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Blockchain Technology for Tracking and Reporting of Carbon Dioxide Emission

A case study on its possible adoption on the container shipping industry

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ABSTRACT

The main objective of the research is to look at the idea invention, innovation and possible future adoption of the usage of blockchain technology for tracking and reporting of CO_2 emissions in the container shipping industry. Guided by the theories of innovation, adoption, and diffusion, the researcher was able to gather necessary data to address the research questions, develop result and to analyze it. Using both empirical data and literature reviews three research outcomes are presented.

First part is the research on the current implementation of Monitoring, Reporting, and Verification (MRV) programs for CO_2 emissions. Second is putting into consideration the use of blockchain technology and its capabilities to address the needs, challenges, and areas of improvement in the current MRV implementations. The process innovation is then created. And lastly, the research looks at the perceived characteristics of the innovation and the challenges of its implementation that may affect the future adoption of it in the industry.

There are several sustainability and MRV programs that are can be mandatory or voluntary. Because of this, there's no standardized CO_2 Methodology for vessel and cargo specific tracking and reporting of CO_2 emissions. In addition, ship operators are accessing different MRV systems. Another challenge is the data reliability and transparency of fuel consumption and other CO_2 monitoring techniques.

The research proposes the use of blockchain technology, mainly its distributed ledger technology (DLT) and smart contract capabilities. The result of technology perspective assesses if blockchain is the best fit to address the industry issues, including the chosen type of blockchain. Then, the stakeholders in the system were identified, their obligations and intentions. After such, the Business Process Model (BPM) which is the process innovation is presented. The business process model presents the document workflow, stakeholders, process milestones, and the capabilities of blockchain as an innovation. Three models are created due to some stakeholder's preferences on both vessel and cargo/TEU specific MRV system. The technology and proposed process innovation are then assessed, and propositions of its perceived characteristics as an innovation are investigated.

The research is currently in the pre-diffusion stage and does not create an actual working blockchain-based MRV system prototype. Therefore, the researcher is not giving a proposition that the innovation can be fully accepted or adopted in the future. Instead, the researcher will just give the factors that will affect on its possible future adoption.

Disclaimer

This is a research document that has been prepared to look at the possibility to use innovation in a specific case study, which is the Monitoring, Reporting and Verification (MRV) of CO_2 emissions. The document represents only the views of the author at the time of writing and not necessarily those of the European Commission, CCWG, Ethereum and Hyperledger Fabric.

Executive Summary

The main objective of the research is to look at the idea invention, innovation and possible future adoption of the usage of blockchain technology for tracking and reporting of CO_2 emissions in the container shipping industry. Guided by the theories of innovation, adoption, and diffusion, the researcher was able to gather necessary data to address the research questions and creation of its analysis. Using both empirical data and literature reviews, three outcomes are presented. First is a research on the current implementation of Monitoring, Reporting, and Verification (MRV) programs. Second is putting into consideration the use of blockchain technologies and its capabilities to address the needs, challenges, and areas of improvement in the current MRV implementations. In this stage, a process innovation is also created. And lastly, the research looks at the characteristics of the innovation and the challenges in the innovation's implementation that may affect the future adoption of it in the industry.

Tracking and reporting the total CO_2 emissions is believed to create a positive impact on the environment, and to the stakeholders involved in the program implementation. The European Union (EU) Regulation 2015/757 called EU MRV is a newly implemented mandatory program which is the main basis of the research for the vessel-specific MRV system implementation. At the same time, voluntary programs such as the Clean Cargo Container Group (CCWG) and its 2015 CO_2 Methodology is also one of the bases of analysis for the cargo/Thirty Equivalent Unit (TEU) specific reporting for ship operator's customer related emissions. Aside from these programs, there are more MRV programs that are implemented, but not within the scope of the research. The stated MRV programs and CO_2 methodology has been a good starting point for container shippers to track their CO_2 emissions at present and in the past years. But these programs also encounter different challenges, problems, and areas of improvements. One of the key problems is that ship operators/company are compliant with different MRV programs. Second is that there is no standardized CO_2 Methodology and ship operator is accessing different MRV systems. Data reliability and transparency of the total CO_2 emissions is also one challenge in the program's implementation.

The research proposes the use of blockchain technology, mainly its distributed ledger technology (DLT) and smart contract capabilities. The use of this technology has the potential to address the issues on the current MRV implementations. The result of technology perspective assesses if the case study needs a blockchain. In addition, the research identifies the type of blockchain that can be best suited on the industry's needs. Then, the stakeholders in the system were identified, their obligations and intentions. After such, the Business Process Model (BPM) which is the process innovation is presented. The business process model presents the document workflow, stakeholders, process milestones, and the capabilities of blockchain as an innovation. Three models are created due to some stakeholder's preferences on both vessel and cargo/TEU specific MRV system.

This technology and process innovation is then assessed, and propositions on its perceived characteristics as an innovation are investigated. This is through looking at the blockchain-based MRV's relative advantage from the currently implemented system, compatibility to future adopter's needs, and complexity of its development and future user's utilization. The research is currently in the pre-diffusion stage and does not create an actual working blockchain-based MRV system prototype. Therefore, the researcher is not giving a proposition that the innovation can be fully accepted and can be adopted in the future. Instead, the researcher will just give the factors that will effect on its possible future adoption.

The implementation of such innovation also incurs challenges. Mainly because the proposed innovation requires a high level of collaboration and execution between stakeholders. And at the same time, the innovation proposes high-level implementation and integration to technology such as IoT and machine learning.

Therefore, future research on this area is also encouraged. Mainly because blockchain is continuously evolving its capabilities as an innovation. In addition, there has been an increasing interest on different climate actions research and development. This explores on the use of blockchain and the distributed ledger technology to address the pressing global challenge, which is the climate change. These types of research can be a very good contributing factor to possibly achieve the green sustainable golden age.

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Acronyms

API	Application Programming Interface
BPM	Business Process Model
BDN	Bunker Delivery Notes
B2B	Business-to-Business
CDM	Clean Development Mechanism
CER	Carbon Emission Reduction
CO_2	Carbon Dioxide
DLT	Distributed Ledger Technology
DoC	Document of Compliance
GT	Gross Tonnage
ICT	Information Communication Technology
IoT	Internet of Things
IT	Information Technology
MRV	Monitoring Reporting Verification
MSP	Membership Service Provider
NDC	Nationally Determined Contributions
NOx	Nitrogen Oxides
PoS	Proof of Stake
PoW	Proof of Work
P2P	Peer-to-Peer
R&D	Research and Development
SOx	Sulphur Oxides
TEU	Thirty Equivalent Unit
VR	Verification Report
VSA	Vessel Sharing Agreement

Organizations

CCWG	Clean Cargo Working Group
CSI	Clean Shipping Index
EC	European Commission
EMSA	European Maritime Safety Agency
EU	European Union
GISS	Goddard Institute for Space Studies
IMO	International Maritime Organization
NAB	National Accreditation Body
NGO	Non-Government Organization
MS	Member State
UNFCC	United Nations Framework Convention on Climate Change

1. Introduction

In the era of innovation, Information and Communication Technology (ICT) offers different solutions to reduce carbon emissions and create a positive environmental impact. In fact, regulators in Europe are using the newly implemented Monitoring, Reporting and Verification (MRV) system to improve its governance on the monitoring and tracking of carbon dioxide emissions. This is implemented in maritime transport under the Regulation (EU) 2015/757 for Monitoring, Reporting and Verification (MRV) of Carbon Dioxide (CO_2) emissions and was enforced on July 1, 2015 and the first reporting period was January 1, 2018 (European Commission, 2015). It has become the top priority of shippers and managers with operations in European waters. Prior to the implementation of this mandatory program, some MRV voluntary programs are already existing for maritime transport being carried out by consultancy companies.

These various MRV programs are implemented because of the CO_2 impact of the maritime transport that accounts to 1000 million tons of CO_2 annually which is around 2.5% of global greenhouse gas emissions (IMO, 2014). In addition, there will be a 50% - 250% increase of emissions in the shipping industry in parallel to the development in both the economic and energy sector (European Commission, n.d.). Olmer, et.al. (2017) stated in the report for CO_2 emissions in global shipping that there are three ship classes that account for 55% of the total shipping CO_2 emissions: container ships (23%), bulk carriers (19%), oil tankers (13%). The remaining 45% of the emissions is accounted to other ship classes.

The second International Maritime Organization (IMO) study showed that there could be 75% reduction of CO_2 emissions in the ships energy consumption through the application of different operational measures and implementation of existing technologies (IMO, 2009). The Regulation (EU) 2015/757 stipulated that there will be a possibility of CO_2 reduction of up to 2% compared to business as usual. This will create an aggregated cost reduction of 1.2 billion EUR by 2030. This reduction will be the result of the reliable data on fuel consumption and energy efficiency to be used on market analysis for the best consumption and mitigation decisions. The current EU Regulation is highly confident that implementation of new innovative technologies can be a tool to achieve further reductions of CO_2 emissions (European Commission, 2015).

Different ways on how to use and implement various innovative technologies have been a global discussion for addressing problems and challenges in climate change and CO_2

reduction actions. The United Nations Framework Convention on Climate Change (UNFCCC) is currently exploring the use of blockchain technology for improving the tracking and reporting of greenhouse gas (GHG) emission reduction and avoidance of double counting (UNFCCC, nd). In fact, identification and tracking of GHG emissions have been a topic of a number of research studies using blockchain distributed ledger technology that explores on translating the data into secure and standard certifications of CO_2 emissions. An example is the MRV system being developed by Gold Standards (CLI, n.d.). There is a growing number of research looking at the usage of blockchain in relation to sustainable development, innovation and its adoption that is specifically related in climate action project such as the Climate Ledger Initiative (Appendix A.1).

Blockchain is one form of distributed ledger technology (DLT), meaning it is distributed across and managed by peer-to-peer network. This means that the set-up is not driven by a centralized authority that manages it because the data is maintained by database replication and computational trust (Ray, 2018).Because of its benefits as a technological innovation, UNFCCC supported the Climate Chain Coalition charter that looks at the application of DLT, including the blockchain. The charter also explored other related digital solutions to addressing climate change by its alignment with the Paris Agreement, DLT's advancement, dissemination improvement, addressing challenges using the application, and all other principles and values (UNFCCC, n.d.). UNFCCC viewed the main potential benefits of blockchain are enhancement of global public good, cost effectiveness, and transparency that is beneficial to different stakeholders (UNFCCC, n.d.).

The benefits of the usage of blockchain and its integration into sustainable development initiatives, and positive feedback on the emerging number of research made the researcher focus on blockchain and climate action topic. With the problem on the increasing amount of CO_2 emissions, specifically in the maritime transport, blockchain as an innovative technology can potentially address the said challenges.

The study will mainly focus on the container shipping industry, which is the highest contributor of CO_2 emissions from the three ship classes which is discussed above. Using adoption and innovation theories and proper data gathering methodologies, the researcher will be able to look at the possible use of blockchain technology and its adoption in the container shipping industry. There will be three steps to be able to address this research focus. First, the researcher will look at the implementation and challenges of the MRV programs. Then, it will look at the blockchain technology and its possible use to address the industry’s current challenges. Lastly, it will look at the perceived characteristics of this technology and the challenges on implementation. The perceived characteristics of the technology can be defined as the relative advantage of this from the previous ones, the compatibility of it on the industry’s needs and preferences, and the complexity of implementing such platforms.

Container Shipping Sustainability Programs

The world’s trade goods are transferred across the oceans in huge vessels called container ships. The ship specifications can be found in Appendix A.2. The term ‘container ship’ comes from the fact that the goods being shipped are efficiently packaged in containers. The containers are specifically called ‘intermodal containers’ because it is being transferred into trains or trucks and ships with the variety of standardized sizes. The capacity of ships is described in terms of Twenty-Foot Equivalent Units (TEU) which is the number of 20-foot containers the ship can carry. Sample ship specification can be found in Appendix A.3. Container ship is thus defined in the Regulation (EU) 2015/757 as the *‘ship that is designed exclusively for the carriage of containers in and on deck.’*

The Regulation (EU) 2015/757 covers the vessel specific MRV CO_2 emissions for maritime transport that are traveling to and coming from the union ports. In addition, the ship’s weight specification has to be 5,000 gross tonnage (GT) or more. But prior to this EU driven regulation, the container ships operators have been using different MRV practices established by different voluntary programs for container shipping by consultancy such as the Clean Cargo Working Group (CCWG), which has been existing since 2003 (Sachweh et al.,2014). Like EU MRV, CCWG also includes the total vessel specific emissions. In addition, CCWG caters the service for per cargo/TEU specific emissions, which Regulation (EU) 2015/757 is not covering. Some container shipping operators are currently doing both MRV program reporting such as Hamburg Sud, Hapag Lloyd and Maersk Line.

The research will look at both programs, the EU MRV as the mandatory regulation for vessel-specific emission and CCWG as a voluntary program mainly focusing at both vessel and cargo/TEU specific emission. The literature review of this programs is described in Chapter 2.

1.1 Problem and Background

The global temperature rise is one of the evidence of climate change (NASA, n.d.). Since the 19th century, a rise of 2.0 degrees Fahrenheit (1.1 degrees Celsius) was recorded that is primarily driven by the increased in CO_2 and other human-made emissions from the Goddard Institute for Space Studies (GISS) data (NASA, n.d.). An increase of 50% of global emissions of carbon dioxide (CO_2) since 1990 was also recorded (UNDP, n.d.). The Paris Agreement within the United Nations Framework Convention on Climate Change (UNFCCC) recognizes the problem on climate change. The goal of the agreement is to reduce the risk and impact by limiting the temperature to 1.5 ° C and holding 2 ° C (UNFCCC, art 2, para 1.a, 2015). The UNFCCC is an international & intergovernmental forum on greenhouse gas emissions mitigation, adaptation, and finance. Also, the Sustainable Development Goal (SDG) number 13 targets to look at the climate-related hazards, policies, strategies, education and awareness, program implementations, planning, and management as a guide for United Nation Development Program (UNDP) policy with funding until 2030 (UNDP, n.d.). In addition, the European Union (EU) also tackles its roadmap until 2050 on its goal on the transformation towards a *'low-carbon economy'*.

One of the largest contributors of the global GHG emission is accounted to global corporations. It covers a total of 20% GHG emissions from its operations associated with the corporation's supply chain involvement (Carbon Disclosure Project, 2011). Because of this impact, there’s an increasing activity in the gathering of information about climate change vulnerabilities and GHG emissions to be able to look at time risk-reduction opportunities for the growth and sustainability of the corporations. The global corporations, whether they are the supplier and/or manufacturer in the supply chain, are very dependent in the transportation sector. The transportation sector takes a crucial part in the management of logistics in the supply chain which determines the efficiency of moving products.

The end to end transportation process to move products from producers to customers may involve different forms of transportation such as trucks, trains, ships (e.g. container ships) and air freights. Approximately 60% of all the world seaborne trade is believed to be powered by the global container shipping industry, valued at around 12 trillion U.S. dollars in 2017 (Statista, n.d.). And this container ships which powers the trade account for the 23% of the CO_2 emissions in global shipping (Olmer & et al., 2017). In 2010, EU maritime transport activities are estimated to amount to 180 Mt CO_2 emissions, this data includes intra EU routes, and incoming and outgoing voyages to and from the EU (European Commission, 2013). This is the reason why there is an increasing pressure on shippers, logistics providers, and container carriers to reduce the CO_2 emissions and become more sustainable through monitoring and reporting of CO_2 (CCWG, 2015). In addition, the public demands for the information such as the GHG emission levels and reduction strategies in the supply chain, which includes seaborne transport, particularly in the container shipping industry.

The implementation of MRV programs, whether it’s mandatory or voluntary program are made to address the increasing CO_2 emissions brought by the maritime transport. It is also believed that the usage of MRV will bring benefits to different stakeholders in the shipping industry. One such benefit is that, MRV system can be beneficial to the sector in a cost-effective way, in the sense that it can create comparable and reliable fuel and energy consumption thus removing market barriers. MRV can be helpful on EU’s goal to achieve emission reduction targets towards low carbon economy by assessing the sustainability of the maritime transport.

But the implementation of MRV is imperfect and encounters different challenges. In the case of container shipping MRV programs, some ship operators are compliant with both mandatory (EU Regulation) and voluntary (CCWG) programs. These two systems have similarities and differences in implementation. First, the two systems have different processes, stakeholders, and scope, but generally should provide almost the same information for vessel specifics emission report. Second, CCWG is implemented on a global scale while EU MRV is limited to the EU member state ports. Also, both must ensure reliability, transparency, and privacy of different stakeholders.

One problem of the whole monitoring process is the accuracy of the data, especially the fuel consumption data, for the estimates are difficult to define due to large tank capacities, and the different kind of system and techniques that are being used. Different implementations mean different techniques for monitoring, data comparison, and computations for regulators. Therefore, the researcher will first look at the challenges, issues, and implementations of the current programs to be able to look at how technologies can address these issues.

1.2 Relevance of the Research

Blockchain has been a popular topic for development and research in the past years. But in the last 2 years, 92% of the 26,000 blockchain-based projects are unsuccessful (Trujillo et al., 2017 & Graham, 2018). This is why it is important in this study to look at the challenges of the industry and if innovation such as blockchain technology can address the challenges.

Through a specific case study in a particular group, the possibility to use the technology can be defined through looking at the specific actions and events that blockchain technology can cater, and if it fits the organization's goals. Buterlin (2015) described blockchain as a tool that gives freedom to create a new mechanism with the new rule set. Blockchain innovation can be the technology that can render the current technology obsolete and/ or can lead to reorganization of business models in different industries (Roiena, n.d.).

Aside from the creation of new mechanisms and rules in blockchain, there are more factors that set off the topic of blockchain in different industries. One of this is the discussion of the usage of it on changing organization from centralized to decentralized structures. The topic of centralization to decentralization has been the basic developmental pattern in the evolving system for creating, establishing and enforcing rules (Davidson et al., 2016). Currently, markets are arranged in a centralized order to easily create rules and establish knowledge structures. Now, blockchain is becoming a platform for decentralization through cryptocurrency and smart contract application where anyone that is on board in the network can write, join and validate transactions depending on the predefined ruleset that is set in the system. Tracing back the history, the shift from centralized to the decentralized system is already seen in computation perspective, like open source and open architecture and P2P networks and use of social media for communication decentralization (Kauffmann, 1993 &

Potts, 2000), and the internet as a global information system for decentralized knowledge sharing platform (Benkler, 2006).

In the perspective of technology adoption process, from centralized to decentralized way of implementing ledgers, the blockchain is in its early phase of adoption. Blockchain as an innovation can eventually '*form a new techno-economic paradigm*' that can set off a new era (Davidson et al., 2016 & Perez, 2009). Perez (2015) describes the new era as the green global golden age, which the ICT contributes to the green growth and can turn environmental challenges to solutions in the society. To achieve this techno-economic paradigm and the green technological revolution, in the early diffusion stage, the new technology, industry and infrastructure should work together harmoniously (Perez, 2015). The first step of this technology adoption process is to invest more on green research and to invest on green practices to abandon the old paradigm and move to a new era that incorporates new green practices that demonstrates rapid growth (Perez, 2015).

In a global level, green research and development are now becoming a major topic to address climate action mitigations, and adaptation of new IT solutions such as blockchain and DLT. In 2018, a newly launched UNFCCC supports blockchain technology and DLT related solution to enhance monitoring, reporting, and verification of climate challenges (UNFCC, n.d.).

Organizations such as the Climate Ledger Initiative (CLI) drives climate actions with the use of blockchain and DLT (See Appendix A.1). Other use cases that has a potential on the usage of this technology is for carbon exchange, market and credit. Organizations such as the Climate Coin (2018) and Poseidon (2018) is currently exploring these innovations.

The topics on the usage of blockchain and DLT technology tackling climate change action can expand to different directions and focus. In this research, it is very important to identify which blockchain innovation can help the industry to understand the types of challenges it presents, the level of collaboration within the stakeholders it needs, so as the consensus can be defined. At the same time, looking at the industrial and technological challenges on the implementation of such systems should be carefully analyzed. This mapping will suggest the kind of processes that can be established to facilitate the adoption of innovation. This process will then be carried out in the research focus which is the CO_2 tracking and monitoring in the container shipping industry. The research analysis can then be the basis for growth measurement in the early phase of the adoption of the usage of blockchain technology in this industry and climate action use.

1.3 Research Questions

In this research, it is very important to understand the industry's current needs and challenges. The first sub-question looks at the industry's perspective on the current MRV implementation. After scoping the current implementation, challenges, issues, and areas of improvements, the research will look at how the blockchain technology can address these challenges. To address the second sub-question, the researcher will provide an MRV process model that is guided by the technology capabilities for implementation and industry's needs. After this, the list of perceived characteristics and challenges on the innovation's implementation will then be presented to be able to give some propositions that may effect on the possibility to use this technology for future adoption.

Main Research Question:
What are the factors that might affect the possibility to adopt the usage of blockchain for tracking and reporting of CO_2 emissions in the container shipping industry?

Sub-questions

1. What are the current conditions and challenges of the tracking and reporting of CO_2 emissions on the container shipping industry?
2. What is the process innovation of a blockchain-based tracking and reporting of CO_2 emissions designed for the container shipping industry?

1.4 Research Objectives

This study aims to look at the possibility to use blockchain technology in the case study of tracking and reporting of CO_2 emissions in the container shipping industry. The objective of this study is to:

1. Investigate the current procedures and the challenges of MRV implementations for CO2 emissions.
2. Create a blockchain-based monitoring, reporting, verification (MRV) process model designed for container shipping industry. This process model will present the level

of collaboration among the stakeholders in the organization, transactions and processes, document workflows and the capabilities of the smart contract.

3. Identify the perceived characteristics of the innovation, and process innovation model and challenges, that might contribute to the future adoption of this innovation in the container shipping industry.

1.5 Scopes and Limitations

To be able to reach the research objectives and answer the research questions, some research scopes and limitations is defined per research objective:

Objective 1:

This research covers the process on a vessel-specific MRV of CO_2 emissions. The research does not fully scope the cargo/TEU specific CO_2 computation in the seaborne transport, but some consideration of adding it to the research result was formulated because of the container shipping industry's nature of the business and ship operator's customer related needs.

The mandatory MRV program under Regulation (EU) 2015/757 which is newly implemented in 2018 will be the research basis of monitoring, reporting, verification process, document workflow, formula, fuel monitoring techniques and data of the vessel-specific emissions. Another MRV program that will be considered in this research is the voluntary program running in business-to-business implementation called CCWG. This program has been running since 2003 and has developed a concrete CO_2 emission calculation and method, that fits the 'global' description by nature of the container ships, in comparison with EU MRV that just do monitoring within the EU ports only and applicable to kinds of maritime transport. These programs will then be the basis of investigating the current challenges, issues, and areas of improvements in the MRV processes. CCWG also doesn't cover the same process as EU MRV as it is just for an initiative for measurement, evaluation, and reporting of the environmental performance in the container shipping industry.

Other mandatory regulation to shippers such as The International Maritime Organization (IMO) Fuel Oil Data Collection System (DCS) and all other MRV programs presented in Chapter 2 is not included for the MRV process analysis and result creation. Still, some insights about the possible role of IMO in the future innovation was discussed.

Objective 2:

The design that will be presented is limited only to a process model for MRV of CO_2 emissions and the evaluation if the study needs a blockchain. These process model only include the identification of stakeholders, high level agreements and processes, document workflows, and an overview of the smart contract capabilities.

The research will propose a possible blockchain architecture that will fit the industry's needs. But the research will not cater a full proof of concept model in that specific proposed architecture. This means it will not create a complete blockchain architecture layers such as the consensus, smart contract, communication, data store abstraction, identity services, policy services, API, and interoperation.

A process innovation represented by a Business Model Process (BPM) will be the research output of the Objective 2 after the technological analysis. BPM does not scope the non-compliant processes.

Objective 3:

The third objective tackles the perceived characteristics of the innovation that may affect the future adoption. This will be done through distinguishing its relative advantage from the previous system, investigating the system's complexity as an innovation, and its compatibility with the industry's needs. The perceived characteristics of innovation identified is based on the investigated MRV challenges. The proposed usage of blockchain does not include all other factors that are not identified in Objectives 1 and 2. Some out of scope research propositions are the cost analysis and some economic and social factors for adoption. Since the goal of the research is not the creation of an actual working

Since the goal of the research is not the creation of an actual working prototype, and at the same time MRV for blockchain is still on a research and development stage, it is difficult to concretely give propositions of the 'adoption' and 'rejection' of this innovation. Due to this limitation and lack of a working blockchain system that can be analyzed, the research can only investigate at the 'pre-diffusion stage' of this specific case study and analyze the characteristics of this technology based on its alignment to the industry's mechanisms, rule set and goals.

At the same time, challenges on the implementation of the process innovation which is the research output in Objective 2 will be presented.

1.6 Summary

As a short summary of the research chapters is discussed below:

Chapter 1 gives the introduction of the research that covers the problem, background, relevance, research questions and objectives, and the scopes and limitations.

Chapter 2 is the first part of the literature review that focuses on the industry's perspective, which is the container shipping MRV programs. This chapter gives an overview of the both mandatory and voluntary program that will be the basis of the research result and analysis.

Chapter 3 is the second part of the literature review that focuses on the technology perspective that gives an overview of the blockchain technology, consensus, smart contract, decision-making process on the usage of the blockchain, types of blockchain and their differences.

Chapter 4 introduces the theoretical background. This will also give an overview of the theories on innovation and adoption.

Chapter 5 presents the research conceptual framework based on the theories of adoption and innovation. This framework will be the guiding tool to answer the research question, address the research objectives and to provide research result and analysis.

Chapter 6 describes 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 7 showcases the result of the research that provides information, design, and representation of the data that was gathered.

Chapter 8 is the analysis of the result gathered in the research. This gives a careful analysis of the three-core objective of the research. It is to look at the idea invention, innovation, and factors that may affect the future adoption of technology.

Chapter 9 gives the major takeaway of the study, limitations of the research results and analysis and some suggestions for future research.

2 Container Shipping Industry Sustainability Programs

Shipping plays a very important role in the transport and logistic sector, which is an essential part of the whole supply chain ecosystem. Monitoring and reporting the sustainability impact of shipping has been a major topic of discussion in policy implementation in a global scale. There is an increasing pressure for shippers, particularly the container shipping industry and its customers to report and comply with regulations in CO_2 emission tracking and reporting.

Currently, there are mandatory and voluntary programs that implements MRV of CO_2 emissions. The Regulation (EU) 2015/757 monitoring and reporting of CO_2 was implemented in January 2018 for all maritime transport. This regulation considers four parameters that ships needed to comply: (1) fuel consumption/CO_2 emissions; (2) distance travelled; (3) time spent at sea; and (4) cargo carried. But aside from this regulation that the ship operators need to comply, there is an additional requirement for the shippers to also compare those obligations with common practice they already have on board (Delft, 2014). In case of the container shipping industry, one of the common and known sustainability initiative prior to EU MRV implementation is the CO_2 methodology that was developed by Clean Cargo Working Group (CCWG). This organization is one of the known voluntary program and became common practice for the container shippers. CCWG offers a business-to-business CO_2 emissions consultancy on the proper use of emissions calculations, benchmarking and evaluation of performance for both vessel and per cargo specifics. It started in 2003 and now carries 40 leading multinational shippers, freight forwarders and container carriers that represents almost 85% of the global container capacity. There are more existing common practices, voluntary programs and mandatory regulations that is not just limited for container ships but also in all other types of maritime transport.

This part of the literature review will look at the two MRV programs that are now being implemented in the container shipping industry: (1) EU MRV in Section 2.1; (2) CCWG in Section 2.2; (3) Characteristics of the EU MRV and CCWG in Section 2.3; and (4) Other MRV system implemented in the maritime transport in Section 2.4.

2.1 EU MRV

The European Union (EU) Regulation 2015/757 has come to force amending the Directive 2009/16/EC on the 'Monitoring Reporting and Verification (MRV) of carbon dioxide emissions from maritime transport'(European Commission, 2015). This regulation is an EU wide legal framework that gives a greater emphasis on the accuracy and transparency of CO_2 emissions data, reporting, and methodologies. Also, Regulation (EU) 2015/757 states that the '*Union MRV system should serve as a model for the implementation of a global MRV system'*. Also discussed in the said paper that the EU MRV will facilitate and support the IMO and other international bodies on the monitoring, reporting and verification of GHG emission in their policy in the future.

The first step approach of the EU is to include the maritime transport to the Union's GHG emission reduction commitment and its goal to have a 'low carbon economy' and is believed to create a lot of benefit upon its implementation. The benefit of the transparency and opening to the public some of the emissions data can remove market barriers and prevent the ship operators from cost negative measures. In addition, the Union's plan after the implementation of an effective MRV system is to price the emissions at a later stage.

The regulation is implemented for the large ships that can be a passenger, ro-ro, container ships and other types of ships that are over 5000 gross tons (GT) which accounts to the 55% of the number of ships calling into the Union Port (European Commission, 2013). One example of this ship with the EU regulation specification is the container ship. The Regulation (EU) 2015/757 described the monitoring on per voyage basis, are the amount of 20-foot equivalent units (TEU) multiplied by default values for their weight as the total weight in metric tons (European Commission, 2015).

EU MRV CO_2 Computation

The formula for calculating the total CO_2 emissions of company/ship operators is Fuel consumption multiplied by the emission factor.

The variable fuel consumption includes different elements such as the main engines, auxiliary engines, gas turbines, boilers and inert gas generators, both at sea or at berth within the ports. There are three methods used for determining CO_2 emissions of each ship through fuel consumption: (1) Bunker Fuel Delivery Note (BDN) and periodic stock takes of fuel tanks; (2) Bunker fuel tank monitoring on board; and (3) Flowmeters for applicable combustion processes. The first technique, Bunker Fuel Delivery Note (BDN) and periodic stock takes of fuel tanks use the fuel sold as the proxy for fuel consumption data over a certain period (Transport and Environment, 2012). The second method is based on the tank readings for all fuel tanks on board (European Commission, 2015). The third method is using flow meters for the main and auxiliary engines to measure the amount of fuel consumed, that is done automatically in the system (Transport and Environment, 2012).

The direct CO_2 emissions measurements is another technique on getting the total CO_2 emitted by the ships. This is the most effective way of getting CO_2 emissions because it is deployed in the funnel without using fuel consumption as a proxy, and directly get the total CO_2 and other Greenhouse Gas (GHG) data as the source of total CO_2 computation (Transport and Environment, 2012).

EU MRV System Implementation

In the implementation of the EU MRV (Regulation (EU), the European Maritime Safety Agency (EMSA) already developed the information system called Thetis MRV as part of its mandate's framework to support the European Commission (EC). Thetis MRV is a web-based application wherein the company, verifiers and flag state can sign up in an account to be able to connect with all the MRV stakeholders in a centralized way to comply with the monitoring, reporting and verification process (EMSA, n.d.). The Thetis MRV is also the system the regulator uses to have the end to end visibility of the stakeholders involved in the module. Thetis MRV is a module wherein the company creates the monitoring plan and emission reports, which is then can be assessed by the verifier.

Monitoring, Reporting, Verification (MRV) Process and Stakeholders

The stakeholders that are involved in the whole monitoring, reporting and verification process are the company, verifier, accreditor and the regulator. The company is defined as the owner or the operator of the ship. Verifier is the legal entity carrying the verification activities with the company, they are also the entity that applies the verification standards of the commission and is accredited by a National Accreditation Body (NAB). NAB is the entity that accredits in pursuant of the Regulation (EC) No 765/2008 of the European Parliament and of the Council and this Regulation. And lastly, the regulator is the European Commission (EC) in pursuant of Regulation 2015/757.

The regulation says that companies shall monitor, and report CO_2 emissions and the relevant parameters carried under the port jurisdiction of a member state (from or to of EU ports). The process and stakeholder mapping of two main stakeholders of MRV which the company or the ship operators, and the verifier is mapped in Figure 1. The MRV process starts with the company creating and submitting a monitoring plan and the submission will be verified by the verifier. After that, an emission report will be checked by the verifier if it is in line with the monitoring plan and regulation. After this verification of the emission, the report will be submitted to the Commission and Flag State (Member State of the commission). Lastly, the verifier shall then issue a document of compliance to the company as soon as the emission reports fulfill all the requirements in the monitoring and reporting.

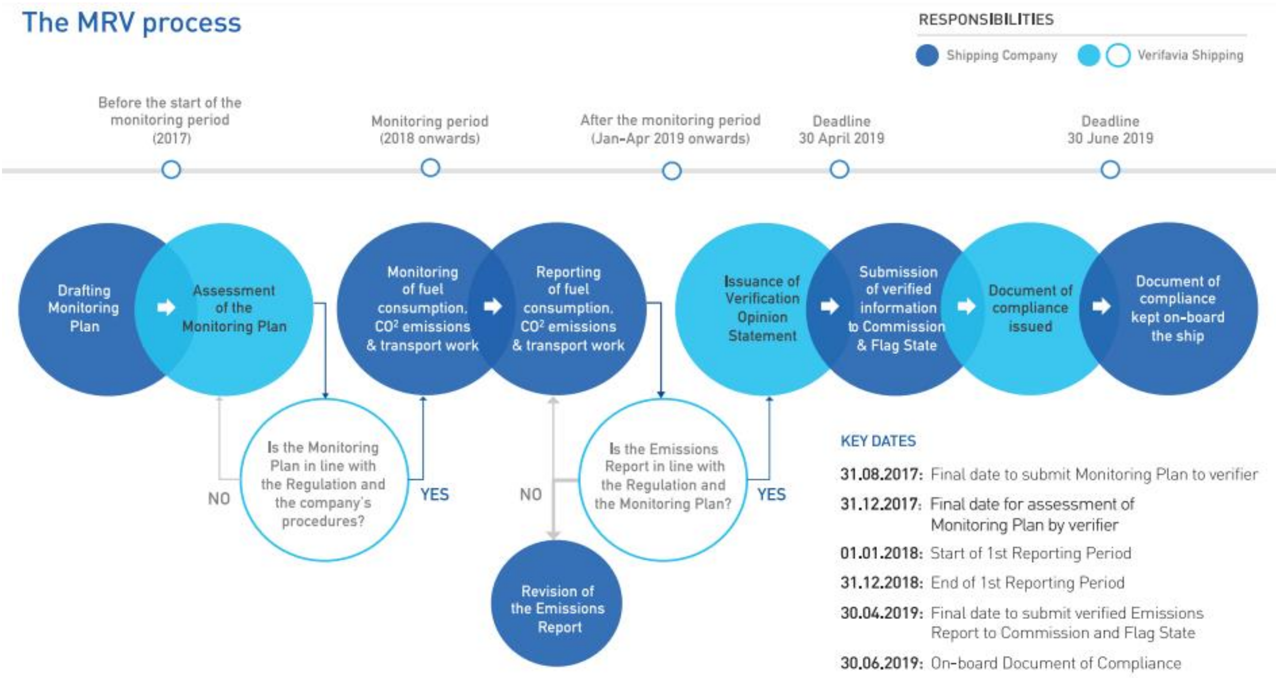


Figure 1: EU MRV steps, roles and responsibilities of stakeholders

Source: Verifavia (2017)

In this process of creation of monitoring plan and emission report, there will be two data sets that will be required. For the monitoring plan, it is the data to monitor which includes the port of departure and port of arrival, date/time of departure and arrival, fuel consumption for each fuel type differentiated by fuel consumed at-sea and in EU ports, emission factor of each fuel consumed, CO_2 emitted, distance travelled, time spent at sea, cargo carried, and transport work (distance multiplied by cargo carried) (Sachweh et al.,2014). Monitoring information can also be extended in ship's ice class and its navigation through the ice. The data to monitor is explained very briefly in the Regulation (EU) 2015/757 in Article 6. The data includes ship details, company details, procedures for monitoring fuel consumption of the ship, etc. This content of the emission report is explained in the Article 12 of Regulation 2015/757 and the data to report is in the Article 11.

All the valid documents in the process which contains the data sets in each report should be represented in a proper format. Using automated system and data exchange formats (electronic templates) provided by the EC, this reporting and documentation will be standardized based on the stakeholder who will create or issue this documents Regulation (EU) 2015/757.

The main process of the MRV system is explained briefly in Figure 1. But there are more stakeholders involved in the whole EU MRV regulation and also a number of different relevant international bodies, consultants, and experts, customers, the public, member state, etc. These stakeholders can be the future supporting bodies of the regulators, provide help to the regulators for the MRV implementation, people that needs to be informed for penalties and expulsions of non-compliant, and all other stakeholders that ship operators need to inform about their sustainability performance.

2.2 CCWG CO_2 Methodology

The Clean Cargo Working Group (CCWG) provides global business-to-business platform that developed '*CCWG CO_2 Methodology'*. It is a CO_2 calculation methodology that is used by container carriers for reporting CO_2 performance in a credible way in terms of data accuracy gathered, and comparable way in terms of the creation and implementation of emission factors standards in container shipping (CCWG, 2015). This methodology is internationally recognized standards such as the GHG supply chain guideline, European EN 16258 standards, and IMO EEEOI guidelines.

$$CO2\ dry = \frac{IMO\ Carbonconversion\ factor * (Total\ fuel\ consumption - Total\ reefer\ fuel\ consumption)}{(dist.\ sailed * vessel\ TEU\ capacity)}$$

$$CO2\ reefer = CO2\ dry + \frac{IMO\ Carbonconversion\ factor * Total\ reefer\ fuel\ consumption(**)}{(dist.\ sailed * reefer\ TEU\ capacity)}$$

(**)

$$Total\ reefer\ fuel\ consumption = reefer\ TEU\ capacity * reefer\ consumption\ per\ year\ (const.) * \frac{days\ vessel\ operated}{365}$$

Equation 1: Total CO_2 Emissions (g CO_2/TEU KM)

Source: CCWG (2015)

The emission factor in CCWG is the CO_2 measure to be able to calculate the CO_2 emissions of the transportation of the specific container or specific amount of cargo and is expressed as grams of CO_2 emissions per container (Thirty Equivalent Unit – TEU) transported 1 kilometer (g

CO_2/TEU KM) (CCWG, 2015). The formula used by CCWG for the computation for the total CO_2 emissions is expressed in Equation 1.

The CCWG CO_2 Methodology is established for *'ONE common standard for the calculation of CO_2 emissions for ocean container transportation'* (CCWG, 2015). It provides credibility to the three main factors: (1) describing and explaining how CO_2 emission factors are calculated; (2) ensuring standardized and comparable CO_2 emission calculations for shippers and carriers; and (3) benchmarking carrier's CO_2 performance.

There are two types of cargo the CCWG CO_2 methodology caters, the regular containers called the 'dry' and the refrigerated containers called 'reefer'. Computation of the emission factor requires a lot of criteria and sources. Criteria such as IMO carbon conversion, total fuel consumption, distance sailed, vessel TEU capacity, reefer TEU capacity, reefer consumption per year and days vessels operated. Each of these criteria has a different source such as the IMO, general agreement – capacity plan, etc. The total fuel consumption and the distance sailed, for example, came from the operators reporting system with the vessels logbook. Operators reporting system uses different ways on fuel measuring techniques and different technologies. In addition to its value proposition, CCWG ensures that there's a common and consistent use of the emission factors through basic principles of how to use it, this includes consideration of other factors such as carbon calculation clause consideration, utilization factor, seaborne transshipments, distance adjustment factor and TEU conversion factor (CCWG,2015). Also, CCWG ensures that there's a proper benchmarking through looking at the trade lane average as industry baseline performance and the individual carrier's trade lane performance. This is to cater the natural characteristics of containerships which operates in the 'global' trade lanes.

CCWG System Implementation

The CCWG is using the Turnkey platform as an online reporting system for data analytics, benchmarking functionality for data comparison of emissions, and provide score sheets to evaluate the carrier's benchmark (Turnkey, n.d.). Only CCWG members can have an account in Turnkey. The main goal of the system is to achieve the carbon reduction goals, optimization of the data by looking at the process and scalable features, and to provide an expertise when it comes to the sustainability of the logistics industry (Turnkey, n.d.).

2.3 EU MRV and CCWG Program Elements and Scope

The table below shows the difference between CCWG and EU MRV program and implementation. The source of the table on the program elements is from Sachweh et al. (2014) literature. Some of the details are modified from the updated information from CCWG website and documentation and Regulation (EU) 2015/757 policy.

EU MRV is a mandatory program for all ships arriving to and departing from a port under a Member State's jurisdiction. CCWG is a voluntary program of container vessels that covers global seaborne transport. Both MRV programs provide ship operators CO_2 emissions data using its methodology. The main difference of CCWG from EU MRV is that this voluntary program also ensures comparable CO_2 emissions calculations for ship operator's customers, which are the cargo owners. Therefore, the efficiency metric used by CCWG is g CO_2/TEU KM which is cargo/TEU specific. EU MRV uses all four fuel measurement techniques, while CCWG covers only fuel tank monitoring on board and fuel flow meters. Both MRV reports must be verified by an accredited verifier. Program elements and characteristics is consolidated in Table 1.

Table 1: Program elements of EU MRV and CCWG

Source: Regulation (EU) 2015/757; Sachweh et al. (2014); CCWG (2015)

No	Program Element	EU MRV	CCWG
1	Type of Program	Mandatory Program	Voluntary program for container shipping by consultancy company
2	Start of Program	2018	2003
3	Ship Threshold	Ships above 5.000 gross tonnage (GT)	Container vessels greater than 400 gross tonnage (GT)
4	Number of ship owners and/or ships involved	All shipping companies arriving to and departing from a port under a Member State's jurisdiction	23 ocean carriers (2018)
5	Reporting Entity	Shipping Company	Container operators/shipping companies

6	Fuels included	All fuel burned in all engines, generators and boilers	All fuel burned in all engines and boilers (main engine, auxiliary engines and boilers)
7	Geographical Scope	Voyages arriving to and departing from a port under a Member State's jurisdiction	Global
8	Temporal Scope	Monitoring per voyage and year, reporting per year	Annual
9	Resolution	Per ship	Per ship, trade-lane and fleet operated by the company. Also includes seaborne transshipments such as VSA, feeder service and Slot Charter Agreement
10	Fuel Measurement Techniques	1) BDN and periodic tank measurements, 2) Fuel tank monitoring on board 3) Fuel flow meters, and 4) Direct measurement of exhaust CO_2.	2) Fuel tank monitoring on board 3) Fuel flow meters
11	Reported Air Contaminants	CO_2	CO_2
12	Supporting Data required	Fuel consumption, days sailed, distance sailed, etc.(See Section 7.1.3)	Fuel consumption, days sailed, distance sailed, other TEU specific factors etc. (See Section 7.1.3)
13	Efficiency metric used	1) fuel consumption per distance 2) fuel consumption per transport work 3) CO_2 emissions per distance 4) CO_2 emissions per transport work	g CO_2/TEU KM
14	Reporting method	Thetis MRV	Turnkey
15	Verification Requirement	Third-party verification by accredited verifier	The CCWG CO_2 verification guideline developed by CCWG and class society (e.g. Lloyds register, DNV, GL etc.)
16	Used guidelines and standards	Regulation (EU) 2015/757	CCWG Carbon Emissions Accounting Methodology 2015

2.4 Other MRV Programs

There are other methodologies aside from EU MRV and CCWG. Table 2 below shows the other implemented MRV systems that shows the type of program and ship threshold of each MRV program

Table 2: Other implemented MRV program

Source: Summary List of Voluntary MRV Systems (Sachweh et al.,2014)

Program	Type of Program	Ship Threshold
Clean Shipping Index (CSI)	Voluntary Program for all main types of vessel by non-profit association of cargo owners	All main types of cargo vessels
Norden MOEPS	Company System	Entire fleet of Norden is Involved (Approx 250 ships)
FRAM	Norwegian Voluntary Program	No requirements for inclusion
French Transport Code	Mandatory regulation	All, no threshold for inclusion

Other implemented MRV programs are CSI, Norden MOEPS, FRAM and French Transport code. These implementations also differ on the type of program, some are company owned, voluntary program, and mandatory regulation. CSI for example is also an MRV program for all types of cargo vessel, but some has no threshold inclusion.

Aside from other MRV implementations that is given in the Table 2, IMO just implemented its new regulation in big ships that came into force last March 2018. On January 1, 2019, the ships of 5,000 GT and above needs to comply with the new regulation on the fuel collection data of ships under the amendment of MARPOL Annex VI, Regulation 22A - IMO Data Collection System (IMO DCS). The ships are required to collect the used consumption data for each type of fuel oil and other data such as the proxies for transport work (IMO,2018).

2.5 Summary

The literature review presented the EU MRV and CCWG. Both programs have similarities and differences when it comes to standards, scopes, computations, and implementation. EU MRV is an already implemented mandatory program, and CCWG is a voluntary program that covers most number of container ship operators and has developed a CO_2 methodology that is specifically for container ships. Some of the container shipping operators/company are compliant with these programs. A short introduction to other MRV programs such as IMO DCS, CSI, etc. is also presented.

3 Blockchain Technology

This section will discuss the fundamentals of blockchain technology and its characteristics. This section will also introduce consensus, smart contracts, an overview of the public and private networks and examples of blockchain that is being used for smart contract applications. In addition, the decision-making process section showcases a flow chart if blockchain can be a right fit technology for a case study, and what type of blockchain can be used based on the anonymity design implementation and a question of trustworthiness of the members of the network.

3.1 Technology Fundamentals

The blockchain is used in some distributed ledger technology (DLT) that transmit and stores data packages called blocks through a digital chain wherein the blocks are connected to each other (World Bank, 2017). It is known to be immutable because the DLT uses cryptography in recording the synchronize data across a network of nodes in a decentralized structure. Buterin (2017) the creator of Ethereum described blockchains as *"politically decentralized (no one controls them) and architecturally decentralized (no infrastructural central point of failure) but they are logically centralized (there is one commonly agreed state and the system behaves like a single computer)*." The concept of blockchain was first introduced by Satoshi Nakamoto (2009) in the form of bitcoin cryptocurrency. Bitcoin is a public blockchain that uses peer-to-peer technology wherein exchange of value and transactions are carried out collectively in the network using bitcoin tokens (Bitcoin Organization, n.d.). After its first application, the adoption of blockchain into different applications has gained considerable interest and the technology has been linked to the attributes of being decentralized, secure, immutable, trustless, and transparent. Although. some blockchain systems may not conform to such definitions that are mentioned. This is because its concept and development are currently evolving and is tailored to a case study requirement, which is built depending on the considered blockchain network (Section 3.4) and the kind of consensus (Section 3.2).

Baliga (2017) explained that through consensus protocols the blockchain is being updated, orders the transactions and blocks, and guarantees the integrity of this transaction across the distributed nodes. The users of the network secure and maintain the blockchain and the shared ledger of data by running this consensus. Aside from Bitcoin introduced as a peer-to-peer payment running in a Proof of Work (PoW) consensus, blockchain is now also being used to enable smart contract which is represented by a computerized transaction protocol and code that executes terms set into it. Example of blockchain which has smart contract capabilities are Ethereum and Hyperledger (Section 3.5).

The blockchain is known to have an attribute as a technology that allows transactions without depending on a Trusted Third Party (TTP) (Wüst & Gervais, 2017). At the same time, non-financial parties can benefit to the transparency of blockchain by allowing multiple parties in a network to have access to the same data. DBS (2016) explained that this can be done by replacing the third-party processes by systems that can automate transactions in real-time which reduces the cost and risk of users which replaces the role of TTP in the system. In addition, users of the blockchain will have a control to the data that uses cryptography to secure transactions.

3.2 Consensus

Before the advent of bitcoin, reaching consensus in distributed computing is one of the fundamental problems because it is believed that it is impossible to achieve a fault tolerant, and attack resistant system. This challenge is known as the Byzantine Generals Problem (Lampot et al., 1982). To address this challenge, consensus implementations in a distributed ledger are proposed to create replicas of agreement in the process of transactions updating (Gramoli 2017), with a financial incentive layer for coordination of the network of participants (Voshmgir & Kalinov, 2017) in cryptocurrency system such as bitcoin. To be able to reach a consensus, an agreement will be generated among the network of participants wherein members of the network needs to validate before a transaction can be considered valid. The characteristics of consensus protocols and the factors of why decentralization is useful in the first place were explained by Buterin (2017). As per Buterin, consensus protocols are fault tolerant, attack resistant and collusion tolerant.

There are different blockchain consensus mechanisms such as PoW, PoS, and the Redundant Byzantine Fault Tolerance (RBFT) are briefly explained below:

Proof-of-Work (PoW)

'The method asks users to repeatedly run hashing algorithms or other client puzzles, to validate electronic transactions through mining' (Voshmgir & Kalinov, 2017). Mining uses high amount of power to be able to solve the puzzles and mine a block. The higher the hashing capability (an example is the CPU/GPU cycles spent checking hashes), the more probability to be rewarded

by a bitcoin token on the transaction that has been processed and rendered. An example of blockchain that uses PoW are Bitcoin and Ethereum.

Proof of Stake (PoS)

In this consensus, there is no mathematical puzzle that needs to be solved, instead, the 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). So instead of using excessive computing power to mine a block, the users only need to own a certain amount of the cryptocurrency to be able to generate transactions. This method cuts out the energy-intensive mining process which saves energy. Ethereum will overlay or hard fork transition its current Proof of Work (PoW) to Proof of Stake (PoS) (Buterin & Griffith, 2017).

Hyperledger's lottery-based and voting based algorithms

The Hyperledger Architecture Working Group (n.d.) described consensus layer in Hyperledger architecture Volume 1 as the one *'responsible for generating agreement on the order and confirm the correctness of the set of transactions that constitute a block'* (Hyperledger Architecture Working Group, n.d). Hyperledger uses two kinds of consensus which are the lottery based and the voting-based algorithm. Lottery based algorithm *'scales to many nodes and the winner of the lottery proposes a block and transmit it to the rest of the network for validation'*. On the other hand, Redundant Byzantine Fault Tolerance (RBFT) is an example of voting-based algorithm which '*lets the majority of the nodes to validate transactions because it requires nodes to transfer messages to each other nodes on the network*' (Hyperledger Architecture Working Group, n.d.).

3.3 Smart Contract

The term 'smart contract' was first coined by Szabo (1997) as a dynamic, proactively enforced form with measures to provide observation and verification. Luu (n.d.) discussed in their paper that the smart contract is a set of rules represented in its programming language which can execute transfers in a predefined set of events.

Ethereum is known for its smart contract capabilities that are built-in *'Turing-complete programming language'* which means that it is open to the public for writing and creation of decentralized applications with own arbitrary rules for ownership, transaction formats, and state transition functions (Ethereum Foundation, 2014). Smart contract process in Ethereum through its PoW consensus, can facilitate different parties of the network to agree on a process that is executed by miners before appending the transaction to the blockchain (Dickerson, 2017).

The smart contract in Hyperledger is referred to as the ‘chain code’ which is the application’s business logic (Hyperledger Architecture Working Group, n.d.). With the blockchain, these smart contracts are protected from revision, removal, and tampering, because it is stored in the shared database within a network in an underlying consensus among the peers. Since Hyperledger is a permissioned blockchain, only the member 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.

3.4 Public and Private Networks

Buterin (2015) described three categories of blockchain-like database applications as public blockchain, consortium blockchain, and fully private blockchain. The public blockchain is the type of blockchain in which anyone in the world can read and see transactions and see if it is valid. These kinds of blockchain are fully decentralized (Buldas, et.al., 2014). Consortium blockchain is a consensus process and is controlled by a pre-selected set of nodes. While the fully private blockchains is the type in which the permissions are kept and centralized to the created network and read permissions may be public or restricted. Buterin (2015) ends up categorizing the three categories into just two (private and public) and clarified it's utterly wrong to believe in the idea that there is 'one true way of blockchaining’.

A good example of public blockchains are Bitcoin and Ethereum in PoW consensus. Some cases like banks which are private institutions used blockchain as a DLT to be able to create a private or federated blockchain (Blockchain Hub, n.d.). Hyperledger is one example of blockchain smart contract distributed ledger technology which is a permissioned blockchain. This is because Hyperledger is being controlled by consensuses such as the lottery- based and voting-based including the RBFT and Paxos (Hyperledger Architecture Working Group, n.d.). This accounts for a write permission being held by an organization (Buterin, 2015) and the read permissions could be public or restricted.

3.5 Ethereum and Hyperledger Fabric

The Hyperledger Fabric and Ethereum are frameworks that are used to power smart contract applications into possible fields of application. Both have differences when it comes to platform description, governance, mode of operation, the consensus being used, smart contracts and currency (Valenta & Sandner, 2017). The primary difference is the mode of participation in the blockchain, whether it is permissionless or permissioned because this has an impact on how the consensus is reached.

Transparency in the network is shown in Ethereum but an issue arises when it comes with the tradeoff between scalability and privacy because it is a public blockchain. However, the Hyperledger fabric is designed to create a modular blockchain platform for business that also solves the performance and scalability issues the permissionless blockchain is facing. The table below presents the two blockchains and describes its characteristics when it comes to governance, mode of operation, consensus, smart contract and currency integration.

Table 3: Characteristics of Ethereum and Hyperledger Fabric

Source: Valenta & Sandner (2017) and Buterin & Griffith (2017)

Characteristics	**Ethereum**	**Hyperledger Fabric**
Description of platform	Generic blockchain platform	Modular blockchain platform
Governance	Ethereum developer	Linux Foundation
Mode of Operation	- Permissionless, public - Permissioned, public (Casper)	Permissioned, private
Consensus	- Mining based on proof-of-work (PoW) - Ledger level - Proof-of-stake (Casper)	- Broad understanding of consensus that allows multiple approaches - Transaction level
Smart Contracts	Smart contract code (e.g., Solidity)	Smart contract code (e.g., Go, Java)
Currency	- Ether - Tokens via smart contract	- None - Currency and tokens via chain code

Ethereum is a generic blockchain platform, open to public and being governed by Ethereum developers. It has its own currency known as ether or tokens via smart contract run by its PoW consensus. In 2017 Buterin & Griffith (2017) introduced Casper, which will bring a significant change in the consensus mechanism of Ethereum that will hard fork the PoW consensus. Hybrid Casper FFG is introduced and was released by developers on May 2018, which is mainly created to push the network away from the mining of cryptocurrency consensus mechanism. This continuous development only shows that the public and open source blockchain such as Ethereum is continuously evolving and developing its version and addresses the issues of the current consensus.

On the other hand, Hyperledger Fabric is a permissioned blockchain that requires Membership Service Provider (MSP) to be able to join the network. This blockchain has several pluggable options to support the MSP members and an ability to create ‘channels’ which the chosen organization/s in the network can share ledgers. The smart contract is written in chaincode, and also used to plug tokens into Hyperledger.

Blockchain types, whether it is public/ private, permissioned/permissionless have some advantage and disadvantages on privacy, access, transparency, scalability, and risks. Designing and deciding on the consensus, types and blockchain framework will depend on the organization’s needs and requirements.

3.6 Blockchain Decision Making Process

Kravchenko (2016) concluded that there are two criteria that matters when it comes to choosing a blockchain and defining the environment of the blockchain for an industry, these are: (1) level of anonymity of validators, meaning, if the identity is known; (2) level of trust in validators, which gives an inevitable punishment for misbehavior in the network. These two criteria are also discussed by (Wüst & Gervais, 2017) and is shown in the Figure 2 below.

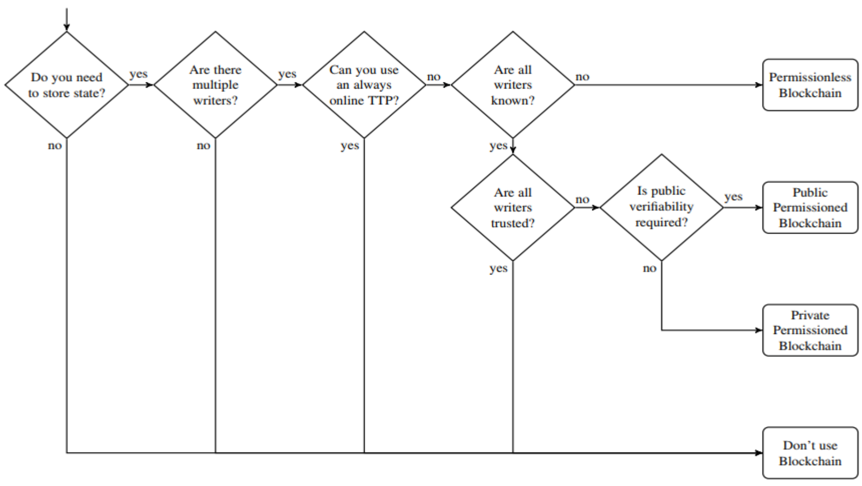


Figure 2: Blockchain Decision-Making-Process

Source: Wüst & Gervais (2017)

The flowchart in Figure 2 gives an overview of the factors of using or not using blockchain in an application. Wüst & Gervais (2017) also explained that blockchain is not necessary if there is no database required, only one writer exist, and Trusted Third Party (TTP) is always online.

TTP is described as the one who issues a certificate of authority in a permissioned blockchain to verify the writer's identity in the network. Once this writer is already verified, TTP doesn't need to be always online to check the validity of the writers in the network. In the case of public blockchain, TTP is not necessary, anyone can just join the network without having a TTP that issues a certificate.

Wüst & Gervais (2017) also added the factors in Table 4 which can also contribute to the decision-making process. These factors are the throughput, latency, number of reader, number of writers, number of untrusted writers, the choice of consensus mechanism and the preference if it will be centrally managed. Throughput is number of items in the process and latency is the delay before one transaction or transfer of data begins. The measure of immutability, is the state of transaction that cannot be modified is dependent on the number of resources in the creation of blockchain, which is then affects the throughput. The number of writers, readers, and untrusted writers can be specifically designed once it has been decided if it is permissioned or permissionless. In the same table, another factor is the consensus that Kravchenko (2016) argues the choice of consensus is based on the use case needs. As Kravchenko (2016) said, '*consensus algorithm is not the driver of blockchain selection, but it is the result*'. The last is the blockchain management, one example in the table is the permissionless blockchain, a kind of blockchain that is a decentralized network by nature, and is therefore not centrally managed by anyone.

Table 4 Other contributing factors for blockchain decision making process

Source: Wüst & Gervais (2017)

	Permissionless Blockchain	**Permissioned Blockchain**	**Central Database**
Throughput	Low	High	Very High
Latency	Slow	Medium	Fast
Number of readers	High	High	High
Number of writers	High	Low	High
Number of untrusted writers	High	Low	0
Consensus Mechanism	Mainly PoW, some PoS	PBFT protocols	None
Centrally Managed	No	Yes	Yes

3.7 Blockchain, IoT and Machine Learning

The multiple number of devices and services that are connected via the internet which makes it possible to automate the collection, analysis, and sharing of data, is referred to as the Internet of Things (IoT). One of the key challenges in IoT infrastructure is its issues on privacy and security vulnerabilities that needs to be addressed (Ahamed & Rajan, 2016). The combination of IoT and blockchain became a topic of interest in both research and industry. IBM (2016) described blockchain as a game changer for IoT. One of the key benefits of using blockchain is the data protection it fosters. It will enable devices in the IoT to participate in blockchain transactions, the new style of digital interactions, as well as cost reduction, and business complexity (IBM, 2016).

Aside from the IoT convergence with blockchain, machine learning can also give an additional value to the technological ecosystem. As machine learning is defined as a self-adaptive and self-learning software which doesn't need to add new rules manually in the system. The integration of machine learning in the blockchain will advance the security of the data, as well as accelerate the analysis of aggregated data (Intersog, 2017).

3.8 Blockchain for Climate Action

Many communities, organizations, and businesses are now exploring the use of blockchain technology specifically to deal with the magnitude of the climate change and its challenges. In fact, as of October 2017, there are already 30 blockchain initiatives and some are presented in Appendix C.1. One example is the carbon on blockchain by a non-profit foundation and startup, Poseidon. This startup encourages everyone to participate in climate action in a novel way. The organization created a tool for embedding to the point-of-sale of the retailers the details of the climate impact of a product purchase. It is integrated to the carbon market and provides transparency and traceability of this impact in forest conservation (Poseidon, 2018). Another organization that created a carbon asset development platform is the Energy Blockchain Labs that is made to be able to comply with governments Carbon Emission Reduction (CER) quotas (IBM, 2018). The CER is the issued carbon credit by the Clean Development Mechanism (CDM) Executive Board for emission reductions achieved by CDM projects, CER backed by the United Nations.

The Climate Ledger Initiative is an organization made to align with the goals of the Paris Agreement in the mitigation, adaptation, and finance using blockchain and DLT (CLI, nd). This organization is calling out for innovation research and idea that focuses on greenhouse gas (GHG) inventory, carbon pricing, carbon market, GHG mitigation instrument and other climate specific aspects of DLT. One project that is tackled in the CLI focused research is the identification and tracking of emissions in the supply chain end-to-end process (CLI, n.d.). Marion Verles, the CEO of The Gold Standard Foundation said in the CLI video: "*Gold Standard - one example application wants to translate production data to a cryptographically secure data that is referenced in the standard certifications of carbon emissions. Through this, we can trust the data and its sustainability attributes. This creates a positive effect on the company to invest in sustainable solutions and projects, and at the same time, it is easier for them to report carbon footprints and carbon data through the available information.*" (CLI, nd).

3.9 Challenges of Blockchain Implementation

Deloitte (2016) presented six key challenges to address as the blockchain evolves in different fields. These key challenges are the awareness and understanding, organizational, culture, cost and efficiency, regulation and governance, and lastly, the security and privacy.

The first principal challenge is the awareness and understanding. Lack of knowledge on how the technology works brings challenges on the implementation. This should address the question if the blockchain is really the right path to go in the business. The second key challenge is defining the organization and the stakeholders that will be part of the network. Defining the stakeholders and their obligations should be the focus. It is because collaboration is the key to be able to achieve consensus in a blockchain. The third key challenge is the culture. Industries are now used to the traditional way of doing business, especially the centralized systems deployed in this industry. Creating a blockchain-based platform for a specific use case should also imply that there should be a proper understanding of how this will change the business as usual.

The fourth challenge is the cost and efficiency. The technology is currently in its research and development stage wherein executions on how to make it more sustainable and less costly is still on the process. An example of this is the emergence of another alternative consensus mechanism of Ethereum which is PoS. This consensus is done to be able to get away with the PoW which requires excessive amount of energy being used for mining process. Another key challenge is the capital cost. Right investment prior to the implementation and deployment is indeed needed by the network participants. Designing the blockchain architecture, the DLT peers, and smart contract features will imply cost and time.

The other factor is the regulation and governance. Understanding of the technology and its use must be aligned with the regulators in the industry to be able to assess the impact it will affect in different stakeholders and the changes that it may incur in the system.

Last key challenge is the security and privacy. There will surely be a tradeoff of advantages and disadvantages on security and privacy when it comes to choosing the type of blockchain. This will depend on the level of anonymity the network peers are willing to open to the stakeholders, and the kind of transparency of the transactions the organization is willing to share.

3.10 Summary

Blockchain technology has been a topic for research and development for the past years and understanding of the technology fundamentals is needed to be able to maximize the benefits of using this technology in different projects. Blockchain can be used in different industries such as banks, supply chain, and even in tackling climate action initiatives. Blockchain consensus is defined to be secure and immutable, and these characteristics will vary depending if it will be used in a public or private network. Choosing one network from the other also brings a lot of tradeoffs when it comes to transparency, transaction performance, and privacy.

The concept of blockchain smart contract was also introduced as the computer protocol that is made to automate transactions within a predefined ruleset. The smart contract on top of the blockchain capabilities which is immutable and secure drives so much attention to different business and stakeholders to solve different organization's needs. Another benefit on using it is building its application with the integration of IoT and machine learning.

Even though there are a lot of benefits of using blockchain, challenges are still foreseen in its implementation. First, the technology is just fairly new in the market and its development is continuously evolving. As the technology is on its research and development stage to be able to create the best infrastructure that can fit on different organization’s needs.

4 Theoretical Background

The theoretical background introduces the research theories on innovation and adoption which is useful in the creation of research conceptual framework, result and analysis. The first part introduces the theories of innovation, open innovation, process innovation and Schumpterian's trilogy of innovation viewed in research and development perspective. Lastly, the chapter looks at Roger's Diffusion of Innovation Theory by focusing on two main processes: Innovation-Development-Process and Innovation-Decision-Process.

The theoretical background will be the main supporting theories for the proposed Conceptual Framework of the research in Chapter 5.

4.1 Innovation

How the innovation is defined by the organization will identify the kind of activity and changes that will take effect on its products, processes and markets (Popa et al., 2010). Innovation is defined as the introduction of new products or changes brought about by an existing product (Schumpeter, 1930 & Popa et al., 2010). In addition, it can imply a new process of innovation in a particular industry that may lead to a discovery of new markets. Rogers (2003) also defined innovation as *'an idea, practice, or project that is perceive by an individual or other unit of adoption'*. Henderson & Lentz (1995) described it as an implementation of innovative ideas. It can also be an ability to look at new perspectives, new combinations of existing concepts and an ability to create and discover new relationships (Evans, 1991).

4.1.1 Types of Innovation

There are different innovation types, it can be radical, incremental, disruptive and sustaining innovation. Radical changes are seen when there's a discontinuity between the old ways and the new (Moore, 1991). It is brought by a change agent that can get a jump on the competition with a comparable business advantage, which brings a revolutionary change. While incremental innovation is how the value of radical innovation potential is captured (Norman & Verganti, 2012). Incremental innovation is a more gradual change, and it also refers to improving products, services and the existing processes (Leonard and Rayport, 1997). The third type is the disruptive innovation which offers an innovation that has less functionality than its competitors. Through the disruptive innovation, a new market can emerge because it tends to be valued only on new markets or new applications (Christiansen, 1995). While the fourth type is called sustaining innovation. Compared to disruptive innovation, sustaining innovation can be both radical and incremental. Christiansen (1995) describes sustaining technologies to give improvement and attributes to the customers on the services that they already value. In addition, sustaining technologies can be from an idea that brings a revolutionary change.

Other than the types mentioned above, another paradigm of innovation called open innovation also exists. Chesbrough (2003) described that businesses are still in the continuum position of moving from a closed innovation to an open innovation model. This is because the companies are looking at different fundamental ways on how to improve the business by bringing up new ideas in the organization and deploy this in the market. The old model which is closed innovation, is very self-reliant to its own business success. This model requires control and self-sustaining ideas and product development to be able to penetrate the market.

The new model called open innovation arises in the 20th century wherein *'firms commercialize both external and internal ideas to be able to deploy both outside and inside pathways of the market'* according to Chesbrough (2003). The new model of open innovation has been used by different companies to commercialize different business ideas, and to in-house these ideas to the company and create a deploying pathway for it in the market. This way of thinking uses the Open Innovation Model which is briefly explained in Appendix D.1. This idea of open innovation also reflects on technology development because it promotes an open collaborative effort to different stakeholders to work holistically to the shared ideas and vision. This grounds on open collaboration is also seen in the different open source movement for software development. In an open source way of development, technology continuously evolve because people can modify, share and improve the technology in a community-oriented way (Linux Foundation, n.d.).

4.1.2 Process Innovation

The kind of innovation can be approached in two different types, these are product innovation and the process innovation (Tushman and Nadler, 1986). Product innovation is based on the needs of the market that is represented by the new products or services that benefits the customers. Process innovations are new elements introduced in the various processes carried out at the level of the organization (Knight, 1967, Utterback and Abernathy, 1975). This literature will focus more on the process innovation.

A process represents an input and output, and the beginning and end of a specific system in a given time and space. Davenport (1993) describes process innovation as the *'combination of the adoption of a process view of the business with the application of innovation to key processes*.' Davenport (1993) compared process improvement to process innovation. Process improvement is making business processes better and effective, while process innovation is '*performing work the radical way'*. Dewar & Dutton (1986) argued that process innovation might also yield on just incremental change, which we can just classify as an improvement. Process innovation means using and creating new work strategies and design activities in different parts, including the organizational, human, and technological dimensions that can trigger a change in an organization. In addition, some literature suggests that both technology and organizational/human factors are the primary enablers of change in an organization (Leonard -Barton, 1990 & DeGreene, 1973). Process innovation can be achieved with the presence of technical and human enablers (Zuboff 1989 and Walton 1989).

The high-level approach of process innovation by Davenport (1993) uses innovation framework which identifies the processes of innovation and its change enablers. After that, develops a business vision and process objectives. Davenport (1993) also considers the understanding of existing process. Lastly, the framework includes creation of prototype of the new process and organization.

One key steps on creating process innovation is through Business Process Modeling (BPM) also called Business Process Modeling Notation (BPMN) that provides a graphical notation for specifying a business process diagram (Simpson, 2004) and flowchart techniques (White, 2008). BPM is used for the enterprise to be able to understand the current process to be analyzed, improved and automated. The BPM shows automation of business processes in whole or part, documentation workflows, task and assignments assigned to each participant and some procedural rules set between the participants.

4.1.3 Institutional Innovation

Davidson et al. (2016) mentioned that it is possible to create new organization and contracts that is powered by new institutional technology. The change that an institutional technology can bring is dependent on behavioral, cultural, technological and environmental conditions which gives alternatives over the market and firms (Davidson et al., 2016). This is what makes this type of innovation interesting from an institutional and public choice perspective. Because it can impact several levels globally, locally and community. This will change the governance structure of society and the change from a pyramidal, hierarchical and compartmented organizations to a dynamic flexible network spanning the globe (Perez, 2010). Also, through institutional innovations, the market and states can work collaboratively for a shared vision through collaboration. Perez (2010) described it as the possibility to construct consensus vision, wherein it can be an *'agreement based on understanding the nature of the opportunities and the national specificities, is the best guarantee that all the actors in the business, society, and the government will converge towards the best possible outcome.'*

When an institutional innovation is in its early adoption stage, it is considered to be on its 'installation period'. Perez (2010) described this period when an innovation defines the new industries with new consumption, production and distribution methods in preliminary period. There are two periods in the great surge of development, the one given above is the installation period as the first period, the second period is the deployment, and there's a turning point in the middle which marks a bubble collapse and a shorter and longer recession (Perez, 2015). This period can be seen in each technological revolution (See Appendix D.2) is driven by new technologies, new or redefined industries, and infrastructure. In each revolution, it brings techno-economic paradigm (TEP) wherein new innovations creates a best practice model for product, process, business organizations and market behavior (2010). Today is in the fifth revolution wherein new institutional technologies that emerges can be a vehicle for the upgrading based on the techno-economic paradigm of 'the common-sense' innovation principles. This is described by Perez (2010) as *'decentralized integration/ network structures; knowledge as a capital/intangible value added; globalization/ interaction between global and local; Instant contact and action / instant global communications*.'

4.2 Schumpeter's Trilogy of Innovation

In Schumpeter's view, innovation and entrepreneurship are occupying a critical role for economic development. In his theory of innovation, Schumpeter focuses on the function of entrepreneurs who are carrying out '*new combinations*', which is also termed as innovation. Entrepreneurs as main drivers of innovation can *'change the core of economic development and breaks the economy out of its static mode'* (Śledzik, 2015). Although Schumpeter's view on economic development might not be appropriate nowadays. In the modern capitalism, businesses also experienced a crisis in the last subprime and euro-debt crises (Śledzik, 2015).

Figure 3: Schumpeter's Trilogy Invention-Innovation-Diffusion

Schumpeter integrated innovation in the economic studies and developed the process of innovation which is called the "Trilogy of Invention - Innovation - Diffusion" as represented in Figure 3. Although Schumpeter's theory of innovation is connected to entrepreneurship and economic development, Schumpeterian trilogy can also be related to research and development, production and marketing. Stoneman (1995) related the Schumpeterian trilogy to R&D which is basic and applied research and development sending.

Stoneman (1995) provides an insight into the Trilogy of Innovation wherein it describes the invention, innovation and diffusion process. First, the invention is termed as the generation of new ideas. The innovation stage is the development of new ideas into a *'marketable products and processes*.' And the last stage is diffusion wherein both '*products and processes spread across potential market*.'

4.3 Innovation Development Process

Pre-diffusion factors should be considered before deciding to develop an innovation. Rogers (1983) developed the Innovation Development Process which looks at the factors prior to the beginning of an innovation's diffusion, specifically the later part events that affect the nature of diffusion. This aspect has been entirely ignored in the past diffusion research and is necessary to be discussed prior to diffusing an innovation. Through the Innovation Development Process, looking at the lens of the problem, the need of R&D, invention, development, commercialization, diffusion and consequences, will help identify if the invention is a pro-invention, and if it can later be developed and diffused.

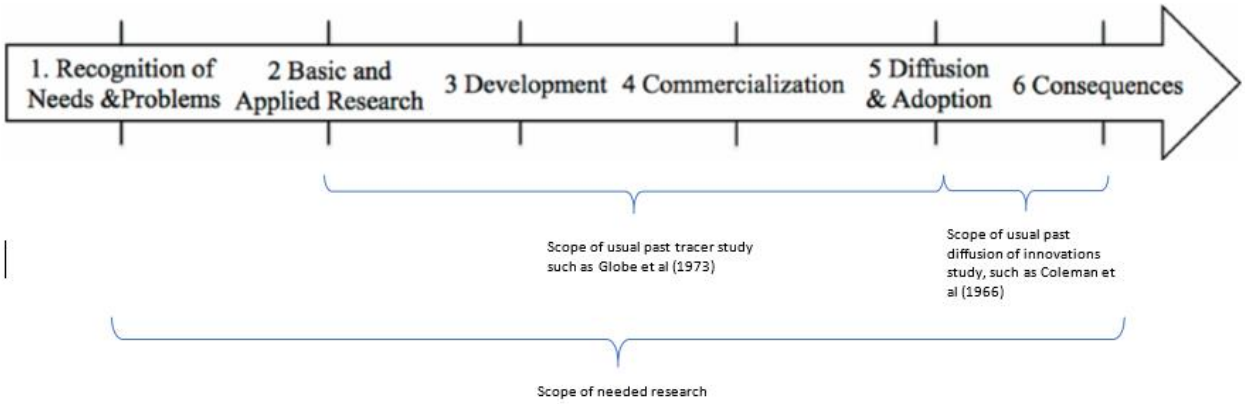


Figure 4: Innovation Development Process

Source: Rogers (1983)

The Innovation Development Process starts from recognizing problems and needs to find out the consequences of an innovation (Rogers, 1983). These six phases are somewhat arbitrary that may not always be in the exact order shown above, and certain part of the phases may be skipped for certain innovations. The investigation of diffusion process began with the recognition of needs and problems which may lead to Research and Development (R&D) activities. This gives that the prior condition is looking at previous practices, assessed needs/problems, and norms of the social system.

The second phase is the sequence of research which has two categories: (1) basic research - original investigation of the advancement of scientific knowledge with no specific objective of applying this knowledge in a practical problem; and (2) applied research - consists of scientific investigation that is intended to solve practical problems. Applied research is concerned on the development of techniques and technology.

The third stage is the development of innovation which is the process that puts the idea in a form that will fit the adopter's needs. In the development phase, it needs to comply the four phases to decrease uncertainty and to formalize R&D, these phases are innovation, imitation, technological competition, and standardization. The fourth phase is commercialization, which (Rogers, 1983) defined as the production and distribution of the innovation. The fifth stage is the diffusion and adoption, this is intended to determine if the innovation should be diffused and will be used by the future adopters. Lastly, consequences are defined by (Rogers, 1983) as the effect that happens on the people and the social system as a result of the innovation adoption or rejection.

4.4 Innovation Decision Process

Rogers (1995) used the technology as a designed instrument that cut downs uncertainties to achieve a desired result. Rogers also used the word technology as synonymous term of innovation. And one key important factor of the adoption and diffusion research is the innovation/technology. Diffusion is defined by Rogers (1983) as *'the process in which an innovation is communicated through communication channels over time among the members of a social system*.' The Innovation-Decision Process (Appendix D.3) describes the key components of the diffusion of innovation which is a factor on the rate of adoption. Innovation might be invented a long time ago, but it can be defined as an innovation if the individuals perceived it as 'new.'

Rogers (2003) described the Innovation-Decision Process as *'an information-seeking and information-processing activity'* so individuals in the social system can weigh the advantages and disadvantages of the innovation to reduce uncertainty. This process has five steps: (1) Knowledge - characteristics of the decision-making unit that includes the socioeconomic characteristics, personality variables, and communication behavior; (2) Persuasion – identification of the perceived characteristics of the innovation that can persuade the potential adopters to adopt the innovation; (3) Decision - leads to the choice to adopt or reject innovation; (4) Implementation - puts innovation into use; and (5) Confirmation - finalizes decision to continue using innovation.

Persuasion is one of the key models of the adoption phase. This stage has five attributes: advantage, compatibility, complexity, trialability, and observability.

- Relative Advantage – Rogers (1995) defined it as the '*the degree to which an innovation is perceived as being better than the idea it supersedes*.' Relative advantage also relates to the advantage of the organization on using the new ways over the previous ways in performing and solving the same task (Agarwal & Prasad, 1997). Rogers (1995) also confirmed that this attribute is usually used for the prediction of innovation's rate of adoption.
- Compatibility - Rogers (1995) defined it as the *'the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters*.' Compatibility as a factor, can either speed up or slow down its rate of adoption in an organization. Compatibility is making sure that it fulfills the needs and wants of the

customers. Tornatzky and Klein (1982) stated that if the innovation is compatible with individuals' job responsibility and value system, it is most likely to be adopted. This is because the compatibility is interconnected to the cultural values and previous ideas.

- Complexity - Rogers (1995) defined it as the *'the degree to which an innovation is perceived as relatively difficult to understand and use*.' Premkumar et al. (1994) described that new innovations that require new knowledge, skills and understanding is more likely difficult to be adopted compared to that new innovation that is easy to understand. The same idea with Agarwal and Prasad (1997) that the systems are perceived to be less complex are more likely to be used by potential adopters.
- Trialability - Rogers (1995) defined it as the *'the degree to which an innovation can be an experiment within a limited basis*.' This is the attribute wherein the potential adopters will be given an opportunity to experiment with an innovation before deciding on to commit to its usage. The potential users are more likely to adopt an innovation when it is more comfortable to use.
- Observability - Rogers (1995) defined it as '*the degree to which the results of an innovation are visible to others'*. Some ideas can be both difficult and easy to be observed and communicated to others. Innovation that can be easily observable is more likely to be adopted than those that are not.

Rogers (1995) also provided five attributes of innovations might not in all cases be the five most important perceived characteristics for a correspondent. The study of perceived characteristics of innovation also has some limitations and it has also extended to some other research about adoption. Tornatzky and Klein (1982) carried out a meta-research of different publications about perceived attributes and rate adoption and found out that some attributes given by Rogers (1995) are usually not consistently related or negatively related to the rate of adoption. Moore and Benbasat (1991) also developed a general set of scale items to measure the five main attributes of innovation and added other attributes that can be applied to any innovation.This attribute is also presented in Appendix D.4, with a broader view that represents the summary of the two innovation processes by Rogers (1983) which are: Innovation Decision Process (Diffusion Phase) and the Innovation Development Process (Pre-Diffusion Phase). These processes are an integral part of the formulation of the Research's Conceptual Framework in Chapter 5.

5 Research Conceptual Framework

The research will be guided by models, processes, and theories of adoption and innovation that is outlined in Chapter 4. Maxwell (2004) described the function of the theory in a conceptual framework as a source of information and guide of research design which can be used to redefine the research goals and questions, choosing appropriate methods and the identification of the validity of analysis and conclusion, including its threats. Jabardeen (2009) defined conceptual framework as a *'network or a plane of linked concepts*.' The use of a conceptual framework has advantages when it comes to research analysis. Miles & Huberman (1994) also defined conceptual framework as the system of concepts, assumptions, expectations, beliefs, and theories designed to support the study.

The models and processes that are used for the creation of this framework relies on the concept of Trilogy of Innovation (Section 4.2), Innovation Development Process (Section 4.3), Innovation Decision Process (Section 4.4), and guided by the theories of innovation.

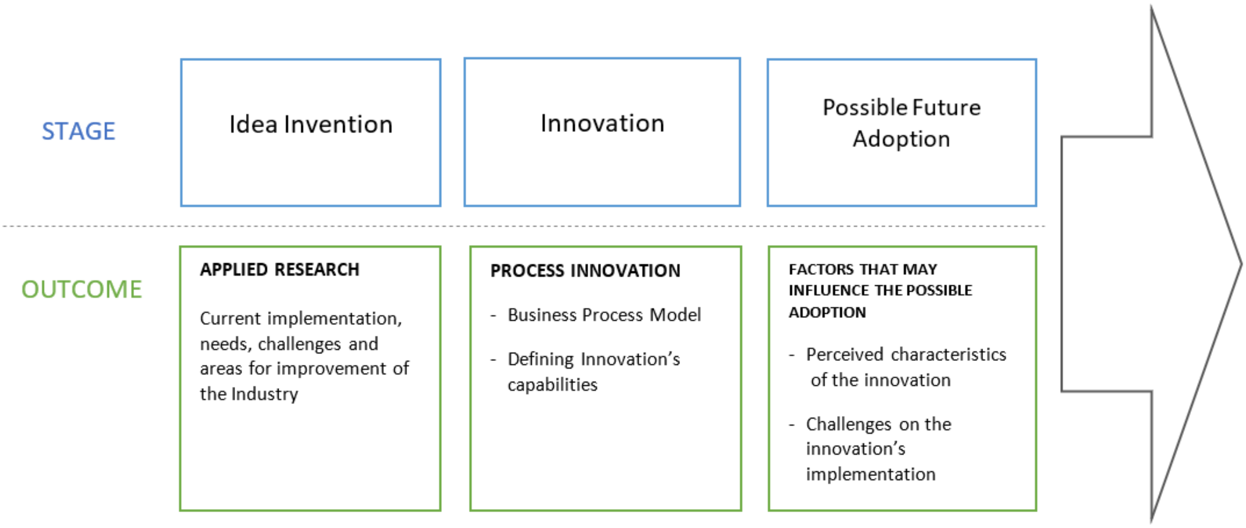


Figure 5: Research Conceptual Framework in a 'Pre-Diffusion Stage'

The Research Conceptual Framework represented by Figure 5 is currently in a 'Pre-Diffusion Stage' (Rogers, 2005) because the research outcome did not consider the creation and/or presentation of a working prototype for blockchain-based tracking and monitoring of CO_2 emissions. This framework also represents three stages to be able to arrive at the research outcome, mainly built upon Schumpeter's Trilogy of Innovation and Roger's Pre-Diffusion Process. These stages are arranged in a sequential manner, which means research outcome from the first stage will contribute to the next stage, and the second stage will contribute to the last stage. The stages are idea invention, innovation, and diffusion & adoption. Each stage has specific outcomes and is guided by different innovation and diffusion theories and model.

Research Conceptual Framework presents three different stages with different outcomes. First stage is the idea invention (Section 5.1), second stage is the Innovation (Section 5.2) and the last stage is the possible diffusion and adoption of innovation (Section 5.3).

5.1 First Stage: Idea Invention

The idea invention is based on Rogers (1995) Innovation-Development Process first step, which is 'recognizing the needs and the problems.' In this research, idea invention will be looking at the current implementation of the container shipping industry's MRV programs. This will represent the first research outcome. The invention phase is the step wherein the applied research is being done. This is about gathering information and getting deeper insights in the study topic.

The idea invention result is presented in Section 7.1 which showcases the current industry conditions by looking at the MRV process, data that is needed in this process, different techniques that is being deployed in the ship on board, verification process of emission report, and current MRV systems that are being used by different stakeholders in the MRV programs. Section 7.1.7 wraps up the challenges, issues, and improvement of the current MRV program. This result will then be the basis for designing the blockchain-based MRV system, which is the result of the research framework's second stage.

5.2 Second Stage: Innovation

Innovation is the second stage in the Schumpeterian's trilogy of innovation after the invention stage. Paul Stoneman's (1995) defined this step as Innovation stage.

The research will only cover the process innovation of the blockchain-based MRV system. This means the research outcome will not create a working prototype. The research outcome will be a Business Process Model (BPM) that represents how the innovation works in terms of the following: who are the stakeholders involved; what are the obligations of these stakeholders; what is the document workflow; what is the relevant data to look at in the system; and what kind of blockchain will best fit on industry's needs and preference. The BPM is presented in the technological analysis in Section 8.1. But prior to defining the process innovation, the case study must be assessed in Sections 7.2.1 and 7.2.2, suggest an example of blockchain that can address this need, this is presented in Section 7.2 3, and data in Section 7.2.4.

5.3 Third Stage: The Possibility to Adopt the Innovation

The third stage can be achieved when the first and second stage result and analysis is already done. The first two stages will contribute to the critical understanding and identifying of the perceived characteristics of innovation that can affect its future adoption. And since there's no actual product prototype, the research will not cover the other factors for diffusion such as time, communication channels, implementation and confirmation to adopt and reject the innovation which is described in Rogers' (1995) Innovation-Decision-Process. At the same time, the research is not measuring the rate of adoption of the innovation in this study. Instead, the research is only limited to looking at the perceived characteristics of innovation in terms of its relative advantage, complexity, and compatibility.

This stage answers the main research question which the identification of the perceived characteristics of innovation. This analysis will be presented in Section 8.2. Other factors that might affect the adoption are also the foreseen challenges of implementation of the proposed process innovation. These challenges are presented in Section 8.3.

6 Methodology

This chapter presents the methodological procedure done in the research. Idea Generation (Section 6.1) explains how the author was able to come up with the research. Section 6.2 explains the purpose of the research, strategy, methodology used to gather empirical data, and literary works. Section 6.2.3 presented data gathering techniques, analysis and validation of each research objectives.

6.1 Idea Generation

The research idea generation started with a broad level interest of the researcher on the use of technology for green solutions with an alignment in an existing policy framework that tackles climate-related actions. So, the research started as an exploratory study. Robson (2002) described this kind of study as a valuable means of looking at what is happening, ask questions and explore new understanding in a new light. In this study, the topic for exploratory research is the usage of blockchain on tackling climate change actions. In addition, Saunders et al. (2007) described exploratory research approach as particularly useful if one wishes to clarify the understanding of the research problem, especially if one is unsure of the precise nature of the problem.

Blockchain as a revolutionary technology has been a topic of interest in many areas such as financial, supply chain, and is also being explored in research, development, and climate action. Through reviewing different literatures and articles relating to climate actions and technology-driven solution, specific topics such as carbon credit market, climate change mitigation, action, adaptation, and GHG inventories emerged as an interesting research topic.

The research idea focuses on the usage of blockchain in the GHG tracking and reporting due to its foreseen benefits to reduce the emissions of CO_2. This is the current dilemma that needs immediate action. With this initial background, the research question formulation and understanding on this study is narrowed to a specific industry, which is the container shipping industry. This topic adheres to the policy framework that is currently being implemented by concerned agencies. Finally, the researcher decided to analyze the problem and look at the opportunities of the usage of the blockchain technology in the maritime related monitoring, reporting and verifying (MRV) of CO_2 emission programs.

6.2 Approach and Design

The focus of the research is a very specific technology and industry-driven topic. This specificity of the research qualifies it as an example of a case study. The case study as defined by Robson (2002) is a study of a real-life context of a distinct subject which involves empirical research. Saunders et al. (2007) defined the case study as a strategy to answer the questions 'why?' 'what?' and 'how?'.

The approach for the case study is through deduction which the researcher uses theories to address the research question and objectives. The idea generation stage (Section 6.1) gave an insight to the researcher to explore different theoretical background that is focused on adoption and innovation. This led the researcher to write the conceptual framework of the research in Chapter 5. This research conceptual framework then become a basis of expanding the research outcome from 'idea invention,' addressed by the first research objective, to adding two other important factors for investigation which are: 'innovation' second research objective, and 'possible diffusion and adoption,' third research objective, which is built on the innovation, diffusion and adoption theory.

In this research, literature review, and semi-structured interview are the two data gathering techniques that are used.

The first technique, literature review, is the use of both scientific and practical information which helps in gathering research information about the specific domains, theoretical background, conceptual framework formation, and guiding the right research methodology. The second technique is the semi-structured interview which is a qualitative data gathering approach. Saunders et al. (2007) defined the qualitative method as a technique that used and/or generates a non-numerical data for the research result and data analysis. Kahn & Cannell (1957) defined the interview technique which consist of two or more people that is conducting a purposeful discussion. Saunders et al. (2007) discussed the use of interviews as a tool to help the researcher gather and validate reliable data that are relevant to the research questions and objectives. Through a semi-structured interview, the researcher could dive deeper into the problem, formulate the research focus and scopes, and create a more scientific analysis of the literature reviews and validations. Table 5 presents the list of interviewees and the role in the company and the description of the industry. This is the only shared information about the interview participants due to the privacy concerns.

Table 5: Interview participants overview

# of Interviewees and Role	# of Interviews	Industry
1 Technical Director 1 EU MRV/IMO DCS Auditor	1	Verifier
1 Manager 1 Associate 1 Researcher	2	Business-to-business leadership initiative for measurement, evaluation, and reporting of the environmental performance (e.g. CO_2) of the container shipping industry.
1 Sr. Global Advisor Transport and Logistics Sustainability	2	Container shipping company
1 Platform Engineer for DevOps and Digital Platform	1	Container shipping company
1 Application Development Manager	1	Container shipping company
1 Research and Development Lead	1	Digital solution provider start-up. Working on a project on blockchain for tracking CO_2 in maritime transport
1 VP for Business and Development & Strategy	1	Business-to-Business initiative that uses carbon market to enable innovative and market driven solution. Business that offers carbon credits and other solutions.
1 CTO/ the Lead of Digital MRV	1	Standard and certification body that caters climate and development projects. Piloting a Blockchain project for MRV program in the supply chain.
1 Blockchain Architect	2	Blockchain development and service company for decentralized ecosystem for movable assets.
1 Founder	1	Carbon on blockchain startup
1 Business Analyst	1	Food Industry

The selection of the interviewee in Table 5 is based on the necessary and important stakeholders that are included in different programs discussed in the Section 2.3. Interviews are presented in the results in Chapter 7 and supporting transcription of this interviews presented in the notes.[1]

The MRV programs main stakeholders are the verifier and ship operator. In this research, only one verifier company and one ship operator were interviewed. The researcher is aware that the result will be subjective in the perspective of these interviewed companies. Therefore, the researcher used the triangulation method, which considers two or more data sources for data gathering to be able to validate the data that was populated and to ensure data reliability. Other sources are the EU policy and the sustainability methodology other than the interviews that are conducted. The result of this data gathered through literature review and interviews are presented in Section 7. In addition, the researcher was able to interview one B2B company who provides CO_2 evaluation, measurement and reporting service to the container shipping industry which includes both vessel and cargo/TEU specifics.

Other relevant interviewees are experts on DLT climate action projects. One company already started a blockchain project on the maritime industry on the measurement of ship emissions. The other one is a sustainability standard and certification body which is currently piloting a project for MRV in the supply chain using blockchain and DLT. One start-up founder was also interviewed who piloted a carbon on the blockchain, including their partner carbon supplier. In addition to the technology related interviews, other blockchain experts were interviewed as well. One is a Hyperledger developer, and the other one is working on an Ethereum project.

Some stakeholders are interviewed twice for data validations of research results which will be discussed further in Section 6.3.

The interviews are both online and personal meetings and was recorded using iPhone audio recording and Zoom video conference recording feature. The interview starts with a presentation of the researcher about the topic, then the researcher asks for interviewee to give an introduction about him/herself. The semi-structured interview was built upon open-ended questions to encourage elucidated answers in the whole research process. But prior to the scheduled interview, the researcher has a prepared topic for discussion and informed the interviewee about the agenda and scope of the research.

To sum up the approach and design of the research, the purpose of the research is an exploratory case study strategy with a deductive methodology research approach using literature review and qualitative methods for data gathering and validations.

6.3 Data Gathering, Validation and Analysis

To be able to address the research objectives and answer the research questions, the right data gathering techniques and analysis should be done. The research objectives (Section 1.4) are: (1) Investigate on the current procedures and challenges of MRV of CO_2 emissions process and systems; (2) Create a process innovation using blockchain technology; and (3) Identify the perceived characteristics of the innovation and challenges of the process innovation implementation that might contribute to the possible adoption of this innovation in the future. This research objectives are addressed in different ways of data gathering, validation and analysis.

1st Research Objective

Research Question: What are the current conditions and challenges of the tracking and reporting of CO2 emissions on the container shipping industry?

The research started with an exploratory approach wherein all three data gathering techniques are done to answer the first research question. The first step for the researcher is to look critically at the pieces of literature that is directly related to the chosen research focus. Review of literature was done in two core topics: (1) Monitoring, Reporting, and Verification of CO_2 emissions in container shipping industry; and (2) Blockchain technology. This initial literature review is helpful in identifying the research significance. The literature came from different primary, secondary and tertiary sources such as reports, thesis, conference proceeding, government publications and policies, journals, white papers and company reports, and books. The researcher focuses on the EU MRV policy and the CO_2 methodology of the MRV programs. This gives a better perspective to the researcher on the nature of the current system implementation which is the basis of analysis.

An interview was conducted to the stakeholders in the MRV system, blockchain experts, and other relevant information sources for the researcher to be able to understand the industry and the technology. A semi-structured interview was done to address the challenges and verify the data gathered in the literature reviews. The main stakeholders from company/ship operators, verifiers, MRV program consultancy company and blockchain experts are interviewed. Validation of some data is through multiple sources of interviews and comparison with the literature review regarding current implementation of MRV programs. Some interviews are done via online video conferencing because the companies and experts are in different parts of Europe, Asia, and the USA. Other stakeholders are interviewed in person.

Another information gathering technique used by the researcher is through investigating the system used for MRV. Access to current MRV systems is only limited to the MRV stakeholders. So, gathering information is done through reading system specifications and watching tutorial videos on how the system works.

2nd Research Objective

Research Question: What is the process innovation of a blockchain-based tracking and reporting of CO2 emissions designed for the container shipping industry?

The literature review of both academic and white papers about blockchain and innovation helped the researcher map and decide that the study will focus on the creation of process innovation as the primary research outcome for this research objective. The first thing that the researcher did is to look at the industry condition. The researcher introduced the current problems and challenges of the MRV programs and consulted it to the blockchain experts via an interview. The researcher used the Decision-Making-Process (Section 3.6) to validate if the case study needs a blockchain. This is then shown to blockchain experts for validation. The choice of the type of blockchain that can be used are then decided and is validated as well by blockchain experts. The process innovation, which is represented by the Business Process Model (BPM) is created, based on the chosen type of blockchain, and built upon the current MRV process. BPM models are checked and presented to professional business analysts and application manager to be able to verify the proper use of notations, semantics, and the use process mapping.[2] Total of three sessions with business analyst and application manager was done to be able to present the results in Section 8.1.3.

The formulation of the first versions of BPM is from combination of the policy, CO_2 methodologies and interviews addressing the first objective of the research. Then the BPM models are presented to stakeholders through an interview. The stakeholders are the MRV program B2B consultant, and a ship operator representative. The first versions of BPM were presented, and some suggestions for revisions was given. This is the reason why multiple number of BPMs are presented in the technological analysis in Section 8.1.3.

3rd Research Objective

Research Question: What are the factors that might affect the possibility to adopt the usage of blockchain for tracking and reporting of CO2 emissions in the container shipping industry?

The 3rd research question will be answered upon looking at the challenges and the current conditions of the MRV system, and analyzing the requirements needed to start a blockchain project for both public and private frameworks. The next step is to evaluate and look at the perceived characteristics of innovation which is the result of addressing the first two research objectives.

Data gathering in this section is the combination of gathered information through literature reviews and interview from both objective 1 and 2.

7 Results of Data Collection

This section answers the research questions and objectives that showcases both empirical and literature work. The primary literature works helped on framing the important scope of the research, and some of these details are validated through an interview. At the same time, the gathered empirical data through quantitative method also contributed to new ideas and suggestions for the innovation. This section has two parts, the first one is the industry perspective which describes the current conditions of the industry, and Section 7.1.7 wraps up the summary of the challenges, issues, and areas of improvement that answers the first research sub-question. The second part is the technology perspective which looks at the possibility to use the technology that addresses the industry's needs.

7.1 Industry Perspective: Current Conditions of MRV Implementation

This section gives an overview of the current MRV implementation for the container shipping industry. The main purpose of the research is to look at the mandatory MRV programs as the basis of the process innovation. In exploring the current MRV program implementation, existence of other voluntary programs also emerged. This section will cover the implementation of both programs and processes, including the data, sources. This section will also cover the fuel consumption techniques as one of the major factors for CO_2 computation. In addition, to be able to look at the current MRV implementations, the summary of MRV systems are also presented including the verification process.

Section 7.1 and its subsections answer the first research question which is looking at the 'Idea Invention' that focuses on looking at the current implementation, its challenges, issues and areas of improvements.

7.1.1 EU MRV and CCWG

The mandatory program, EU MRV processes is mapped by the researcher based on interview and the policy implementation. The reason of choosing EU MRV as the main process of this research is because it is known to be the *'model for the implementation of the global MRV system'* (European Commission, 2015). In addition, EU MRV focuses on vessel specific CO_2

emissions. The figure below shows the main steps for the monitoring, reporting and verification that is based on the regulation, overview of the stakeholders that is involved, and the documents needed to be created and verified. This process model was checked by a verifier who is an expert of EU MRV process through an interview.**3**

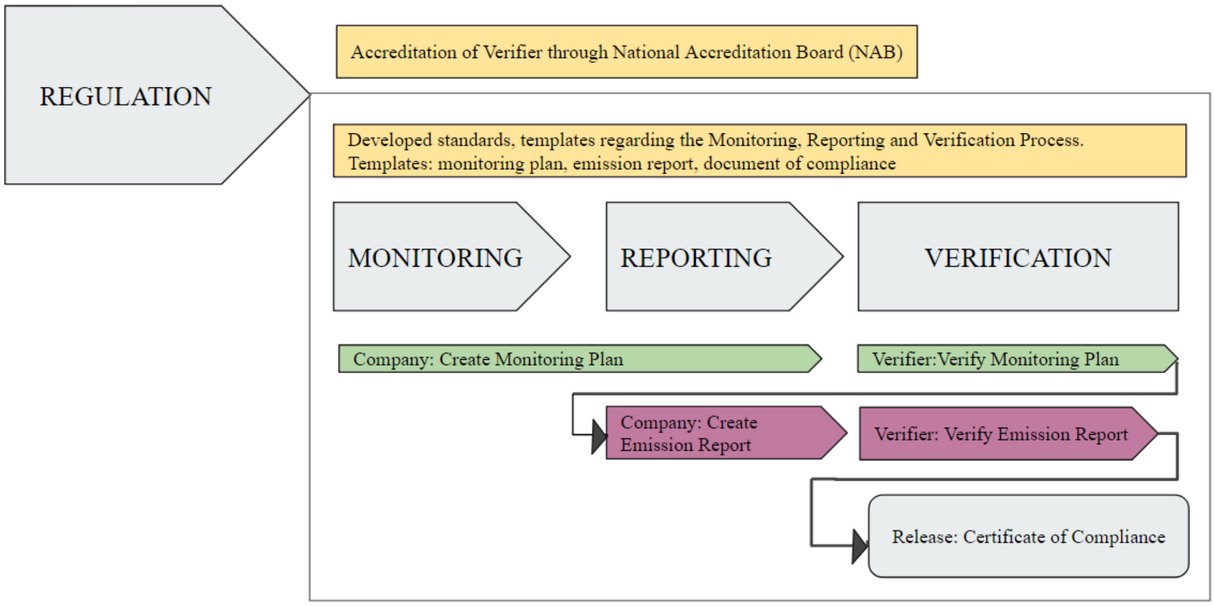


Figure 6: Monitoring Reporting and Verification (MRV) Process

Source: Regulation (EU) 2015/757

The Regulator has the overview of all the process: monitoring, reporting, verification and accreditation. The regulators also set the standards, templates and processes of the whole system. Verifiers needs to be accredited by the National Accreditation Board (NAB) prior to verifying both monitoring plan and emission report. The company needs to comply with two important documentations which are the monitoring plan and the emission report. The monitoring plan must be verified first, and is the basis of the emission report, which also needs to be verified. A Document of Compliance (DoC) is then released, which is the proof that a company is compliant with the regulation.

The table below explains in more details the complete process from its source which is the Regulation (EU) 2015/757. The MRV process involves different stakeholders with different roles for document creation, reporting, verification, data sources fetching, legalities, etc.

Table 6: EU MRV process, implementation, stakeholders and actions

Source: Table mapped from Regulation (EU) 2015/757

Roles of the Entity in-charge		**Monitoring and Reporting**	**Verification**	**Accreditation**	**Regulation**
Stakeholder		**Company/Ship Operators**	**Verifier**	**National Accreditation Body**	**European Parliament Council**
Process to be fulfilled by entity in-charge	LEGALITIES: Accreditation of Verifier		Receive accreditation certificate	Issue accreditation certificate to Verifier	Assess methods of accreditation
	STEP 1: **Monitoring Plan** creation and verification	Creation of monitoring plan and submit to Verifier.	Verify and issue the monitoring plan to the Company.		Provide elements for verification of 'monitoring report plan' to the Verifier. Report plan is line with the regulation.
		Receive verified monitoring plan.			Receive verified monitoring plan.
	STEP 2: **Emission Report** creation, verification and publication.	Creation of emission report and submit to verifier. The emission report is based on the verified monitoring plan	Verify and issue the emission report to the Company.		Provide elements for verification of 'emission report plan' to the Verifier. Report plan is line with the regulation.
		Receive verified emission report from Verifier and submit to Commission and State Flag.			Receive verified emission report from Verifier and submit to Commission and State Flag.
	STEP 3: **Document of Compliance** (DoC) issuance, publication and information	Receive the DoC from the Verifier. The DoC should be displayed in the company ships for inspection.	Issuance of DoC. The DoC is issued after the issuance of verified emission report and the submission of verified emission report to the Commission and State Flag.		The Commission will be informed by the verifier regarding the issuance of the DoC.

Aside from the stakeholders stated in Table 6, which are the company, verifier, regulator (Commission) and accreditor, there are other relevant stakeholders that is stipulated in Regulation (EU) 2015/757. The stakeholder and the clause in the policy is stated below:

Member State and its Ports

The ports shall check and inspect the document of compliance of ship in a port (Regulation (EU) 2015/757, art. 19). Member state may lay down rules on penalties of non-compliance and can issue expulsion order which is then communicated to the National Authorities. In addition, Commission, European Maritime Safety Agency (EMSA), the other Member States and the flag EU State concerned shall be notified (Regulation (EU) 2015/757, art. 20).

International Maritime Organization (IMO) and relevant international bodies

As the EU MRV is the 'model for the implementation of a global MRV system,' the commission shall support other international bodies and organization such as IMO (Regulation (EU) 2015/757, art. 22).

Experts and Member State Experts

Commission to carry out usual consultation practice with experts before delegated tasks (Regulation (EU) 2015/757, art. 23).

European Maritime Safety Agency (EMSA)

The organization that will assist the Commission to comply with format of emission report (Regulation (EU) 2015/757, art. 12), publication of information and Commission report (Regulation (EU) 2015/757, art. 21), DoC (Regulation (EU) 2015/757, art. 17). EMSA shall be notified in case of penalties regarding the compliance (Regulation (EU) 2015/757, art. 20).

Public

The information is stipulated in Regulation (EU) 2015/757, art. 21 that CO_2 emissions reported will be open to the public.

Company Ships

The company shall give a copy of DoC to the company ships as an obligation to carry valid document on board (Regulation (EU) 2015/757, art. 18).

The CCWG, which is a voluntary program also handles the reporting process of the container ships. The difference is that, CCWG also include cargo specific CO_2 emissions which is expressed in grams of CO_2 emissions per container transported 1 kilometer (g CO_2/TEU KM). This specific inclusion of cargo adds more value for the ship operator's because it supplies the container shipping nature of the business. This level of granularity of voluntary program such as CCWG is helpful for proper tracking of container operator's customer related emissions. In the interview with a verifier, it was confirmed that CCWG and EU MRV has almost the same data on vessel-specific emissions. There are differences in the data, processes, and systems being used in each program. The verifier also deliberated that CCWG and EU MRV has almost the same process of verification.[4]

Aside from this two MRV programs, the international body IMO just implemented the IMO DCS regulation for all maritime transport, with monitoring and reporting period that will start on the early month of 2019. As per the interview conducted for this study, there will be a possibility to stop EU MRV regulation ones it has been agreed that the IMO will be the global governing body for the MRV programs for maritime transport.[5] Also in the interview, it was discussed that the current MRV implementation is confusing because of various implementation on different levels (EU and global level). This brings challenges to the CO_2 methodology standardization. So, some ship operators and MRV experts agreed that there should just be one implementation of MRV on a global level and one system that every container ship operator should use. Some stakeholder suggested that the IMO should be the regulator that will handle the global MRV.[6]

7.1.2 Mandatory and Voluntary Programs Process

In this section, the MRV process presented in Section 7.1.1 will be explained further in terms of the stakeholder's obligations.

Figure 7 shows the AS IS Model of current MRV program stakeholders and obligations. The first part shows the mandatory and voluntary program which sets the policy and standards for CO_2 emissions tracking and reporting, on both vessel and cargo specifics. The main obligation of the company/ship operators is to be able to track and monitor the fuel consumptions/total amount of CO_2 being emitted. At the same time, track all other data that is necessary for the computation of CO_2 (Section 7.1.3).

Figure 7: *AS IS model of current MRV system stakeholders and obligations*

The accredited verifiers on the other hand are the ones who checks and makes sure that whatever the company/ship operators are reporting must be compliant to the rules set by the regulator which is, in this case, are both mandatory and voluntary programs. The regulators and other stakeholders needs to be informed regarding the completion of the reports and the compliance of the ship operators.

Figure 7 shows that the main stakeholders in the MRV process are the program regulator (mandatory or voluntary), company/ship operators, verifiers, accreditors and other stakeholders. Other stakeholders that are part of EU MRV that is not mentioned in this section are the member state, member state port, IMO and other relevant international bodies, EMSA, experts, and the public. In addition, voluntary program such as CCWG involves all other stakeholders for cargo specific tracking and reporting of CO_2. Other relevant stakeholder is the ship operator’s customers who demands to know the total CO_2 their cargo cause to emit while at sea.

One important process that can be added in the current system is to add the emissions of the seaborne transshipments such as Vessel Sharing Agreements (VSA), feeder service, and Slot Charter Agreements. This seaborne transshipment is done by different ship operators for optimizing their sea network by subcontracting other companies and ship operators to transport their customer's cargo. In this case, the carrier does not have the CO_2 data because they do not own the vessel, this emitted data must be fetched to this subcontractor to be used for cargo specific tracking of CO_2 emissions (CCWG, 2015).

7.1.3 Data for Vessel and Cargo/TEU Specifics

CCWG and EU MRV both measures the total CO_2 emissions of the vessels, in addition, CCWG offers an additional value, which is the computation of cargo specific emissions. That is why the CO_2 computation for CCWG is different than the EU MRV when it comes to data granularity. The similarity is that, they both compute the total fuel consumption and the emission factor data are the same. The Table 7 below shows the data that is needed by the EU MRV and CCWG to be able to get the total CO_2 emissions (See Appendix B.1 for data description).

Table 7: CCWG and EU MRV data

Source: Regulation (EU) 2015/757 and CCWG (2015)

EU MRV (Vessel – Specific Data)	CCWG (Vessel and Cargo Specific Data)
● Carbon Emission Factor ● Total fuel consumption or direct CO_2 emissions ● Days vessel operated ● Distance sailed ● Cargo-on board ● Transport work ● Energy efficiency parameter ● Other ship operator's information (name, owner/s, address, contact details, etc.)	● Carbon emission factor ● Total fuel consumption ● Days vessel operated ● Distance sailed ● Other ship operator's information (name, owner/s, address, contact details, etc.) ● Vessel TEU Capacity ● Reefer TEU Capacity ● Reefer Consumption per year ● Seaborne transshipments - VSA, Slot Charter Agreements & Feeder services specific calculations ● Aggregated emission factors Vessel-specific Carrier-specific trade lane trade lane average emission factor Industry average per trade lane

The policy (Regulation (EU) 2015/757) is covering all kinds of maritime transport and gave a generic overview of the necessary documents needed to comply with the regulations and at the same time a general formula to compute total emissions of vessels. For the commission to have a more specific way of assessing the ship's emission depending on its type, the companies are obliged to submit monitoring report under the EU MRV regulation together with their previous and current MRV practice. In this case, the previous/current MRV practice can be the CCWG which covers more granular data. These data are used for benchmarking for vessels and cargo specifics, vessel's TEU and reefer capacity, reefer consumption per year and seaborne transshipments. Other factors CCWG is looking at is the data from the carrier's/company average aggregated data. Other factors are also considered in CCWG such as methodology utilization factor, distance adjustment factor, TEU conversion factor, volume vs weight, and the average trade lane performance (CCWG, 2015).

In a ship operator perspective, these two programs have formula similarity, and both needed to generate total CO_2 emissions based on the fuel consumption and emission factors for vessel specifics. And since these two are both different programs and two different regulating bodies, there is also two separate verification processes for the ship operators. At the same time, the ship operators must work and submit emission reports in two different systems. This causes inconvenience for the ship operators to be compliant in different programs, which almost generate the same data, but must cost more because of the separate processes. The best-case scenario for more convenient reporting is to have one single system which handles all the CO_2 computation. In the interview, ship operators addressed that they need both vessel and cargo/TEU specific emissions data, and it will be ideal to have this in one system. 7 But challenges of this kind of implementation is also foreseen. This involves generation and source of fuel consumption and other vessel specific data, and at the same time, inclusion of all other cargo/TEU specific data. But regulators such as IMO and EU MRV only cover the vessel-specific. So, there should be an alignment with B2B organizations such as CCWG which handles the cargo/TEU specific data. This kind of organization is the one who takes care of this kind of customer related requirements and specificity. [8]

7.1.4 Fuel Consumption and Direct CO_2 Techniques

Aside from the emission factor that is being provided by the IMO as one of the most important data in the computation for total CO_2 emissions, the other important data to be generated is the total fuel consumption of every ship. Company/ship operators deploy measurement systems in the ships for determining CO_2 emissions to know the actual measurement of the fuel consumption and total CO_2 emitted. There are different techniques on fuel consumption monitoring and direct CO_2 emissions, and different systems are deployed in the ships. The Table

8 summarizes all the four types of measuring techniques, current implementation, technology, accuracy, enforceability, and transparency.

Table 8: Fuel measurement techniques characteristics, implementation and technology

Source: Sachweh et al. (2014); Delft (2014); Transport and Environment (2012)

Monitoring Technique	Implementation	Technology	Accuracy	Enforceability	Transparency
Bunker Fuel Delivery Note (BDN) and periodic stock takes of fuel tanks;	EU MRV	Automated bunker fuel monitoring equipment	Potentially Low	Low	Low
Bunker fuel tank monitoring on board	EU MRV, CCWG	Tank sounding system	Low	Low	Low
Flow meters for applicable combustion processes	EU MRV, CCWG	Flow meters	High	High	High
Direct CO_2 emissions measurements	EU MRV	Direct Emissions Monitoring System	High	High	High

The Table 8 is based on different literature sources and interview results. EU MRV uses these four main methods. The monitoring technique and the current MRV implementation came from Sachweh et al. (2014) report. The table also presents the different technologies and systems that are being used in each technique such as the automated bunker fuel monitoring equipment, tank sounding system, flow meters, and direct emissions monitoring system. The data output can be total fuel consumption as the basis of CO_2 emission, or direct CO_2 measurement (Delft, 2014). The categorization of different techniques whether it is accurate, enforceable and transparent came from the Transport and Environment (2012) literature. It describes that there is a high accuracy, transparency, and enforceability of the last two techniques which uses the flow meters and combustion process, and direct CO_2 emission measurement systems. This is because flow meters automatically record the direct fuel consumption from the tanks, and the direct CO_2 emissions have an automatic logging system from the gas data which does not rely on the fuel consumption data itself. Interviewees said that the direct CO_2 emissions technique has high accuracy, but implementation of it in a large scale is not yet enforced. One of the challenges is that, it is expensive and there's no standard in implementation, in a global scale.[9]

The two other techniques which uses automated bunker fuel monitoring equipment and tank sounding system are comparably lower in accuracy, transparency, and enforceability because these two techniques involve approximations of fuel consumption and some involve manual data inputs and reporting to monitor the consumption. The interviewee also mentioned that the most unreliable technique is the BDN which involves a lot of manual work. At the same time, the verification of the total fuel consumption is not reliable as well.[10]

The interviewee suggested that an implementation of an Internet of Things (IoT) system and satellite integration for MRV can be a very good solution to address the problems on different fuel consumption techniques. There's a lot of companies who are already looking at this and implementation of this, and it shouldn't be so difficult due to the availability of technology.[11]

7.1.5 MRV Tools and Systems

The result of the research also looks at the current system implementations of different stakeholders that is involved in the MRV process for both CCWG and EU MRV programs. This section will be the summary of the deployed software and technologies for both EU MRV and CCWG that are being used for data gathering, reporting, communication and generation of the regulation's electronic templates and processes.

Table 9: MRV stakeholders, current systems and tools

Source: EMSA (n.d.); Turnkey Group (n.d.); Interview

Stakeholder	Current System	Owner / Administrator
Company/ Ship operators	Own Legacy Systems Electronic Spreadsheet Program Thetis MRV Turnkey	Company Company Purchased EMSA Turnkey – c/o CCWG
Verifier	Own legacy system Electronic Spreadsheet Program Thetis MRV Turnkey	Verifier Company Purchased EMSA Turnkey – c/o CCWG
Regulator (Commission)	Thetis MRV	EMSA
CCWG	Turnkey Electronic Spreadsheet Program	CCWG Company Purchased

The Commission as the regulator provides the process and format of electronic templates under the Regulation (EU) 2015/757 to European Maritime Safety Agency (EMSA) which is tasked to create Information System named Thetis MRV. This system is also used by the regulator to monitor the end-to-end process.

CCWG uses the Turnkey platform as a centralized system that puts its customers such as shippers, logistics providers, and verifiers on board. According to the interview, the shippers and verifiers have their own accounts to see, submit and exchange documents and data in the Turnkey which is the CCWG system. This is only accessible for CCWG members to protect their customer's privacy. [12]

The shipping companies has different working legacy system that is implemented in the ships that consolidate all the necessary data to be reported such as fuel consumption, time sailed, distance sailed, etc. For fuel consumption measurement, companies deploy different techniques such as the automated bunker fuel monitoring equipment, tank sounding system, flow meters and direct emissions monitoring system (See Table 6). In the interview, a ship operator representative shared that they are using their own legacy system called Fuel Reporting System for automation and report consolidation. But there are still manual works that are being done, especially for the customer or cargo/TEU specifics related reporting. 13

Maersk Line, Hapaglloyd, and Hamburg Sud are the example of container shipping company that are both compliant to the EU MRV and CCWG CO_2 methodology. In the EU MRV, the company must sign up in THETIS MRV web-based application and log the CO_2 monitoring and reporting obligations. At the same time, the company is also part of the MRV voluntary program CCWG wherein the company has an account in its web-based application called Turnkey to submit the emission reports and other supporting documents.

In the interview, one verifier confirmed that they have their own legacy system within the organization used for communication and data sharing. They also use electronic spreadsheet programs for some verification process, this is aside from the MRV systems already stated. [14]

7.1.6 Verification Process

Program rules for the two programs differs from one another. But the verification criteria of two programs is under ISO 14065 & ISO14064-3 (Verifavia, n.d.). The verification for CCWG and EU MRV reports have different process and data sets (Chapter 2). With the current implementation of the EU MRV, verifiers can carry out verification process for EU MRV and

CCWG at the same time. CCWG verification process (Verifavia, n.d.) involves the first phase which is the desk review, or the review of the company's documents and testing the data submitted to the Turnkey system.

The second step is the office audit that includes observation of the reporting process of the company, the systems that are used, manual task such as interview of the staff is also being carried out. In the office audit, data sampling is also carried out for a vessel.

The last step is the final review of the report submitted by the company in Turnkey, which has the data for the total emissions to be verified. Verifier then issues an audit report and then issue a verification certificate.

EU MRV verification process on the other hand carry out both monitoring plan assessment and emission report verification. The monitoring plan assessment audit aims to look at the alignment of the company's submitted monitoring plan, EU MRV regulation and existing company procedures which consists of three phases (Verifavia, 2017). The verifiers task for the first phase of monitoring plan assessment is the contract review, contracting, audit preparation, assessment plan. Second phase is an on-site visit in the head office, interviews with the key staff, review of documents and observation of the IT system. The last phase is the issues log, independent technical review and assessment of the report. These 3 phases are from Verifier's EU MRV monitoring plan assessment. The other report the verifiers need verification is the emission report, this consists of seven stages: risk analysis, verification plan, process verification, data verification, internal verification report, technical review, and verification opinion statement (Verifavia, n.d.).

CCWG and EU MRV has almost the same process of verification. The CCWG and EU MRV both covers the computation for vessel specific, and CCWG has an additional factor that is cargo specific computation of CO_2 emissions.

7.1.7 Challenges, Issues and Areas of Improvements

The current MRV systems, process and implementations encounters challenges, issues and some areas of improvements. Looking at the current implementation of the MRV program in this chapter, the researcher was able to conclude the following:

Currently, there are too many regulations and MRV programs that the company/ship operators need to submit a report of their total CO_2 emissions. Some of these are government and international body regulations such as EU MRV, IMO DCS, and some are voluntary programs such as CCWG. Ship operators must access different centralized systems and manual process of each MRV programs and undergo different sets of monitoring, reporting and verification process that includes different stakeholders.

Also, the company/ship operators are tasked to monitor, track and report CO_2 emissions depending on the CO_2 emission monitoring systems they have on board, different systems mean different standards. MRV programs both regulated and voluntary, has developed different CO_2 methodologies to be able to cope up with data reliability of the reported total CO_2 emissions based on different fuel consumption or direct CO_2 emissions techniques.

But not all the fuel consumption techniques cater transparency and accuracy of data. In addition, not all fuel consumption techniques trigger a more enforceable environment due to the limitations of the deployed systems on the on-board ships. Therefore, the regulators need an accredited third party to be able to check, audit, and make sure that the monitoring plans and emission reports generated by the company is within an MRV program standards.

The verification process is a tedious process which involves a lot of manual work, different system usage, and data verifications. As soon as all the obligations are submitted, and is verified, the regulators, company/ship operators and other stakeholders are informed regarding its compliance. Relevant stakeholders, for EU MRV case are the member state, other international bodies and the public. Both CCWG and EU MRV process maintains the confidentiality of commercial or industrial information of the company.

This is the list of the challenges, issues and areas of improvements of the current MRV implementation based on the data gathered in Section 7.1 and its sub-sections:

Ship Operators/Company is compliant to many MRV Programs

Ship operators/company needs to cater its obligations on MRV of CO_2 emissions in the mandatory program. In parallel, ship operators also need to adhere to its voluntary programs encouraged by regulators so as there would be a means to compare the output data of the two systems. There are a lot of disadvantages on following different sustainability programs in the container shipping industry. This brings confusion, additional repeated works, and cost. The MRV process must be handled by only one international body, specifically the IMO, and not by the EU. This is to be able to cover a global coverage for the MRV program.

The IMO DCS will come into force in 2019. The discussion on implementing IMO DCS standards is still ongoing.

CO_2 Methodology Standardization

Every MRV program has different CO_2 methodology standards, scopes and processes. One standardized CO_2 Methodology is needed to lessen the amount of efforts, costs and repetition of works. The standardization has been a problem for MRV schemes because of multiple programs. Container ships for example has a unique way of calculating the total CO_2 emissions due to its global characteristics and cargo specifications. Monitoring of CO_2 emissions for containerships should cover all the ports it travels, and not just limited to member state ports, which is the case of EU MRV implementations.

Also, looking at the ship operator's needs, they are not just tracking and monitoring their vessel specific CO_2 emissions, but also the per cargo's total CO_2 emissions for their customer's use. It is better to have one single point of MRV reporting where it covers both vessel and TEU/cargo-specific CO_2 emissions. But consideration on regulators MRV scopes should be done for proper alignment of the projects. It is because regulators only cover the vessel-specific. CCWG is part of a voluntary scheme which handles customer related emissions which is cargo/TEU specifics. Regulators such as IMO and EU MRV is not covering this kind of requirements of the ship operators.

The possibility to integrate the blockchain MRV process with other climate action projects can also be an area for improvement and integration, according to the interview. One benefit of using such is the verified and validated data of CO_2 emissions that a blockchain-based MRV system can offer in the carbon market integration. In addition, some interviewees shared other possible climate projects that blockchain can be a good tool for solving climate-related problems. Example is the solution on the double counting problem in the carbon market. 15

MRV systems challenges and improvements

There are many systems that the ship operators need to create an account and log emission data and the verifiers needs to check. There are also implemented MRV System features and capabilities that needs improvement from manual process. The non-integration of systems causes inconveniences to all stakeholders that needed to log and access different systems.

Fuel consumption techniques challenges

There are too many fuel consumption measurement techniques that regulators need to standardize so as to consolidate its monitoring process and formula. Aside from that, not all measurement techniques are implemented with high transparency, enforceability and accuracy. Trust and data reliability is a problem in the deployed fuel monitoring techniques, and verification of it is not reliable as well. The usage of IoT, and new technologies such as satellite can address the said dilemma.

Another effective way to track the total CO_2 emissions is to use the Direct CO_2 emissions technique because it automatically and directly tracks the CO_2 gas, and does not need the fuel consumption data. This technique is the most reliable, transparent and enforceable solution. The only problem of using such, is that it is expensive, and the standards on using this technology is not yet implemented in marine transport by international bodies.

Data Reliability and Transparency Issues

Not all ship operators are transparent and willing to open their emission data. In addition, regulation such as the EU MRV has confidentiality clauses which protects and maintains the privacy of the data in the MRV process. CCWG also has an aggregated data that is private to the organization and open only to the member CCWG. Although this is to the advantage of the individual shareholder, it is detrimental to the cause of unifying the standards of MRV systems. To be able to create a one global standardized CO_2 methodology, and benchmarking of global shipping data, transparency is highly encouraged to the whole MRV process. In addition, data reliability is a problem in some fuel consumption techniques.

7.2 Technology Perspective: Blockchain

This section presents the technology part of the research result. First part will be assessing the research case study if blockchain technology is a fitted innovation in the associated project. The second part will be assessing the kind of blockchain that will best fit the industry's preference and demand. Section 7.2.3 presented an example of blockchain architecture that can cater to the industry's preference and an explanation on how to use the smart contract. Section 7.2.4 tells about the data that is needed on both vessel and TEU/cargo-specific MRV systems.

7.2.1 Assessing if Blockchain is Fitted in the Industry's Needs

The use of blockchain has been associated with different product integration on the supply chain, finance, and now to tackle climate actions. The use of blockchain has been a topic of interest to different MRV stakeholders, as validated in the interviews. This technology is seen to be used for the implementation of a global calculator, CO_2 methodology for both vessel and cargo/TEU specific monitoring and tracking of CO_2 emissions. Lastly, it can also be used in addressing the challenges of the fuel consumption techniques such as BDN. [16]

Assessing if blockchain is a suited technology is to be able to prove that there is an additional value for the organization in integrating this solution. The Table 10 showcases three scenarios of the decision making for tracking and reporting CO_2 emission in the container shipping industry. The table is based on the literature review in Section 3.6.

Table 10: Three Scenarios for choosing the type of blockchain

Source: From the Flow Chart of Wüst & Gervais (2017)

Decision Making Process	**Scenario 1** **Permissionless Blockchain**	**Scenario 2** **Public - Permissioned Blockchain**	**Scenario 3** **Private – Permissioned Blockchain**
Do you need to store state?	Yes	Yes	Yes
Are there multiple writers	Yes	Yes	Yes
You can use an always online TTP?	No	No	No
Are all writers known?	No (public and permissionless)	Yes (Permissioned)	Yes (Permissioned)
Are all writers trusted?		No	No
Is public verifiability required?		Yes (Public)	No (Private)

There are three scenarios that must be answered to assess if a specific case can use a blockchain or not. These scenarios in the decision-making process are: (1) 'Do you need a store state?'; (2) 'Are there multiple writers?'; and (3) 'You can use an always-online Trusted Third Party (TTP)?' Addressing the first question, the data in the CO_2 tracking and reporting should be organized and stored in a database. The data that is needed to be accessed, organized and saved electronically in a database are fuel consumption or direct CO_2 emissions, the number of days sailed, weight and volume of cargo, distance sailed, reports, etc.

For the second question, there will be multiple writers because of multiple data sources. Aside from the regulators and ship owners as the writers, the possibility to integrate with the Internet of Things (IoT) and other systems can also be considered as the writers in the system.

In the case of the third question 'You can use an always-online TTP?', the TTP will not be always online in a permissioned blockchain setting, and TTP doesn't need to exist on a permissionless blockchain. The TTP issues certificate of authority in the permissioned blockchain because the identity of the writers needs to be verified. Once the writers are verified as trusted part of the blockchain system after TTP issued the certificate, then the TTP doesn't need to always verify the identity of the writers, therefore TTP doesn't need to be always online.

The three questions above describes the current state of the research focus, while the next questions will be identifying the types of blockchain that can be used. This will be based on the anonymity and trust factors for the writers, and if the blockchain needs a public verification.

Scenario 1 shows that, if the blockchain will be designed openly, meaning, the writers don't need to be known, the kind of blockchain that will be used is a permissionless public blockchain. One example of this is the Proof of Work (PoW) based consensus of the Ethereum.

The Scenario 2, a public permissioned blockchain such as the Ethereum Casper Proof of Stake (PoS) consensus, must be set up that the writers are known before they can be allowed to join in the network. The writers are untrusted, and so the public verifiability is allowed and required to complete each transaction.

Scenario 3 is an example of private permissioned blockchain. When the writers are known, it is a permissioned blockchain, and if public verification is not needed, it is a private blockchain.

7.2.2 Assessing the Kind of Blockchain for CO2 Tracking and Reporting

The Table below discusses the factors on how to decide if the blockchain will be permissioned/ permissionless, private/public in technology and industry perspective. Through the decision-making process explained above, it turns out that blockchain can be used for the tracking and reporting of CO_2 emissions. It has been verified that it needs a store state, there will be multiple writers in the system, TTP is not always online and the writers are not trusted. The model and the decision process were shown to a blockchain expert who is doing almost the same project scope. From the interview, the researcher got a confirmation that blockchain can be used in MRV for CO_2 emissions, specifically using it for smart contract application. [17]

The next step is to identify whether it will be a public/private, permissioned/ permissionless blockchain. The table 11 shows the data gathered from the interviews, policies, and pieces of literature. It shows the industry's challenges and demands, technology insights, and the kind of blockchain, whether it is public-permissionless, public-permissioned, and private-permissioned.

Table 11: Blockchain choices for MRV needs

Sources: Ethereum Foundation (2014); Regulation (EU) 2015/757; Hyperledger Fabric (2017); Interviews

Factors	**Public Permissionless**	**Public Permissioned**	**Private Permissioned**
Industry Preference on transparency and confidentiality of data	Transparent public data on CO_2 methodology and reports.	Transparent public data on CO_2 methodology and reports.	Preserve the confidentiality of commercial or industrial information on CO_2 methodology and reports. Only transparent to the members of the network and defined data set that can be open to the public.
Technology Perspective: privacy and anonymity	The public can join the network which requires computer processing power to confirm transactions (mining). This is known to be costly and not sustainable because of its computer processing power.	The public can join but needs a stake upfront before they can join the network to process and confirm transactions. PoS method as a more greener and cheaper distributed form of consensus than PoW	Only members of the network can read, write and verify transactions.

The interview with blockchain developer brought up that using Ethereum is good for smart contract application. It is also because Ethereum has a good community of developer support. This blockchain can resist heavy attacks as well. In addition, the Ethereum community is in the development stage of the PoS to get away with the PoW mining consensus which uses an enormous amount of energy. This kind of development is foreseen to create a more sustainable blockchain consensus solution. But PoS is also imperfect and has some flaws, this is because the higher the stake the person has in the network, the more chance this specific person can validate the transaction which they can then collect more transaction fees. This means the rich get richer in the network.[18] There are a continuous research and development for the PoS consensus in the Ethereum community to understand the risks and better development.

In the container shipping industry perspective, the gathered research information on choosing the kind of blockchain is only limited on whether it will be a public or private, and not in the case of permissioned/ permissionless blockchain. In a perfect world, ship operators should provide a fully transparent emission data. If this will be the case, a public blockchain, whether it's permissioned or permissionless can be used. But with the current condition of the industry, a public blockchain will not fit on the industry's preference. In the interview, multiple stakeholders agreed that companies and regulators preferred not to fully share their sustainability data, although there are still existing companies who are willing to share it in a more transparent way in the public.[19]

Also, as stipulated in the Regulation (EU) 2015/757, there should be a preserved confidentiality of commercial or industrial information through some restrictions on the publication of emission data including fuel consumptions.

This kind of needs and preferences when it comes to privacy and confidentiality of the industry can lead to the usage of private-permissioned blockchain such as the Hyperledger, wherein only members of the network can read, write and verify transactions.

In an interview with the R&D head of a blockchain company focusing on the monitoring and reporting of GHG emissions, the suggestion is to use Hyperledger. This is seen as the best fit for the stakeholder's preferences and needs on the MRV process. Through the guidance of a blockchain developer, Hyperledger Fabric using Practical Byzantine Fault Tolerance (PBFT) can be one of the blockchain choices that is right in this project. At the same time, it is a permissioned blockchain that integrates the use of smart contracts to create a platform for distributed application. This is specifically made as a DLT that is not necessarily used for the exchange of value or money but just record of transactions. [20]

7.2.3 The Hyperledger Fabric

There are different requirements for an enterprise to be able to look at the use of blockchain that will fit in their value proposition. Most enterprise would like to maintain the privacy and confidentiality of transactions and data. In addition, a high transaction and throughput and low latency of transaction confirmation are required. The Hyperledger Fabric established under the Linux Foundation caters this enterprise-grade requirement for a blockchain and/or DLT. The Hyperledger Fabric is an *'open source enterprise-grade permissioned distributed ledger technology (DLT) platform'* that is created to be modular, scalable and secure with some key differentiating capabilities over other DLT such as Ethereum and Bitcoin (Hyperledger Fabric, 2017).

Hyperledger Fabric as a permissioned blockchain took a different approach on integrating smart contracts to create a platform for distributed applications. It is a permissioned blockchain because the participants in the network are known (Hyperledger Fabric, 2017). Blockchain expert explained how access is given in the participant of a permissioned network. A legal agreement is created to be able to govern this network of participants. In the interview with Hyperledger architect, it is mentioned that through the channel architecture, visibility of specific transactions and sharing of data can be governed in the network. [21] When it comes to its consensus, it has a pluggable consensus protocol called Byzantine Fault Tolerant (BFT).

The Hyperledger Fabric blockchain will be used by the researcher for the process innovation design in Section 8.1.3 of this research. This is because the Hyperledger Fabric caters the study's needs when it comes to privacy and confidentiality of the data and transactions that the stakeholder requires. In addition, its characteristics as modular, scalable and secure blockchain adds value to its implementation. Hyperledger is a permissioned blockchain that integrates the use of smart contracts to create a platform for distributed application that is not necessarily used for the exchange of value or money.

7.2.4 Data

Mandatory and voluntary MRV program both covers the computation of the vessel specific emissions. The needed formula to be able to compute the total emissions are the total vessel fuel consumption multiplied by the emission factor. Some vessels use direct CO_2 emissions monitoring system, which is more accurate and covers not just CO_2, but also all kinds of GHG gases. Other important data for this computation are the days sailed and distance sailed.

The blockchain-based MRV system proposed in the process flow in Figure 8 in Section 8.1.1 is tailor fitted not just for the mandatory MRV program, but also for the voluntary program, which includes the TEU specific emission that is useful to ship operator's customers. These are aggregated factors that is useful for benchmarking for ship operators and customers. The data needed for the computation of vessel specific and customer's cargo specifics is presented in the table below (See Appendix B.1 for data description).

The data on the Table 12 is a representation of the merged data set of both EU MRV and CCWG programs as stated in Section 2.1 and 2.2 respectively. Some fuel consumption data might not be necessary if the fuel consumption technique that is being used is the direct CO_2 emissions.

This technique doesn't necessary need to collect fuel data. The technology is made to directly fetch total CO_2 emissions and automatically log it in the system deployed in the ships.

Table 12: Data in the blockchain-based MRV for container ships

Source: Regulation (EU) 2015/757; CCWG (2015)

Type	Data
Vessel – Specific Data	• Carbon emission factors • Total Fuel Consumption or direct CO_2 emissions • Days vessel operated • Distance sailed • Cargo-on board • Transport work • Energy efficiency parameter • Other ship operator's information (name, owner/s, address, contact details, etc.) • Aggregated emission factors - Vessel-specific - Carrier-specific trade lane trade lane average emission factor - Industry average per trade lane
Cargo/ TEU Specific Data	• Aggregated emission factors: Cargo specific data (reefer and dry plugs) that can be vessel specific, carrier-specific trade lane average, industry average per trade lane • Seaborne – Transshipments (VSA, Slot Charter Agreements & Feeder services specific calculations) • Number of dry and reefer plugs (in TEU) • Dry and Reefer (in TEU) consumption per year • Vessel dry and reefer capacity (in TEU)

8 Analysis

This chapter is the analysis of the results gathered and theories used in the research. This section has three parts, the technological analysis, and the identification of the perceived characteristics of innovation and the challenges of implementation of the innovation. The technological analysis section presented the blockchain-based platform, smart contract capabilities, and stakeholders mapped to be able to achieve the consensus. The technological analysis covers the Business Process Model (BPM) created to be able to present the process innovation. The second part of this chapter is the identification of the perceived characteristics of the innovation that may contribute to the future adoption of the innovation. The last part is the challenges and constraints in the implementation of the process innovation.

8.1 Technological Analysis

The proposed process innovation in the technological analysis is addressing the issues and areas of improvements to the current MRV system. These challenges includes ship operators/company is compliant to several MRV Programs with different CO_2 methodology standards; having multiple IT systems to use; different fuel consumption techniques and measurements challenges; and the data reliability and transparency issues.

The smart contract capabilities, stakeholder mapping, and document workflows are mainly defined to address these issues. This innovation is based on a private permissioned type of blockchain. Lastly, the final output of this section is the presentation of a Business Process Model (BPM) for tracking and reporting of CO_2 emissions presented in Section 8.1.3. There are three different BPMs that are presented: (1) Vessel Specific MRV system; (2) Vessel and Cargo/TEU specific MRV system designed for two separate regulators; and (3) Combined Vessel and Cargo/TEU specific MRV system.

8.1.1 High Level MRV Process and the Smart Contract Feature

The project will be built on a permissioned blockchain, Hyperledger Fabric. The Hyperledger's smart contract will play an important role on the implementation of the innovation, and at the same time addressing and solving the challenges and issues of the current MRV implementation. As smart contract is referred to as the chain code in Hyperledger which is the business logic of the application. This smart contract controls and triggers actions that are pre-defined in its code. Figure 7 in Section 7.1.2 describes the current implementation of the MRV programs, the challenges are also stipulated.

Using blockchain, and the smart contract, some processes and stakeholders can be removed in this current implementation. Figure 8 below shows the new process flow chart that describes the stakeholders and their obligations implemented on a blockchain, and how the smart contracts can be used. In this model, the individuals, organizations, machines, and algorithms have a predefined process flow wherein interaction and transactions can be done without a TTP which can reduce costs for the implementation of monitoring and reporting of CO_2 emissions.

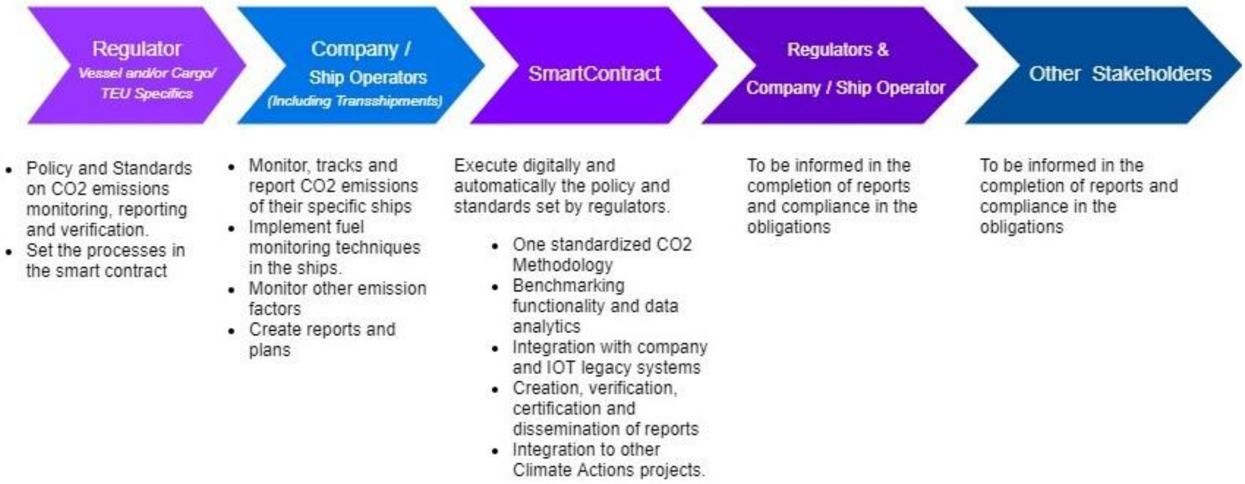


Figure 8: Blockchain-based MRV process model and stakeholders

In this process model, Regulator can be categorized in two, the vessel specific, and TEU/customer cargo MRV. This process proposes that these two categories will be both called ‘Regulator/s’ which can be one or separate entities which sets all the policy, the standards and define the system processes and implementations for the GHG inventory for containerships.

Company/ship operators then use only one single global system to submit monitoring report and emission reports to comply its sustainability CO_2 emissions obligations. This company/ ship owners can then integrate some of its company legacy systems and/or IoT systems deployed in the ships. This is then connected in the global system to be able to monitor and track data accurately with high transparency and reliability and create reports and templates for compliance. This data submitted by the company/ship operators is processed in the smart contract.

In line with the regulators policy and standards, the smart contract will be able to process the end to end monitoring and reporting mechanisms. The smart contract contains the following five characteristics: (1) One global standard CO_2 methodology; (2) Obtain and integrate globally recognized emission factors and standards; (3) Benchmarking functionality and data analytics for container ships; (4) seamless integration with company legacy and IoT systems; and (5) creation, verification, certification and dissemination of reports.

The smart contracts perform all the reporting mechanisms such as the verification of the monitoring plan, emission reports, and certification of the document of compliance. This document is then disseminated to all relevant stakeholders such as the regulators, ship operators/company, other stakeholders such as the national government and ports, customers and investors, public, etc. Using the smart contract, middleman or Trusted Third Party (TTP) might not be necessary for the network, according to an interview with blockchain expert and a verifier. But implementation of blockchain and the smart contract features will face challenges when it comes to stakeholder's preparation and acceptance. [22]

Discussion below is the more defined characteristics and features of the smart contract as defined in Figure 8.

One Standard CO_2 Methodology

This includes process automation and optimization of all the data needed to be able to compute the total CO_2 emissions for container ships. It can also fetch and generate global standards of data and emission factors for maritime transport, eg. carbon conversion factors. This should also include all the necessary factors to be able to compute the CO_2 emissions of container ships with different fuel consumption techniques, or if the system being used is direct CO_2 emissions system. This CO_2 methodology is guided by the benchmarking functionalities and data analytics feature.

At the same time, an opportunity to look at capturing other emissions of conventional air pollutants such as Sulphur Oxides (SOx) and Nitrogen Oxides (NOx) is also suggested to be part in the standard of CO_2 methodology. It is termed as *'CO_2 Methodology'* although it includes other air pollutants, this is because CO_2 is the prominently emitted GHG.

The one standard CO_2 methodology should be encouraged to be implemented by a regulator which covers container ships in an international scale. IMO can be the regulator that can handle this MRV program needs.

Benchmarking functionality and data analytics for container ship operators and customers

Through the data analytics, it will be able to create individual and aggregated data for all the container ships. At the same time, it will have a benchmarking functionality to be able to compare ship operator's data. It will be easier to generate aggregated data and average of different factors such as the utilization factor, distance adjustment factor, TEU conversion factor, volume vs weight, average tradeline performance, other CO_2 emission factors because of the data analytics capabilities of smart contracts.

Seamless integration with company legacy and IoT systems

Smart contract and the blockchain should be designed that it can be seamlessly integrated with company's legacy and IoT systems to provide a more reliable and accurate data. Possible integration of the different systems deployed in ships which are the: (1) Bunker Fuel Delivery Note (BDN) and periodic stock takes of fuel tanks; (2) Bunker fuel tank monitoring on board; (3) Flow meters for applicable combustion processes; (4) Direct CO_2 emissions measurements; (5) and other possible systems in the future. Aside from this fuel consumption techniques, data that can be fetched directly from the company legacy and IoT systems are number of days sailed, the distance travelled, and other relevant data.

Creation, verification, certification and dissemination of reports

With the standard format, template and timelines set by the Regulator, the company/ship operators should be able to input the monitoring plan and emission report. The smart contract should be able to assess and verify if the submitted reports are aligned to the CO_2 Methodology and regulator's standards. Monitoring plan needs to be submitted and verified prior to submission of emission report, which also needs to be verified. The emission report is then certified, and a release of certified DoC follows as the proof of complying to the mandatory regulations. These reports can be disseminated in the pre-defined stakeholders.

MRV of CO_2 emissions integration on other climate action programs

This also looks at the possibility to integrate the certified emissions of the ship operators and its customers in other climate action programs. One of the integration is on the greenhouse gas (GHG) emissions reduction programs. The reliable data on the total company's emission in the seaborne-transport will contribute to the precision of the company's computation on company's targets, and total carbon offset. This will mitigate fraud and other forms of carbon crimes. In addition, this will serve as a tool for the monitoring of the Nationally Determined Contributions (NDC) under the Paris Agreement which is beneficial to national authorities.

8.1.2 Stakeholders Analysis to Achieve Consensus

The Business Process Model (BPM) that will be presented in Section 8.1.3 will be based on the main stakeholders in Figure 9 below:

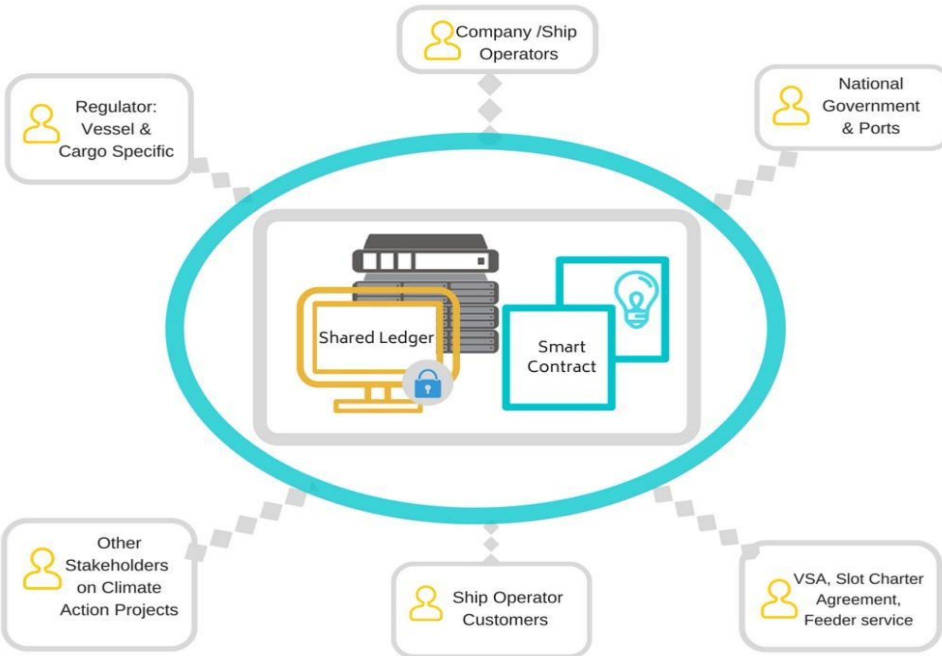


Figure 9: Stakeholders in blockchain-based MRV to attain consensus

The identification of the relevant stakeholders on the blockchain-based MRV platform is based on the literature review results, empirical data gathered through interviews, and MRV policy. To be able to design the blockchain-based platform and decide the design of the DLT, stakeholders and their obligation in the network must be defined. Achieving consensus or general agreement will involve the stakeholders mentioned below. The stakeholders and their primary obligation is described as:

Regulator

One of the main members of the network is the Regulator which creates and implements the standards and the processes of the MRV system. Also, the stakeholder designs and decides for the functionalities and implementation of the smart contract, which is described in Figure 8 in Section 8.1.1. Identification of regulator plays a very crucial part on creating the BPM and the process innovation.

As stated in the high level blockchain-based process model in Section 8.1.1, Regulator/s can be one or separate entities, this can be regulators who handles the vessel-specific emissions, cargo-specific emissions, or the combination of two. Because of the changes of the regulator's scope, there are three BPMs that are presented in Section 8.1.3: (1) One regulator for the Vessel Specific; (2) Two separate regulators for the Vessel and Cargo/TEU specific; and (3) One regulator for both Vessel and Cargo/TEU specific.

The reason of separation of these regulators depends on the organization's intentions on the use of blockchain. Some proposed that regulators such as IMO should only cover the vessel specific data which will fit on BPM 1 in Section 8.1.3.1 and exclude the container/TEU specifics. In BPM 2 (Section 8.1.3.2), it is proposed that both vessel and cargo/TEU specific MRV should be handled by two separate regulators. Lastly, BPM 3 (Section 8.1.3.3) is designed to merge both vessel and cargo/TEU specific MRV and be handled by only one regulator.

Company/Ship Operators

They are obliged to report their vessel and customer related CO_2 emissions. Also needs to ensure that they have a proper and effective fuel consumption/ CO_2 emissions monitoring and system deployed in the ships.

National Government and Ports

The current MRV model implemented by EU only came into force within its Member State and their ports. In the proposed model, checking of DoC is not just limited to the member state. This model covers the National Governments and their ports all over the world. This will fit on the container ships nature and scope that travels globally and not just in the EU. National governments will be checking the DoC in their respective ports, and at the same time gives penalties and expulsion to ship operators which is non-compliant to regulator's standards and processes.

Ship Operator's Customers

For ship operator's perspective, it is better to have a one MRV system which also caters the TEU/cargo-specific data, for the easier broadcasting of these data to their customers. At the same time, the ship operator's customers also demand reliable data of the total CO_2 emissions of their cargo being transported at sea.

Seaborne-Transshipments (Vessel Sharing Agreement (VSA), Slot Charter Agreement, and Feeder Service)

Another important member of the node is the seaborne-transshipments. The ship operators should also get the total CO_2 emissions of the subcontracted companies that provide VSA, slot charter agreement, and feeder service. This additional service also accounts for additional CO_2 emissions, which is then should be added to the total CO_2 computation of the ship operator's vessels. This factor is essential on determining the cargo/TEU specific tracking and reporting of emissions.

Other Stakeholders on climate action projects

The CO_2 market, reduction programs, and stakeholders for NDC implementations are not part of the MRV process in the current MRV implementation (Section 7.1.2). Consideration on adding them in the network came from the result of various interviews. It is said that integration of MRV can cater towards reliable data. This will create a more integrated and transparent data sharing when it comes to the real carbon footprint of the industry and proper accounting of carbon credits.

Other Stakeholders

This consensus also considers adding other stakeholders such as the ship operators and its customer's investors, and other partner organizations such as Non-Government Organization (NGO). This stated 'other stakeholders' plays a very important role in the container shipping industry, that they are entitled to know the sustainability of ship operators and its customers. This stakeholder can also be considered *'off-chain'* or not included in the blockchain network because their role will just be '*to be informed.'*

The 'public' is also considered as a stakeholder but cannot be part on the private permissioned blockchain model. The ship operators and regulators can decide the specific data that they can share to the public, but not necessarily include the public in the blockchain network. Therefore, public can be 'off-chain' or out of the designed blockchain's 'possible' network of stakeholders.

These are the identified stakeholders of the CO_2 MRV system for both cargo and vessel specific tracking and reporting of total CO_2 emissions. This set-up is considered as shared and distributed ledger, but that doesn't mean that all the stakeholders in the network will have all kinds of data in the network. The blockchain that will be used in this study is a private permissioned which means that the data sharing, communication, and transactions will be programmed and customized based on data privacy and confidentiality clauses of each stakeholder.

8.1.3 Process Innovation: Business Process Model

The process innovation in this research is represented by a Business Process Model (BPM). The model is consisting of the MRV process that shows collaborating organizations in the platform, document workflow and sharing, smart contract capabilities in a general overview and the verification process. The BPM uses different notations and shapes which provides semantics on different underlying mechanisms.

There are three BPM presented in this section. The first one is a BPM specifically focus on the vessel related tracking and reporting of CO_2 emission. After some data gathering and considerations of the future improvement of MRV system, the inclusion of the cargo-specific emissions was also considered, and therefore a second and third BPM Model (Section 8.1.3.2 and Section 8.1.3.3 respectively) are presented. The BPM is composed of both systems and human stakeholders. The smart contract is the algorithm used to perform different features. The features promote one standardized CO_2 Methodology, benchmarking functionality and data analytics and integration with companies and IOT legacy systems. In addition, it will create, verify, validate and certify transactions and documentation. Lastly, smart contract can be integrated to other climate actions projects.

BPM Format

The BPM format are represented in swim lane where each stakeholder is represented by rectangular boxes which contains the business processes. The swim lane is arranged horizontally which shows the flow of objects from right to left. Each specific lane is performed by a specific participant, and in this research, is referred to as the stakeholders discussed in section 8.1.2. The upper part represents a milestone of the process in the BPM, in this case, a completion of a monitoring plan, emission report and the DoC.

All the processes in the smart contract is run by the system, represented in the swim lane ‘blockchain smart contract’. The gear represents the main algorithm of the system in the smart contract.

8.1.3.1 BPM 1: Vessel Specific MRV System

The first BPM (Figure 10) shows the vessel-specific blockchain MRV platform. Given that there’s only one MRV system, all the stakeholders have an account and can only access transactions that depends on the role each stakeholder plays in the network.

First, the regulator creates policy and standards on GHG inventory for the container ships that is specific for vessel MRV. The regulators also define the smart contract functionalities, data to be processed, algorithms, and the transaction processes. In this BPM, regulators only focus on the vessel specific emissions. One stakeholder that can benefit from this model is the IMO.

The smart contract plays a very important role in the system because it digitized and automates all the processes, document workflows, CO_2 computations, data fetching from different integrated systems, and data analysis. Guided by the templates and processes set by the regulator in the smart contract, the ship operators then create and log their monitoring plan in the blockchain system.

The ship operators then submit their monitoring plan in the MRV system and the smart contract verifies the validity of the data. If the data is not accurate based on the smart contract MRV standards, then the ship operators are notified to revise the monitoring plan that is submitted. Ones the data in the monitoring plan is verified and proven to be correct, the system then processes and release the verified monitoring plan to necessary stakeholders such as the ship operators and the regulators.

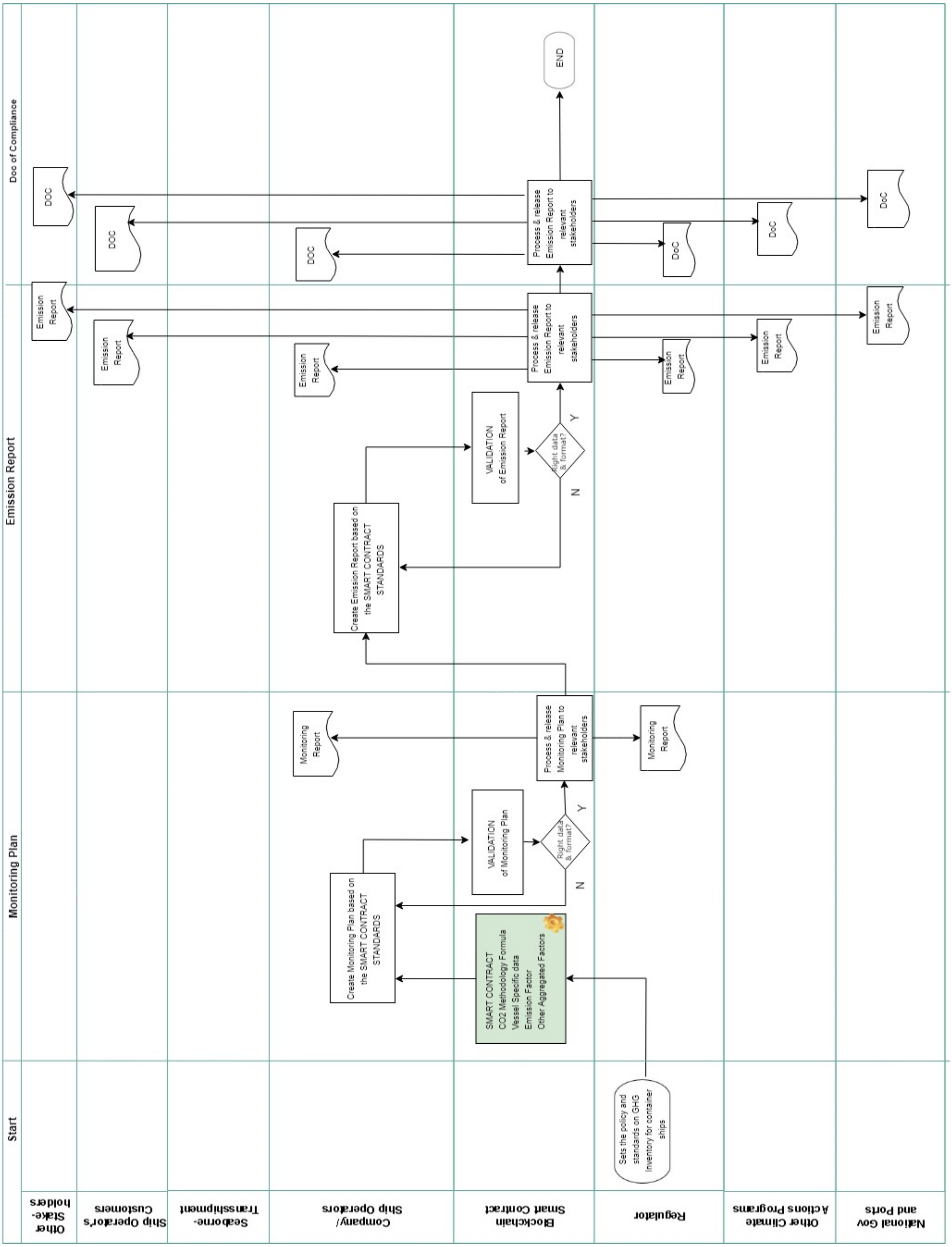
The verified monitoring plan is then a proof that the company can now submit an emission report within a given deadline and rules set by the smart contract. The emission report is generated through the help of integrated IT systems in the ship and deployed IoT systems. This emission report is then verified again by the smart contract. If the report did not fit on the pre-defined rules, the company will then again need to edit and check the submitted emission report. If the submitted report is proven to be accurate, then the smart contract verifies and release the emission report.

After this verification, the smart contract will then generate and release the Document of Compliance (DoC). The DoC represents the certified document of the ship operators/company that they are compliant to the regulator's mandatory program.

Documents such as the monitoring plan, emission report and DoC are processed by the smart contract and then broadcasted to different stakeholders in the network. The broadcasted report and data can be modified based on the templates, standards and data restriction on what the regulators and ship operators allowed to be shared.

BPM 1 uses and processes only the vessel specific data for tracking and reporting of CO_2. These data sets are presented in Section 7.2.4.

Figure 10: BPM1: Vessel Specific MRV System



8.1.3.2 BPM 2: Vessel and Cargo/TEU MRV System as Separate Regulators

The ship operator/company stakeholder through an interview gave a feedback on separating the vessel specific MRV and TEU/cargo specific MRV. The reason is that, international organization for maritime transport such as the IMO would only like to cover just the vessel related emissions in their MRV process. This means that the cargo related emission is out of their scope. The regulators don’t need the level of granularity of the cargo specific data. Therefore, there will be one regulator for the vessel specific MRV process presented as Regulator 1. Regulator 1 works exactly as BPM 1 as it is focusing only on vessel emissions data represented in Figure 11.

Containership operators doesn’t just monitor their vessel emissions, but also the cargo that is loaded and unloaded in the ships. This is also why container ship operators are members of other MRV voluntary programs because it also caters the MRV process of TEU/cargo specific emissions. This cargo/TEU specific MRV system is presented as the Regulator 2 in Figure 12 below.

Therefore, in the BPM 2, the model presented will be two separate regulators that processes the ship operator’s report. The Regulator 2 in Figure 12 below is connected to Regulator 1 (Figure 11) blockchain smart contract. Regulator 1 is connected to Regulator 2 and feeds vessel specific data, computation, monitoring and emission reporting. Some data that is gathered and/or generated by the Regulator 1 should be shared to Regulator 2 systems. This can be possible through the channel architecture of the Hyperledger blockchain. Data that are commonly shared are the container operators/company administrative data, the total vessel fuel consumption, days sailed, distance sailed, and emission factor. The data sharing from Regulator 1 to 2 is represented by the round figure with number 1. Both figures are numbered 1 because data sets will be coming from just one organization.

Other data that is cargo specific (See Section 7.2.4) is only processed and catered by the Regulator 2. Regulator 2 is then responsible on looking at the seaborne transshipments and making sure that the cargo transfers in different vessel or feeder service is also added in the total emission report that the ship operators are submitting. The validation of emission report of the Regulator 2 is then only focused on the cargo related emission data because the validated emission data of the vessel came from the Regulator 1. In this case, repeating of vessel related reporting and validation work in both organizations will be mitigated. The report that is produced by Regulator 2 is just a validated emission report of the TEU/cargo specifics which is then given to the ship operators, seaborne transshipment companies, and its customers.

The research doesn't explain if the two organizations will be designed in an on chain (one blockchain network) or off chain (not in one blockchain network) setup, therefore it is suggested for further research.

BPM 2 uses and processes both vessel and cargo/TEU specific data for tracking and reporting of CO_2 in two separate regulators. These data sets are given in Section 7.2.4.

Figure 11: BPM 2 (Part 1 of 2): Regulator 1 - Vessel MRV System

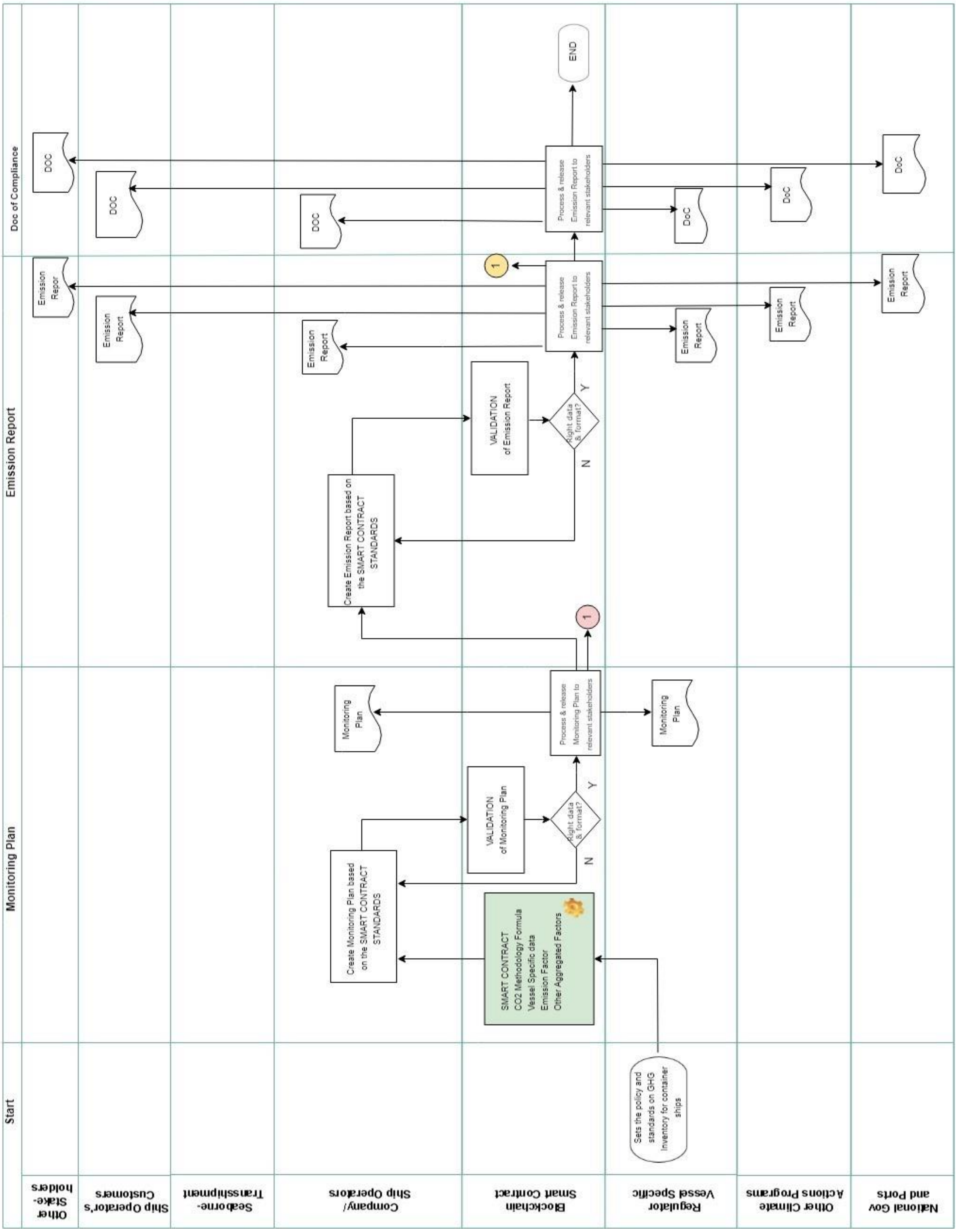
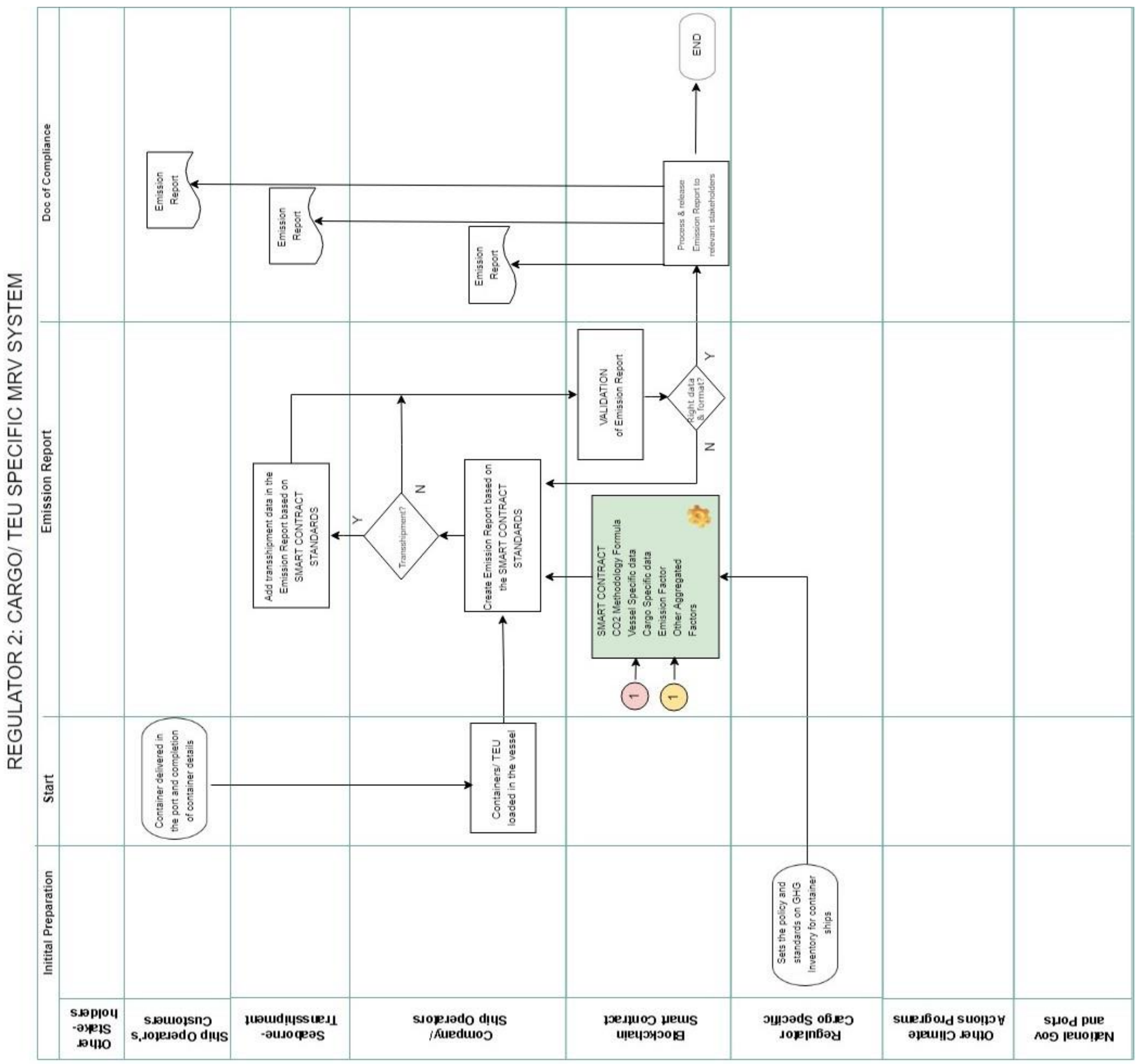


Figure 12: BPM 2 (Part 2 of 2): Regulator 2 - Cargo/TEU MRV System



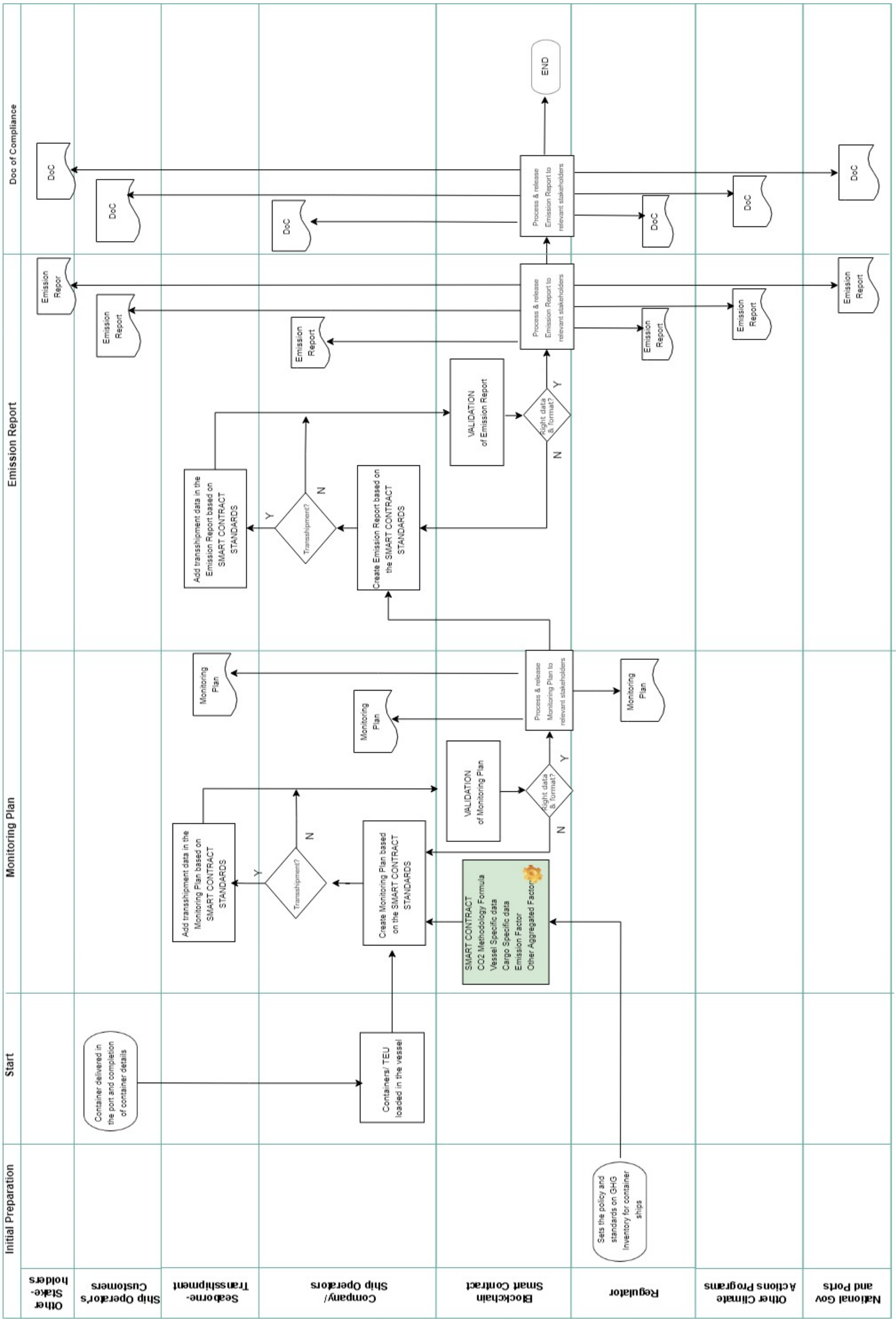
8.1.3.3 BPM 3: Combined Vessel and Cargo/ TEU MRV System

This third BPM diagram in Figure 13 merges both the vessel specific and the TEU/cargo specific MRV. BPM 1 and BPM 3 has almost the same processes when it comes to document workflow and validations. The key difference is that the smart contract is also configured to cater the TEU/cargo specific emissions, computations and process. In addition, seaborne transshipment data such as VSA, feeder service and slot charter agreement total CO_2 emission are also considered and integrated in the completion of both monitoring plan and emission report. Nonetheless, the process is the same with the BPM 1 vessel specific tracking and reporting method.

Also, BPM 3 is a representation of a the merged regulators in BPM 2, given that there will be one regulator that will cater both the vessel specific and cargo/TEU specific MRV. This model creates an optimized solution for ship operators' dilemma of complying to a lot of MRV programs, because both mandatory and voluntary program processes, data capturing, document workflows are included. Therefore, the regulator in this BPM model both caters the current MRV mandatory and voluntary program.

BPM 3 uses and processes both vessel and cargo/TEU specific data for tracking and reporting of CO_2. These data sets are given in Section 7.2.4.

Figure 13: BPM3: Combined Vessel and Cargo/TEU MRV System



8.2 Perceived Characteristics of Innovation

This section is the discussion of the five key attributes of the perceived characteristics of the innovation. Section 8.2 and its sub-sections answers the first part of the main research question. These attributes are the relative advantage, compatibility, complexity, observability, and trialability.

8.2.1 Relative Advantage

To describe the relative advantage attributes, comparison between the current system and the innovation that is being proposed must be carefully analyzed. The relative advantage of the blockchain-based MRV can offer a better solution on addressing the MRV needs compared to the current centralized MRV implementation. This section provide comparison between permissioned blockchain vs central database, and the smart contract features vs the current MRV implementations.

8.2.1.1 Permissioned Blockchain vs Central Database

Some contributing factors for blockchain decision making are throughput, latency, number of readers, number of writers, number of untrusted writers and consensus as stated in Section 3.6 Table 4 which are throughput, latency, number of readers, number of writers, number of untrusted writers, consensus mechanism and the choice if it will be centrally managed.

First, in a blockchain-based platform, the throughput is high, but the throughput of a central database is higher. When it comes to latency, central database has a faster latency compared to the permissioned blockchain. Both permissioned blockchain and central database is being managed by an organization. The number of readers can be high as well, for both cases.

In setting up a central database, trust should be automatically given to its writers, but a lot of security measures must be defined, as well as verification processes of data and transactions. This is where the third party is needed in a centralized database system, such as the verifiers in the MRV programs. In a central database, there's no consensus mechanism implemented in a distributed network that can make the transactions tamper-proof. Wherein the blockchain can offer this consensus mechanism that can make the transaction distributed, reliable and more secure. This specific characteristic gives an additional benefit in using blockchain in this case study.

Central database significantly is better than permissioned blockchain when it comes to throughput and latency. But the central database has no distributed ledger characteristics that use cryptography to be able to synchronize data across the network of nodes in a given network. The added value of the usage of permissioned blockchain is that it can also be logically centralized, but it is also architecturally distributed with the use of cryptography and incentive mechanisms.

8.2.1.2 Smart Contract Features vs the Current Implementations

Currently, MRV has a lot of CO_2 methodology standardizations and scopes. Therefore, ship operators are adhering to number of these different MRV programs. But some processes, data to be gathered and generated are just the same. This multiple type of programs, whether mandatory and voluntary causes ship operators to spend significant amount of money and manpower to be able to submit reports to these various regulations. At the same time, company/ship operators need to log in and create an account to different IT systems.

The blockchain-based platform through its smart contract capabilities addresses this challenge by proposing a one standard CO_2 methodology being implemented by one international or global regulator, whether it's vessel and/or cargo/TEU specific tracking and reporting of CO_2 emissions. This will give a more decentralized way of CO_2 methodology standardization, data gathering from IT systems, and one CO_2 computation, methodology, and emission factors that can also be based on different aggregated data. Repetitive works for ship operators will be mitigated.

The blockchain-based platform also has a capability to accurately monitor the fuel consumption whether it's BDN and flow meter techniques through the deployment of IoT systems that are integrated into it. The data being sent to the core blockchain-based system is encrypted.

The use of direct CO_2 emissions technique is one of the methodologies that is highly encouraged to be used due to its high reliability, transparency and enforceability characteristics. The use of this technology will also give an opportunity to measure all other air pollutants such as NOx and SOx. The use of direct CO_2 emission technique and including other air pollutants is not yet fully implemented because of lack of standardization and enforcement from the regulators.

Data reliability issues will also be solved because blockchain is known as distributed, secure, and immutable transactions compared to centralized database. At the same time, there will be a benchmarking solution for both vessel and cargo-specific, this will contribute to data reliability because of this aggregated factor. Though the benchmarking solution is already implemented in other programs, the blockchain-based MRV system is more reliable because of the smart contract capabilities which add trust to the data and system.

An implementation of this key characteristic of smart contract might remove the use of trusted third party such as verifier and CO_2 methodology business-to-business consultations. This is because the system contains algorithms and codes that automates the processes, computations of CO_2 emissions, verification of data being sent to the system, creating of report and auto-validation.

Another advantage of the blockchain-based platform is its ability to be integrated with other climate action programs such as GHG reductions and NDCs. This will give a more transparent and reliable data that can mitigate CO_2 market frauds because reliable data of CO_2 emissions are presented. Currently, this is not integrated with the MRV system mandatory program.

8.2.2 Compatibility

Definition of compatibility in this study will be the ability of the innovation to be aligned with the existing processes and goals of the MRV programs. This means catering to the stakeholder's needs. At the same time bringing an additional and better service, as stated in relative advantage in Section 8.2.1.

Three process models are presented in Section 8.1.3. This process model is mainly inspired by the EU MRV programs when it comes to monitoring, reporting, and verification. At the same time, the stakeholders that are mapped in the blockchain-based innovation is also based on both the EU MRV and CCWG programs. This gives consideration on both vessel and cargo/TEU specifics tracking and reporting methods.

BPM 1 presented in Section 8.1.3.1 is compatible with stakeholders that looks at the vessel-specific MRV system only. This model suggests that this should be implemented on a global level and will best fir to a maritime organization specifically just for vessel tracking and reporting. Compatible stakeholder that can use this process innovation is the IMO.

BPM 2 presented in Section 8.1.3.2 is compatible with the ship operator’s needs. This gives a solution to ship operators to re-use their vessel specific data to cargo-specific data through the connection of data points and smart contract capabilities of two regulators. This model can also be used by the IMO as Regulator 1 and integration with CCWG as a B2B consulting company that provides cargo-specific data, can be Regulator 2. This innovation model lets the ship operators coordinate to two separate organizations.

BPM 3 in Section 8.1.3.3 is the combination of Regulator 1 and 2 in BPM 2. In this case, one regulator is covering both vessel and cargo/TEU specific CO_2 emissions. This system can be the best-case scenario design for company/ship operators because only one single entity handles all the MRV processes. Regulators that can be interested in this can be a stakeholder that considers the data on vessel emissions and cargo emissions. This can also be good integration on supply chain by tracking and reporting the emissions not just on the seaborne-transport but also the goods that it carries.

8.2.3 Complexity

The blockchain topic for MRV of CO_2 emissions and addressing climate action activities become popular to different stakeholders. At the same time, this curiosity also gave a notion of the technology's complexity to the stakeholders. The Thetis MRV for the mandatory program was just implemented this year, while the CCWG Turnkey has been used by stakeholders in the past years. And since there's no actual system developed in this research, the level of complexity for its use cannot be carefully analyzed and compared to the existing MRV systems.

Instead of system comparison, level of complexity will be analyzed more on the 'pre-diffusion stage' when it comes to its development. Having a one standardized CO_2 methodology running on a single blockchain-based system will be one of the most convenient implementations for the MRV stakeholders. But development and adoption of this might take some time for all stakeholders.

In the development side, the level of complexity to be able to start a blockchain-based project needs to be carefully analyzed. Hyperledger Fabric defined different important layers to consider in its architecture before starting a project. This covers a good research and development when it comes to defining its different layers such as the consensus, smart contract, communication, data store abstraction, identity service, API, and interoperation.

Challenges are also seen when it comes to adoption of the future stakeholders in the implementation of the would-be prototype using the research process innovation. The challenges are already raised through the research interview regarding MRV users. First, there are still company/ ship operators that are reliant on manual processes of recording of emissions data and finding it difficult to access and use computer-based systems. Second, shifting from the current MRV IT system to a new one, which involves additional stakeholders on board might take a greater time of adjustments to all future users. This may also entail more work for dissemination in the regulator's side to be able to fully implement the system.

8.2.4 Observability and Trialability

The research will not assess the possible future innovation adoption based on observability and trialability, which is the last two attributes. This is because there's no system prototype that is presented in this research. Therefore, future users will not have an opportunity to try and experiment with the blockchain-based system, which is referred to as the attribute named trialability. Also, observability is not possible because this process innovation is a newly developed innovation that hasn't been visible to others and is not clearly examined with all stakeholders for validation. This innovation is also not easy to observe because there's no working prototype that can be examined by future adopters.

8.3 Challenges on the Implementation of Blockchain-based MRV

Technological analysis and the perceived characteristics of the innovation was presented in the past two sections. The innovation presented in this research is indeed addressing the challenges and gives the solution to the current issues in the MRV process. Solutions are presented but the implementation of this solution will involve challenges. When these issues are addressed, then stakeholders in the MRV process can fully maximize the use of the proposed innovation for this specific industry.

There will be two parts in this section. The first one tackles the smart contract implementation challenges as mentioned in Section 8.3.1. The second part will tackle about the six key challenges that needs to be addressed on the implementation of a blockchain-based application.

8.3.1 Smart Contract Capabilities and Constraints

The presence of the smart contract capabilities and the permissioned blockchain characteristics in the process innovation that is proposed creates a desirable outcome for the stakeholders included in the MRV process. But challenges to its implementation 'if this smart contract features are feasible to be developed and used' must be addressed.

It will be challenging to implement one standardized CO_2 methodology that is run by a global regulator. First, MRV implementation is relatively new. In 2018, the EU MRV reporting period just started, and on 2019 the IMO MRV reporting will also kick off. New centralized systems were just deployed, and new amendments were just released. The first years of MRV implementation shall then be dedicated on the testing of the newly implemented systems, and consideration on looking at blockchain for this industry might take some time. In addition, development of blockchain-based platform will also take more time for research and development.

Having all the stakeholders (Section 8.1.2) to be on board on the blockchain-based platform will be a challenge. In the interview, MRV stakeholders and blockchain expert addressed that a global enforcement of MRV that includes different stakeholders will incur a big challenge. The main issue will be the technology adoption especially its understanding. At the same time, the standardization in the reporting which reflects the proper methodology used.[23] This can only be possible when a globally recognized regulator creates this mandatory program that guarantees the presence of all the actors in the industry, whether it's a business, public, or the government. This consensus should create a shared vision and opportunities and caters to the intentions of each stakeholder. When this consensus is agreed to be implemented, there will be a better communication between stakeholders, seamless MRV document workflow and have a single agreed process for the entire industry.

Currently, the IMO is focusing on vessel specific tracking and reporting of CO_2 emissions of vessels and ships of all kinds. Consideration of adding the cargo/TEU based calculations and CO_2 methodology might be the least of their priority for integration. As the proposed design in BPM 2 and 3, an integration of vessel and cargo/TEU specific MRV should be looked upon for implementation. Integration of both vessel and cargo/TEU specific will give convenience to ship operators and its customers. In addition, one stakeholder shared in the interview that there's complexity on the tracking and reporting of the seaborne transshipments that is necessary on the cargo/TEU specific emissions. The challenge is the collection of the emissions data from the unowned vessel (e.g. charter vessel). This requires a lot of effort and integration.[24]

The possibility to implement IoT systems especially in fuel consumption monitoring and direct CO_2 emission techniques can be possible due to the availability of technologies. Addressed in the interview with technology experts, they shared that the enforcement and standardization of IoT based systems, including the set-up of the technology will be challenging and expensive.

Incentive mechanisms such as releasing of the green certificate can be done so it can encourage more companies to comply with this integration.[25] There should be a high-level research and development when it comes to IoT system deployment, scalability and data management of IoT enabled project. This kind of implementations might take a lot of time for development because up until this moment, most of the ships still use manual processes of logging CO_2 emissions. The best possible technique for the IoT integration is the direct CO_2 emissions which can also monitor SOx and NOx but still not being used mostly by ships. This is because it is more expensive than all other techniques, and at the same time global standards regarding this are not yet implemented.

When the smart contract mentioned in Section 8.1.1 is implemented, there's a possibility that TTP and business-to-business (B2B) MRV programs can be excluded in the main list of stakeholders in the MRV processes. This smart contract capability includes high-level learning of different technologies. Some of these are machine learning, seamless IoT integration functions, and secured and decentralized blockchain network.

TTP will still exist if smart contract automations and features are not fulfilled in the blockchain-based system. Based on the interview after showing the BPM to a blockchain expert, it was suggested that TTP are still necessary stakeholders for the MRV process. TTP will be the ones who will verify the data, certify transactions, and the ones who will be creating incentives for the MRV complaints. They might not work as they were tasked today, but they are still necessary to exist in the system. 26

Integration with other climate action program is one of the best add-ons that the blockchain-based MRV system is offering in the researcher's process innovation. Designing its integration might also take some time. Because this mandates also includes different processes and stakeholders.

8.3.2 Other Challenges

Section 3.9 in the literature review presented the six key challenges that involved blockchain implementation in different fields. The first one is the awareness and understanding. In the proposed process innovation, to be able to implement it, a careful awareness and understanding of all relevant stakeholders should be done. Some stakeholders are new to the blockchain topic, some already have a research and development that is in-house in their respective companies that looks at the possible use of it in their business. Realizing the research complexity related to awareness and understanding is also discussed in Section 8.2.3.

The next key challenge to look at is the careful understanding of the stakeholders that can be included in the network. Although the stakeholders are defined in Section 8.1.2, there should still be a more granular understanding of what will be included in the network, and which can be off-chain in the network. This challenge can be resolved by looking at the Hyperledger Fabric consensus definition and choosing the right consensus model that will fit the industry's needs. Looking at this can also be a subject for future research.

The third key challenge is the culture. The mandatory program for MRV process is new in the industry and some voluntary programs have been running already for years. These programs run in centralized systems and their specific program standards. Having one key standard for MRV process will bring and will create a huge impact on all the stakeholders involved. This will change the culture of processing document workflows and decision-making processes for most of it are being run by automatic systems and algorithms. This will significantly change the culture of the industry.

The cost and efficiency are the next challenges for implementation. The compliance of ship operators to the current MRV programs induce high administrative and system cost. At the same time, the implementation of EU MRV THETIS and CCWG Turnkey also incurs a cost for development and maintenance. This is also the same with the development and implementation of blockchain-based MRV system. The system should be efficient and will be designed based on the stakeholder's needs but will also incur a cost to the regulators which will be implementing the system in a global scale, and ship operators that need to be compliant in the system. This research was not able to examine cost analysis and comparison when it comes to efficiency, therefore cost analysis is also recommended for future research.

The next challenge is the regulation and governance. Currently, the EU with its Regulation (EU) 2015/757 is the active mandatory programs for MRV for CO_2 emissions. Such amendment like this is needed to be able to implement a global MRV program for containerships. The suggested regulator that might implement the process innovation presented in Section 8.1.3 is the IMO.

Constraints on looking at the implementation of a blockchain-based MRV in a global level might take some time. The IMO, for example, will just kick off the first reporting period of the IMO DCS at the beginning of 2019, and this is a centralized system for all maritime transport. At the same time, they might not be interested in the implementation of an MRV that also covers cargo/TEU specific MRV system, which is ship operator's customers specifics reporting. B2B programs such as the service CCWG is catering will continue its business and will handle the regulation and governance for the cargo/TEU specifics MRV system in case IMO is not interested in scoping this.

The last key challenge is the security and privacy. The chosen blockchain for this research is permissioned one, which is known to be more private than that of the permissionless blockchain. The public cannot join the permissioned network and start validating transactions in the Hyperledger Fabric designed process innovation. Therefore, transactions are only kept in privately distributed ledgers. But public blockchain is known to be more secure than the private permissioned ones. This is because in the PoW consensus, for example, the more users that are on board on the network, the longer the chains it generates, the more immutable the transactions become because the level of algorithmic complexity increases. Permissioned blockchain, on the other hand, has very limited writers and validators in the network which are just the key stakeholders of the industry. So, the permissionless blockchain is more secure than the permissioned one.

9 Conclusion

This chapter summarizes the results and analysis of the addressed research questions and objectives. In addition, the 'next steps and the mental paradigm shift' in Section 9.2 summarizes the researcher's view on how to make the proposed innovation actionable in the future. At the same time, some possible future research for this case study is also presented. This part of the chapter offers a comprehensible interpretation of some literature reviews that reflects the research results and analysis.

9.1 Research Summary

The research has three phases to be able to address the research questions and objectives.

First Phase

The first phase looked at the current implementation, needs, challenges, and areas for improvements in the industry. Mandatory and voluntary programs such as EU MRV and CCWG has been existing and became a good tool for CO_2 tracking and monitoring. But challenges, issues, and areas of improvements are still present and are addressed in this research.

One of the key issues is that there are multiple MRV programs that ship operators are mandated to track and report their CO_2 emissions, and these programs involved different systems, processes, and mandate. Standardization of the used CO_2 methodology should be done on a global level. There are also different fuel consumption techniques, and current implementations in containerships don't guarantee transparency, data reliability, and high enforceability. Stakeholders suggested that there should be a one global MRV system that handles the MRV processes for both vessel and cargo/ TEU specifics.

Second Phase

The second phase looked at technologies that can address the challenges and issues that the current MRV system is facing. The use of blockchain technology to address these challenges through its DLT characteristics and smart contract feature can be a solution. Blockchain guarantees a new level of security and immutability compared to the current centralized database system that is being used.

In the case of the research, the use of permissioned blockchain is chosen because of the future user's preference in terms of anonymity and level of trust to the stakeholders that will be part of the network. At the same time, the smart contract features will address the challenges of the current MRV Programs through the implementation of technologies such as machine learning, IoT and its integration with the blockchain technology. The suggested smart contract features are: (1) One standardized CO_2 Methodology; (2) provide benchmarking functionality and data analytics for container ship's customers; (3) Seamless integration with company legacy and IoT systems; (4) Creation, verification, certification and dissemination of reports; and (5) MRV of CO_2 emissions integration on other climate action programs.

The Business Process Model (BPM) that was presented, is the research output labeled as the process innovation. If all these smart contract features will be properly implemented, there will be no need for a TTP such as a verifier service because transactions will be automatically executed by the smart contract. And if some of the pre-conditioned characteristics of a smart contract will not be, there will still be a possibility that TTP is still needed to verify, validate and certify transactions and documentation.

Third Phase

The third phase of the research looks at the perceived characteristics of the innovation for the future adoption. The comparison is presented between the current MRV systems in a centralized architecture and the blockchain MRV based innovation. There's a higher advantage on using the blockchain – based system because of the smart contract features, and the added security and immutability of the DLT using cryptography. When it comes to the attribute compatibility, the BPM presented caters different types and needs of future adapters. The third attribute complexity is the most challenging characteristics for project implementation. This is because the blockchain architecture and the smart contract features and design requires high level of development and research before its implementation. Future users of the innovation might also take some time to adopt to the use of the technology.

Since working prototype is not available, trialability and observability attributes cannot be presented. The researcher has some limitations in the process innovation, including the unavailability of a working prototype. Because of that, a concrete proposition of its future adoption, if the innovation will be accepted or rejected is not presented. Future research and development of a working blockchain-based MRV system is highly encouraged.

Challenges on the Implementation

Execution of a blockchain-based system and implementation of its smart contract features demands great IT infrastructure set up, seamless IoT integration, and machine learning. And these are the foreseen challenges in this kind of implementation because all these technologies are currently in the development stage. The challenges of the technologies scalability and capabilities should be addressed. Other challenges should be addressed as well, which are awareness and understanding, defining the stakeholders that can be part of the network, culture, capital cost, regulation and governance, and lastly, security and privacy. A more detailed study of this factors is encouraged for future research.

9.2 Next Steps and the Mental Paradigm Shift

Building the Consensus Vision

Solving climate-related challenges is a global initiative that involves multiple stakeholders. Programs such as MRV for the maritime industry especially the container shipping covers global trade lanes and territories. Working on multiple programs that is not on a global scale will not work in the current globalized economy. At the same time, a mandatory regulation that can be implemented in a global scale is highly encouraged to be able to have a faster lobbying of policies, efforts, and avoidance of multiple compliant works, and obligations of different stakeholders. Consensus-building for policy design is needed in a global implementation of MRV, wherein collaborative work will be distributed to all the stakeholders involved to make the policy design successful.

Institutional innovation such as blockchain technology can make it possible for implementations of new types of contracts and organizations. Through the proposed innovation, the market and state can work collaboratively for a shared vision wherein pre-defined agreement will be met. The institutional innovation, such as blockchain is on the early phase of research and development that might impact not just the business and economics, market (Schumpeter view), but all other institutions (Neo Schumpeterian view) as a whole.

Shift from Close to Open Innovation

Regulators that can handle a global scale system is necessary to be able to work on a shared consensus vision, especially the MRV process. A closed innovation model will not work for designing policy driven innovations. Having a more collaborative environment wherein different stakeholders can share, communicate and open their intentions on policy implementation is needed. Regulators such as the IMO is highly encouraged to work closely with different stakeholders and promote open innovation. The regulator also needs to be more open to stakeholder's suggestions and ideas and promote continuous innovation. The main role of using the open innovation model is to be able to scope the necessary technology needed, challenges that needed to be addressed, and at the same time, aligning the technology and industry needs. Leveraging ideas from different stakeholders will create a more collaborative and innovative environment for policy building and implementation.

The innovation can also be designed in a public blockchain, when the regulators choose to implement the MRV and data presentation in a more transparent way.

Blockchain-based MRV System as a Sustaining Innovation

The proposed blockchain-based process innovation is a radical innovation, and the blockchain consensus and other technologies that are used in designing it is an incremental innovation. Therefore, the research innovation falls into the category of a sustaining innovation.

The blockchain-based process innovation is radical because of the impact it can create on the operations in the maritime industry. In addition, implementation of the smart contract features includes IoT and machine learning implementation, and deployment of a blockchain-based system which is more secure and immutable than the previous system. This will change how the current MRV program is implemented and can make previous systems obsolete. At the same time, it will remove the existence of TTP such as the verifier and other B2B consulting companies for sustainability as presented in BPM 3 because of the capabilities of the said technology.

At the same time, it is also an incremental innovation because the current blockchain consensus that is chosen for process innovation design is continuously evolving and improving. The consensus choice only reflects on the researcher's current understanding on the blockchain implementations available at present. And implementations of blockchain-based MRV platforms can also extend to other consensus models. Since other consensus models are still on its process of improvement to be able to cater a more sustainable and efficient way of blockchain implementations.

The process of incremental improvement in different IoT and machine learning innovation is also in its research and development stage. This improvement is made to address the concerns on the scalability and efficiency of technology and to be able to cater the best technological solution for different demands of the industry. It is highly recommended to look at the progress of these technologies to be able to maximize the benefit and weigh the feasibility of implementing best smart contract features in a blockchain-based implementation of the MRV system.

The Product Innovation and its Diffusion

The presented innovation is very limited to process innovation. The lack of a working technology as a unit of analysis of this research is the reason why the rate of adoption of innovation and its adoption and rejection is out of the scope of this research.

Prior to the creation of an actual product innovation for this specific industry, challenges of its implementations should be addressed, and more research should be done. Once a working product is available to the market and puts the innovation into use, other attributes such as observability and trialability can be analyzed. At the same time, confirmation from the users will be clearly seen if there will be an adoption, discontinuance of use and continued rejection of an innovation. Given that this innovation is implemented in a certain communication channel and specific time span. This can also be a topic for future research.

Other Climate Change Mitigations and Reduction Research

Green research that addresses climate actions and mitigations has gained popularity among regulators, researchers, and developers. In the Neo Schumpeterian view, the first step in the adoption process of technology is to invest more in green research and invest in green practices in order to solve environmental challenges with the aid of technology. This kind of research can contribute to the new techno-economic paradigm which is the green global golden age. Other research that focuses on the use of technology such as blockchain, DLT, IoT, machine learning in different industries such as the carbon market, reduction project, climate finance, renewable energy is highly encouraged to be a topic for research and development in the future.

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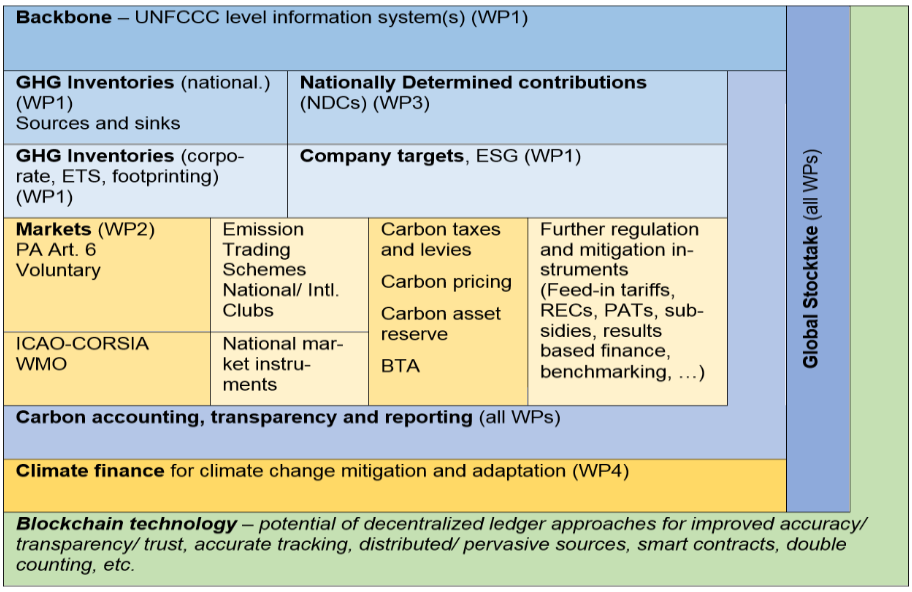
Appendices

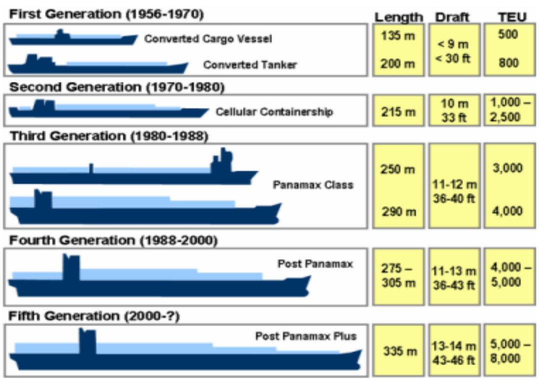
A.1. CLI Blockchain for Climate Action – Paris Agreement Implementation Research

Source: CLI (n.d.)



A.2 Generation of Container Ships

Source: Ting (n.d.)



A.3 TEU Specifications: General purpose container size 20'

Source: Hapaglloyd Group Communications (2016)

The sample of a general-purpose container. TEU means Twenty Equivalent Unit, which is the container size basis with a specification of 20ft length, 8ft width and 8ft and 6in height.

B.1. Data for the Computation for total CO_2 emissions

- Aggregated emission factors – this is used for benchmarking performance. CCWG (2015) defined the following types of aggregated emission factors:
    - Vessel-specific – individual performance of vessel benchmarked data.
    - Carrier-specific trade lane trade lane average emission factor – this is the average of all vessels operated by the company/ ship operator.
    - Industry average per trade lane – this is measured in a specific trade lane. This is the average of all vessels operated by all carriers sailing.
- Carbon emission factor – the source is the IMO. It is measured whether it is a heavy fuel oil or diesel/gas oil measured in g CO_2/kg.
- Days vessel operated – number of days the vessel sailed in a year.
- Direct CO_2 emissions – other technique on getting total CO_2 is by deploying this technology which directly records the total amount of CO_2 the vessel emitted.
- Distance sailed – total distance travelled by the vessel sailed in a year.
- Other ship operator's information – this includes important information of the business such as the company name, owner, address, contact, etc.
- Reefer TEU Capacity – CCWG (2015) defined this as the number of reefer that is plugged in the vessel multiplied by the number of TEU per reefer plug.
- Reefer Consumption per year – this is a CCWG CO_2 Methodology carrier average which is 1914 kg/reefer year (CCWG, 2015)
- Seaborne transshipments – an example of this is the Vessel Sharing Agreement (VSA), Slot Charter Agreements (SCA) & Feeder services. This specific service is needed when the ship operator/ company does not own a vessel (VSA or SCA) or the ports is too small (feeder) in a specific region. Then ship operators/ company purchases container slots in

another carrier service. The CO_2 emissions that was done for the cargo transported should be accounted as well in the cargo/TEU specific total emissions.

- Total fuel consumption – can be from different types coming from the vessel engines such as the boilers, main and auxiliary engines. This can be both at sea or port that is measured in one reporting year.
- Vessel TEU Capacity – maximum number of cargo/TEU a vessel can carry.

C.1. Climate and Sustainability Initiatives using Blockchain Technology

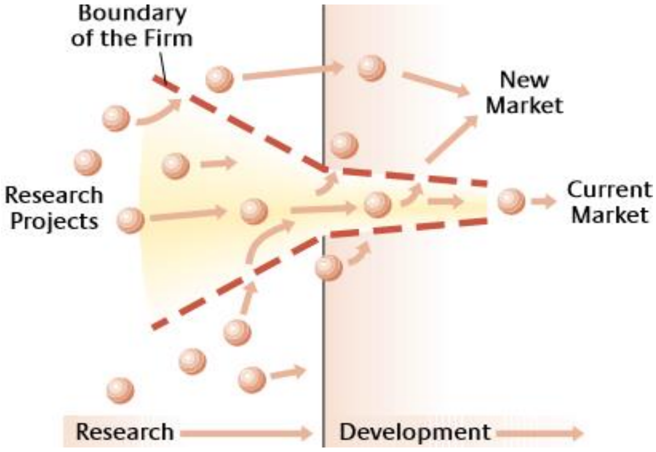
Source: Baumann (n.d.)

Presented in this table is the name of the initiative and/or the project and the website.

Name	Website
Carbon Coin	www.carboncoin.cc
Carbon X	www.carbonx.ca
Climate Ledger Initiative	www.climateledger.org
Earth Token	www.earth-token.com
Energy Blockchain Labs	www.energy-blockchain.com
Grid+	www.gridplus.io
Poseidon	www.poseidon.eco

D.1 Open Innovation Model

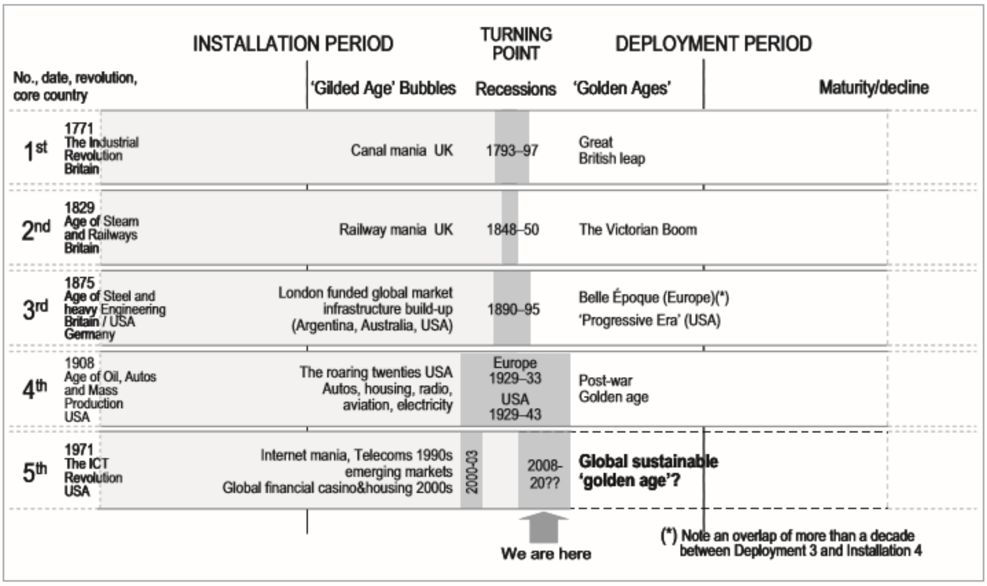
Source: Chesbrough (2003)



Open Innovation Model presents the current boundary of the firm, looking at different research projects and ideas inside and outside the organization. These ideas can be used and developed in the future to cater the market's needs, improve the current business model, or to completely create a new opportunity for the business. Dash line represents the boundary of the firm and its surrounding environment (Chesbrough, 2003).

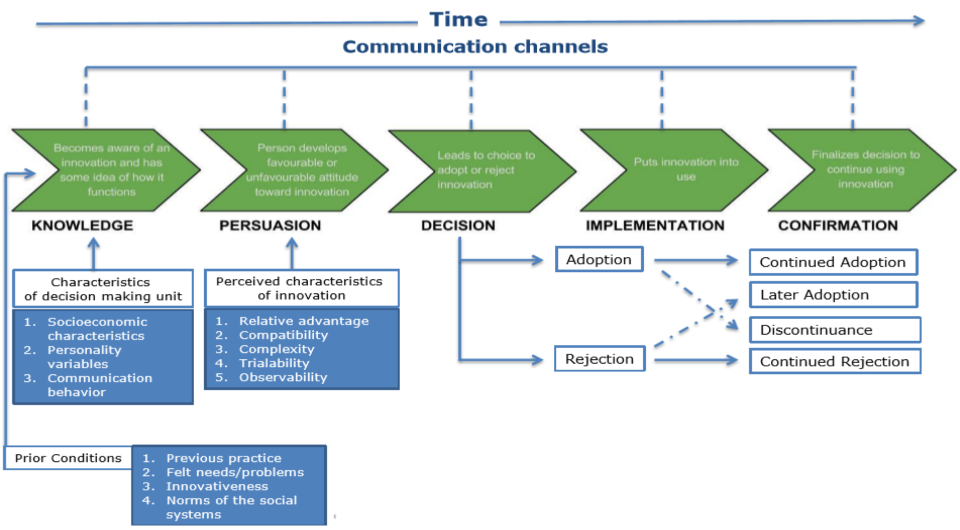
D.2. Five Revolutions in its Installation, Turning Point and Deployment Period

Source: Perez (2015)



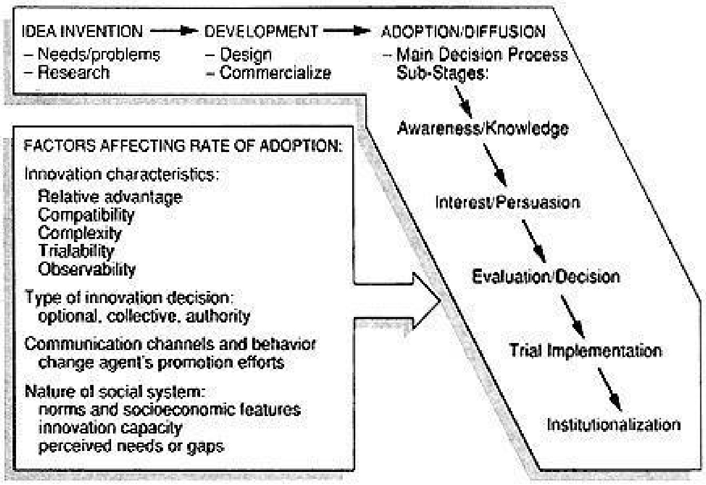
D.3. Innovation Diffusion Process – Diffusion of Innovation Theory

Source: Rogers (1995)



D.4 Process stages in idea invention, development, and diffusion and adoption

Source: Rogers (1983)



Notes

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[1] Interviews that are presented in the results is linked in the note number 3-26. This interview notes are the chosen statements from the transcribed in interviews featured in results and analysis. The interview notes are already edited in a more comprehensive format.

When referring to the interviews, indicated is the month/date/year of the interviews, as well as positions of interviewees and type of company:

Interview 04/06/18 / Technical Director and EU MRV/IMO DCS Auditor/Verifier

Interview 05/08/2018 & 06/21/2018/ Manager, Associate and Researcher /B2B for measurement, evaluation, and reporting of the environmental performance (e.g. CO_2) of the container shipping industry.

Interview 04/25/2018 & 06/18/2018/ Sr. Global Advisor Transport and Logistics Sustainability/ Container shipping

Interview 06/18/18 / Research and Development Lead/Blockchain for maritime sustainability

Interview 06/12/18 / VP for Business and Development & Strategy/ B2B for sustainability and carbon market

Interview 06/11/18 / Digital MRV Lead - CTO/ Standard and certification body that caters climate and development projects

Interview 04/29/18 / Blockchain Architect / Blockchain development and service company for decentralized ecosystem for movable assets.

Interview 04/17/2018/Platform Engineer, DevOps and Digital Platform/Container shipping

Interview 04/10/2018/ Founder / Carbon on blockchain startup

[2] Validation and checking of the Business Process Model (BPM) was made though some series of session with business analyst and application manager. Below is the month/date/year of session, as well as positions of interviewees and type of company.

06/25/2018 & 07/25/2018 / Application Manager / Container Shipping

06/25/2018 / Business Analyst / Food Industry

[3] ***This process model was checked by a verifier who is an expert of EU MRV process through an interview.***

Interview 04/06/18 / Technical Director and EU MRV/IMO DCS Auditor/Verifier

It's good, it is a correct process.

[4] ***In the interview with a verifier, it was confirmed that CCWG and EU MRV has almost the same data on vessel-specific emissions. There are differences in the data, processes, and systems being used in each program. The verifier also deliberated that CCWG and EU MRV has almost the same process of verification.***

Interview 04/06/18 / Technical Director and EU MRV/IMO DCS Auditor/Verifier

In CCWG the trade lane aspect is the important one, which is not the case for EU MRV. The scope of the voyages, EU MRV is the voyages to from between EU ports, while CCWG's worldwide system. So, there are some differences. Overall, I think in practice if we verify fully your ship for EU MRV, it means we investigated fuel consumption, emission calculations, distance, time and carbon carried. So, ones verified in EU MRV, this data can also be used in CCWG verification, then the process will be shorter. In EU MRV the process is that there's an initial test on the submitted in the reporting processes and IT system done in each vessel. So, it's going beyond CCWG requirements. But the final review of each report is also the same. So, the IT system is different, but the principle is the same. Only MRV investigates reasonable assurance. And for CCWG we need fewer evidence, to reach and accept the verification.

EU MRV process includes risk analysis, verification plan, process verification, data verification and then technical review before the issuance of the final documents. The CCWG part is coming from CCWG guidance on how to do the verification. And there are some common steps. CCWG uses a dedicated IT system called Turnkey. So, the process desk review, office audit and final review is the official process for CCWG. One of the difference is for example for EU MRV the process is applied to every vessel. For CCWG, the detail and the data verification can be done on a subset of vessels (pertaining to cargo specifics), and the conclusion applies to all of the vessels of the operator. But, I mean globally the process is the same in both programs even though the systems used are not the same.

Additional Data in Note [6]

[5] ***As per the interview conducted for this study, there will be a possibility to stop EU MRV regulation ones it has been agreed that the IMO will be the global governing body for the MRV programs for maritime transport.***

Interview 06/18/2018/ Sr. Global Advisor Transport and Logistics Sustainability/ Container Shipping

Since we spoke last time, they (the EU) agreed on the IMO. This regulation naturally says if EU agrees that the IMO is good enough (for MRV implementation), they will cancel that EU (MRV) regulation. But we don't know yet. They will see over the next 2, 3 years. EU prefer a global MRV implementation.

EU MRV only covers the EU. And only for a small which is just the vessel-specific emissions. EU MRV does not cover, Asia, North America for example.

[6] ***Also in the interview, it was discussed that the current MRV implementation is confusing because of various implementation on different levels (EU and global level). This brings challenges to the*** CO_2 ***methodology standardization. So, some ship operators and MRV experts agreed that there should just be one implementation of MRV on a global level and one system that every container ship operator should use. Some stakeholder suggested that the IMO should be the regulator that will handle the global MRV.***

Interview 04/25/2018 Sr. Global Advisor Transport and Logistics Sustainability/ Container Shipping

There's no doubt we see that there are many ways of calculating things today. And if you ask different companies, you'll get different things. Per department (cargo/TEU specific) is more complex than per vessel. For example, there are 6,000 containers per vessel, then you have millions of containers to track. Getting the verification is the relevant thing to ensure that it is done correctly. I think it makes sense to do is to have one central database that everybody (all container shippers) uses. Cause then you can ensure that everybody does it exactly the same. This approach will then use the same distance and all other data. Everybody has their own calculators and then there hundred external calculators. I think no matter which one you choose you will never get the same result. Cause there will always be so many results on getting and computing the data. Do you use an average? Do you average for service? Do you use the best specific? Do you use it for an average for a year or what do you use? Do you use transshipment for example? You should. But how to do that? What do we add to that? There are so many questions you need to answer when you do these reports. And you need to make a hundred choices. And there's almost no chance that everybody makes an exact same choice. Therefore, the central database makes sense (pertaining to implementation all container ship operators).If we have one global calculator (also mentions the blockchain as a possible technology to use for that) where everybody put data in and then the customer gets the result out of that. You will surely have exacted the same methodology so if you could get rid of this problem, you will just have calculated one way, you just put into that system because we need, one global calculator to calculate. EU MRV is only from the choice of regulators, and shipping lines and all these, and I know there are no customers related in its implementations. So, the data is not standardized to be used to calculate for customer related. There's a complexity on the completion and consolidation. This has a similar scope on CCWG, but this program is implemented on a global scale. There are similarities between those two. If we want something that must be on a global scale, that's a bit more complex. The company will support it if it is done the right way. An example is the pricing of the cargo related to the emission penalties. So, whatever the ship operators pay on these penalties should benefit on some technology development in the shipping, for example.

Interview 06/18/2018/ Sr. Global Advisor Transport and Logistics Sustainability/ Container Shipping

There are a lot of different programs and it's confusing. Ideally, we need one, and we don't need more. And that's also our company's official position. We need one system and I know we don't need a system in EU. We need one system in IMO.

Interview 04/06/18 / Technical Director and EU MRV/IMO DCS Auditor/Verifier

In my opinion what is a bit annoying for the ship operator is that they must report the same information to different people with just the same data. Also, they must go through different verification processes for the same data. From their perspective, I guess that they can perceive this as not very efficient and puts a burden that could be avoided. On top of that, you should also probably be aware of IMO Data Collection System (DCS). Basically, it is the same as EU MRV but applied worldwide. So, operators will again comply to IMO DCS reporting of the same data. Although it has some particularities and details. Verification for IMO DCS requires the same data as EU MRV. But I think that the main challenge for them is to streamline the reporting and verification so that the data is verified once and then used down to a line by to whichever program (mandatory or regulatory).

Just to add to this, another challenge is the uniformity of systems because of the familiarity of it in the shipping world. But the shipping world is global in nature. It is necessary to have one part of the world which has a very good IT system that takes care of everything such as EU MRV, CCWG, IMO DCS. But the challenge is that others struggle to create an excel file. So, standards and uniformity are the biggest challenges. Our resources are not there with the people. People don't have enough information about the regulation.

There's another voluntary scheme named Clean Shipping Index (CSI). It covers everything related to CO_2 emissions and other pollutants such as NOx, etc.

Interview 05/08/2018 & 06/21/2018/ Manager, Associate and Researcher /B2B for measurement, evaluation, and reporting of the environmental performance (e.g. CO_2) of the container shipping industry.

The of the IMO and the goals of the Paris Agreement especially for shipping are incredibly aggressive. It is certainly hard for me to envision a future where we can achieve those goals without some type of centralized database (pertaining for all MRV stakeholders use).

Interview 06/18/18 / Research and Development Lead/Blockchain for Maritime Sustainability

In general, maritime is a regulated industry in general. And I think standardization is the biggest challenge in maritime. Also, the biggest problem is finding something that everyone in the IMO or in the EU can agree upon (in terms of MRV implementation).

Interview 06/12/18 / VP for Business and Development & Strategy/ B2B for sustainability and carbon market

There are some decisions that would need to be made regarding the standardization or compliance in different programs (MRV). There's a political challenge on having a top-down decision process on things.

[7] In the interview, ship operators addressed that they need both vessel and cargo/TEU specific emissions data, and it will be ideal to have this in one system.

Interview 06/18/2018/ Sr. Global Advisor Transport and Logistics Sustainability/ Container Shipping

Interviewee answered when it will be better to have both cargo specific and vessel specific data in one system.

Yes, it will be good to have vessel specific data. And then you can add some things on top that is for the customer (pertaining to other data that is cargo specific). That would be ideal.

[8] ***But regulators such as IMO and EU MRV only cover the vessel-specific. So, there should be an alignment with B2B organizations such as CCWG which handles the cargo/TEU specific data. This kind of organization is the one who takes care of this kind of customer related requirements and specificity.***

Interview 06/18/2018/ Sr. Global Advisor Transport and Logistics Sustainability/ Container Shipping

There are a lot of different programs and it's confusing. Ideally, we need one, we don't need more. And that's also our company's official position. We need one system and I know we don't need a system in EU. We need one system in IMO. The clean cargo is a bit different cause that's of course for the customers (meaning cargo/ TEU specific). There are still some question marks around EU MRV and about IMO implementation. When all those question marks are gone, we know exactly how to report, or they will be reported. When that's settled, then we could start adjusting the clean cargo to see its alignment with the IMO or the EU MRV.

Ideally, we should have one measure. The clean cargo will then extract the same data as IMO. CCWG is for the customers so we use it for different purposes, that means, raw data is the same (in the vessel), but then there might be some additional information in CCWG. For example, for clean cargo needs the data on the euro trade lane or the ones internally in South America. In IMO you can't see those details. It's just a lot of data and it's a mess. Therefore, there's still a bit need for something in clean cargo that can take that IMO data. I hopefully align with it as much as possible, and then translate it into a customer package, that fit the customer need.

IMO will not fit that (pertaining to customer related emissions). I think that's a misunderstanding that we don't need CCWG. CCWG helps caters the cargo/TEU specific emissions which the customer related needs. Secondly, IMO will not be publicly available, it will be closed. So, you can't see any of the data in IMO. So, you need to ask for it and then you could get some. CCWG sliced in a different way (data availability). But there will be a challenge for clean cargo to align with it (pertaining to IMO). And then you have this one which also confusing like EU MRV and ideally, all of it should be aligned.

Interview 06/18/2018/ Sr. Global Advisor Transport and Logistics Sustainability/ Container Shipping

This is the suggestion from the interviewee when the BPM (model of the combined vessel and cargo/TEU specific MRV) was shown. Interviewee suggested on having two separate *organizations who handle vessel and cargo/TEU specific due to stakeholder's preference and scope of the program.*

The regulators (e.g. EU MRV and IMO) will not regulate the customer related emissions (cargo/TEU specific). The regulators will probably never look at the trade lanes (which CCWG is looking at) because that's not a regulatory purpose.

Regulators look at it differently, they look only at the vessel-specific. They don't look at the shipment, they are two different things. And a customer looks at the vessel and the transshipment of the product. So that's two-separate process. But it is where you have different and the requirements which are vessel and cargo/TEU specific.

I don't think they (IMO or EU MRV) can and will look at cargo/TEU specific. The regulator here is IMO and EU, but most likely IMO will be the one and EU will go out at some point because they trust the IMO. The customer related or cargo/TEU specific is for the voluntary market to solve it (e.g. CCWG). So, I don't think regulators (IMO or EU MRV) will play any role in that.

[9] Interviewees said that the direct CO_2 emissions technique has high accuracy, but implementation of it in a large scale is not yet enforced. One of the challenges is that, it is expensive and there's no standard in implementation, in a global scale.

Interview 04/25/2018 & 06/18/2018/ Sr. Global Advisor Transport and Logistics Sustainability/ Container Shipping

When an interviewee was asked if they are using the direct CO_2 emission technique

So, nobody has that. It's expensive equipment.

Interview 06/18/18 / Research and Development Lead/Blockchain for Maritime Sustainability

IMO covers BDN and fuel meters. In the EU MRV, we can also use the direct emissions which looks at the fumes that are coming off the ship. The IMO monitoring plan is calculating how much fuel consumption instead of looking at the real emissions on the ship. And I don't know why they're (IMO) not accepting the direct emission monitoring plans. There might be some reasons for it, like not being as accurate or maybe, it's just infeasible to install monitoring meters on all ships. In addition, it is the most expensive. There are some issues for implementing these newer systems. That’s why we’re looking at BDN because it’s already there. Everyone’s using this technique already.

[10] The interviewee also mentioned that the most unreliable technique is the BDN which involves a lot of manual work. At the same time, the verification of the total fuel consumption is not reliable as well.

Interview 06/18/18 / Research and Development Lead/Blockchain for Maritime Sustainability

The Bunker Delivery Notes (BDN) that we are running a project in Singapore is the project we are working on. To be honest, we found out that there is no transparency in BDN. Its super hard to verify them because they are on a paper format or carbon copies and that the bunker industry is generally super shady. There’s no transparency and there’s no trust in the network of bunkering. So, we will use some blockchain at least in the deport area when the fuel has come in to deport to the terminal. This is to actually track what’s happening and that is both for securing the chain of custody of who’s demanding the fuel. In addition, do quality tests on the fuel to make sure that it's compliant with standards and other emission reporting. Right now, when you submit your BDN, its barely just a receipt and you can’t really track anything on quality and the quantity is also a bit off.

[11] The interviewee suggested that an implementation of an Internet of Things (IoT) system and satellite integration for MRV can be a very good solution to address this problem. There’s a lot of companies who are already looking at this and implementation of this, and it shouldn’t be so difficult due to the availability of technology.

Interview 06/18/18 / Research and Development Lead/Blockchain for Maritime Sustainability

Right now, there are no connections (pertaining to the network) on the sea. So, if you have an automatic reporting, you would have to figure out a way to approve this device while it’s at sea. At the same time, data capturing, and submission should be done. But this process is getting better now. It is because there's a lot of the connections that are established. Before it was only by a satellite and it’s super expensive to do that. I think IoT is probably the best, the best shot right now or it. This will be the future of both controlling the ships and monitoring ship systems. That’s a lot of companies working on that as well. IoT is in an easy in implementation itself. But probably difficult in enforcing it, especially on buying the idea of having it in one system. And that would need to have a standard for this, both emitters and IoT devices and the connections they needed to have.

Interview 04/06/18 / Technical Director and EU MRV/IMO DCS Auditor/Verifier

I guess ultimately you could think of a system where there is no use for verifier because everything is done automatically via the blockchain. But I think, we are still a very long way from that. Some set up such as satellite observation of ships can be used to make reports sent from the operator on the ports. These reports will contain quantities of fuel consumed and other data that was served. And then, for the observation or confirmation that systems and procedures are in place, you could think of some automated text which would make verification work as we know (verifier task now), maybe different to the least. I guess depends on the level of automation that you could reach, with a check of data and with the check of compliance in terms of systems and procedures.

Interview 06/11/18 / Digital MRV Lead - CTO/ Standard and certification body that caters climate and development projects Combination of IoT and DLT can really help on MRV process. A specific example is the MRV for the cook stove project we are working. Through IoT, it will make more transparent, more efficient system.

[12] ***According to the interview, shippers and verifiers have their own accounts to see, submit and exchange documents and data in the Turnkey (CCWG System). This is only accessible for CCWG members to protect their customer's privacy.***

Interview 05/08/2018 & 06/21/2018/ Manager, Associate and Researcher /B2B for measurement, evaluation, and reporting of the environmental performance (e.g. CO_2) of the container shipping industry.

CCWG uses an online database that's accessible to all the members. Carriers (ship operators) and shippers have their own accounts. Carriers only see is their own data and their own scorecard. It contains a standardized set of KPIs and results.

The sensitivity of the data and CCWG member is set through an agreement with members. This is to protect their data privacy. So right now it is only available to members of CCWG.

Verifiers have an account in Turnkey because they have to issue a verification statement, which they upload into the system once they've completed the verification.

CCWG is using excel-based files for most of our data manipulation processes. And the way that essentially turnkey operates on the back, dynamic excel file, graph or user interface that's online, and web-based. The carriers will go on, input the data into the web-based portal back. A macro excel file allows CCWG to do the data processing on the back end.

Interview 06/18/2018/ Sr. Global Advisor Transport and Logistics Sustainability/ Container Shipping

Verifier such as Lloyd Register comes in and spend the time to look at the data and examine how ship operator's ways of reporting. And then, verifiers have access to Turnkey, takes the data and then put it in a statement.

[13] In the interview, a ship operator representative shared that they are using their own legacy system called Fuel Reporting System for automation and report consolidation. But there are still manual works that are being done, especially for the customer or cargo/TEU specifics related reporting.

Interview 04/25/2018 Sr. Global Advisor Transport and Logistics Sustainability/ Container Shipping

We use the reporting system that is in the company's operations called the Fuel Reporting System. It's a pretty good system. This was all internal systems. We need to improve it, there need to be certain things we should be better looking and so it can be easier to share data with customers. It should be as easy as pressing a button, then we can share the details as well. Now we need to do it manually, so everything needs to be automated as much as possible. Of course, this is a big task that will take some time.

[14] In the interview, one verifier confirmed that they have their own legacy system within the organization used for communication and data sharing. They also use electronic spreadsheet programs for some verification process, this is aside from the MRV systems already stated.

Interview 04/06/18 / Technical Director and EU MRV/IMO DCS Auditor/Verifier

We do have a separate system. We have current tools, but it mostly excel files. So, most of the data analysis we do it via excel. We use different tools for monitoring the progress of the various projects. For shipping, we use a system that ship operator can also use. This is for the preparation of the monitoring plan. Also, we use it to validate every section of the plan.

[15] The possibility to integrate the blockchain MRV process with other climate action projects can also be an area for improvement and integration, according to the interview. One benefit of using such is the verified and validated data of CO_2 emissions that a blockchain-based MRV system can offer in the carbon market integration. In addition, some interviewees shared other

possible climate projects that blockchain can be a good tool for solving climate-related problems. Example is the solution on the double counting problem in the carbon market.

Interview 06/18/18 / Research and Development Lead/Blockchain for Maritime Sustainability

I think it has a very good point for being able to make a system that works where you are not able to double spend anything. Carbon credits today are now created from ship fuels. If you use green fuels for your fineries or factories or so, you create carbon credits which create incentives to lower GHG emissions. It's a good idea if you create carbon credits when you cut off CO_2 emissions. And I think blockchain is extremely good for this.

And I know the world economic forum and world bank is looking into doing a system to do so. So, for carbon markets, blockchain is, would be incredible.

Interviewee view on the integration of blockchain based GHG inventory to other climate action project

Exactly (pertaining to a good notion). This is just small piece of the pie. You would be able to submit whatever data is on MRV because it's validated, and it's verified. You can create a certification that this is a real data, then you can submit it to one of these carbon markets and get money for being compliant or having low CO_2 emissions. The integration of MRV to this is a very good idea.

Interview 04/06/18 / Technical Director and EU MRV/IMO DCS Auditor/Verifier

In the world of emission reduction units and quotas, there is a bigger issue with the transparency and the quality of the different type of carbon credits. And I think the choice of using blockchain for that will be a great application. Because there is a lot of different type of projects and different countries that generate these credits and some of the very strict rules and that some others don't see. I think there is a big need for more transparency and more information in this domain. Of course, in the monitoring and reporting as well. At the same time, it is separate to pick with traders and project officers and all that.

Interview 06/12/18 / VP for Business and Development & Strategy/ B2B for sustainability and carbon market

The key thing for us at that point is to make sure that there's no double counting, which does relate to MRV. So, when a country submits its Nationally Determined Contribution (NDC) of the Paris Agreement, it needs to ensure that there are no overlapping emission reactions that country is claiming and shouldn’t be claiming. It is also to ensure the countries with MRV systems are currently separated into different categories. So, there will be no overlap or double counting when it comes to emission reduction goals.

[16] The use of blockchain has been a topic of interest to different MRV stakeholders, as validated in the interviews. This technology is seen to be used for the implementation of a global calculator, CO_2 methodology for both vessel and cargo/TEU specific monitoring and tracking of CO_2 emissions. Lastly, it can also be used in addressing the challenges of the fuel consumption techniques such as BDN.

Interview 04/25/2018 & 06/18/2018/ Sr. Global Advisor Transport and Logistics Sustainability/ Container Shipping

Yes, I would believe but we could also use something like a blockchain.

Through blockchain, global calculator and standardized calculation (CO_2 methodology) can be done. This will use the same methodology, so we could get rid of the problem on calculation and standardization.

Interview 05/08/2018 & 06/21/2018/ Manager, Associate and Researcher /B2B for measurement, evaluation, and reporting of the environmental performance (e.g. CO_2) of the container shipping industry.

DLT can potentially facilitate the monitoring of vessel level emissions. It will significantly facilitate the reporting of the actual ship data once they arrive in port.

As opposed to the goal of monitoring the ships’ emissions, for us, it’s more about understanding the goal of the EU MRV and the IMO with monitoring the individual ships. Because this is related to the company's focus, which is understanding the customer's needs.

We can get better data on the emissions goals and the reporting on emissions that is enabled by technology like blockchain and satellites. Looking at enabling factors for the customers of the shipping companies to have access to the data. This will give a format that enables customers to make decisions towards their own environmental goals. By investigating the potential use of technology in terms of changing the way we do data collection from the carriers. And in that sense, that’s where we’re really interested in the DLT and in IoT solutions. We are also interested in ways to have databases that can be repackage into different formats that can then be inputted into the shippers, to the cargo owners into individual internal databases.

Interview 06/18/18 / Research and Development Lead/Blockchain for Maritime Sustainability

The Bunker Delivery Notes (BDN) that we are running a project in Singapore is the project we are working on. To be honest, we found out that there is no transparency in BDN. Its super hard to verify them because they are on a paper format or carbon copies and that the bunker industry is generally super shady. There's no transparency and there's no trust in the network of bunkering. So, we will use some blockchain at least in the deport area when the fuel has come in to deport to the terminal. This is to actually track what's happening and that is both for securing the chain of custody of who's demanding the fuel. In addition, do quality tests on the fuel to make sure that it's actually compliant with standards and other emission reporting. Right now, when you submit your BDN, its barely just a receipt and you can't really track anything on quality and the quantity is also a bit off, actually.

In terms of the MRVs, the challenge is the data reliability of the data the companies is submitting.

[17] ***The model and the decision process were shown to a blockchain expert who is doing almost the same project scope. From the interview, the researcher got a confirmation that blockchain can be used in MRV for CO_2 emissions, specifically using it for smart contract application.***

Interview 06/18/18 / Research and Development Lead/Blockchain for Maritime Sustainability

This is probably the most important question. Do you even need a blockchain? I think before you start looking at blockchain, you should look at the factors like this trust. Blockchain is good at handling one big issue and that is the trust between intermediaries. Right now, there are fairly trusted intermediaries like Verifavia or Lloyds. And they might be able to handle this or that's actually how they are doing it the MRV systems right now. One thing that blockchain would be useful for is to remove these third parties that you have to submit this data to. And that's why there are multiple writers, and you can't really trust people for writing the right data.

I think that's the biggest problem with blockchain is that the data is only as good as the stuff that you put in right? So, you need to figure out a way to securely write data that is trusted. Because when data is written to the blockchain, you can validate it, but you cannot verify it. And those are two different things. Validating is just looking at two pieces of paper and they're the same, but verifying is going to the source and checking out if it is the right data. That's why I initially looked at something that's automatically for reporting the emissions, for example, direct emission technique. That could be one, solving the problem. Another way of doing this is some automated system that's looking at flow meters or submitting the BDNs which already verified.

In the terms of this using permissionless blockchain, I see studies that they are probably not interested in fully enclosing all the different emission factors. That is probably also why the IMO monitoring plan is not getting publicly released. While the EU is transparent. EU is anonymizing the data I think, but they're publicly announcing it.

The biggest issue of the permission-less blockchain that uses Proof of Work (PoW) is it is a super bad consensus. Especially on the tracking carbon emissions because you are emitting carbon doing that. So, it's a bit oxymoronic that you would use such a system. And I think, it's a silly argument for not using it because it has a lot of strong points, but on the other hand, do you really need fully public permissionless blockchain for doing so? Because the people who are going to report to this system, they should already be verified, I mean they're ship owners and vessel-owners. And maybe everyone shouldn't be able to validate data.

So, I think, in my opinion, you should more look into the public permission or the private permission blockchains for capturing some of these things right. The most important I think is when you're looking at these permissioned blockchain governance on implementing these systems. So, finding the right players and stakeholders who want to be the validators wherein validators can be trusted on these data. Because I think it's a misconception in blockchains that they're fully trustless. You still need to somewhat trust the people or validating of running the nodes.

And I believe those type of blockchains without cryptocurrencies are more aligned for systems like this (pertaining to MRV system) than Ethereum or Bitcoin or one of these cryptocurrencies. I think Hyperledger is perfect for just transactions, which are not monitoring transactions. It would just, submitting data which you don't have to pay for if I choose to submit those data

[18] The interview with blockchain developer brought up that using Ethereum is good for smart contract application. It is also because Ethereum has a good community of developer support. This blockchain can resist heavy attacks as well. In addition, the Ethereum community is in the development stage of the PoS to get away with the PoW 'mining' consensus which uses an enormous amount of energy. This kind of development is foreseen to create a more sustainable blockchain consensus solution. But PoS is also imperfect and has some flaws, this is because the higher the stake the person has in the network, the more chance this specific person can

validate the transaction which they can then collect more transaction fees. This means the rich get richer in the network.

Interview 04/17/2018/Platform Engineer, DevOps and Digital Platform/Container Shipping

So, I would say the protocol (in the MRV case study) could be an Ethereum virtual machine. Let's say it could be, Ethereum itself. But the actual problem (in the case study) is actually the trusting of the data and its validation.

The other reason why Ethereum can be a good choice is the people factor. The Ethereum network has a much more developer working on different specific cases (e.g. business cases). In addition, the support for developments is high because it is easier to find Ethereum developers.

Working on this blockchain means setting up the whole virtual machine. Ethereum is capable of having smart contracts and works with the real programming languages. In addition, Ethereum offers multiple kinds of nodes in the network that is robust and can resist heavy attacks.

The Ethereum network is actually moving forward from Proof of Work (PoW) to Proof of Stake (PoS). This is very energy efficient.

Interview 06/18/18 / Research and Development Lead/Blockchain for Maritime Sustainability

There's a lot of other proof of stake mechanisms in other blockchain systems. But the issue in this consensus is that it might centralize the system even more because you need to stake a lot. You must be a big blockchain player, or you have to have a lot of cryptocurrencies (Ether) to actually start staking anything. So that will remove the possibility for small miners or people who don't have that much on the line. I don't really like the proof of stake because you must stake a lot.

Interview 04/29/18 / Blockchain Architect / Blockchain development and service company for decentralized ecosystem for movable assets

Ethereum is a public blockchain which means anyone in the network can have access to data. It is built to run smart contracts using a Proof of Work (PoW) consensus mechanism, like what bitcoin has. It has a built-in currency called Ether.

Basically, running PoW is costly in terms of electricity so bitcoin blockchain has issues in its consensus. So right now they're looking to move to Proof of Stake (PoS) using the Casper. They actually call it Casper, the new protocol. And they think it, it will solve this issue of the PoW.

[19] ***In the interview, multiple stakeholders agreed that companies and regulators preferred not to fully share their sustainability data, although there are still existing companies who are willing to share it in a more transparent way in the public.***

Interview 04/25/2018 & 06/18/2018/ Sr. Global Advisor Transport and Logistics Sustainability/ Container Shipping

I don't know my competitors' emission factors. I can't see it and that's of course, there's a lot of conservativeness in the data. Companies don't want to show to competitors their sustainability data. Of course, no customers forced them to share it. But companies don't want it to be out of the oven because some of them, the data are bad and not performing very well. We want full transparency and everything, so it's difficult for you to use a cheat sheet. I'm sure there's some of us cheating or not doing it good enough. This is not necessarily a purposely cheating but maybe just having a really bad quality data.

Our company is doing quite good. We are the only carrier that supports 100% transparency to all of these and customers. In our sustainability reform, we have been the big note to follow our mission. We don't know to popularize many things. How we are doing and how we are improving, we share our absolute numbers. This is presented in the sustainability reports which is publicly available. We basically want to share almost everything.

We are not sharing the customer related emissions. We don't want to disclose this (pertaining to the data of the customers). We let the customers decide whether they will share it.

Interview 04/06/18 / Technical Director and EU MRV/IMO DCS Auditor/Verifier

For MRV, there's a lot of issues with the industry because the objective is to make the annual report to publicly available. There's a lot of issues because of the confidentiality aspect. This is particularly the total emissions of cargo on board. Is a very sensitive information likewise the actual quantity of fuel consumed for specific voyages or so are quite sensitive data. In the IMO data collection system, the data will not be perfectly available, or it will be anonymized first. So, I think there are two levels of information. You have the aggregated, the detailed information, their voyage per day, which is I would say very sensitive. And then the aggregates some data in the early level for example is a bit less sensitive.

Interview 05/08/2018 Manager, Associate and Researcher /B2B for measurement, evaluation, and reporting of the environmental performance (e.g. CO_2) of the container shipping industry.

The only ones who see their own data are the members. The carriers/ ship operators themselves can choose whether they want to share the results and the KPIs via the scorecards with their customers. But the information is very much proprietary, it's very much operational data around where they're operating. These contain the amount of fuel they're using, volumes and capacities. These are sensitive business details that we've developed a workaround in a reporting system.

Interview 06/18/18 / Research and Development Lead/Blockchain for Maritime Sustainability

I think it's also private (pertaining to emission data). I mean, the emission data could be used to track a lot of things. I mean you could derive a lot of data from or a lot of information from this data. And you could use it to brand somebody as both being green and anti-green company. The sensitive data are the raw data on the type of fuel being used, fuel usage, and whole compliance issue. I don't think anyone is interested in putting that, like implementing it in a fully public permissionless ledger.

I mean in my perfect world, I would really love them to be fully transparent so there's nobody cheating. But I bet that there's a lot of companies who do not want to be fully transparent about what they're running on.

[20] In an interview with the R&D head of a blockchain company focusing on the monitoring and reporting of GHG emissions, the suggestion is to use Hyperledger. This is seen as the best fit for the stakeholder's preferences and needs on the MRV process. Through the guidance of a blockchain developer, Hyperledger Fabric using Practical Byzantine Fault Tolerance (PBFT) can be one of the blockchain choices that is right in this project. At the same time, it is a permissioned blockchain that integrates the use of smart contracts to create a platform for

distributed application. This is specifically made as a DLT that is not necessarily used for the exchange of value or money but just record of transactions.

Interview 06/18/18 / Research and Development Lead/Blockchain for Maritime Sustainability

And I believe those type of blockchains (e.g. Hyperledger) without cryptocurrencies are more aligned for systems like this (pertaining to MRV system). This is in comparison with the Ethereum or Bitcoin blockchain. I think Hyperledger is perfect for just transactions, which are not monitoring transactions. It would just, submitting data which you don't have a payment transaction for submitting those data. So, I think Hyperledger would be my preferred blockchain. Additional details on the choice of blockchain is presented in Note [18]

Interviewee answered when asked what is the blockchain they are using in their current sustainability project for maritime which has almost the same scope as the research: We're looking into working on Hyperledger and I think it's so far, it's very promising.

Interview 04/29/18 / Blockchain Architect / Blockchain development and service company for decentralized ecosystem for movable assets

Hyperledger Fabric is a permissioned blockchain meaning you decide who'll be part of the network. Meaning you decide who'll be the stakeholders. So, it also has a concept of channels which allow certain data in the network to be visible only to some, which makes it a perfect for enterprise-level applications. It uses the PBFT Practical Byzantine Fault Tolerance as consensus and it doesn't have a native currency. Cause it's not built for a payment system. It actually built for just recording transactions and smart contract.

[21] In the interview with Hyperledger architect, it is mentioned that through the channel architecture, visibility of specific transactions and sharing of data can be governed in the network.

Interview 04/29/18 / Blockchain Architect / Blockchain development and service company for decentralized ecosystem for movable assets

Hyperledger Fabric is a permissioned blockchain where stakeholders that can be part of the network is limited. This also means that stakeholders in the network can be decided. It has a concept of channels which allow certain data that can be shared in the network is only visible to some nodes. This makes it as perfect blockchain for an enterprise level application usage. It uses the Practical Byzantine Fault Tolerance (PBFT) as consensus. Also, it doesn't have a native currency because it's not built for a payment system. It built for just recording transactions.

[22] ***Using the smart contract, middleman or TTP might not be necessary for the network, according to an interview with blockchain expert and a verifier. But implementation of blockchain and the smart contract features will face challenges when it comes to stakeholder's preparation and acceptance.***

Interview 04/29/18 / Blockchain Architect / Blockchain development and service company for decentralized ecosystem for movable assets

Smart contracts are the lines of code, it's a computer program. These are uploaded or runs in the blockchain network, which enforces the rules and terms of the contract without the need for a middleman.

Interview 04/06/18 / Technical Director and EU MRV/IMO DCS Auditor/Verifier

If you think of the full implementation of blockchain (with smart contract features) a critic body is not required at least on the data site. Then we can imagine that the people submit their documents and there's an automatic verification. Because if you have a sufficient actor that ensures independence and confirm the accuracy of the data provided, in this blockchain, then I think, maybe, verification would not be required.

Interviewee answer when asked about challenges on implementation of such:

But I guess certain conditions and protocols that should cater the whole system, right? And if all the stakeholders are involved and they will be able to comply with each of this. And at the same time, all stakeholders are also prepared to implement such a thing. So, there's a lot of considerations before we can implement this kind of system.

The challenge is the acceptance, like for any change in your organization. Acceptance is key and especially when it comes to use and governance of this system by operators, by flag administration, and by companies, then it is even a bigger challenge.

[23] ***In the interview, MRV stakeholders and blockchain expert addressed that a global enforcement of MRV that includes different stakeholders will incur a big challenge. The main issue will be the technology adoption especially its understanding. At the same time, the standardization in the reporting which reflects the proper methodology used.***

Interview 05/08/2018 Manager, Associate and Researcher /B2B for measurement, evaluation, and reporting of the environmental performance (e.g. CO_2) of the container shipping industry.

I don't know if there any examples of a global enforcement of anything. I mean that is a challenge in the shipping industry because it is operating globally. And it is very difficult, you know these ships are moving everywhere, moving to every port in the world. And so, how would you implement something that is global. That, where especially if you needed to for example trust on or rely on the participation of nations, you know hundreds of nations that, or flag states, etc.

Interview 06/21/2018/ Manager, Associate and Researcher /B2B for measurement, evaluation, and reporting of the environmental performance (e.g. CO_2) of the container shipping industry.

The user adoption of the technology is going to be the biggest hurdle. The company themselves are not going to walk and implement new technologies and make the investment in upgrading their infrastructure from an IT perspective until they realized that it is not the best technology for their use case. It should also be a standardized technology that everybody is going to use.

Another hurdle is the standardization of reporting. Companies inevitably select different IT ecosystems to go about doing this remote monitoring and DLT. How do we ensure that we're updating our methodology at the CCWG to ensure that there's continued standardization on the output of that process? Because the data collection might be desperate, but the output must be the same and comparable.

Interview 06/11/18 / Digital MRV Lead - CTO/ Standard and certification body that caters climate and development projects

I think the technology and understanding it is one issue. Stakeholders in the system need a lot of partner support. The other concern is: will the systems that really work well together? eg. IMO or UN for climate action projects.

Interview 04/10/2018/ Founder / Carbon on blockchain startup

Perspective on the challenges on carbon ecosystem implementation

The challenges I think that affect the adoption of blockchain is two folds. The one is the public understanding of blockchain because even the corporates, shareholders, clients, and if the public doesn't understand blockchain is, it's really difficult for them to say what we want that. Another is the legal frameworks, oversight and maturity of the system. What I mean with maturity is, there are couple of systems out there where people think, oh let's do it this way and that way. I have an idea, I also have an idea, oh here's another idea. So, there's so many different ways to do it. What needs to happen is that, it needs to have a consensus that creates certain ways, which are the right way. That needs to be in legal frameworks, that needs to be in a regulation. And then the carbon markets will adopt blockchain technology faster.

[24] ***In addition, one stakeholder shared in the interview that there's complexity on the tracking and reporting of the seaborne transshipments that is necessary on the cargo/TEU specific emissions. The challenge is the collection of the emissions data from the unowned vessel (e.g. charter vessel). This requires a lot of effort and integration.***

Interview 06/21/2018/ Manager, Associate and Researcher /B2B for measurement, evaluation, and reporting of the environmental performance (e.g. CO_2) of the container shipping industry.

Another hurdle is the complexity of container shipping when it comes to the cargo transport such as seaborne transshipments (e.g. charter vessels). How do you go about reporting or monitoring of through these types of technologies that you require installation and maintenance and everything else on a vessel that you don't even own? It is a vessel from another company that implies two challenges. First, it will be difficult if there is no IoT solutions or remote monitoring solutions installed on board in that vessel. The second challenge is the compatibility of systems being installed, in case there's an IoT system in that vessel.

[25] ***Addressed in the interview with technology experts, they shared that the enforcement and standardization of IoT based systems, including the set-up of the technology will be challenging and expensive. Incentive mechanisms such as releasing of the green certificate can be done so it can encourage more companies to comply with this integration.***

Interview 06/18/18 / Research and Development Lead/Blockchain for Maritime Sustainability

IoT can be implemented easily. But probably can be difficult on enforcing it, especially on buying the idea of having it in one system. There will be a need for a standard for this. There should be a connection on the IoT devices. I think one way of implementing this is to release a green certificate, so you need to create some incentives for submitting these data and complying with this setup.

Interview 06/11/18 / Digital MRV Lead - CTO/ Standard and certification body that caters climate and development projects

Through IoT, it will make more transparent, more efficient system. IoT technology has been around but they're quite expensive and not adopted for various reasons.

Interview 04/17/2018/Platform Engineer, DevOps and Digital Platform/Container Shipping

IoT implementation is connected to different sensors and machines. Those machines are gathering and collecting a lot of data. And you need somehow to have a process that is calculating averages or calculating the right amount of what you want to write into the blockchain. Through this implementation, you can now put those data continuously into a blockchain. A large amount of data that will be pushed in the blockchain network in the IoT infrastructure will be a challenge. Also, the data is not coming directly from one single point but has to come from multiple points. Another challenge is trusting of the data that is coming from the IoT set up before putting it in the blockchain network.

[26] ***Based on the interview after showing the BPM to a blockchain expert, it was suggested that TTP are still necessary stakeholders for the MRV process. TTP will be the ones who will verify the data, certify transactions, and the ones who will be creating incentives for the MRV***

complaints. They might not work as they were tasked today, but they are still necessary to exist in the system.

Interview 06/18/18 / Research and Development Lead/Blockchain for Maritime Sustainability

I think you would be able some system, say blockchain that gets all these sustainability information and data, then it calculates the yearly report or something like that. But I think you would still need to have organization that looks at the following: release the green certificate; publishes the data in a way that makes it useful for the ones who's been reporting. So, I think the regulators will, or the verifiers will probably be different than in this day today, that doing a lot of work looking well this document. But they (verifiers) should probably be the ones who are creating incentives, so the ship operators will report in the blockchain based MRV.

In the blockchain based MRV, IMO and maybe the local authorities will be the enforcers of this regulation. But there's a possibility that IMO might probably put verifiers in this role.

Interviewee comment when the BPM model was presented, presenting a process innovation without a verifier stakeholder:

I think this is very sound and I see the correspondence to the MRV systems right now. And this, like the validation, it can only validate the data that's put in in the right format or it hasn't been changed from last time it checked. And so, I still see a point in having a verifier at some point that that looks at the data or verifies it if the data is right. Because we can only validate the data we can't really verify it. And that's why the verifiers today are so important. But this would make it much easier for a verifier to check the data (in a blockchain based). Because I still think it needs to go through these verifiers, it's hard to totally hard to remove them (the verifiers or the TTP).