EUAs need a metric or a standard of measurement.

This metric must follow a procedure that can be expressed by a mathematical structure/algorithm. This mathematical structure will be the primary algorithm for a blockchain system under the EU ETS framework which is connected to the case study's emission registry. Each energy operator or transacting party can have their own algorithm or different parties can adopt a common algorithm. Under the EU ETS, an unlimited number of potential algorithms could be established. Each of the transacting systems will have a base-unit where the metric of the unit does not change, and that unit is clear and stable. If different types of credit units (CERs, AAU and RMUs) are entered into the system, a different algorithm would govern each type of units and determine their exchange rates. As such, blockchain can be used to establish different sets of algorithms with different units and conversion methodology. This will provide a clear and transparent way of transacting carbon credits, and eliminate any multiple entities having the same single credit: double counting. Once an issue of monitoring transactions is addressed, there exists the possibility to integrate the process with other climate action projects such as carbon green finance investments and carbon offsetting, due to the technology's transparent nature. However, the effectiveness of blockchain to solve the problem of monitoring transactions and double counting is dependent on a careful institutional set–up that is transparent and accountable.

***3) Lack of standardized methodology for calculating CO2 emission and compliance***

There exist over 200 methodologies for calculating CO2 emissions (described in section 5.5). Energy operators are allowed to choose a methodology that best suits them. In other words, every monitoring and reporting process for CO2 emissions by individual energy operators is different which results in different CO2 methodology standards, scope and processes. The lack of a standardized CO2 methodology creates confusion, sometimes repeated works if an operator is following more than one methodology and less credibility to CO2 computation. These disadvantages lead to disinterest of some of the energy operators to participate in carbon trading due to its cumbersomeness as revealed in the data interpreted ( section 8.3). Non participation equals non compliance to the mandatory EU ETS for Member States.

To address the issue of standardization, one global standard CO2 methodology should be adopted for the calculation of CO2 emission in the EU. This proposed solution is similar to what is already adopted in China as described in the pilot case study ( section 7.2). This standard should include process automation through smart contracts and optimization of all data needed to be able to compute CO2 emissions for the energy industry. The standard methodology should also include all necessary factors required to compute CO2 emissions e.g CO2 from manufactured steels for wind turbines for energy production, to its distribution.

***4) Carbon allowance over allocation and politicization***

From the literature (section 5.4), over allocation occurs as a result of economic crisis and industry lobbying of Member States within the carbon market. Despite the Council Decision 93/389/EEC of 24 June 1993 of developing monitoring mechanisms for CO2 for Member States in determining the total quantity of allowances to allocate ( as described in section 5.3), the challenge still persists. Member States have a great influence in the distribution of and allocation of allowances. Additionally powerful companies could be involved in lobbying allowances according to the Sustainability Advisor from the interview, especially high CO2 emitters. In order for these operators to maintain market dominance through monopolistic or oligopoly competition, credit allowances are raised high. This creates market barriers for new entrants as well as free competition within the carbon market system. Such power dominance of the market is what Castells (2011) referred to as networking power: the ability of an actor to include and exclude others, thereby controlling the makeup of the network (section 3.1.1). Furthermore, this power dominance by powerful actors could further constitute the re-programming of the network to fit the actors values and needs. It could take the form of strategic alliances between dominant actors within the network or other networks. This can lead to oligopoly competition ( as described in section 3.3). This other type of power in a network is what Castells (2011) referred to as network-making power.

A way to manage the problem of overallocation, is to introduce low allowance prices especially during economic recession that does not weigh heavily on big and small CO2 emitters in the energy industry, When the economy starts to grow again, the allowance price will slowly increase and operators will be better able to bear it. Subsidized carbon allowance prices  also be introduced as an incentive to encourage small emitters to participate in carbon trading. Also, an independent body such as the Independent Energy Agency (IEA), can be responsible for the distribution and allocation of carbon allowance after verifying that the stakeholders meet all criterias for carbon trading instead of Member States. This will remove the politicization of network power within the carbon market and allows small operators to compete freely.

Although, the study recognises that it could be difficult to predict business growth predictions for the economic boom: could also be optimistic and turn out lower than expected. Nonetheless, these are some possible solutions that could be explored.

### 9.2 Part 2: *Requirement Engineering (RE):* Technology perspective

As described in the conceptual framework ( section 4.2), the RE process will be guided by six main questions that are important to address objective 2. These are: i) who are the stakeholders involved? ii) what kind of power/relationships exist between them?; iii) what are the obligations of these stakeholders? iv) what is the document workflow?; v) what is the relevant data to look at in the system?; and; vi) what kind of blockchain will best fit the industry's needs and preference? Reflecting on these questions, part 2 presents the research analysis in four stages. First part is the elicitation and analysis. This part will be assessing if blockchain technology is feasible for the case study needs and challenges in the monitoring and reporting of CO2 emission trading.

This section will also mirror the pilot cases reviewed and blockchain literature following the conceptual framework (section 4.2). Following the analysis, the section will assess the kind of blockchain that will be best for the industry needs and demands. The second part presents a conceptual blockchain system for monitoring and reporting CO2 emission trading according to the said needs. This model will show the smart contract capabilities, and stakeholders mapping to achieve consensus. It will also present the type of data that will be stored in the proposed blockchain model. Third part will present the requirement specification for the proposed model. Lastly, the requirement validation of the model will be presented.

### 9.2.1 Elicitation and analysis

***Decision making process: assessing if blockchain is fitted for the industry's needs***

Assessing the suitability of blockchain requires proving that it can solve the needs of the organisations. In other words, the technology should bring an additional value for the organisation or industry integrating the solution. The table 5 below represents three scenarios of the decision making for the monitoring and reporting of CO2 emission trading in the energy industry. This table is based on the literature (section 6.6).

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| *Decision Making Process* | *Permissionless Blockchain* | *Private – Permissioned Blockchain* | *Public - Permissioned Blockchain* |
| Do you need to store data? | Yes | Yes | Yes |
| You can use a Trusted Third Party (TTP) that is always online? | No | No | No |
| Are multiple parties/writers involved? | Yes | Yes | Yes |
| Are all writers known? | No (public and permissionless) | Yes (Permissioned) | Yes (Permissioned) |
| Are all writers trusted? | | No | No |

| | | | |
|---|---|---|---|
| Is public verifiability required? | | No (Private) | Yes ( Public) |

Table 5 : Choosing the appropriate blockchain for CO2 emission trading.
Sources: Kravchenko (2016), Wüst & Gervais (2017) and Lo et al. (2017).

The table 5 represents six questions that must be answered to assess if blockchain can be applied to a specific case or not. The first three questions: Do you need a store data?; Are there multiple writers?'; and, You can use an always-online TTP addresses the monitoring and reporting of CO2 emission allowances. This is the main research question. From the first scenario, data related to CO2 emission monitoring and reporting should be stored in a database. Following the case study (section 7.4), there are five main data types that are accessed, organised and stored electronically within the database. These are: i) the national implementation measures; ii) accounts of operators, iii) companies allowances; iv) transfer of allowances; v) annual reconciliation of verified CO2 emissions and allowances.

For the second scenario, there will be multiple writers due to multiple data sources and stakeholders. Besides the regulators and the energy operators who are the main writers, there is the Authorised Verifiers who verifies emissions. For the third scenario 'You can use an always-online TTP?', the TTP will not always be online for a permissioned blockchain. On the other hand, there is no need for a TTP in a permissionless blockchain setting because the identity of writers is anonymous. The TTP issues authorized certificates because the identity of writers needs to be verified in a permissioned blockchain. Once writers are identified as trusted parties of the blockchain system, then TTP does not need to be online. Hence, TTP does not always need to be online.

The first three questions express the research focus as described in the main research question while the remaining three questions will be used to help identify the type of blockchain that can be used for monitoring and reporting CO2 emission trading. This will be based on some of the characteristics of blockchain as reviewed in the literature (section 6.6) such as anonymity and trust for the writers. The first scenario presented in table 5 above shows that if blockchain will be designed publicly (an unrestricted system), then writers do not need to be known. Such type of design qualifies as a permissionless public blockchain. Ethereum that runs on PoW is an example of this type of blockchain. The second scenario presents a private permissioned blockchain, where writers are known and public verification is not needed. This is a private permissioned blockchain. An example is the Hyperledger that runs on PBFT consensus. As revealed in the pilot case (section 7.1), having multiple writers in a system was a reason for leveraging blockchain.

From the IBM expert focusing on research and development at IBM, "*trust*" is the only reason and primary benefit of using blockchain over other technologies for monitoring and reporting. The pilot test case ( section 7.1) also showed that the absence of trust in the registry environment is a major reason for leveraging blockchain for carbon trading. The case study further stressed the importance of registries work with predefined sets of rules for all stakeholders, through the smart contracts without having to trust its counterpart. Multiple stakeholders from the interview also agree that blockchain is a trustworthy system. In addition, from the industry perspective, the Senior Lead Originator from the energy company recommended blockchain as a fit for the industry due to its traceability capabilities. Arguing that when it comes to financial accounting, and ability to trace back information, a technology as blockchain is a good fit since CO2 emission allowances tracked through blockchain cannot be used two times. This will solve the problem of double counting.

The blockchain Consultant (E), from the interview also mentioned that tokenization capabilities of blockchain: replacing a sensitive data element with a non-sensitive equivalent is an advantage for securing commercial and sensitive data. The technology can furtherly be used for monitoring and tracing green investments acquired from carbon trading and offsetting projects, as suggested by the Sustainability Advisor from the interview. The public permissioned blockchain is the third scenario which is set up in a way that writers are known before they are approved to join the network. As such, the writers are untrusted and public verifiability is allowed and required to complete each transaction. An example of such a blockchain is Ethereum that runs on Proof of Stake (POS) consensus. These points place blockchain in the position of recommending the technology to address the case study needs and challenges of the monitoring and reporting CO2 emission trading.

***Identifying the type of blockchain for* monitoring *and reporting CO2 emission trading***

In order to assess the kind of blockchain that will fit the industry and technology needs of monitoring and reporting CO2 emission credits, some factors will be discussed below.

These factors are based on the literature reviewed and the data collected from the expert interviews as it relates to the research focus. Discussions will be based on permissioned vs, permissionless, and private vs public type of blockchain. From the previous analysis, it can be argued that blockchain can be adopted for monitoring and reporting C02 emission trading. The information above shows that the technology can store data, and there will be multiple writers in the system. Also TTP is not always online and writers are not trusted. This decision process was also validated by one of the blockchain experts who was interviewed for the study. From the interview and literature, the researcher confirmed that blockchain can be used for monitoring and reporting of CO2 emissions trading, particularly with the use of smart contracts features. This section will focus on identifying whether the blockchain to be adopted will be public/private, as well as permissioned/permissionless blockchain. The table 6 below represents the data gathered from the data interpreted (section 8.3) . This table describes blockchain technology, the industry's challenges and demands, insights, and the blockchain to meet these needs.

| Factors | Private Permissioned | Public Permissioned | Public Permissionless |
|---|---|---|---|
| Industry preference: transparency and confidentiality of data | Confidential data is only transparent to the members of the network and defined data set that can be open to the public.<br><br>Confidentiality of commercial information on CO2 methodology and reports are preserved. | Transparent public data on CO2 transactions and reports and CO2 allowances accounting. | Transparent public data on carbon transactions and CO2 allowances accounting.<br><br>Transparency is beneficial to carbon markets because if makes people feel comfortable and are likely to transact |

| | | | |
|---|---|---|---|
| Technology perspective: Privacy and anonymity | Generally, only members of the blockchain network can read, write and verify transactions.<br><br>The blockchain network can have two layers: a central layer and a decentralized layer. Only the main writers will have access to the network. | The public can join the blockchain network with a Proof of Stake (POS) consensus for verification purpose before joining the network to transact.<br><br>PoS method is more sustainable in terms of energy consumption compared to the Pow. | The public can join the network, but this will require computer processing power to confirm carbon transactions (through mining).<br><br>Pow consensus is unsustainable due to its high energy consumption and also known to be costly. |

Table 6: Blockchain possibilities for monitoring and reporting CO2 trading according to industry needs. Sources: Friebe (2017); Regulation (EU) 2018/1999 of European Parliament; study interviews.

From table 6, there are three choices to choose from in the possibilities of using blockchain for the industry. These are private permissioned, public permissioned and public permissionless blockchain. In the interview with the Blockchain Consultant (E), it was stated that Ethereum as a public blockchain is a better choice due to its network effects. Also due to its already established community of Ethereum developers that can provide support. Additionally, the community is working on improving the PoW consensus mechanism away from the PoS which is seen to be unsustainable and consumes a lot of energy during mining. Although PoS is still under development as it has some setbacks as the higher the stake a person has within the network, the greater chance of this person to validate a transaction, which serves as an advantage to collect more transaction fees. This works similarly to when stocks are purchased and held in an investment market, to be later sold at a higher fee. This can create imbalances within the network which Ethereum developers already recognise this issue. This is why there is a continuous research for the PoS consensus for better development.

In the information gathered from the energy industry perspective, response was in regards to choosing a private or a public blockchain and not permissioned/permissionless blockchain. With the exception of the current challenges faced in the industry, energy operators should provide fully transparent emission data as well as reports to show additionalities when a trade is made. In such a case, a public blockchain (permissioned or permissionless) can be used. However, with the current conditions and challenges of the industry, a public blockchain will not fit the industry preferences or demands. According to the interview, the stakeholders from the energy industry are committed to share sustainability data in a transparent way as it gives a competitive advantage to be at the forefront of reducing CO2 emissions in the industry.

Also, the energy company mentioned that its recent commitment to reducing CO2 is not due to regulation but voluntary, as they believe it is the right thing to do according to the expert interviewed. Although, some stakeholders may not be willing to fully share their sustainability data in a transparent way to the public. In terms of regulation, it is stipulated in Regulation (EU) 2018/1999 (section 5.3), Member States shall make available to the public comprehensive information concerning the parameters and methodologies used for calculating CO2 emissions, taking into account data restrictions, commercially sensitive data and compliance with data protection rules.

To fulfil this type of privacy and confidentiality needs of the industry, it will require the usage of a private-permissioned blockchain such as the Hyperledger fabric. This is because Hyperledger, as opposed to a public blockchain, is restricted and only verified members have access to data stored and can control the level of privacy within the network. In the interview with the IBM expert in research and development, a Hyperledger blockchain was recommended. This will best fit the current conditions and needs, as well as stakeholders preference for carbon trading. From the literature (section 6.5), Hyperledger uses the PBFT consensus mechanism, and is a private blockchain with permissioned and smart contract capabilities. Also, it consumes less energy in its consensus mechanism, making it more sustainable, compared to Ethereum PoW. This can be one of the blockchain choices that fits the proposed conceptual blockchain model for this study.

A feature of the DLT is that it is specially developed not necessarily for exchange of value or money transactions as it has no native currency, but for monitoring and recording of transactions. From a pilot case (section 7.2), Energy Blockchain Labs, uses the Hyperledger due to the network capabilities of allowing collaborations with only permissioned parties in a transparent manner. Leveraging its smart contract capabilities, over 200 carbon asset methodologies have been compiled into the Hyperledger blockchain for calculating allocation of allowances for companies that need to reduce emissions in China. This way, stakeholders can easily track their carbon footprint and better understand when to buy or sell in the carbon asset market. Regulators, on the other hand, can easily monitor progress against quotas to ensure that carbon reduction goals are met by participants.

Both pilot cases reviewed in the study adopts the permissioned and private mode of operation of blockchain for carbon trading which uses smart contracts and can be controlled in a closed system. Also, in the interview with the Program Director at CLI, combining a hybrid system (centralized and decentralised layer) was suggested. The centralised system will be operated by the regulator and Member States will be connected to the network. While the decentralised layer will be opened to the public or inter-states outside the EU. However, this case study is focused on Danish energy operators within the EU and not states outside of the EU. As such, only one central layer will best fit the industry specific needs and focus of this study. However, for this study, it will be useful to have two connection types within the Hyperledger network: an 'on-chain connection layer' and an 'off-chain layer.' On-chain transactions are digital transactions that occur **on** the blockchain network, while the off-chain ( as described in section 6.6) will hold information stored outside the network. When it comes to allocation of allowances, acknowledgement of allowances and units, generation and distribution of equivalent token credits (with different characteristics), and registry account management, it would be managed on-chain. Stakeholders that will have access to this layer include the EU Commission, Dansh Business Authority and authorised representatives of the energy operators. The 'off-chain layer' will contain information and non-sensitive data that will be made accessible to the public.

***Hyperledger Fabric***

When it comes to the industry preference and needs, there are different factors to consider in order to choose a blockchain type that will compliment its value proposition. Most companies will like to maintain privacy and confidentiality of transaction data for security reasons. The Hyperledger Fabric provides these characteristics mentioned. The DLT is an offer a permissioned network with an integrated security architecture for authentication and authorization. As described in ( section 6.5), Hyperledger is built on a modular architecture that allows for adjustments and addition of further functions, making it more scalable and can be configured for confidentiality and security of transactions. This possibility is enabled by its smart contract feature for distributed applications. For a permissioned Hyperledger, a legal agreement is entered through the smart contract to govern the network participants.

In the pilot case ( section 7.2), it was also revealed that this digital feature promotes collaboration across participating parties. Its consensus mechanism: PBFT, also consumes low energy compared to Ethereuem's PoW. As such, Hyperledger will be used by the researcher for the conceptual model design of the study. This is due to the fact that it caters for the study's needs when it comes to confidentiality and privacy of data transactions required by the stakeholders. Furthermore, its characteristics such as scalability, modularity, security and low energy consumption bring value to its implementation for monitoring and reporting CO2 emission trading. Its smart contract capabilities also allow the verification of transaction compliance and will be useful for monitoring and reporting.

***Smart contract feature and capabilities***

The study will be built on a permissioned blockchain, Hyperldger fabric which has a smart contract feature. The Hyperledger's smart contract will play an important role in the implementation of the conceptual model for the study. Simultaneously, it will address the challenges of the current EU ETS implementation. The smart contract as described in (section 6.2) is an agreement between two or more parties in the form of a computer chain-code. They are typically computer protocols that digitally facilitate, verify or enforce negotiation of a contract without the middleman. They also include features such as data analytics for creating and visualizing graphs as well as monitoring metrics in real-time. Already, (section 9.1) describes the current conditions and challenges of monitoring and reporting CO2 emission trading under the EU ETS. Applying the smart contract feature in blockchain, some processes and stakeholders can be removed in the current implementation process of the framework. Figure 5 below shows a new process flowchart that describes the stakeholders and their roles implemented on a blockchain and how smart contracts can be utilized. In the figure, the entities described have a predefined function and flow whereby communication and transactions can be done without a TTP. This will also cut down transaction costs.

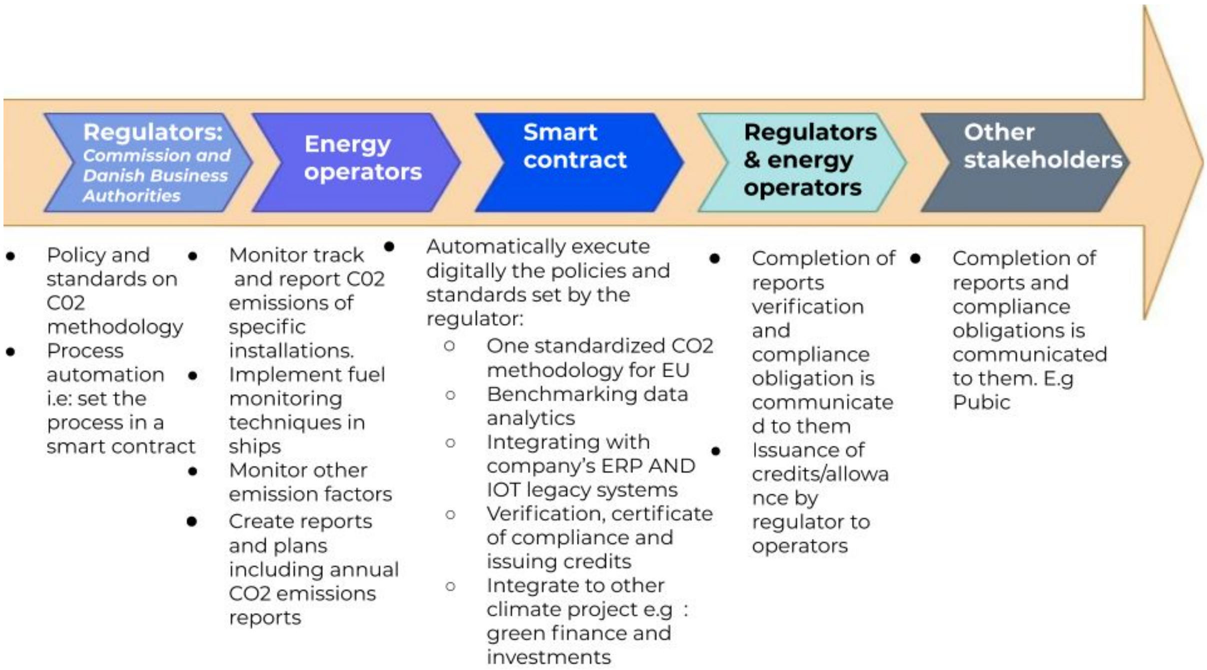


Figure 5: Flowchart of a smart contract feature and its role in the monitoring and reporting of CO2 emission trading. Source: researcher's own work. Adapted from Tabirao (2018).

As seen from figure 5, the general function of regulators will be to set all the policies, standards and define the system and process implementations, ensuring the country meets its energy and carbon targets. The summary of the figure above is that energy operators should use one global system which complies with a standardized methodology to submit their emission reports which complies with the CO2 sustainability obligations under the EU. These operators could also integrate some of its company legacy systems like Enterprise Resource Planning (ERPs) and/or IOT systems used by its other suppliers/stakeholders. E.g will be IOT systems used in ships which are used to transport steels for wind turbines. This is then connected to the global system for the monitoring and reporting of emission data, whilst being transparent and reliable. This process can also be used to create templates and reports for compliance. Data submitted by the energy operators is then processed in the smart contract. Following the regulatory policies and standards, the smart contract will be able to process monitoring and reporting functionalities. It will contain the: i) one standardized CO2 methodology for calculating CO2 emissions ii) Easy integrating with companies legacy systems e.g Enterprise Resource Planning (ERP) systems, IOTs and and other technologies; iii)verification of emission and issuing carbon allowances ; iv) integration with other climate action projects e.g green investments and finance (below is a detailed explanation).

The process of verifying $CO_2$ emissions submitted by energy operators, checking monitoring plans and annual reports, certification of document of compliance and issuance of allowances is performed through the smart contract. This documentation process is then disseminated to all relevant stakeholders. As such, the use of the smart contract eliminates an intermediary or a Trusted Third Party (TTP) within the network. According to the Program Director working at CLI: the pilot case for this study, blockchain smart contract "... *removes the middleman and saves transaction cost*". However, the implementation of blockchain with a smart contract feature will require educating and creating awareness on how to use the technology, according to multiple stakeholders from the interview. Below is a more detailed information about how the smart contract feature will address some of the current conditions and challenges of the EU ETS framework as described in the figure 5 above.

*i) One standardized system and method for calculating $CO_2$ emissions*

To address the issue of standardization and compliance, one global standard system and method for $CO_2$ computation should be adopted in the EU. The system should include process automation: use of digital technology to perform a process, and optimization of all data needed to be able to compute $CO_2$ emissions for the energy industry. On the other hand, the standard methodology should include all necessary factors required to compute $CO_2$ emissions, e.g from manufacturing steels that produce energy to its distribution. The creation of such a $CO_2$ methodology could be guided by benchmarking functionalities to serve the purpose of $CO_2$ emission calculations. The advantage of having a standardized method in the industry is that it eliminates confusion and provides a framework for the verification of GHG inventories including $CO_2$. This gives more credibility in the $CO_2$ emission data and GHG-reduction process. This way, it is easier for companies to automate their process and compliance can be easily achieved. In the interview with the Senior Policy Advisor at the energy company, "... *maintaining a standardized reporting of emissions from suppliers and sub-suppliers will be a precondition for suppliers to work with us.*"

*ii) Integration with companies legacy (ERPs), IOT systems and other technologies.*

Blockchain and its smart contract feature should be implemented in such a way that it can be easily integrated with existing systems within the energy industry. It should be simple whilst providing reliable and trustworthy data. This will make the system easily adaptable and easier to use for both the operators and its subcontractors e.g ship operators and turbine manufacturers. As such, this will provide a competitive advantage for the energy operators, according to the Program Director at CLI. Data such as combustion of steel in manufacturing wind turbines, and CO2 emission from coal and gas burning can be derived directly from the energy operators and subcontractors through their systems.

Additionally, other data that can be derived from company legacy systems are the distance traveled, fuel consumed etc, from ship operators who help transport wind turbines for the energy industry. Also, technology such as machine learning: artificial intelligence and data analytics can be integrated in the process of verifying emission rights . According to the Vice President from the interview (I), "...*machine learning and data analytics could play a role in cleaning the data entered on the blockchain network which affects the overall outcome of carbon trading*." While the Program Director at CLI mentioned that the combination of blockchain with machine learning and IOT creates a "... *huge impact"* in fostering a robust carbon trading system. In the expert words "... *artificial intelligence and machine learning can analyze the data generated by IOT and, excerpt, certain patterns and findings to see the effect on carbon emissions*."

*iii) Verification of emission rights and issuance of emission credits/allowances*

Once a standardized methodology is established for verifying emissions, a verification and agreement of carbon emission rights platforms can be interlinked with policy segments in the smart contract. Energy operators should be able to input monitoring plans and emission reports into the system. Simultaneously, the smart contract already programmed by predefined sets of algorithms should be able to assess and verify if submitted reports are in compliant with the CO2 methodology and regulatory standards. A certificate of compliance (DoC) is then released after the verification process is completed. This serves as a proof of compliance to mandatory regulations. Such reports can then be shared to respective stakeholders.

After certification is complete, carbon token equivalents are generated and distributed to respective operators in a form of allowances. These tokens could be commercialized as an asset in an open exchange carbon market where token owners can sell it to consumers to offset emissions. This will take place on the permissioned on the on-chain blockchain layer as described above. The governing body will ensure that the amount of actual credits and emission units matches the total amount of tokens generated on the on-chain layer. The study recognises that the middleman will not totally be eliminated especially at the developmental phase of implementing blockchain for monitoring and reporting CO2 emission trading. This is because it will need time for a gradual transition and enhancement of the smart contract rules settings and establishing token specifications etc. The first phase of adopting the technology will require a proper work issuing credits and accounting for them, which will require humans overseeing this. Also, because the participating stakeholders will need some time to learn about the technology before a full transition to using it.

*iv) Integration with other climate action projects e.g green investments and finance*

There is also the possibility of integrated certified emissions of energy operators in other climate action programs. Examples of such integration is the Danish energy Agency involved in matters relating to efforts to reduce CO2 emissions from the energy industry in Denmark. Companies data represented through a reliable and trustworthy system as blockchain will contribute to the data quality when it comes to calculating factors like company's carbon targets and total carbon offset. Furthermore, a transparent system using a smart contract feature in blockchain will mitigate fraudulent activities within the network. This in turn is beneficial to not just the Danish carbon markets but on the national and global level of reducing carbon emissions.

***Stakeholders analysis: their roles to achieve consensus***

Following the conceptual framework (Chapter 4) and to address the main research question, the figure 6 below looks at the main stakeholders and other connected stakeholders involved in the carbon trading emission for the case study: Danish emission trading system.

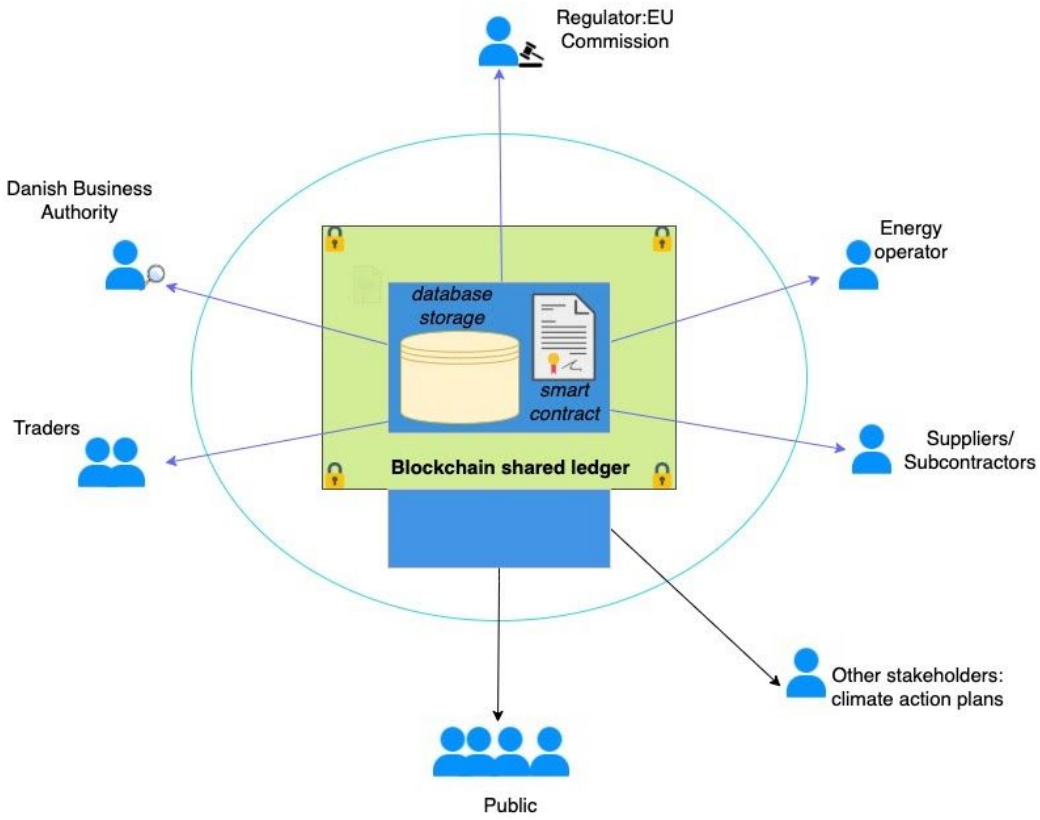


Figure 6: Stakeholders analysis to attain consensus through blockchain smart contracts . Source: Researcher's own work.

From figure 6, the identification of relevant stakeholders is based on the data interpreted (section 8.3) and EU ETS policies. To be able to design the blockchain system, the design of the DLT, stakeholders and their roles in the network must be defined. Figure 6 is a representation of the researcher's understanding of what the relationship and connections of stakeholders will look like in a blockchain shared ledger system. This is also part of the research findings which originated as a result of the researchers qualitative reviews of the EU ETS handbook, literatures, and the data interpreted in Chapter 8. From the figure 6, there are a total of seven stakeholders of which five are main stakeholders (icons above). These main stakeholders include: i) the EU Commission, ii) the Danish Business Authority, iii) authorised representatives of energy operators; iv) traders; and v) public.

*i) Regulator: The EU Commission:* One of the primary parties of the network is the EU Commission who acts as the regulator. The Commission creates and implements the standards as well as the processes of the carbon trading system under EU jurisdiction. Their main responsibility is to set annual allowances caps in order for the emission reduction goals to be met by Member States. As a governing body of the network, it will be centrally responsible for designing and deciding the functionalities of the smart contract as seen in figure 6 whilst ensuring Member States are compliant.

ii) *Danish Business Authority:* This stakeholder represents the state: study's case which is Denmark, and is responsible for overseeing the affairs of the registries. Activities such as accounting of credits issuance, holding, transfer, acquisition, cancellation and retirement of EUAs. It is also responsible for managing the carryover of ERU'S, CER's, and AAU's transactions in the emission registry.

iii) *Authorised representatives of the energy operators:* They legally have the right to access and change confidential data in the registry. This includes data such as reported emissions or performing a transaction. On an annual basis, operators are mandated to submit an emission report under the EU MRV sustainability program (as seen in section 5.2). This will be verified by the smart contract that it meets predefined conditions as already defined in the contract. However, the researcher is aware that setting standard computational algorithms for the verification of CO2 emission reports within smart contracts may take some time to fully scale since blockchain is still evolving in terms of scalability (section 6.8). Also, stakeholder's need to be educated about blockchain and acceptance, as pointed out by multiple experts from the interview which will take some time (section 8.3).

iv) *Traders*: These are other industries under the EU ETS such as aviation and maritime. They are also consumers in the system of the EU ETS. Like the energy operators, they can buy and sell EUAs. In most cases, industries buy EUAs in order to later surrender them for the right to emit GHG (Danish Business Authorities, n.d). Traders are substantial stakeholders of the system because they determine the market structure through the activity of buying and selling permits, harnessing forces to find ways of reducing carbon emissions.

v) *Public*: They are part of the main stakeholders because it is mandated by law following Regulation (EU) 2018/1999 9 9 as described in section 5.3). However, they will be connected through an off-chain layer of the system. This means that only public and non-confidential data required by law will be shared with the public.

*Other stakeholders*

The consensus mechanism in figure 6 above also considers adding other stakeholders such as energy suppliers/subcontractors, investors, climate action plan: Danish energy agency and NGOs. This is because they play a vital role in the energy industry, and it's contribution to CO2 emissions reductions and sustainability. For example subcontractors such as a steel manufacturing company that produces wind turbines for an energy company plays a role in reducing its emissions. Also ship vessels responsible for transporting these turbines to installation sites is another example. There is a possibility to include these stakeholders in the blockchain network where they can submit their monitoring plans and emission reports based on the predefined smart contract standards in the system. Other stakeholders can also be connected off-chain for the purpose of 'keeping them in the know.'

These are the identified stakeholder necessary for the implementation of a conceptual blockchain system for monitoring and reporting of carbon emission trading in the Danish carbon market. The above set-up is considered a shared and distributed ledger system. The set up in figure 6 shows that not all stakeholders within the network will have the same access to all the data in the network as explained. A private permissioned blockchain will be used in this study. This means that data sharing, communication and transactions will be customised based on data privacy and confidentiality clauses of each stakeholder following data protection rules as defined by the EU (section 5.3).

### 9.2.2 Blockchain conceptual model

**Process flow and networked (PFN) blockchain format**

The blockchain conceptual model in this study is represented as a diagram showing the process flow and network connections of the stakeholders in the system. This is otherwise called a Process Flow Network (PFN) model. This system consists of two stages in the monitoring and reporting of CO2 emission trading. The first stage is the EU Monitoring Reporting and Verification (MRV) process of CO2 emissions, and the second is the CO2 trading process. In the model, the collaborating stakeholders, their relationships, roles, smart contract capabilities, document workflow, and shared ledger are also represented. The study used different symbols, shapes and notations to distinguish the semantics, and show the relationship between each stakeholder and how they exchange data within the system.

The first figure 7 below specifically focused on the MRV of CO2 emissions is the mandated process carried by the energy operators and relevant stakeholders before they are eligible for trading carbon allowances (as described in section 5.2). The second phase ( figure 8) is the carbon trading process that shows the relationship between the stakeholders, trading, roles, smart contract capabilities, document workflow, and shared ledger. In the PFN blockchain model ( figure 7 and 8), all stakeholders are vertically represented from bottom to top, while the business process and roles are represented in a horizontal direction from left to right. This is a swim lane representation where each specific lane is performed by a specific stakeholder within the system. The smart contract runs most of the processes in the system and is represented in the swim lane called the 'blockchain shared ledger and smart contract.' The padlock symbol represents the restricted access in the system. Generally, the upper part of the model represents the milestone of the process in the PFN model, which is the completion of a monitoring plan, emission report and document of compliance (DoC). Both figures 7 and 8 are explained in more details below.

**First stage:** ***EU MRV process flow and networked system based on blockchain***

Figure 7 below represents specifically the EU monitoring reporting and verification (MRV) based on blockchain. Given that there is only one standard MRV system, all stakeholders have an account and access to their account as defined in the stakeholder section above. The first step is that the regulator: EU Commission, creates the standards and policies on GHG inventories including CO2 emissions for the energy industry under the EU ETS. As such, the regulator is also responsible for defining the agreement in the smart contract as well as the data types and functionalities, algorithms and the trading process. All this data is defined and inputted in the shared ledger of the blockchain system. The smart contract feature is very vital in the shared ledger because it is digitized, as such, automates processes, document workflows, CO2 computations, data gathering from the different integrated systems. The function of the Union Registry and EUTL as described in (section 5.1.1) is replaced by blockchain shared ledger and smart contract capabilities respectively. The shared ledger records the accounts of the energy operators and relevant other stakeholders (e.g climate action initiatives). The smart contract with predefined standards and algorithms, automatically checks, records, and authorises all transactions that take place between accounts in the system. This verification is to ensure that transfers of allowances from one account to another is consistent under EU ETS rules.

Following the templates and mandates set by the regulator in the smart contract, the energy operators then create and log their monitoring plan in the blockchain shared ledger system. A monitoring plan is submitted by the operators in the MRV system and the smart contract verifies the validity of the data. At this point, the smart contract replaces the job of the Authorised Verifiers, who are stakeholders in the current EU MRV system as seen in (section 5.1.2). The smart contract detects whether the data is accurate or not based on predefined algorithms and set standards. If the data is not accurate, the energy operators are notified to revise the monitoring plan. If data is verified to be accurate, the system then processes and releases the monitoring plan to the relevant stakeholders such as the regulators and energy operators.

The algorithm in smart contracts is used to perform different functionalities. Such functions include having one standard CO2 methodology, integration with companies ERP and IOT systems as described in ( section 9.2.1). The smart contract is also responsible for creating, verifying and validating certified transactions as well as documentation, and can be integrated into other climate action plans. The verified monitoring plan represents a proof for the operators to submit their annual emission report as defined by set rules and deadlines in the smart contract. Details such as the installations from CO2, emissions from manufacturing steels, travel emissions from transporting wind turbines for energy generation, etc. is submitted. The model also shows the possibilities of energy operators partners such subcontractors, suppliers and ship vessels to add their monitoring plan and emission reports directly to the system based on smart contract predefined agreements. Emission reports are then verified by smart contract. If it does not meet predefined rules, the relevant stakeholders are notified to revisit and revert. If the report meets the set standard and proven to be accurate, the smart contract then verifies and releases the emission report. After the process of verification is complete, the smart contract then generates and releases the Document of Compliance (DoC). This is a certified document to show that the energy operators or companies are compliant to the EU MRV program under the EU ETS. Other documents such as monitoring plans, emission reports and DoC are processed by the smart contract and then released to the different stakeholders within the network. Documents can only be modified by any of the stakeholders based on the type of access granted as predefined in the smart contract. Stakeholders such as the public can be connected to the blockchain network based on an off-chain connection as described in (section 9.2.1) where they only have access to view the documents only.

Given that the model is built for the study's case: Danish energy industry, on the national level, stakeholder such as the Danish Business Authority is also included in the network flow. It will be responsible for overseeing and ensuring proper functioning of the system especially and to help maintain flexibility regarding ETS events like allocation of allowances or acknowledgment of offset units especially in the early stages of its implementation. It is considered as part of the stakeholders in this conceptual model based on the feedback from the interview. Multiple experts stated that it will take some time to learn about the technology, as well as adaptation and its full acceptance. As such the early stages of the blockchain model will be a learning phase for the stakeholders. Figure 7 below represents the process flow and network structure for monitoring and reporting of CO2 emissions before energy operators are eligible for trading carbon allowances under the EU ETS framework.

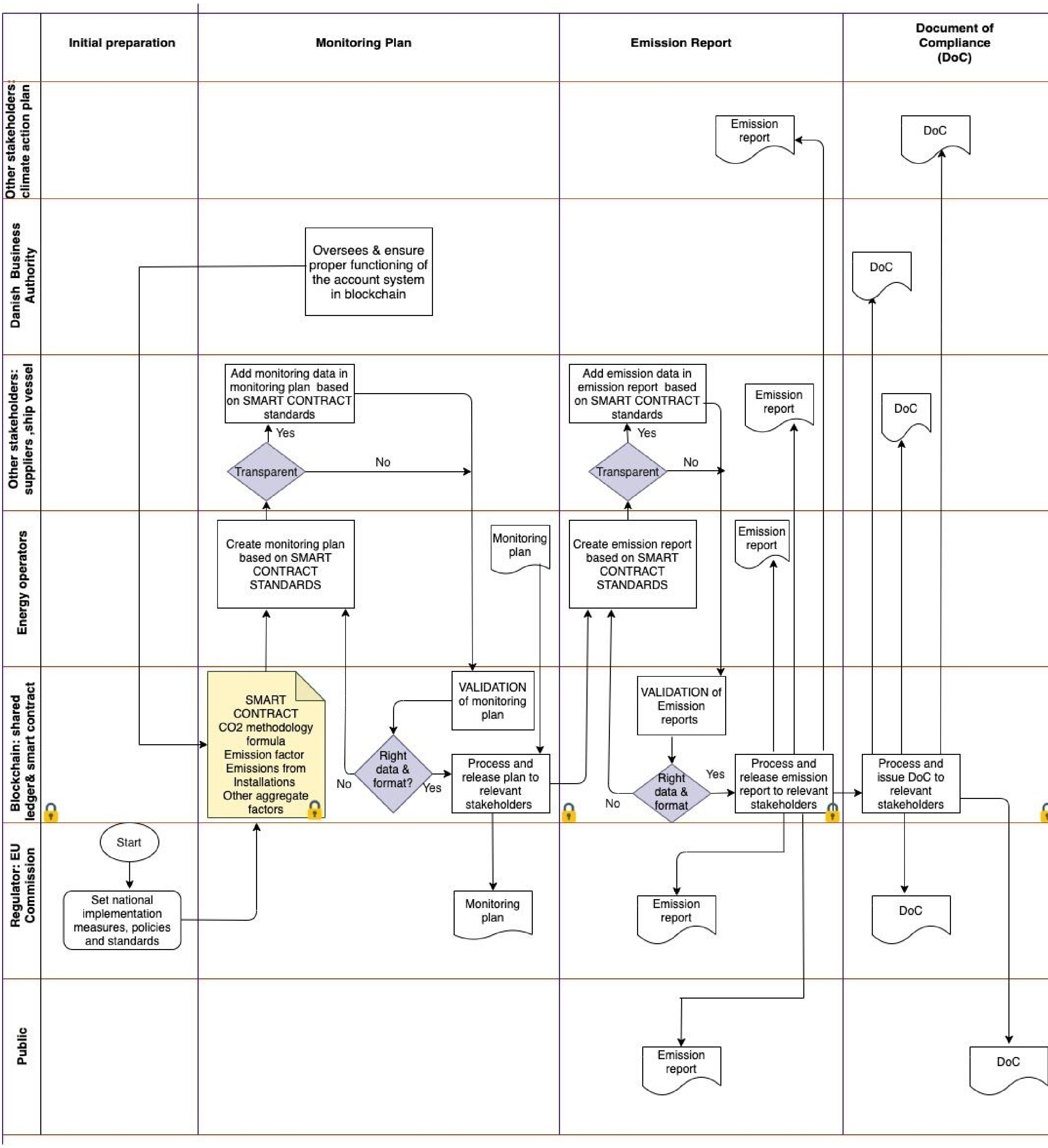


Figure 7: First stage - The EU MRV process based on a blockchain system

Source: Researcher’s own work.

***Second stage: Carbon emission trading process.***

The second stage shows the trading and documentation of carbon allowances in the form of EUAs. After the energy operators have completed the process of the MRV program and a DoC is released, operators become eligible to trade carbon allowances in the carbon market. The second phase begins with the regulator setting the overall caps and allocating credits in the form of EUAs to the industry. The regulator defines the type of carbon allowance which will be represented in the form of tokens. Based on the literature ( section 7.4) for Denmark, only EUAs such as certified emission reductions (CERs), assigned amount units (AAUs) and removal units (RMUs) are allowed to be traded. EUAs after being defined are then stored in the shared ledger as 'tradeable tokens'. Energy operators are able to trade their assigned credits in the form of tokens and transfer ownership from one party to another. The blockchain model below also shows the possibility of integrating other traders involved in the buy/selling and auctioning of allowances as well as other EU Member states in the trading process. This will require a hybrid layer of a decentralized and centralized system for an effective implementation process as suggested in the pilot case reviewed ( section 7.1 of the study). However, the study's case is on the Danish energy industry, thus the model represented below is sufficient for the study. All transactions performed within the network are stored in the shared ledger and financial information is recorded for the purpose of monitoring transactions just in accounting. As described in (section 9.2.1 of the study), data can be linked to pseudonyms (public keys) on the blockchain network for privacy purposes.

Once the trading process is complete and transactions are recorded in the ledger, the operators surrender their allowances following the predefined standards in the smart contract and the deadlines stipulated in the contract. Surrendered EUAs are recorded in the ledger and ready to be reconciled. As described in (section 7.4 of the study' case), surrendered allowances must match the actual CO2 emitted by the company. To verify this, the smart contract verifies that the emission report submitted in the MRV process matches the actual CO2 emitted by the operator as agreed in the smart contract. If the data is inaccurate, a penalty is issued such as fines and energy operators are notified. If verified to be accurate, the system then stores this information for the next carbon trading cycle. Figure 8 shows how blockchain can be used for the monitoring and reporting of carbon emission trading in the Danish energy carbon market. The data sets for the system are given in the data type section below.

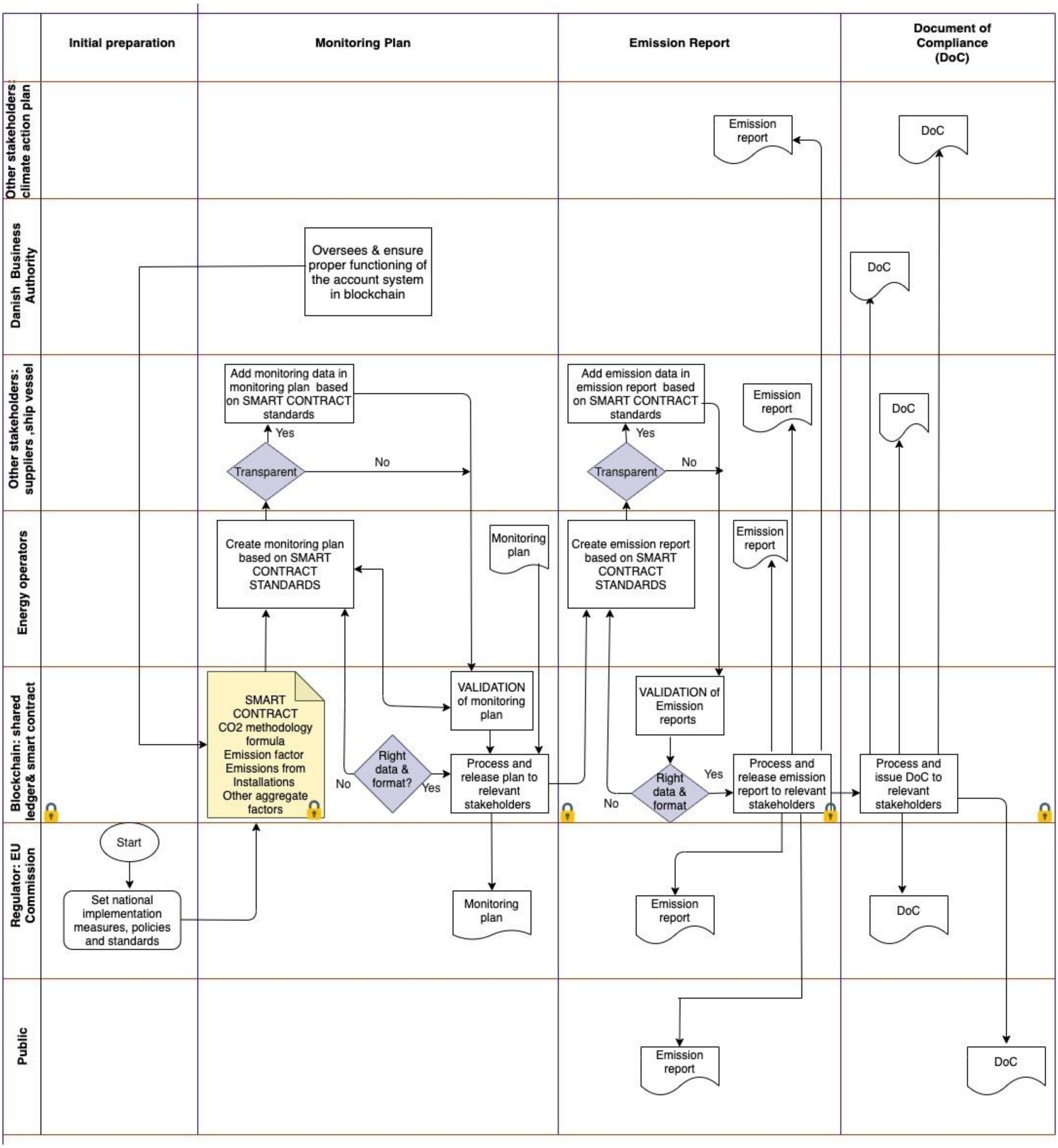


Figure 8: Trading CO2 allowances based on blockchain system

Source: Researcher’s own work.

***Data type to be stored in the blockchain-based system***

For the proposed blockchain PFN system, it is also important to understand and define the data that will be entered into the system and tailor it to the industry needs of confidentiality and privacy. The factor of privacy and confidentiality as described in (section 9.2.1) are pertinent for benchmarking the type of data that will be shared between the network participants. There is a need to take into account the type of data that will be accessible on-chain and the data that will be available off-chain as described previously. Table 7 below represents the type of data to be included in the blockchain model of the study.

| # | Data type | Description |
|---|---|---|
| 1 | National implementation measures | A list of installations covered in the ETS Directive in each EU country. It also contains any free allocation to each of those installations in the third phase (2013-2020) |
| 2 | Accounts of companies or individuals holder with allowances | This includes energy operators, individuals or groups that are participating in carbon trading under the EU jurisdiction |
| 3 | Transfer of allowances | These are transaction performed by account holders that shows the movement of allowances from one another to another |
| 4 | Annual verified CO2 emissions from operator's installations | These are annual reports submitted by energy operators and will be verified by the smart contract based on predefined rules. |
| 5. | Annual reconciliation of allowances and verified emissions | This is the process of matching permitted allowances for emissions and surrendered emissions by the companies. After the Danish Business Authority has verified emission data, the operators are obliged to surrender the requisite number of allowances to cover their emissions by end of April every year. |
| 6. | Financial data | These are information related to the sale of carbon allowance such as date, time, amount etc. |

Table 7: Data in the blockchain conceptual system for Danish CO2 emission trading.

Sources: European Commission (2015) and researcher's own work.

From table 7, the first five types of data are currently stored within the emission registry as described in (section 7.4.3 of the study). These are i) national implementation measures: accounts of companies or individuals holder with allowances, transfer of allowances ; iv) annual verified CO2 emissions from operator's installations; and annual reconciliation of allowances and verified emissions (European Commission, 2015). To implement blockchain design that monitors and reports carbon emission trading while meeting the industry needs, it is important that the architecture provides full information about the transactions in the system for the purpose of accounting . This is not the current situation as reviewed in (section 5.1.1 and 7.4 of the study).

Providing data such as financial information (as described in table 7) related to the sale of credit allowance will enable transactions performed within the system to be more transparent and allowances can be easily monitored and accounted for. For privacy concerns following the rules as stipulated under Regulation (EU) 2018/1999 ( section 5.3), confidential data can be protected using pseudonyms while non-confidential data can be shared off-chain. Also linking off-chain information about account owners to their pseudonyms (public keys) on the blockchain network could also be adopted depending on the stakeholders needs and preferences.

### 9.2.3 Requirement specification and documentation

The scope of this study is not to provide an actual working prototype as described in the scope of the study (section 1.5). As such the research will cover the functional requirements for the blockchain architecture to be implemented for monitoring and reporting CO2 emission trading as described in the conceptual framework ( section 4.2). The functional requirement will provide basic functionalities for transferring, trading and surrendering allowances within the blockchain system as (described in figure 7 and 8). There are five specifications that must be fulfilled for the implementation of the proposed blockchain system. These requirements are: representation of the EUAs, inclusion of a linear reduction factor, recording of transactions, stability of EUAs supplies, and an auctioning mechanism.

**R1**: Representation of EUAs : The proposed solution needs to include a representation of EUAs on the blockchain that can be transferred, traded and surrendered.

**R2**: Mechanism for stability of EUAs supplies: As identified from the data interpreted (section 8.3), one of the issues of monitoring and reporting CO2 emission trading is overallocation of EUAs. As such the system needs a mechanism that automates or quickly reacts to change in demand or supply in order to control the allocation of EUAs. When companies surrender EUAs, the supply of EUAs automatically reduces in the system. This is also mandated by law following Regulation (EU) No 525/2013 as described in (section 5.3).

**R3**: Inclusion of the linear reduction factor: The proposed design software for the conceptual model needs to be implemented in line with the LRF that defines the annual cap of the EUAs in the system ( section 5.1). It should be implemented in a way in which regulators can change the factor and distribute shares of the EU-wide cap to Member States.

**R4**: Recording of financial transactions: The proposed architecture needs to provide full information about transactions as opposed to the current system, while protecting the privacy of account owners. Due to privacy concerns and regulations, a mechanism that links off-chain information about account owners to their pseudonyms (public keys) on the network must be used within the system.

**R5**: Auctioning mechanism: The proposed architecture also needs to have an auction house mechanism where operators and traders can auction off new EUAs allocated to them. Metrics and parameters need to be clearly defined for the auction to be carried out successfully. From the pilot case reviewed ( section 7.1), the intransparent nature of distributing allowances via auctioning is a problem of the current system which was why blockchain was introduced. With blockchain, this problem can be addressed due to its transparent nature.

9.2.4 Requirement validation

As described in 9.2.1 and 9.2.2, the figure 4, 7 and 8 were developed by the researcher from interpreting and analyzing the research data. The figures were also validated by three experts in a post-expert interview to increase the credibility and validity of the study results (as described in methodology 2.2.1). For figure 4 (section 9.1.1), the Program Director from CLI (G) confirmed that it is an "*accurate*" representation of the current system in terms of governmental oversight. According to the expert the figure "shows the most relevant pillars of ETS operations." However, it was suggested to add limited use of EUAs, the amount of allocated permits which decreases over time to avoid allowances from running out. This is because ETS mostly work in trading periods "e.g 5- 8 years in the EU." and when allowances become surrendered by companies, the supply of EUAs automatically reduces in the system. As a result of this feedback, the inclusion of a stability mechanism for EUAs supplies was added to the study analysis as described in requirement 2 above.

For the figure 7 and 8 which shows a blockchain PFN system for monitoring and reporting CO2 emission trading, EU ETS Verifier ( F), stressed that supplied information from both the energy operators and the suppliers/subcontractors has to be in one standard format because there are multitude of formats currently used for data collection as at the time of this study. This is only when a blockchain smart contract can help with standardized algorithms with predefined rules. It was also revealed that having one “blockchain rule” also means that some local rules will apply via competent bodies which can lead to small local differences e.g different emission factors for each country, different reporting conditions e.t.c.

Additionally, the second half of the submission of the emissions and registry figure 8 (carbon trading process) is probably where the most impact of replacing Verifiers will be beneficial and not totally replacing Verifiers in the figure 7 (the MRV process). According to the expert, “... *some of the verification processes require some human intervention especially if things go wrong such as failures in metering/measuring equipment, and then assessment of what the energy operator has done to demonstrate they are being conservative”*. In the expert words “... *I don't think even the smartest of algorithms can pick up minute sensitivities in data that I have spotted over the years, e.g. stuck gas chromatographs*.”

On the other hand the second stage of the monitoring and reporting as described in figure 8 involves manual verification of emissions to make sure that the EU ETS emissions reported in the registry are the same as the verified emissions. Replacing this process with blockchain ““would save verifiers a step and also energy operators sending emails to close off data in the registry.” the expert added. In theory, this can be executed through predefined standard algorithms in the smart contract. To conclude, the Co-Architect at IBM focused on used cases in research & development (D), stated that the conceptual requirement of the study “.... is comparable and realistic. It is not a product of idealism but an emerging trend that we are seeing in other businesses." Additionally, the expert at IBM gave feedback on a more accurate process flow networked diagram which the researcher included to the final diagram as presented in figure 7. As a result, some of the process flow in the figure 7 was adjusted to fit requirements validation based on the feedback received from the expert.

9.3 Part 3: Factors that may affect blockchain implementation

This section identifies seven main factors: blockchain smart contract capabilities and constraints, technical constraints, politics, stakeholders cooperation, the market structure, cost and efficiency and sustainability factors: social, economic and environmental. More details explained below.

***1) Blockchain smart contract capabilities and constraints***

The use of blockchain and its smart contract features for monitoring and reporting CO2 emission trading will achieve a more transparent and robust system for the case study. However, the challenges of implementing the feasible smart contract for achieving desired outcome must be addressed. Implementing one standardized CO2 methodology that is controlled by the regulator will be challenging to achieve. According to the Expert at IBM (D), semantics around standards are understood differently and it is important to have a basic standard that is understood by all stakeholders. Standardizing blockchain language is important and the ".... *technology is ten times faster than the speed of these standardization processes*." The technology "... *has to evolve as humans evolve*". The case (section 7. 2) revealed that developing carbon assets alone is a complicated process and takes about 10 months with multiple parties involved. The Blockchain Consultant ( E) from the interview also stated that ".... *it is going to take another two years or 18 months, to fully develop a standardized working system if you start today because you will need to build a lot of the network*." Given that blockchain is still an emerging technology, it will take some time for its research and development and to be implemented in its full capacity.

Furthermore, the blockchain model developed for the study ( figure 7 and 8), the smart contract shows the possibilities of replacing TTP: Authorised Verifier who is a main stakeholder in the current system ( section 5.1). From the post-expert interview, the EU ETS Verifier also mentioned that TTP are still important stakeholders as some of the verification process requires some human intervention especially if things "*go wrong*" ( see 9.2.14 for details). Furthermore, the pilot case ( section 7.1) recommended that for smooth transactions in the emissions registry, an intermediary should be present to run the registry on a technical level especially at the early stage of implementation. As such a

TTP will still exist if smart contract automations and features are not fulfilled as presented in the blockchain system especially at the early implementation stage.

To conclude this point, the interview and literature ( section 6.7) showed machine learning and IoT as technologies that can add a huge impact and are integrated with blockchain for monitoring and reporting CO2 emission trading.However, such a set up will be challenging and expensive to implement and a high level of research will be required for its development in terms of scalability and data management.

***2) Technical constraints: interoperability, technical know how***

Technical constraints such as knowledge on how to use the technology: technical legacy and interoperability are some challenges that need to be addressed. From the interview, it was revealed that regulators and the industry will need to be educated about the technical know-how of the technology. Additionally, challenges such as the integration of the different stakeholders' legacy systems to exchange information seamlessly could arise.
The implementation of the proposed blockchain model can only be possible if the EU creates one technical standardized process for all operators, public, private or governmental to seamlessly access the system. Such standards should include the shared vision and cater to the goals of each stakeholder. "... *participants should be able to read and write over the network*," as suggested by the Co-Architect at IBM. However, this will be dependent on the type of access each participant has according to the smart contract agreement as explained (in section 9.2.1).

Implementing such a system will allow for a better communication and better stakeholder relationship within the network industry. To implement the blockchain model proposed in the study, a careful understanding of what semantics and communication protocols, pseudonyms for privacy should be included in the network model. Though, it may seem pretty basic but there should be a more granular understanding of what will be included in the network, as well as what can be shared off-chain. A prudent approach to solving this challenge will be to look at the Hyperledger fabric consensus definition as recommended for the study and choose the right consensus model to fit the industry's needs and preferences. Looking at this can also be a subject for future research.

***3) Politics: changing business as usual and shifting mindsets***

When it comes to changing business as usual, it will be tough to convince policy makers and regulators. This is because there exists an already working system for monitoring, reporting CO2 emissions, although with some challenges (section 5.5). According to the Program Director ( G), challenging a working system will require convincing policy makers and shifting mindsets, which may be slow and expensive. It will also require pilot testing and a proof that blockchain is a far much better system than existing systems. Other critical questions that may come up are 'is it really necessary?' 'Is it a good business case?' 'Does it give a competitive advantage?' 'Is it compatible with existing systems?'

In contrast, the Digital and Strategy expert (C) is of the opinion that it all comes down to making a good business case of why blockchain is a better system. Also, since the EU ETS begins its fourth trading period from 2021, this could be a good opportunity to implement a more robust and transparent system as the blockchain, as suggested by the Senior Lead Originator at the energy company interviewed. The data from the interview suggested that it has to be sort of mandated to use blockchain for energy operators, otherwise, enthusiasm to use the system may be low. To sum up, the interview also revealed that to achieve the goals of the Paris Agreement ( as described section 1.1), a policy driven transition is needed.

Data from the interview showed that people admit there are weaknesses in the process of monitoring and reporting processes of the system which has led to double counting, complexities and controversies around it. However, there is an ongoing discussion on how to create a better system. Therefore, it could be an opportunity for implementing blockchain for monitoring and reporting carbon emission trading in the energy industry. However, this is only a part of the puzzle as there are many other aspects to it as stated by one of the experts from the interview.

***4) Stakeholders cooperation***

Having all stakeholders on board may also be challenging. Following a top-down approach, the EU leaders have to agree first to work together as stated by the Senior Policy Advisor at the Danish Energy Agency, from the interview. The Vice President (I) also added that "... *wherever there are humans, there are always challenges in the aspect of agreeing with each other*." From an industrial perspective, companies may feel reluctant to share data for the fear of losing it to spies over a network, according to the IBM Co-Architect (E) from the interview. "*There has to be willingness of companies to* *want to communicate with each other and that is the bigger challenge.*" This aligns with the SDG 17; of partnership for goals (section 5.4.2) which stated the need for different stakeholders to cooperate and share knowledge, expertise, technology to achieve the Climate action: SDG 13. Also, the stakeholder theory described in the study ( section 3.2) suggested building a consensus vision for all stakeholders with a shared value ( Freeman, 2018).

***5) Market structure***

According to multiple experts from the interview ( section 8.3), the current EU ETS carbon market is politicized which is a huge challenge. The Sustainability expert from the interview revealed that "... *big companies are bigger emitters and have big carbon liabilities.*" As such, they tend to shape government decisions which could monopolize or in some cases oligopolies the market, thereby removing free market competition. Having a monopolistic or oligopolistic market structure are the types of competition that may influence the market structure as described in the theoretical section of the study (section 3.3). On the contrary, a free and open market is an important aspect of economic restructuring which is an enabler of social structures, according to Castell (2004) (section 3.1.2).

Confirming Castell's study and the phenomenon as observed in the study, companies and industries have been making bold commitments about going 'carbon neutral' given a timeframe in recent times. Like the case of Ørsted, a Danish energy company that has made a commitment to be carbon neutral by 20225 as revealed in the interview which has an impact on social structures. Other industries are not left out like in the case of Microsoft that wants to go carbon positive and offset historical emissions as revealed by the Sustainability expert in the interview. Also, companies who are not transparent with their business processes may not be open to participate in the system since blockchain's transparent nature may expose any fraudulent activities when it comes to their CO2 emission trading and reporting.

However, the positive side of things is that competition could lead to faster process results as stated by the Program Director ( G) from the interview. Multiple stakeholders agree that competition is essential for the acceleration of blockchain use for the carbon market trading. "If one competitor sees that it's a working system, then he would probably also follow up", argued the Program Director at CLI. Sustainability Advisor also added that such a phenomenon is already happening where companies have asked to do peer events in order to understand what level of carbon emission reduction ambitions and targets are out there from other companies. Furthermore, competition is driving more action than it would not if businesses are not making commitments, argued the Sustainability Advisor. Business Manager (K) stated that it could serve as a competitive advantage for companies who use blockchain for carbon trading because of its immutability nature, since companies can show a track record that they practice what they preach. This could also create a network effect as described by Castells (2004), on not just the energy industry but other industries. The social implication of implementing blockchain for carbon trading is global as the role of the technology will play a big role in creating new social structures in the industry and the society at large. Other markets systems and industries can also learn from the possibilities of adapting blockchain to drive competition and for climate action. However, the Sustainability Advisor stressed the importance of creating a free market where there are no competition restrictions or impositions from the government and allowing it to run on its own.

***6) Cost and efficiency***

Another key challenge identified is cost and the efficiency of implementing a more robust system for monitoring and reporting CO2 emission trading based on blockchain. Already the compliance of energy operators to the mandatory EU ETS program involves high administrative cost. From the interview, the Program Director at CLI argued that the cost to participate in the EU ETS carbon market is relatively expensive especially for low emitters of CO2. Stating furtherly that it only makes sense for big emitters to participate in the EU ETS from an economic point of view. This is only when replacing intermediaries with blockchain will lower cost and faster process results, but for high CO2 emitters. On the contrary, Blockchain Consultant ( E) and the Vice President (I) argued that blockchain replacing intermediaries reduces transaction cost. The Vice President stated that the enormous amount of paperworks being issued for contracts can be reduced by standardizing blockchain technology for carbon trading. This will save money and provide a more efficient system. This research was not able to examine the cost analysis and compare it when it comes to efficiency, thus the researcher recommends this for future research below. However, designing an efficient system will require meeting stakeholders needs and regulators backing the system up, such that it is implemented on a global scale and mandatory for all energy operators.

***7) Sustainability factor: social, economic and environmental***

The concept of being ‘sustainable’ a buzzword for a lot of businesses especially in the energy sector. Companies more than ever are making bold commitments to be sustainable and go carbon neutral within a certain timeframe. The competition to stay relevant in the industry and have a competitive advantage over others can be used as a tool to promote the implementation of blockchain for carbon trading. Also this has a social implication as revealed from the interview. Multiple experts argue that the social well being of the society will be negatively impacted. The replacement of intermediaries, like the case of authorised verifiers as seen in the conceptual model described in the ( figure 7 and 8), will create unemployment. This economically affects the society and the nation at large as described in (section 5.4.1). Therefore carrying out the implementation of blockchain for carbon trading needs to be a carefully thought-out process which will include jobs for those that might be displaced as a result of the technology. From the environmental perspective, the energy consumption level has to be taken into account. When it comes to blockchain consensus mining, it is important to choose a blockchain that consumes less energy and saves the environment from pollution according to the data interpreted ( section 8.3).

***Other factors:***

Other factors as reviewed in the literature ( section 6.8) are security and privacy. A permissioned blockchain which is private, as recommended for this study, is less secure than a public permissioned blockchain. This is because transactions are validated in a public blockchain by multiple entities but are kept in a privately distributed ledger. Public blockchain are designed to be more secure compared to private permissioned ones. This is due to the POW consensus mechanism because the more users validate a transaction within the chain of blocks, the longer the chain becomes within the network and the more immutable it becomes because the level of algorithmic computation increases. On the other hand a permissioned private blockchain has limited writers and verification processes in the network which are only the participants of the network.

## 9.4 Summary

Chapter 9 presents the analysis of the results gathered from the data and theories used in the research. The main analysis of the study covers the third aspects: the current condition and challenges of the EU ETS, the technology analysis of blockchain and factors that may affect implementing the technology in the energy industry. Part 1 (section

9.1) shows how the data interpreted in Chapter 8 are connected with each other. Theories of network stakeholder and market structure were used to analyse the literature and case studies. Part 1 section addressed objective 1 of the research as described in the conceptual framework of the study (section 4.1). Understanding the current procedures and its challenges will help the researcher understand how blockchain can be applied for monitoring and reporting CO2 trading in the Danish context.

Part 2 which presents the technology perspective, which addresses the main research question on how blockchain can be used for the monitoring and reporting of CO2 emission trading. Part 2 addresses objective 2 of the research as described in the conceptual framework (section 4.2) This the requirement engineering development which includes pilot case studies, and blockchain literature to elucidate on how the technology can be implemented and its fits for industry needs. The technology perspective also combined data gathered from experts interviews to achieve the consensus mechanism for stakeholders. Next, a blockchain conceptual model for monitoring and reporting CO2 emission trading was presented. The requirement specification also shows five lists necessary for the blockchain conceptual model's implementation. The validation of the blockchain conceptual model from a post-expert interview is also presented in the study and seen to be a concept that is feasible for monitoring and reporting CO2 trading in the energy industry.

Part 3 presents factors that might affect the implementation of the blockchain model for monitoring and reporting CO2 emission trading. This presents seven main factors: i) blockchain smart contract capabilities and constraints; ii) technical constraints; iii) politics; iv) partnership among stakeholder; v) market system; vi) cost and efficiency and, vii) sustainability factors: social, economic and environmental. Other possible factors that might affect the implementation of the proposed model were also presented to support the main factors: cost and efficiency. Part 3 addresses objective 3 of the research as described in the conceptual framework of the study (section 4.3).

## 10. Discussion of results

Chapter 10 presents the meaning, importance and relevance of the study results. It focuses on explaining and evaluating what was found in the study and how it relates to literature, case studies and research questions. As described in the methodology section (2.1.1), the researcher applied the grounded theory using inductive reasoning. The research started with gathering data on the process of monitoring and reporting CO2 emission trading under the EU ETS framework. Primary data was gathered through semi-structured interviews while secondary data gathered through case studies ( Chapter 7) and literature of the EU ETS (chapter 5) and blockchain (chapter 6). Next, the researcher broke down the data into themes through thematic analysis ( as described in 2.2.1) to summarize the data and interpret what they could mean. After the data was interpreted, it was further analysed in detail in chapter 8 to explain various concepts, theories, literatures and cases to uncover new meaning. The new meaning developed by applying the research methodology is presented under four key elements:

1) Summary of key findings: what new meaning does the research bring? What do the results mean?;
2) Implications: why do the results matter? What are the implications in social context?;
3) Limitations: what can’t the result tell us?;
4) Recommendations: what practical actions or scientific studies should follow?

### 10.1 Summary of key findings and what they mean

After interpreting the study data by combining a qualitative methodology of grounded theory through inductive reasoning, case study and requirement engineering, a new knowledge was discovered from what was already known, which modifies existing knowledge. The main result elucidates on “how blockchain can be used for the monitoring and reporting of CO2 emission trading in the Danish energy industry”. This addresses the main research question: ‘*how can blockchain be used for monitoring and tracking CO2 emission trading in the Danish energy industry?*’ However, to answer the main research question, it was important for the researcher to first look at: ‘*what the current conditions and challenges of monitoring and reporting CO2 emission trading are in the energy industry.*’ This is the first research sub-question. The findings from the second subquestion: *what are the factors that might affect the implementation of blockchain for CO2 emission trading?* are also presented. The breakdown is as follows:

10.1.1 Study findings that answers sub-question one:

**What are the current conditions and challenges of monitoring and reporting CO2 emission trading?**

In answering sub-question one (the current conditions), the study data shows that the Danish energy operators are non-compliant to the EU ETS mandatory program. This contradicts the literature (section 5.1) reviewed in the study. The EU ETS handbook (European Union, 2015), as reviewed in (section 5.1) stated the program to be a mandatory requirement for the monitoring and reporting of CO2 emission in the energy industry. Under these settings, the authorities; EU Commission is responsible for setting standards such as emission caps, and issuing allowances for the energy industry under the EU ETS. On the other hand, the case study ( as described in section 7.4) shows that the Danish Business Authority monitors GHG emissions of the energy operators including CO2, and ensures that they comply with the regulations laid down by the Commission (Danish Business Authority, 2019). This is what Castells (2011) of network theory referred to as “network power” as described in the theory (section 3.1).The power to set mandatory rules and regulations required to coordinate a network. By setting emission caps and issuing permit allowance, energy operators are mandated by law to comply with the baseline set-up through the EU ETS cap and trade system as described in ( section 5.1).

The system is designed for energy operators and other industries under the EU ETS to reduce their CO2 emissions by buying allowances to later surrender them for the rights to emit CO2. Surprisingly, the study found out from the semi-structured expert interview that the mandatory rules of abiding by the EU ETS program as laid down in the EU ETS handbook is not practiced by the energy operators in reality. In the study interview, both the Senior Lead Originator and the Senior Policy Advisor at the energy company mentioned that they are only involved in small scale carbon trading projects such as offsetting employees travel emissions. According to the new information gathered, most operators are waiting for the EU ETS fourth phase to begin from 2021 as described in the literature (section 5.1) with an expectation of a system that is “... *more robust and transparent*”, as stated by the Senior Lead Originator. If the EU ETS is a mandatory program, why are energy operators non-compliant? Are there any penalties for non-compliance? What are the implications of operators not being compliant to monitoring and reporting their $CO_2$ emissions in a wider societal context? This critical question raises an eyebrow on the monitoring and reporting process of the current EU ETS system for $CO_2$ emission trading. As described in the critical analysis of the study literature (section 5.5), it creates gaps in the current system and shows defectiveness in the monitoring and reporting process of the system. All these put together modifies existing literature about the EU ETS which is said to be mandatory. A plausible way to define the EU ETS is as a 'voluntary program' not 'mandatory' since companies are non-compliant according to the findings from the study. In such a situation where companies are non-compliant and do not follow required standard procedures, there are bound to be issues and challenges.

The second part of the research sub-question identifies these issues and challenges. There are four key challenges from the study findings. These are the: 1) lack of transparency and data reliability in $CO_2$ accounting; 2) Issue of double counting 3) Lack of standardized methodology for calculating $CO_2$ emission and compliance; and 4) Carbon allowance over allocation and politicization. Four of the challenges identified from the primary data agrees with previous studies when it comes to the challenges of monitoring and reporting $CO_2$ emission trading under the EU ETS program.

For the first one, multiple experts (section 8.3) and Bohm (2013) pointed out that the lack of transparency in the process of monitoring and reporting creates room for carbon cheating and corruption within the market (section 5.1). The second is the issue of double counting where multiple experts from the interview (section 8.3) pointed out. This findings compliments the UNFCCC report (2017) and Schneider et al (2014) that mentioned double counting as a challenge of the current system of monitoring and reporting $CO_2$ emissions. The third findings that agrees with the literature of IETA (2013; King 2018) which is the issue of lack of standardized methodology for calculating $CO_2$ emission. The data showed that the system has over 200 methodology for $CO_2$ emission calculations which is complex and confusing to follow through. Such complexities make it difficult for energy operators to follow through leading to non-compliance.

The fourth challenge highlights the carbon allowance overallocation and politicization. The literature by FutureLearn (2018) stated that overallocation of allowances is caused by economic crisis and industry lobbying. In the interview, the Sustainability Advisor pointed out that big companies with big carbon liabilities have the power to influence government decisions. These decisions include allowances allocation leading to industry lobbying and politicization of the system. Such politicization is what Castells (2011) referred to as "network-making power" in the theoretical framework ( as described section 3.1.1). This is the power a stakeholder or actor has, to reprogram a network according to its values and specific interests. Other new findings from the primary data revealed that when it comes to data reliability, the verification of CO2 emission reports is manually done, according to the EU ETS Verifier for the interview. This questions the validity and reliability of such data for the monitoring and reporting process of CO2 emission trading.

10.1.2 Study findings that answers main research question:

**How can blockchain be used for monitoring and reporting CO2 emission trading in the Danish energy industry?**

After looking at the current conditions and challenges, the researcher proceeded in elucidating on how blockchain can fit the industry challenges when it comes to addressing the aforementioned challenges for monitoring and reporting CO2 emission trading. The elucidation involves developing a private-permissioned Hyperledger blockchain. The conceptual model is otherwise referred to as a Process Flow Networked (PFN) model which describes in detail how the technology can be used to address the said challenges seen in figure 7 and figure 8 (section 9.2.2 of the study). The finding shows that there are two stages in the process of monitoring and reporting CO2 emission trading. The first stage is the monitoring, reporting and verification (MRV) of CO2 emissions. For this stage, the study shows smart contracts as a key function of the blockchain PFN model which can replace the function of the European Union Transaction Log (EUTL) as described in literature (section 5.2.1) of the study. This is because of its computational ability to digitally facilitate and enforce negotiations without a middleman. The finding agrees with the literature by Shermin (2017) and Rosic (2018) that described the smart contract as computer protocols that digitally facilitate verify or enforce negotiations without intermediaries.

To achieve this, a predefined rule has to be set within the contract using algorithms wherein each stakeholder of a private permissioned network needs to validate a transaction before it can be considered valid (as described in section 9.2.2) . There is a major precondition to be met when it comes to how smart contracts can mitigate the said challenges as documented by the study findings. The precondition is that the regulatory body will need to approve the use of a standardized global system that conforms to one

$CO_2$ methodology for the submission of monitoring and emission reports. This standardized system will be used to submit monitoring plans and emission reports by the energy operators and then processed in the smart contract to validate and ensure that reports submitted meet predefined rules as set in the smart contract. The system can also be used to automate the process of creating reports for compliance. Such documentation process is then disseminated to all the relevant stakeholders. That way, the use of smart contracts eliminates an intermediary or a middleman in the MRV process of $CO_2$ emissions within the network. As such, the proposed solution addresses some of the issues mentioned in the said challenges: i) transparency: all data and information are shared on the blockchain network; ii) data reliability: the verification of $CO_2$ emission data becomes automated as opposed to being manual done; iii) standardization: through using one global system and standardized methodology; iv) compliance: through the automation of document of compliance. This findings demonstrates a correlation with Tabirao (2018) study which mentioned that smart contracts can be used for automating the process of monitoring verification and reporting (MRV) $CO_2$ emissions in the shipping industry.

However, the difference between the two study findings is that this study indicates that the technology cannot be 'fully' maximized for the purpose of monitoring and reporting $CO_2$ emissions trading. This is because blockchain is still emerging at the time of this study, A such smart contract is still evolving and not fully scalable (as described in section 9.2.2) This critical point in the study was validated through expert's post-expert interview. Somewhat surprisingly, the post-expert interview result shows that the verification of $CO_2$ emission data would be challenging to achieve with the current state of blockchain as described in the figure 7 (analysis section 9.2.2). This is because of scalability issues with the technology as suggested by previous studies (Kravchenko 2016; Wüst & Gervais 2017; Burlakov, 2019). A programmed algorithm in a blockchain cannot pick up actions, perform sense checks or pick up when things go 'wrong' but can only perform what it is programmed to do. As such it is 'garbage in bad data, garbage out bad data'. According to the EU ETS Verifier from the study interview, the verification of $CO_2$ emission data requires not just verification that operators follow the right standards but checking measuring equipment of installation sites and plants remotely for 'failures' or missing gaps in $CO_2$ emission data. As such, the remote verification of $CO_2$ emission data still requires a Trusted Third Party (TTP) which will require "… *human intervention especially when things may go 'wrong' such as failures in measuring equipment and assessment of what the operator has done to demonstrate they are being conservative. The smartest of* *algorithms cannot pick such minute sensitivities in data that have been spotted over the years"*, according to the expert. Therefore, the process of the MRV of CO2 emissions still requires a TTP who will act as a middleman. The new findings also modifies existing knowledge from the pilot case studied and literature reviewed. The first pilot case (section 7.1) suggested a hybrid model of Ethereum blockchain with a central authority to ensure proper functioning of the Emission Trading System (MIEN and GIZ , 2019). The study did not mention Verifiers as a required stakeholder of the blockchain system but a central body who controls the process of monitoring and reporting. The second pilot case (section 7.2) described how over 200 carbon methodologies are compiled into a standardized blockchain smart contract for calculating quotas for companies that want to reduce their emissions (IBM, 2018). It does not say anything about blockchain replacing the job of an Authorised Verifier during the CO2 emission verification process.

Other research suggested that having blockchain integrated for monitoring and reporting CO2 trading will enable common rules to be set up through the smart contract without having to trust any parties within the system ( Shermin, 2017; Pauw 2018). These previous studies might suggest that blockchain can be used for monitoring and reporting of CO2 emission trading. Quite surprisingly, experts gave feedback on the importances of still having human intervention in the verification process of monitoring and reporting process of CO2 emission trading. Such new findings from the post-expert interview adds credibility to the study data and could be relevant for other research works.

For the second stage of monitoring and reporting CO2 emission trading (as described in section 9.2.2., figure 8) the smart contract can be utilized fully for validating that the reconciled allowances surrendered and the recorded CO2 emissions as submitted in the emission report matches. This findings was validated by the Co-Architect expert in Blockchain working on use cases in research and development and the EU ETS Verifier from the post-expert interview (as described in section 9.3 of the study). The Verifier also concluded that having a blockchain replace such a process ".... *would save verifiers a step and also energy operators sending emails to close off data in the registry*." The expert at IBM also added that the proposed conceptual blockchain PFN model as described in the study ( (figure 7 and 8) "... *is comparable and realistic. It is not a product of idealism but an emerging trend that we are seeing in other businesses*."

From the study findings based on the second stage, the proposed solution described in (figure 8) can address the issue of double counting which is one of the challenges of the current system as mentioned ( section 10.1.1). Given that all transactions regarding CO2 emission trading will be recorded on the blockchain network, the system can account and trace every entry entered based on its characteristics of transparency and immutability (as described in section 6.1 of the study) . This way entering two entities as a single entity can be eliminated.

The summary of the key findings of the research as described above highlights how erroneous it is to assume that blockchain can be used to 'totally' replace TTP: Verifiers, who are stakeholders in the current CO2 emission trading system as described in figure 7 of the study ( section 9.2.2). As such, the study suggests that having a TTP within the proposed model is a determining factor for an effective implementation of blockchain for monitoring and reporting CO2 emission trading. Nonetheless, blockchain can solve three out of the four current challenges of monitoring and reporting CO2 emission trading as described (in section 10.1): i) lack of transparency and data reliability in CO2 accounting; ii) issue of double counting; iii) lack of standardized methodology for calculating CO2 emission and compliance.

10.1.3: Study findings that answers the second sub-question:

**What are the factors that might affect the implementation of blockchain for monitoring and reporting CO2 emission trading in the Danish energy industry?**

The study data shows that there are seven possible factors that might affect the implementation of the proposed solution for monitoring and reporting of CO2 emission trading. These factors are i) blockchain smart contract capabilities and constraints; ii) technical constraints; iii) politics; iv) market structure v) stakeholders cooperation; vi) cost and efficiency; and vii) sustainability factors: social, economic and environmental. Previous study showed smart contracts to have scalability limitations and failing to foresee unexpected eventualities by means of human errors (Shermin, 2017) as described in the literature (section 6.2). However, as intelligent as it sounds, smart contracts may fail to foresee unexpected eventualities within the institutions, by means of human errors or subversive actors (Shermin, 2017). In such cases, smart contracts might need to be overridden by supermajority consensus (Shermin, 2017). Other constraints such as the inability of the smart contract to pick up sensitivities in data as described by one of the experts could also affect its implementation.

For the second factor: technical constraints, the study findings from the expert interviews showed that all the stakeholders will need to be educated on the technical know-how of the system and need some time for the pilot test stage to fully replace the current system with blockchain. This corresponds to the case study findings from CLI (section 7.1) which suggested a span of three years for the pilot test phase of blockchain for monitoring and reporting CO2 emission trading. Another study by Burlakov (2019) corresponds with this findings which mentioned that a principal challenge for potential implementers of the technology is the technical-know.

The third factor which is politics is connected to the fourth challenge identified in the study: carbon allowance over allocation and politicization ( as described in 10.1.1). It all comes down to shifting mindsets. The study shows that blockchain cannot directly solve the issue of shifting mindsets and convincing policy or decision makers to implement the system. Multiple experts from the interview revealed that a policy driven transition that supports a technology as blockchain is needed for its implementation. These findings can be related to literature reviewed under Regulation (EU) 2018/1999 of the European Parliament which promotes research, innovation and digitalisation towards a sustainable low-carbon economy as described in (section 5.3 of the study). Therefore, there is a possibility of welcoming such a system implementation as a blockchain for monitoring and reporting CO2 emission.

The fourth factor: market system is currently politicized by influential big CO2 emitting industries based on the study findings. Castells (2011) findings described in the politicization of a system or network as network-making power. This is a phenomenon where actors have the power to restructure a network according to its values and specific interest. Such power can lead to monopoly: one actor dominating the market or oligopoly: a small group of actors dominating the market system as described by the market structure theory according to Richard (2019) (section 3.3). If the market is politicized, it can discourage small players/emitters from participating which affects the overall effectiveness of the system.

The fifth factor: stakeholders cooperation is a factor the study found out that could affect the implementation of the proposed blockchain. As described in the study ( section 9.2.1) stakeholders and their roles to achieve consensus through smart contract agreement within the blockchain require the cooperation and partnership of the participating actors. The findings of the study reveals that there are always challenges with humans agreeing with each other. The non-cooperation of stakeholders contradicts the goal of the UN SDG 17; partnership for goals according to Pierce (2018) (in section 5.4.2), which described the need for stakeholders to collaborate and share knowledge expertise and technology. Another study by Freeman (2018) suggested building a consensus vision for all stakeholders with a shared value as described in the theoretical (section 3.2). Provided the participating stakeholders cooperate, this could accelerate the impact of combating climate action through the blockchain monitoring and reporting system for CO2 emission trading.

The sixth factor is cost and efficiency. The study findings show that there exist high administrative costs in participating in the EU ETS monitoring and reporting program ( e.g cost of hiring a Verifier, carbon broker, agency, lawyer etc). As such companies will be interested to participate in such a blockchain implementation if it will save cost. For example, removing the middlemen such as a carbon broker will lower the transaction cost. The findings also revealed that enormous amounts of paperworks issued for contracts can be reduced by standardizing blockchain technology for CO2 emission trading. Blockchain's efficiency in terms of power consumption is also an ecological factor that might affect its implementation. A report by Deloitte (2018) blockchain consensus mentioned that the blockchain consensus mechanism is continually improving to consume low power.

The seventh factor which is sustainability can be used as a positive tool to drive the implementation of the proposed system. The study revealed that the competition for companies to stay relevant and have a competitive edge over each other can influence the implementation of blockchain. This in turn could either boost the economy or deflate it. On the positive side, provided all stakeholders work together, UN SDG partnerships for goals are strengthened as described in the literature by Pierce (2018). The societal factor is that it could cause people to lose their jobs through the replacement of the middlemen. On the flip side the study findings also showed that trading CO2 can bring some sort of wealth to a community or society through offsetting units of allowances on carbon projects e.g An offset unit from carbon trading can be used for tree planting that forms a forest in a community thereby providing jobs and wealth to that community. This also brings environmentally gains by protecting the environment and tackling climate action. The literature by the United Nations (2018) showed that climate action: SDG 13, amongst the top priority for nations.

## 10. 2 Implications of the study findings

### 10.2.1 Why do the results matter?

The findings from the study builds on existing evidence that blockchain can be used for the monitoring and reporting of CO2 emissions for climate action. Interestingly, Tabirao (2018) and UNFCCC (2017; 2018), found out that blockchain is a potential technological solution for monitoring and reporting carbon emissions against climate action due to its decentralized and transparent nature. In a report by UNFCCC (2017), the use of blockchain is being explored for monitoring and reporting GHG emission reduction and avoidance of double counting. Since all the data on blockchain can be accessed on a distributed shared ledger among the participants of the network, activities on the network are transparent and can be easily monitored.

While previous research has focused on the suggesting blockchain for monitoring and reporting, this result findings explains in detail how this can be done. It also goes further to show that the verification of CO2 emissions data should be taken into account when considering how to implement blockchain for the monitoring and reporting of CO2 emission trading. Therefore, the study findings confirm that some of the functions of the TTP: Verifiers cannot be totally replaced by blockchain since the technology is still evolving. Researchers are still exploring its scalability and integration with other technologies such as IoT and machine learning. Blockchain's scalability in running large volumes of transactions and at high speeds is still a challenge with implementing its technology (Burlakov, 2019). Previous studies also suggested that combining blockchain with machine learning and IoT unlocks credible and accurate ways of measuring, reporting and verifying carbon emissions (Intersog 2017; Tabirao, 2018; CLI, 2019).

Such research indicates that combining blockchain with machine learning and IoT can be useful in solving the issue of verifying emission data for CO2 trading. Interestingly this corresponds with multiple responses from the study's expert interview that combining machine learning and IoT with blockchain can create a huge impact in the monitoring and reporting of CO2 emission trading. An expert suggested that machine learning can be used to 'clean' the data before it is entered in the blockchain network (as described in section 9.2.1). IoT on the other hand, can be used to automate the process of data entry when connected to measuring devices used for reporting CO2 emission data (section 9.2.1). But not just the technology's maturity should be of concern, one must also question the policies and regulations that will support the implementation of blockchain for monitoring and reporting of CO2 emission trading.

The study reveals that it will require regulatory back-up from the authorities for implementing blockchain for monitoring and reporting of CO2 emission trading. Following the Directive 2003/87/EC of the European parliament as described in the literature (section 5.3), there exist policies and measures through multi-stakeholder partnerships in GHG emission allowance trading, that support digital technologies that have the potential to reduce CO2 emissions (European Union, 2018). Also Regulation (EU) 2018/1999 of the European parliament (section 5.3) stated that the Commission is committed to implementing policies that promote research, innovation and digitalisation towards a sustainable low-carbon economy (European Commission, 2018).

However, to implement such a system is not only reliant on policies and regulations but willingness of stakeholders: energy operators, traders, business authority etc, to cooperate and exchange information with each other. Stakeholders must be willing to work together for the implementation of such a system from the study findings. This aligns with the SDG 17: partnership for goals as reviewed in the study (section 5.4.2). The energy company interviewed in the study expressed willingness for the company to work with an implemented blockchain system for monitoring and reporting CO2 emission trading because it will provide a competitive advantage.

### 10.2.2 Reflecting on the general implications in a wider social context

***Building a networked society and empowering actors***

A blockchain system for monitoring and reporting CO2 trading in the industry can empower actors. Similar to the revolution of the internet, blockchain can create a phenomenon whereby social, political, economic and cultural changes are caused by the spread of its networking, digital information and communication technology capabilities. In turn, it empowers the industry, country and the world at large. This phenomenon aligns with Castells (2000, 2004, 2011) theories of a network as described in (section 3.2 ) of the study. By establishing a decentralized approach to connectivity, a networked society can be formed. Data that is mandated by law to be openly shared to the public, can create new ways of assessing information. Furthermore, its implementation can also empower a sharing economy through collaborative effort and cooperation of all the stakeholders which can potentially accelerate the process of inclusion in economic prosperity, as opposed to competition, inequalities and conflicts. Not just the energy industry but other industries and sectors such as maritime, aviation, etc, can implement the technology to resolve a lot of issues they are faced with in relation to trust. Implementing such a system can establish a networked society in the future.

***Establishing an innovative solution***

The blockchain model proposed in the study is disruptive because of the impact it can create in forming new processes in the energy carbon market. Existing systems and processes can be replaced or rendered obsolete if its implementation is thoughtfully carried-out and all stakeholders are on board to work collaboratively. Furthermore, the convergence of IOT and machine learning with the smart contract features can also create a huge impact. Analyzing data generated by IoT by machine learning and, excerpted to find certain patterns and/or see the effect on carbon emissions is a potential game changer in how CO2 emission can be monitored and reported going forward.

Furthermore, deploying a blockchain system creates a more transparent and immutability system compared to the existing EU ETS and the Danish emission trading system. Also, there will be no need for TTP: Verifiers in some of the current processes of mentoring and reporting since the smart contract function will replace them as presented in figure 8. Although the said technology is continually evolving as described in the literature, the consensus chosen for the study only shows the researcher’s current understanding on the application of blockchain as at the time of this study. This is because blockchain consensus mechanism can be extended to other consensus models in the future which fits the industry needs in a more sustaining way as the technology continues to evolve . This makes the technology innovative.

***Market structure reformation: institutionalizing digital technologies and regulations***

Policy makers, regulators and decision makers need to embrace and institutionalize new types of digital technologies such as blockchain for implementing systems and processes. This is because these actors have the potential to influence the process of implementing blockchain for monitoring and reporting carbon trading in the case of this research. However, embracing such changes have the potential influence to reform the market structure and introduce monopoly or oligopoly where the 'winners take it all' as described in (theoretical section 3.3 of the study).

Nonetheless, the industry is currently undergoing a double transformation that involves energy transition and digitalization(Peter et al. 2019). Institutionalizing digitalization and mandatory CO2 emission programs in the form of regulations have the potential to drive positively large scale changes when it comes to climate action as seen in the study analysis (Chapter 8). The study analysis also reviewed that mandated regulations are a necessity to back-up a successful implementation of the proposed blockchain model. Implementation of blockchain for monitoring and reporting carbon trading will automatically change the value chain for not just the energy industry and carbon market, but all other institutions can learn from such reformation.

***Stakeholdership: collaboration not competition***

To solve the climate challenge of CO2 emission, it will require the collaboration of different stakeholders. There has to be willingness of stakeholders to work together towards a shared vision of tackling climate change. According to Freeman (2018) from the stakeholder's theory reviewed in (section 3.2 of the study), aligning stakeholders interest in the same direction is important for the success of a system or process. Collaboration and not competition is necessary for actioning the institutionalization of blockchain for monitoring and reporting of CO2 trading in the energy markets. This will not only contribute to great stakeholder involvement but promote transparency and build trust among stakeholders. Furthermore,it will establish a collaborative market structure that will accelerate the SDG 17: partnerships and goals (as mentioned in section 5.4.2 ), whilst addressing one of the biggest issues the world is facing right now which is the climate crisis.

***Strengthening the sustainability agenda and  other climate initiatives towards CO2 emission reductions and research***

Blockchain as a technology for monitoring and reporting CO2 emission trading creates a large amount of communication and collaboration and clearer sets of information within its network. All of which can help to address the issues of sustainability and community. Blockchain standards will improve the reputation of the EU ETS program as a useful layer for monitoring, reporting, data exchanges and transactions, which makes it an invaluable tool for achieving transparency and trust in sustainable development programs. Should the implementation of the proposed blockchain for monitoring and reporting CO2 emission trading be successful, it can become a blueprint for other European countries and a tangible example that pursuing climate action is technically feasible and economically and politically viable.

Furthermore, there has been a growing number of  applying blockchain to mitigate climate actions among regulators, developers, researchers and climate initiatives. One of such is the  UNFCCC exploration on the use of blocking for monitoring GHG and solving the problem of double counting (UNFCCC, 2017), as stated in problem background (section 1.1) of this study.  Some other research is already developing blockchain DLT  for carbon asset tokenization (CFI Education, 2020), as mentioned in section (1.1) of the study. Investing in digitalization, green research and practices to tackle climate change  is a  step in the right direction that will establish not just a national techno-economic paradigm but a global one.

### 10.3  Limitations: what can’t the result tell us?

Limitations are boundaries and constraints that cannot be controlled by the study. They appear from the objectives, context and methodology set by the research. The generalisability of the result is limited to the Danish case study which is distinct from the business models of other European countries or industries. This context sets clear limits here. As mentioned in (section 2.1.2 of the study), it was important to consider the context in which the implementation of CO2 for emission trading would occur, thus the application of a case study methodology. Nonetheless, the research findings can serve as a foundational base to build other cases for Scandinavian countries or European countries under the EU ETS framework. The use of a case study method presents a broader perspective on the particular case studied. Furthermore, when it comes to the fourth challenge of monitoring and reporting CO2 emission trading: Carbon overallocation and politicization, the study findings cannot directly solve this challenge. It all comes down to shifting mindsets and ethical behaviours. The researcher however provided some recommendations on how this challenge could be addressed in the (section 9.1.2 of the study).

The study findings cannot also confirm if the Danish Business Authority who is an important stakeholder in implementing the monitoring and reporting of CO2 emission trading for the Danish energy industry will be interested or not. The researcher contacted two experts from the said organisation but got no feedback. Also, it is also beyond the scope of the study to test the empirical knowledge formulated from the result findings. As described in (section 1.6), the study objective is not to provide a working prototype but add to existing knowledge by elucidating on how blockchain can be implemented for monitoring and reporting CO2 emission trading. Therefore the study encourages future work. Other general study limitations are furtherly discussed in Chapter 11 ( Conclusion).

## 10.4 Recommendations: what practical actions or scientific studies should follow?

Future work is needed to unravel the specific details of the proposed model in terms of a full proof of concept. This will involve the fourth stage of the requirement engineering methodology used in this research in which the study's scope does not cover: prototyping and pilot testing, due to time constraints. Further research is also needed to establish how other technologies such as machine learning and IoT can be integrated with blockchain to solve the issue emission verification of CO2 to fully maximize the potential of blockchain for the study focus. As such the study recommends the following as important to be further studied:

1) Prototyping and testing full proof of the conceptual model. Specific details such as blockchain architecture layers, consensus mining identity providers, smart contract of the proposed architecture need to be tested. This is the fourth stage of the requirement engineering as described in the conceptual framework of the study ( section 4.2).

2) How other technologies such as machine learning and IoT can be further integrated into blockchain for monitoring and reporting CO2 emission trading to achieve credibility of information stored on blockchain (as mentioned in section 6.9)

3) A clear break-down of cost and benefit analysis in setting up a blockchain system for monitoring and reporting carbon trading emissions. Theories such as cost benefit and transaction theories should be looked at to understand the cost implications of implementing the proposed model.

Further factors that may be useful for further studies for implementing the proposed system for carbon trading include bridging the knowledge gap about the technology: educating and awareness, understanding cultural differences of stakeholders; market pricing system; regulation and governance; and addressing security and privacy needs.

Other general limitations about the study are highlighted in the conclusion chapter (Chapter 11).

## 11. Conclusion

Chapter 11 presents the concluding sections of the research. First a summary of the research milestone and possible pitfalls of implementing the proposed blockchain system are presented. In order to answer the main research question, the first sub-question has to be answered which is: what are the current conditions and challenges of monitoring and reporting CO2 emission trading in the Danish energy industry ( section 1.2). This addresses objective one. Answering the first sub-question helped the researcher to apply to context how blockchain can be used to address these needs and challenges in the monitoring and reporting of CO2 emission trading which is the main research question. The main research question addresses objective 2.

Third the researcher looked at the factors that might affect the implementation of the proposed blockchain for monitoring and reporting CO2 emission trading in the energy carbon market with recommendations. This addresses objective three of the research. Each section is presented in detail below.
The concluding part of the chapter describes the possible pitfalls of implementation. It also shows the actor(s) that have the power to influence the implementation of the proposed system and the beneficiaries. Lastly the general study limitations and relevance of implementing the study findings are presented.

### 11.1 Research milestone

After analyzing the data in chapter 9, the findings of the study demonstrates how blockchain can be applied for monitoring and reporting of carbon emission trading in the case studied. However, it is not without challenges. The study goes further to point out factors that could affect the implementation of a blockchain system for monitoring and reporting carbon trading and provides recommendations to address these factors. Addressing the main research question of *'how can blockchain be used for the monitoring and reporting of CO2 emission trading in the Danish carbon energy market?*' the researcher applied a conceptual framing to answer the question. Also the sub questions "what are the current conditions and challenges of monitoring and reporting of CO2 emission trading in the energy carbon trading market?" and " what are the factors that might affect the implementation of blockchain in the energy carbon trading market?" were addressed. By applying a combination of qualitative methodology: grounded theory, case study and requirement engineering, the researcher developed a blockchain conceptual framework to address the study objectives and answer the research questions. By applying the study methodology (Chapter 2), the conceptual framework (Chapter 4) was then divided into three main phases to address the study objectives as described in (section 1.3). Phase one addresses objective 1: to investigate current procedures of monitoring and reporting CO2 emission trading in the energy industry; phase two addresses objective 2: to create a blockchain conceptual model for monitoring and reporting CO2 emission trading; and phase three addresses objective 3: to identify the factors that might affect the implementation of the proposed blockchain system whilst providing recommendations. More details are discussed below.

***Phase one: objective 1***

The first phase of the research addresses the current conditions, and challenges and areas for improvements for monitoring and reporting carbon trading in the energy industry. Following the conceptual framework of the study, the researcher applied the network and stakeholder theory to frame the analysis and findings. The EU ETS framework and the Danish carbon trading system were also qualitatively reviewed and evaluated in great details. It was discovered that despite the current working systems, there apparently still exist challenges, issues and areas to be improved upon which were addressed in this study. Two major problems that stood out are the problem of double counting and issues of having many standards for calculating CO2 emissions. It was suggested in the study that a way to solve double counting is to record all data pertaining to a transaction ( offset, unit, transfer etc) in the blockchain shared ledger which is transparent and can be easily monitored and tracked. The other problem around standardization can be addressed by having a standardized process and system for the computation of the EU MRV process under the EU ETS program.

***Phase two: objective 2***

The researcher applied the requirement engineering methodology in this stage to elucidate on how blockchain can be used for monitoring and reporting CO2 emission trading. Also to access the feasibility of the implementation process. The application of blockchain as a decentralised ledger technology with smart contract features was analysed in great detail how the technology will be implemented for the research focus. Through the elicitation and analysis of the requirement process, a private permissioned hyperledger blockchain was proposed as a solution. This is due to the industry's preferences and needs as it relates to transparency and confidentiality within the network system. The smart contract capabilities of blockchain is also an important feature to address the challenges of the current system. The core components of the the smart contract features suggested include: i) *One standardized system and method for calculating CO2 emissions* ; ii) *Integration with companies legacy (ERPs), IOT systems and other technologies*; iii) *Verification of emission rights and issuance of emission credits/allowances*; iv) *Integration with other climate action projects e.g green investments and finance*.

A blockchain conceptual model was furtherly developed and labeled in the study as a Process Flow Networked (PFN) model. However the study findings revealed that the verification process as described in the blockchain proposed model (figure 7) still needs an Authorised Verifier to validate CO2 emission data remotely. This is because the technology is still emerging and the functions of the smart contract as defined for the blockchain model (figure 7) will still need a TTP in the person of a Verifier. However, previous studies showed that integrating blockchain with other technologies such as machine learning and IoT can maximize its full potential. As such the study encourages further research.

***Phase three: objective 3***

This phase is focused on the factors that might affect the implementation of the blockchain for monitoring and reporting CO2 emission trading and recommendations. The study identified seven main factors which are: i) smart contract capabilities and constraints; ii) technical constraints; iii) politics; iv) partnership among stakeholders; v) the market system; vi) cost and efficiency and vii) sustainability factors. When it comes to smart contract capabilities, it is challenging to create standard semantics around the smart contract since languages are understood differently by different stakeholders. It will require a detailed guideline for interpreting the standardized methodology in the same way by the different stakeholders. The second factor which is the technical constraints involves educating the stakeholders about the technical legacy and use of the technology which may take some time. Also, interoperability could be a challenge when it comes to exchange of information by the different stakeholders legacy systems over the network. However, a global standardized system that is easily integrated into a company's legacy systems can easily solve this problem.

The third factor which is the politics which involves a shift from business as usual is a factor that could affect blockchain's implementation. It might be tough to convince policy makers to change an already working system. However, it all comes down to making a good business case as stated by the Digital and Strategy expert at the energy company. Partnerships and cooperation among stakeholders is the fourth factor. All stakeholders must be willing to work together for the implementation of such a system. The fifth factor which is the market system is heavily politicised at the moment. This has an effect on implementing blockchain in the market system.

The sixth factor presents cost and efficiency as determining the implementation of the proposed system. Since most companies are about reducing cost, a good business case that presents blockchain as a technology that reduces costs and is more efficient than the current system has to be presented for easy adoption. The seven factors are the pillars of sustainability: social, economic and environmental. Implementing blockchain may cause people to lose their jobs which has an impact on the economy. On an environmental level, blockchain consumes energy which causes pollution. As such the study recommends a Hyperledger blockchain which consumes low energy compared to Etereum's POW.

Other significant factors are security and privacy. Due to multiple validation processes in a public blockchain, involving many writers on the network, its security is more guaranteed and compared to a private blockchain.

### 11.2 Possible pitfalls on blockchain implementation

The implementation of the proposed blockchain model for monitoring and reporting CO2 trading does not come without challenges and pitfalls. The following pitfalls have been identified:

1) The availability of Information technology (IT) infrastructures : For the implementation of a blockchain system and its smart contract features, it will require great IT infrastructures in place, and easy integration of both IOT and machine learning. This can be demanding to achieve due to the fact that the technologies in question are still in the developmental stages, especially blockchain which is still an emerging technology. Issues such as scalability and capabilities of 'what can be achieved' and 'what may be achieved' at this stage of research and development should be looked into.

2) Ethical considerations: Issues such as privacy, security, data ownership, job loss, environmental impact are challenges that may likely arise in the decision to implement the technology. These need to be addressed in order to maximize the positive benefits and minimize negative sides of the technology.
3) Standardization of the EU ETS: When it comes to using blockchain for monitoring and reporting CO2 emissions trading, the system has to be clearly defined and a global standardized methodology for reporting CO2 emissions in place. Clearly, blockchain cannot fix all this, it all comes down to regulations.

Other arising pitfalls are education and awareness, cultural differences of stakeholder, capital cost, regulation and governance. As such the researcher recommends a more detailed study of these factors for future work.

To be clear, the implementation of such a system comes with challenges. Similar to any revolution, there will be winners and losers. What the EU Commission and authorities should do is provide a clear sense of direction to both society and industries, and put in place mechanisms to ensure that the most vulnerable segments of the society are not left behind.

### 11.3 Who has power to influence blockchain implementation and its beneficiaries?

As described in the study literature, blockchain is a technology that is continuously evolving and its scalability capacities are being explored. Due to the potentials the technology has to address the issue of climate change, it has become a topic of interest for climate related research (UNFCCC, 2017; Lo et al. 2017; Tabirao, 2018; CLI, 2019, IBM, 2018; CFI Education, 2020). Not only research and development are interested in the capabilities of blockchain for solving climate issues, authorities and regulatory bodies have also showed interest in the technology for addressing global warming as seen in the pilot study cases described in the study (case of China and Mexico) ( (MIEN and GIZ , 2019; IBM, 2018). However, the implementation of such a system will not only require the collaboration of all stakeholders as (described in 10.3.4), but regulators and authorities to influence the process. It will require a top-down approach with the regulators heavily backing-up the system ( as described in 10.2.1).

Already, the EU Commission has laid down policies that support implementing digitalisation, research and development towards low carbon-economy under Regulation

(EU) 2018/1999 (as described in section 5.3) (European Commission, 2018). For the study case, the Danish Business Authority has the power to influence the implementation of such a system because they control the regulatory affairs of the Danish Business industries. This includes tracking reports of CO2 emissions of the Danish energy industry as described in the case study ( section 7.4) (Danish Business Authority, 2019). The study recognises that it may be costly to implement such a system, the benefits are perceived to be worthwhile from the study findings. Stakeholders of the system (as described in section 9.2.1) who will benefit from its implementation include:

1) the EU Commission: who controls the cap and trade system of the EU ETS as described in the (section 5.1.1). The system can help the EU be on track towards achieving its emission reduction targets which is currently lacking as described in the (section 1.1). The EU Regulation (EU) 2015/757 is positive that the implementation of innovative digital technologies can accelerate climate actions and reduce CO2 (European Commission, 2015);
2) Danish Business Authority: who manages all Danish accounts in the EU ETS Registry including monitoring and reporting process of the EU ETS in Denmark as described in (section 7.4);
3) Energy operators: especially energy companies who are open to be transparent with the monitoring and reporting of their emissions. Already the energy operator interviewed in the study declared interest in the adoption of such a system from because it will give them a competitive edge from the study findings;
4) Subcontractors and suppliers of the energy operators: provided using blockchain is a precondition for the suppliers to work with the energy operators;
5) Climate initiatives and action plans: such as the Danish Energy Agency and the UNFCCC who are both working towards enabling a low carbon economy will benefit from such implementation. UNFCCC as an international body can also apply the proposed solution to other countries under its umbrella.

## 11.4 General study limitation

The study is limited by financial resources and time constraints, as research was carried out during the COVID-19 global health pandemic, which prevented the contributions of some experts' input to the study. As a result, the study was limited to one case company and one EU ETS Authorised Verifier who are also important stakeholders in the study. To mitigate this limitation, the research applied a triangular data collection method which considers two or more data sources. However, a more divergent primary empirical data would have been a great addition. Furthermore, blockchain as an evolving technology is still developing and not mature yet which might result in a limited amount of relevant information for the study. Nonetheless, both primary and secondary data gathered for the study are valid and up to date for the purpose of answering the research questions.

## 11.5 Concluding notes

The research proposes a novel blockchain solution on how blockchain can be used for monitoring and reporting of CO2 emission trading to improve transparency and compliance of the EU ETS program. While 92%  of 26,000 blockchain-based projects have been recorded as unsuccessful as suggested by Trujillo et al ( 2017) and (Graham, 2018) in (section 1.4 of the study), implementing the proposed system can add to improving such a record. This is because the proposed system directly addresses the challenges specific to the industry needs and preferences.  As described in the relevance section of the study (1.4)  and study's objectives (section 1.3), it was of paramount importance for the researcher to first look at the current needs and challenges of monitoring and reporting CO2 emission trading under the EU ETS. Next, ascertain if blockchain is the right solution, before developing a blockchain conceptual system to address these needs.

Taking advantage of the benefits of blockchain characteristics such as decentralization, automation, immutability and transparency, the system can be considered trustworthy and reliable for improving the issue of monitoring and reporting CO2 emission trading. Seeing that the energy industry is currently undergoing a double transformation of energy transition and digitalisation (Peter et al. 2019), as described in (section 1.4), now is the right time to act. The findings from the study can also be relevant for other industries: aviation, maritime, etc, looking for innovative ways to monitor and report their emissions. As the technology continues to evolve, the capabilities mainly of its smart contract continues to evolve. Blockchain DLT and transparency nature continue to pick the interests of individuals, industries and countries as a technology that can combat climate change in different research and developmental projects. Such type of research can be a very good contributing knowledge to possibly achieve a sustainable society the world needs and initiate a new age of a global techno-paradigm shift.

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Appendices

1.0 Climate and sustainability initiatives supported by digitize MRV systems linked to Blockchain technology

| # | Name | Websites |
|---|---|---|
| 1 | Climate Ledger | https://www.climateledger.org/ |
| 2 | IXO | http://ixo.foundation/ |
| 3 | Veridium | https://veridiumid.com/ |
| 4 | Xpansiv | https://www.xpansiv.com/ |
| 5 | Provenance | https://www.provenance.org/technology |
| 6 | Climate Chain Coalition | https://www.climatechaincoalition.io/ |
| 7 | Power Ledger | https://www.powerledger.io/ |
| 8 | Solar Coin/Electric Chain | https://solarcoin.org/ |
| 9 | CCEG Seratio Coins | https://seratio-coins.world/news?handle=theCCEG |
| 10 | Blockchain for Social Impact Coalition | https://blockchainforsocialimpact.com/ |
| 11 | DAO IPCI | https://ipci.io/ |
| 12 | Greeneum | https://www.greeneum.net/ |
| 13 | Poseidon | https://poseidon.eco/ |
| 14 | Carbon Coin | https://cryptoslate.com/coins/carboncoin/ |

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| 15 | Carbon X | https://www.carbonx.ca/ |
| 16 | Earth Token | https://earth-token.com/ |
| 17 | Earth Dollar | https://earthdollar.org/home/ |

Table . Climate and sustainability initiatives supported by digitized MRV systems linked to Blockchain technology.

Source: (Collaborase Interactive Leader, 2017)

2.0 Summary of Interview response

| EU ETS challenges | EU ETS possible solutions | Carbon emission trading monitoring and reporting (process) | Carbon trading benefits |
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| Interviewee1 : "People admit today that there are weaknesses in the system … there are ongoing discussions about reaching further CO2 reduction in EU and how this can be done"<br><br>Interviewee1: "Politicians and authorities are trying to implement a new phase of the EU ETS or see if they can implement a new one which is more robust but a better system , it is part of the current negotiations, we need to see where this will end."<br><br>There exists the problem of double counting where people register the same projects in several registers which is not the intent… " When mentioning double counting, there are many aspects, double counting could come from if you register the same projects two which can be avoided by blockchain."<br><br>"The other aspect of double counting is the aspect where some carbon projects do not provide the additionality which | Interviewee 1: "if carbon trading should be relaunched as a new method, it has to either be one register where all projects are registered, to avoid the over registering of the projects."<br><br>...Legislation should be the main target so you do not have double counting issues on carbon credits | Interviewee 1: Competent Authority approves the methodology or carbon project first, before sent out for possible Certified Emission Reductions (CERs) or carbon credits | Interviewee 8: investing in carbon trading/offsetting equals to investing in a community making it more resilient… "you are not only creating carbon credits, which is your main objective, but you're also sort of creating a positive impact in the community."<br><br>… from an economic point of view, by creating employment through carbon offsetting, you are bringing sort of economic activity into the area.<br><br>… if a company invest in a developing/poor country for |

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| were expected. And that that has been the cause of some criticism."<br><br>The EU ETS is on hold at the moment due to the challenges faced with double counting, complexities and controversies surrounding it | | | carbon offset which is what most companies do, it contribute to the country being less poor and directly fulfills the SDG 1 |
| Interviewee 3: The EU ETS need to be clearly defined and blockchain cannot fix that, it comes down to regulations | Interviewee 13: if EU leaders can agree to a higher target in the EU and work towards it, maybe the EU ETS will be strengthened but they have to agree first. | Interviewee3 : Today's trading system works perfectly fine, the problem is that there is not a market for carbon trading because it has to be regulated… but if you look into the future it becomes more crucial for business to carbon trade<br><br>… people try to make it look like carbon trading is complex but it all comes down to making a good possible business case and legislation backing it up…<br><br>… "technical solutions are available and we can't make a viable case for carbon trading because fossil fuels are extremely cheap" | |
| Interviewee 7: "The transaction cost to participate in the EU ETS carbon market is just too high… You need to be a big emitter for it to make sense to participate from an economic point of view." | | Interviewee 7: A centralized register for carbon trading, controlled by the government is more manageable and straightforward… than decentralized carbon registries<br><br>A hybrid carbon trading system with a central and decentralised layer increases interoperability... | |
| Interviewee 8: The monitoring and evaluation process of the | | Interviewee 8: The main standard used across the | |

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| EU ETS carbon trading are just too robust… and if not done properly could be overstating or understating carbon emissions… this puts the process at risk to achieve sustainability<br><br>“CO2 accounting needs to be more transparent and robust and I think blockchain can help solve that” | | world for carbon accounting is the GHG protocol… a good starting point and methodology for accounting carbon<br><br>Carbon offset should be the last resort for a company, businesses should start from reducing their carbon footprint | |
| Interviewee 6: The “EU ETS is pretty robust” verification alone is at installation level which involves a lot of processes and this is the complete GHG submission, only fuel combustion calculation. | | Interviewee 6: Emissions are verified from operational sites which are then used for the EU ETS compliance and annual submission of GHGs…<br><br>“Most companies prepare their data on some form of excel sheet… It's a good old process of verifying activity data… “verifiers use an excel calculator based on ISO 6976. It's not high-tech, but it's pretty smart.” | |
| Interviewee 13: There is an ongoing discussion in the EU for EU to be carbon neutral in 2050 and how to get there but it is yet to be implemented by law | | Interviewee 10: at the moment “Carbon trading is already an established market” | |

| **Blockchain requirements for carbon trading implementation** | **Blockchain challenges for carbon trading** | **Blockchain benefits for carbon trading** | **Blockchain disadvantages carbon trading** |
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| Interviewee 1: “it would take a group of companies or authorities to develop this and make it available to anybody who wants to do this”...<br><br>“It has to be sort of mandated that you have to use the blockchain. otherwise, you can't get any credits. So that | Interviewee 5: There are a lot of challenges around standards…. It is important to write a sort of general standard for the technology so that the regulators can also understand… | Interviewee 1: “blockchain is actually secure... you can't use the same credits two times. They have a stamp. So that's a very efficient way” of monitoring<br><br>“...you avoid the same credits to be used two times. So I think it's a good solution for the | Interviewee 3: ..There's no additional value in using blockchain.... If you want to collect data through blockchain, it's just as good as any other database “from my point of view.” |

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| could be one way, but it has to be politically decided.”<br><br>“It is a robust solution. Many companies are trying to set up such systems (blockchain for carbon trading)but I think it has to be approved by the authorities as well.”<br><br>“Even with blockchain you cannot avoid having some people be the judges of what is additional or what institution should participate… that point is not solved by blockchain” | ...It is going to take another 2 years or 18 months, to fully develop if you start today... you need to build a lot of the network.. | coming carbon trading system.”<br><br>… it might be good, insurance in case the politicians can’t agree on one registry.” | |
| Interviewee 5: It is better for the technology to be outsourced by an independent body and not within the firms operating in the trade…<br><br>“You need regulators to back this up”...<br><br>Businesses who want to carbon trade need to be educated about the technical legacy of the technology for carbon trading | Interviewee 4: Companies do not want to lose data to spies by sharing information over a network. That is a challenge to get them to use blockchain<br><br>… semantics are understood differently so standardizing blockchain language is important… and the technology is 10 times faster than the speed of these standardization processes<br><br>Blockchian has to evolve as humans evolve… for it to be massively adopted it has to have better performance, more secure, easier to use, just like how | Interviewee 2: Blockchain gives credibility (quality of being trusted) | Interviewee 7: in terms of environment, you have to consider the energy consumption…<br>in terms of mining consensus.<br><br>“Users of decentralized blockchain systems have a high self responsibility…. the decentralized system does not have something like a hotline so if something goes wrong or is missing in the decentralized system, it is gone for good.”<br><br>technical: “user experience has to be improved.”<br>Eliminating intermediaries has social and economic implications... people lose their jobs |

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| | the internet evolved.. "from it usage by the technical experts to normal people like you and me"<br><br>… there has to be willingness of companies to want to communicate with each other and that is the bigger challenge<br><br>…" you have to have good programmers to breach the codes on the blockchain network" | | |
| Interviewee 4: For "carbon trading, I will recommend a private blockchain"<br><br>"I would have recommended ethereum because of the public network, but it is not politically correct to use because of the high consumption of electricity during mining… hence Hyperledger fabric is better fit<br><br>… all participants within the network should be able to read and write over the network | Interviewee 7: Making a case for blockchain for carbon trading is a challenge " is it really necessary?" "where is the big trust issue?" | Interviewee 7: Blockchain make sense in situations where there are trust issues<br><br>Creating a level of trust in the network<br><br>Eliminating intermediaries will lower transaction cost and speed up transaction process<br><br>"well I assume it will. it will increase competition, because it leads to lower transaction costs and to faster processes results.... This question will be answered by practical outcome."<br><br>Interviewee 7:<br><br>…"well I assume it will increase competition, because it leads to lower transaction costs and to faster processes results.... my response is only proven right by practical outcome." | Interviewee 9: "Blockchain is strictly a ledger... like an accounting ledger. So bad data in bad data out. "<br><br>"For its immutability purpose and data privacy ... I guess you need to be selective in terms of where the application is that it's being used."<br><br>If it is "For the sake of just trading, it's not, particularly better or worse than anything else that's already up there." |

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| | | “So one competitor sees that it's working like this day. Then he would probably also follow up.. at one point they realized that it doesn't make sense that everyone uses its own blockchain. It's connected. And this is by the way, how the internet was created, right?”<br><br>"you've got to look at the cost benefit analysis of things.... Like if I'm gonna invest in a project that he's gonna abait, these many emissions, say, I'm gonna, you know, average three times more emissions than if I was investing in changing my equipment within my organization... that's more impactful" | |
| Interviewee 7:<br><br>The hybrid approach is a bit of a compromise ( decentralized and centralized layer of blockchain), but it is a better approach<br><br>“you need to start doing policy work and convincing policy makers and challenge an already working carbon trading system... they might be slow, they might be expensive, but they work. So how do you change the mindset here, so you need to start with a pilot test and so on...:”<br><br>The government will completely be in charge of assigning quotas and credits within EU for its members states<br><br>“When trading outside the EU | Interviewee 9: Wherever there is human, there is always challenges in the aspect of agreeing with each other | Interviewee 8: it creates more transparency around carbon accounting and carbon trading<br><br>Blockchain can be furtherly used to trace green investments… all the money that goes into investing in a community for example, or sustainable developments in developing countries, how do we track them? | |

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| states, credit will be traded on a decentralized layer of the blockchain where it will be completely transparent”<br><br>...So one competitor sees that it's working like this day. Then he would probably also follow up.. at one point they realized that it doesn't make sense that everyone uses its own blockchain. It's connected. And this is by the way, how the internet was created, right?” | | | |
| Interviewee 9: Define the problem you are trying to solve first and see if blockchain is the best fit to solve that<br><br>The use of blockchain will definitely help in the monitoring and reporting of carbon but that is only a part of the puzzle… there are many other aspects to this, data collection, storage, verification, etc | | Interviewee 10: … transparency and that is beneficial to the market because if people feel comfortable they they are likely to transact | |
| Interviewee 12: blockchain implementation will occur in many stages... | | Interviewee 5: ..tokenization :the ability to replace a sensitive data element with a non-sensitive equivalent, which can be traced back through a blockchain network instead of a physical instructor.<br><br>...reduction in the middlemen, the financing costs and the transparency”<br><br>… moving the reliability of human operators and a lot of the carbon credit trading and supply chain system from human errors<br><br>“Secondary benefit is | |

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| | | transparency provided through regulators and consumers.” | |
| | | Interviewee 4: Trust is the primary benefit of using blockchain<br><br>Keeping record of history due to its immutable nature<br><br>“It is difficult to manipulate”<br><br>‘ blockchain can actually help organizations initiate actions regarding this CO2 emissions reduction.... I've seen use cases that we've helped”<br><br>Blockchain identity capabilities… it is evolving and in the future could be used to identify humans<br><br>Interviewee 9: It reduces transaction cost… the amount of paperwork that gets reduced by standardizing these things ( done through bilateral contracts.), uh, is enormous<br><br>Transparency is the reason why we use blockchain… so that our customers can make informed decision<br><br>Immutability provenance… to be able to track data back in time is incredibly useful for accounting ledger…<br><br>Interviewee 12: It can be trusted<br><br>“ you can trace back to history”<br><br>It is a transparent system” | |
| | | Interviewee 11: it can serve as a competitive advantage for companies who use it, | |

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| | | because of its immutability nature, companies can show a track record that they practice what they preach... | |
| | | Interviewee 9:<br>…"when it comes to financial accounting, and monitoring financial things, or things it's absolutely imperative to have immutability "<br><br>Interviewee 13: "blockchain seem to be relevant for Double counting" | |

| Blockchain convergence with other technologies | Ørsted and blockchain application | Ørsted and carbon trading/reduction techniques | Government/ regulation in the energy industry |
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| Interviewee 4: Machine learning is useful to help analyse the data...<br><br>IOT automates the process of data entry which can help the data entered into the blockchain network more trusted | Interviewee 1: If the international climate discussions end up saying that, companies need to use the blockchain,for a new EU ETS for carbon trading, we would, support this because we support this because it clearly a trustworthy system, which gives additionally in carbon projects | Interviewee1 : We don't do the CO2 trading because today, this, that's not functioning... it's not a working system" the system has to be renewed and made more robust and trustworthy.<br><br>… I think many companies are not doing projects on CO2 trading because they're waiting for a new system to come alive…<br><br>To say carbon trading in EU does not exist in totality may be wrong, but the big volumes, which are needed or which would be needed to | Interviewee 1: …"the companies which have the most challenges are the companies located in areas that don't have sort of a renewable focus… where there are no ways of reporting carbon.. this will be sort of a new thing for them"<br><br>The EU Emissions Trading Scheme is perhaps the best known example of a system that can facilitate trading of carbon credits and allowances.<br><br>"For the sake of our own supply chain targets, it's important to note that our recent commitment is not due to regulation, but a voluntary commitment, as we believe it's the |

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| | | reach an efficient solution to this global challenge is not there yet. | right thing to do" …. "we hope it can give us a competitive advantage to be on the forefront of this development"<br><br>"This also means we don't need any specific regulation to be put in place – although politically imposed standards might perhaps in some cases make the task of getting our suppliers to report their emissions easier." |
| Interviewee 7: The convergence of machine learning and IOT with blockchain can create a huge impact<br><br>"Blockchain manages all the data that is generated by IOT."<br><br>"Artificial intelligence and machine learning can analyze the data generated by IOT and, excerpt, certain patterns and findings to see the effect on carbon emissions" for example "if that worked here, why can't it work here?"<br><br>"Analyzing a mass data generated by IOT and in order to ensure that this data is credible you need blockchain technology because you can associate the data to specific accounts, specific ledgers in a distributed network." | Interviewee 2: "there is a project that we have been working on with blockchain with our external suppliers, not something that we've been developing ourselves…<br><br>"we are making sure that whatever electricity you use is being matched down to the minutes by electricity that we put into the system. And that's a specific solution that was based on blockchain in order to secure accountability."<br><br>"We are currently at a pivotal spot in our business development. where, we are basing our focus on the retail consumers…"<br><br>"We see blockchain as potentially a very relevant technology to overcome these issues with double counting of | Interviewee 2: "what we've seen in the last 5 - 10 years is that it's been increasingly relevant for consumers to sort of buy green certificates in order to, to make sure their own energy consumption is matched by green generation."<br><br>…"we plan to stop trading gas whenever our current contracts have been sort of fulfilled"<br><br>"The gas contracts are binding and were made so long ago that we didn't give ourselves any way of getting out of it. So, that'll take care of the main part regarding reducing carbon, by 2032 or thereabout."<br><br>"We won't have any more coal in our power construct or | Interviewee3 :<br><br>"Governments need to set up rules saying that companies need to buy a certain amount of certificates, limit the amount of certificates"<br><br>Interviewee 8: "I think regulations are a good thing for emissions trading schemes, being set up by governments… that drives carbon abatement… it's a good tool"<br><br>"To achieve the goals of the Paris agreement, we do need a policy driven transition."<br>It doesn't need to always be like through mandates or regulations. It can be through subsidies, financial incentives…"<br><br>"carbon market, it's quite politicized at the moment, that's probably the biggest challenge. |

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| | credits., However, we are not currently looking into developing services for ourselves.”<br><br>“We 're not using blockchain now because we encountered some difficulties to convey the message because..... the electricity generated by our offshore wind farms in the UK. and, the geographical distance here in Denmark was simply too large for it to be relevant.” not a good business case<br><br>“The commercial, implication of the project we used blockchain for was that it wasn't attractive to our customers, that’s what we deemed, hence we put that project”<br><br>So for “the previous project with blockchain,it wasn't really a blockchain issue. It was a communication issue we experienced.” communicating it as a viable solution for business<br><br>“Obviously it's going to be relevant with accountability especially within our supply chain”<br><br>“while I'm not currently aware of any blockchain and the limitations, it might be relevant at some point to look into | power mill either by 2032 … we have committed to phasing out coal entirely within the next three years.”<br><br>We are going to go into dialogue with our suppliers, in order to reduce the emissions as much as possible… “we don't have a concrete roadmap, but we do have the commitment now” ….“we need to work out ways of doing it within the next 12 or 20 years”<br><br>“Fortunately, some of our big suppliers they have said that they would like to make their supply chains carbon neutral within the same time span as ours”<br><br>“we'll work with our suppliers and see what can be done… what cannot be done must be then, offset through credit schemes or other compensation schemes.<br><br>“ we're buying forest credits from some verified supplier that we trust will actually resolve in actual carbon reductions, or, sinks out in the world. So, that is one example of trading we are doing, | And if you've got big corporations in a country, basically posing these kinds of mechanisms, because that would mean that they have a huge carbon liability themselves…”<br><br>“Big companies are bigger emitters and you know, they will have a bigger carbon liability.And because sometimes when you see they have a lot of power, um, in terms of. You know, shaping government decisions.” this is a challenge in the carbon market<br><br>The climate action tracker (CAT) is an independent website that helps the government to evaluate,, the different policies, um, at the country level if they are meeting climate target<br><br>We have these decades, the 2020, and 2030 to make significant changes in carbon reduction...that should be should be policy driven |

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| | blockchain so that we can be sure that when we are in 2032, we can say that we've reduced our supply chain emissions by 50%, that we can also document."<br><br>For us " finding technologies for producing steel without carbon emissions or finding technologies for ships that don't use fossil fuels. That is quite challenging"<br><br>"we are looking into different ways of using digital tools to reduce our resource consumption and hence our top innovations. But, I'm not aware that we are looking into one or two single tools that need to have everything" | although at a significantly smaller scale"<br><br>"recently that we have, sort of committed to asking our largest suppliers to document the carbon emissions and to set science based targets"… but no concrete actions yet on how to get there<br><br>we are taking steps to source electric mobility within our company lead, source green energy and sort of facilities, our buildings"...<br><br>Scope one and two emissions are "our own emissions", those are considered quite manageable..<br><br>"Our scope three emissions are the challenges.. the bulk of those are from gas trading contracts… the real challenge is to find ways of finding suppliers of renewable steel that have been made without C02 emissions.<br><br>Scope 4 emission reduction challenge: ... today I am not aware we have good solutions for replacing diesel fuels in ships with other | |

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| | | fuels….<br><br>Scope 3 and 4 are reduction emissions are perhaps the largest technical difficulties at the moment when it comes to technology.<br><br>maintaining standardized and robust reporting of emissions from suppliers and sub-suppliers will be a precondition for suppliers to work with us... | |
| Interviewee 9: machine learning and data analytics could play a role in cleaning the data entered on the blockchain network which affects the overall outcome of carbon trading…. “the use of blockchain is just one tool in the toolbox” | Interviewee 3: “blockchain is just one technology. You can use any other protocol for carbon trading” … “I mean the technology is a hyped” | | |

| **Responses directly connected to the theories** | | |
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| Network theory | Stakeholder theory | Market structure |
| Interviewee 8:<br><br>“Competition has an effect on other industries "that's why we're seeing a lot of those like pretty bold commitments , for example Microsoft, from different organisations recently saying I'm going to go carbon positive and I'm going to offset | Interviewee 5: "the Decision-Maker energy sustainability officer, or the CeO or the CTO, the regulators... from a top down... you basically need to make sure that they have knowledge of the technology, how it works at our basic level"<br><br>Interviewee 5: “that's why a public blockchain with the most potential users, or you know, actors naturally, is the one that achieves a network effect.” | Interviewee 7: …”well I assume it will increase competition, because it leads to lower transaction costs and to faster processes results.... my response is only proven right by practical outcome.”<br><br>Interviewee 8:<br><br>"I think once you've created the market, then the market behaves like a market. Like it's no longer |

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| my historical emissions and things like that."<br><br>Interviewee 5:<br><br>"A public blockchain is better for carbon trading because it achieves more network effect" | Interviewee 9: "customers don't really want to know about the technology.they need to know that it works... " | the government, um, imposing that much is, is simply like you've created a market and they run on it own"<br><br>…"I think competition will accelerate emission reductions companies competing against each other and that having a positive impact"<br><br>"Competition has an effect on other industries "that's why we're seeing a lot of those like pretty bold commitments , for example Microsoft, from different organisations recently saying I'm going to go carbon positive and I'm going to offset my historical emissions and things like that."<br><br>" if you want to be a market leader, you want to do more or do it earlier."<br><br>.. "we've had companies asking us to do peer events, marking, to understand what the level of ambition is out there"<br><br>"My client has a supermarket team here like their competitors, that have a set carbon neutral commitment by 2025, my client too wants to be carbon neutral this year .... that way they are better than the others....It's definitely driving more action than it wouldn't if, if people were not making commitments." |

| What other industries can learn from monitoring and reporting carbon trading in the energy sector |
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| Interviewee 8<br><br>..“the impact it has on other sectors.....that's why we're seeing a lot of those pretty |

bold commitments like Microsoft's, recently saying they're going to, go carbon positive and offset like my historical emissions and things like that"...

.. "we've had companies asking us to do peer events, marking, to understand what the level of ambition is out there"

Interviewee 11: " Unilever, I think they are still the single largest user consumer… during the last five, 10 years, something like that, uh, planted a lot of new, uh, Palm trees around the globe…. I think they could be interested in promoting a system like this because they cannot, they can in a way, uh, do surveillance of the sub, contractors all the time…. with a system like blockchain for carbon trading, you can go back and change, that would make sense also."

Interviewee 11: Food production in Denmark is responsible for, I think, one third of all, carbon in Denmark…. Carbon trading with blockchain could also be good for them…. Because we have a really, really huge farming industry in Denmark. They have problems with carbon also.

3.0 Feedback from experts during post- interview (after reviewing the blockchain conceptual model proposed in the study)

| Roles | Notes |
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| Interviewee 6: Principal Auditor & EU ETS Verifier | "some of the verification process does require some human intervention - especially if things "go wrong" - failures in metering / measuring equipment - and then assessment of what the operator has done to demonstrate they are being conservative. I don't think even the smartest of algorithms can pick up minute sensitivities in data that I have spotted over the years....eg stuck gas chromatographs. Also the supplied information would have to be one format? There are a multitude of formats used for data at the moment. Some form of central platform could be useful though and for country reporting there is ETSWAP. "<br><br>" remote" verification of data would be a tough one with the current state of technology I think. There still needs to be verifiers in my view (well I would say that!), as I don't think any computer programme can pick up whether the actions taken when things "go wrong" (e.g. metering) and sense check that they are correct. Things do go wrong quite a bit of the time as well - some of the installations are in tough climates (e.g. offshore)." |
| | "the second one - verified emissions into the registry - would be good. It would save verifiers a step and also operators send us emails saying "can you close our data off in the registry", as we dont get notified of this. We have to physically check the system, and when the deadline is near, it gets a bit pressurised. I mentioned the repository called ETSWAP - this is where the verifiers and operators submit the opinion (and also the operator corresponds with the Regulator (UK = EA and OPRED). When a client makes a submission into ETSWAP, we do get notified by auto email" |

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| | The second half on the submission of emissions and registry is probably where I see great benefit - so at the moment it's a manual verifier check to make sure that the EU ETS emissions reported in the EU Registry are the same as the verified emissions. That would definitely save time and should in theory be easy to do. |
| | Having one "blockchain rule" also means that some of the local rules applied via the competent bodies can lead to very small local differences - eg different emissions factors for each country, different reporting conditions etc. |
| Interviewee 7: Program Director (CLI) (G) | “your illustration is accurate in terms of governmental oversight - it shows the most relevant pillars of ETS operations”<br><br>What may be added (but would add complexity to the illustration): limited use of offsets, the amount of allocated permits decreases over time, ETS mostly work in trading periods (e.g. 5-8 years in EU) |
| Interview 4: Co-Architect at IBM in Research and Development (D) | "Overall, what you describe is quite similar to other cases that our team has implemented (and is also implementing right now). The differences are the subject, the participants and the regulations but, if we forget the word "carbon", it is comparable and realistic. So, it is not a product of idealism but an emerging trend that we are seeing in other businesses."<br><br>"In other examples we had to implement, the crucial difficulty was to find a fair translation of the raw materials into tokens, i.e. some rules and parameters that all participants would agree on. That was a major obstacle to the success of the idea and it caused heavy discussions... I guess that AAUs, RMUs and CERs address the issue today. If they are currently accepted, you already have the half of the requirements done "<br><br>"Every change implies winners and losers. In your case, you explicitly mention the Authorised Verifiers as "replaced". I would say that if they can actually be replaced it is because they have no added value. Indeed, humans do not need to do what robots can do... If the Authorised Verifiers do a robotic job, it is better that they do other things. However, I guess that there might be a value that they could add somewhere. It is time for them to transform and think how to contribute better to the case and not just checking numbers or storing papers. Blockchain technology is not here to increase unemployment but for open new opportunities, be more creative and more human. I am sure that you write something similar in other parts of your thesis."<br><br>"I think I catched an error in Figure 1. A blue diamond (a decision symbol, "Right data & format?" ) on the bottom left corner that has two outputs but no input. I guess that the input should come from the "VALIDATION of monitoring plan". I think the small vertical arrow that goes down from "VALIDATION..." to "Process..." should go to the blue diamond."<br><br>"Every change implies winners and losers. In your case, you explicitly mention the Authorised Verifiers as "replaced". I would say that if they can actually be replaced it is because they have no added value. Indeed, humans do not need to do what robots can do... If the Authorised Verifiers do a robotic job, it is better that they do other things. However, I guess that there might be a value that they could add |

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| | somewhere. It is time for them to transform and think how to contribute better to the case and not just checking numbers or storing papers. Blockchain technology is not here to increase unemployment but for open new opportunities, be more creative and more human. I am sure that you write something similar in other parts of your thesis." |

4.0 Full transcription of all interviews can be found here in the folder text files