“Increasing transparency in the carbon markets using blockchain”
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Θα ήθελα να ευχαριστήσω ιδιαίτερα τον Αρ. Μάριο Τρίγκα και τον Αρ. Κωνσταντίνο Παπασπυρόπουλο για την υπομονή και την πολύπλοκη βοήθεια τους της εκπόνηση αυτής της διπλωματικής εργασίας δε θα ήταν δυνατή.
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SUMMARY

Blockchain technology has emerged as an innovative technology during recent years with applications on nearly every aspect of life, since it can provide a secure, decentralized and transparent distributed ledger of actions. In this thesis we attempt to evaluate the application of the innovative blockchain technology to carbon markets. This is achieved through a literature review of the aspects of carbon markets, the blockchain technology and its components and the identification of the problems that are faced during the implementation of carbon markets. An evaluation of blockchain applicability to carbon markets also takes place through the utilization of a framework. Overall blockchain seems like a suitable technology for carbon markets but since it is still a newly emerging technology with a variety of drawbacks (scalability issues, high energy consumption, high cost of implementation, need for specialized knowledge) that have to be overcome, it should be approached with great consideration.

Key Words: Blockchain, Decentralized Ledger Technologies, EU ETS, Carbon Markets, Carbon Trading, ETS, Emission Trading Schemes, Paris Agreement, Decentralized Emission System
Η τεχνολογία blockchain έχει αναδειχθεί τα τελευταία χρόνια ως μία τεχνολογία με εφαρμογές σχεδόν σε κάθε πτυχή της ζωής, καθώς αποτελεί μία ασφαλή, αποκεντρωμένη και διαφανή τεχνολογία κατανεμημένου καθολικού (Distributed Ledger Technology). Στην παρούσα διπλωματική εργασία γίνεται μια προσπάθεια αξιολόγησης της καινοτόμου τεχνολογίας του blockchain σε συνδυασμό με τις αγορές άνθρακα. Αυτό επιτυγχάνεται μέσω μιας βιβλιογραφικής ανασκόπησης των αγορών άνθρακα, της τεχνολογίας blockchain και των συστατικών μέρη της, του εντοπισμού των προβλημάτων που αντιμετωπίζονται κατά την εφαρμογή των αγορών άνθρακα. Πραγματοποιείται επίσης αξιολόγηση της δυνατότητας εφαρμογής της τεχνολογίας blockchain στις αγορές άνθρακα μέσω της αξιοποίησης ενός πλαισίου. Συνολικά, το blockchain φαίνεται να είναι μια κατάλληλη τεχνολογία για τις αγορές άνθρακα, αλλά δεδομένου ότι εξακολουθεί να είναι μια καινούρια τεχνολογία με ποικίλα μειονεκτήματα (προβλήματα ταχύτητας, υψηλή κατανάλωση ενέργειας, υψηλό κόστος εφαρμογής, ανάγκη για εξειδικευμένες γνώσεις) που πρέπει να ξεπεραστούν, θα πρέπει να προσεγγιστεί με μεγάλη προσοχή.
THESIS OUTLINE

The thesis is divided in 7 main chapters.

The first chapter contains a brief description of topics related to the main subject of the thesis. Such topics are the climate change, the greenhouse effect, the most important international actions against climate change and the blockchain technology.

The second chapter is the main incentives that led to the choice of this particular subject for the thesis.

The third chapter contains the main questions that are sought to be answered through the conduction of the thesis.

The forth chapter describes the methodology that was used in order to conduct the literature review.

The fifth chapter contains the results of the literature review which are divided to:

- An analytical description of the Emission trading systems – Carbon markets in general and a specific description and analysis of the Kyoto Protocol & EU ETS.
- An analytical description of the blockchain and its components.
- The problems that are faced on the carbon markets
- The application of a framework from the World Economic Forum entitled “Blockchain beyond the Hype A Practical Framework for Business Leaders” which will assess the applicability of the blockchain while presenting the most suitable methods of blockchain application to carbon markets according to literature.

The sixth chapter is contains the discussion of the results

The seventh contains the conclusions
1 INTRODUCTION

1.1 Weather, Climate, Climate Change

Weather is defined as the short term status of the atmosphere for a defined area. Weather is strongly connected to variable conditions such as temperature, humidity, barometric pressure, wind, particles of the atmosphere etc.

Climate is defined as the long term status (from months to centuries) of the atmosphere for a defined area; it can also be described as the average conditions of the variables of the weather.

So we can simplify these meaning by considering weather as the state of the atmosphere in a defined time and climate as the average of the weather conditions for a defined period (Wallington et al, 2001).

According to the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, climate change is defined as “a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods of time”. Such changes can be easily spotted if someone compares the today’s enviromental situation with the environmental situation of the previous century. Ahrens (2003) defines climate change as the increasing or decreasing change of the averages of the meteorological conditions, mostly those concerning the temperature and the rainfall, following a series of continuous thirty-year observations. United States Environmental Protection Agency in 2016 defined climate change as any significant change in the measures of climate lasting for an extended period of time. The Intergovernmental Panel on Climate Change (IPCC), referring to climate change, attributes its variability to both nature and human, it repatriated it in 2016 to the United Nations Framework Convention on Climate Change, at which the human factor is defined as the main perpetrator, either directly or indirectly to the climate change.
1.2 Greenhouse effect

Greenhouse effect is defined as the natural atmospheric processes, thanks to which, the conditions of our planet create the appropriate prerequisites for the development and survival of life, since the retention of incoming heat, contributes to the increase of surface temperature (Katsafados & Mavromatidis, 2015).

The phenomenon takes its name from the mechanism of glass greenhouses use where the Ultraviolet radiation (UV) emitted from the sun is passing the glass of the greenhouse and is absorbed by plants, soils and objects within the building (Darkwah et al. 2018). Infrared radiation which is the weaker part of the radiation is deflected by all the surfaces and hits the glass barrier (radiation blanket) from which it cannot escape thus reemitted to the ground and plants transforming to thermal energy and creating the suitable conditions for plants (Jones & Henderson, 1990).

Something similar takes place also on the atmosphere of earth. Solar energy is emitted to earth as visible radiation, 30% of this radiation is deflected back to space by clouds and liquid elements of the planet, a 19% is absorbed by clouds and ozone and finally the biggest part of the radiation (51%) is absorbed by soils and the ocean. The temperature of the planet regulates the re-emission of this thermal radiation as infrared radiation back to space. GHGs contribute through the creation of an atmospheric blanket to the establishment of the phenomenon by reflecting a big part from the radiation that is emitted to them back to earth in form of thermal energy raising the global temperature and sustaining it to an average of 14°C which would be -19°C in the absence of the phenomenon making life on earth as we know it uncertain (Mikhaylov et al., 2020). The global climate is determined by the balance between incoming and outcoming radiation, in that manner a change on that ratio can create variations in global energy balance which can finally lead to climate change.
The greenhouse effect can be divided to the natural occurring greenhouse effect and the enhanced greenhouse effect.

The natural greenhouse effect is a natural phenomenon that takes place millions of years. Natural existing greenhouse gases (GHGs) manage to deflect thermal radiation back to the earth, this action creates a cycle of heat inside the earth’s atmosphere which leads to the increase of global temperature and the sustainability of life, a big part of the phenomenon is taking place by water vapor (Archer, 2007). On the other hand, since the industrial revolution the emission of GHGs related to human activities have been radically increases this increase is leading to an intensification of the Greenhouse gas effect which eventually leads to global temperature raise and climate change.

As defined before, climate change is the subject of direct or indirect human activity. The website ourworldindata.org by combining data relative the CO2 emissions of human activity sectors from 1990 to 2016 categorizes the top activities that contribute to climate change as the following.
The first scientist who managed to identify the phenomenon of greenhouse effect is the mathematician – physician Jean-Baptiste Fourier in 1827 who was the first to mention the similarities of the phenomenon with green houses. After Fourier, the British scientist John Tyndall in 1860, through the estimation of the amount infrared radiation captured by carbon dioxide and water vapor, ended up with the conclusion that the ice ages of the earth are due to the decrease of atmospheric carbon dioxide. Thirty six years later, the Swedish chemist, Svante Arrhenius, estimated that the global temperature that would be risen by 5°C-6 °C if the amount of atmospheric carbon dioxide was doubled, which can be considered as one of the first attempts to correlate the CO₂ produced by human activities with climate change. Based on his work, Callendar (1940) estimated the amount of warming caused by the use of fossil fuels. The most important recognition of the phenomenon is dated in 1992 when the climate convention took place.

According to the “NOAA ANNUAL GREENHOUSE GAS INDEX (AGGI)” that was published and updated in 2021 the GHGs that contribute the most to the intensity of the phenomenon and their use has been radically intensified during the modern
years are Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O) as shown on the diagrams below

![Concentration of CO2, N2O, CH4 and CFCs during the years](https://gml.noaa.gov/aggi/aggi.html)

IPCC in 2007 points out that GHGs created by human activities from 1970-2021 have contributed to a rate of 0.2 °C of temperature raise every decade. This rate, regardless the emission policy that is going to be applied, is not expected to be changed radically due to the fact that GHGs need at least 10 years to disappear from the atmosphere. (Kirtman B. et al., 2013).

![Global greenhouse gas emissions and warning scenarios](https://ourworldindata.org)

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Information is correct as of 2021.
As we can understand climate change and greenhouse effect are communicating vessels and both eventually lead to global warming. Global warming according to USGS is defined as the rise in global temperatures due to mainly increasing the concentration of greenhouse gases in the atmosphere. A pretty similar definition is also given by NASA who defines global warming as the “he long-term heating of Earth's climate system observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere”.

The anomaly of the global temperature has been monitored and visualized by [https://ourworldindata.org](https://ourworldindata.org) in the below graph:

![Image 5 Average temperature anomaly, Globally (Source: https://ourworldindata.org)](https://ourworldindata.org)

If this graph is compared with the graph that visualizes the concentration of CO₂ we can see that there can be a correlation between the temperature deviation from the predicted average and the concentration of CO₂ in the atmosphere.
According to the websites of IPCC, the EU and the WWF the most important results of climate change are concluded to the following:

- Severe weather phenomena
- Increase of infrequent weather phenomena (such as hurricanes in the Mediterranean areas)
- Severe droughts and heat waves
- Rise of the sea level
- Melting of the ices and glaciers in the arctic
- Acidification of the oceans

1.3 International Acts against climate Change

The major problem of climate change has been a big concern for the global scientific community since the 1960s. In order to respond to the greatest threat to the planet, the international institutions, with a sense of shared responsibility because of its transboundary nature, met at the United Nations in 1972 in Stockholm. This conference was attended by delegations from 113 states, with the absence of the Soviet Union. The Stockholm Conference ended with the conclusion of a programme responding to a non-binding general framework of principles of great political significance, known as the Stockholm Declaration, which is the starting point of the international efforts to find common policies to resolve the environmental issue.
A number of conferences and agreements followed, with the common goal of finding strategies to deal with polluting emissions. The World Environment Conference held in 1992 in Rio de Janeiro, Brazil, the Earth Summit, as it is widely known, among the five international conventions that emerged, defined the binding Framework Convention on Climate Change (UNFCCC) with the aim of stabilising concentrations of greenhouse gases originating from anthropogenic activities and sharing responsibility between countries. Among other things, a comprehensive, cross-sectoral and participatory action plan (Agenda 21) was adopted on global sustainable development for the 21st century.

1.3.1 Kyoto Protocol
The first international framework that expressed the urgency to take action against the climate change is the United Nations Framework Convention on Climate change (UNFCCC), which was signed during the United Nations Conference on Environment and Development in Rio de Janeiro in 1992 between the parts of COP. The main objective of the UNFCCC is to take actions against the global warming (Kuyper et al. 2018). One of the main tools to achieve this objective was the negotiation of the international treaty of “Kyoto Protocol”.

The Kyoto protocol is considered as one of the first and probably the most famous international environmental agreements, ratified by 192 countries, whose main objective was to “stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (Gechev, 2020).

1.3.2 The Green Paper
The Green Paper presented by the EU Commission in Brussels on 08/03/2000 laid the foundations for the debate on emissions trading and the cooperation of the forthcoming action, in combination with other climate policies, within the community. The ambitious European initiative aimed at gaining experience and practical familiarity in implementing this new measure through the establishment of a Community trading scheme by 2005, gaining a comparative advantage in anticipation of the entry into force of the international scheme in 2008. It was proposed to adopt a coordinated implementation framework at Community level, aiming at a single unit price and therefore equal treatment, economies of scale with consequent cost savings, lower administrative costs and avoidance of distortion of competition.
1.3.3 Directive 2003/87/EC
In 2003, on 25/10, Directive 2003/87/EC of the European Parliament and of the Council was published in the Official Journal of the European Union, establishing a functioning Community scheme for greenhouse gas emission allowance trading, with the aim of limiting the negative economic impacts within the Community by fulfilling its international commitments as set out in the Kyoto Protocol.

In more details, it mentions that from 1 January 2005, large emission installations within the European Union will not be able to operate without a permit for the greenhouse gas emissions produced. Each authorized installation will have to offset its emissions annually with allowances (European Union Allowances - EUAs, equivalent to 1 tonne of CO2eq), which can be bought and sold by the individual operators concerned. Installations will be able to buy and sell allowances in European public auctions or receive them free of charge, based on the allowances of the national scheme to which they belong.

1.3.4 Paris Agreement
On 12 December 2015, the first legally binding universal, albeit flexible, agreement involving 196 Parties, known as the Paris Agreement, takes place in Paris at the 21st Climate Change Conference (COP21). It is a comprehensive, strongly humanitarian action plan, with the long-term goal of keeping global warming well below 2°C above pre-industrial levels, and continuing efforts to limit it to 1.5°C, always comparing it to pre-industrial levels, through the decoupling of the global economy from fossil fuels.

A clear call is made for countries to take intensive action through ambitious actions and investments towards sustainable, low-carbon development. The European Union is committed to carbon neutrality by the second half of the 21st century. Article 10 sets out the establishment of an integrated technology framework, a collaborative approach to facilitating access to technology. In Article 6, appreciating the importance of international carbon markets, it encourages Parties to use them on a voluntary basis to achieve their individual national targets. At the same time, it establishes a comprehensive monitoring and oversight framework. During the Conference, comprehensive draft national response policies were submitted by the country Parties. In order to support developing countries vulnerable to the effects of climate change funding and voluntary cooperation was mentioned by the agreement. The Agreement was signed by 195 Parties, including the European Union, which signed this
Agreement on 22 April 2016. It proceeded to ratify it on 5 October 2016, followed by all its member states, aiming for a leading role in climate action. The Agreement has been in force since 4 November 2016.

1.3.5 The Green Agreement
On 11/12/2019, the European Green Deal was announced in Brussels, a new development strategy, as it is called in the document, which aims to reshape the Community's development so that the European Union becomes a just and prosperous society, with a modern, efficient and competitive economy, with regard to the management of resources, protecting, preserving and enhancing both its natural capital and people from environmental impacts. A central pillar of the Agreement is the establishment of a climate law which aims to make Europe a leading zero-carbon continent by 2050.

In the framework of the Agreement, it is proposed to revise Directive 2003/96/EC on energy taxation. Also with an aim to reduce the phenomenon of carbon leakage, a border adjustment mechanism is proposed in selected sectors. The proposal is made to include additional sectors in the ETS, starting in 2020, such as building, shipping and road transport, as well as a reduction in the allocation of free allowances to airlines.

It is worth mentioning that the European Union, in its Opinion REX/531, regarding the carbon markets on 20/02/2020, which was published during the pandemic, urges the attention of the Member States to continue with the Agreement on a timetable in order to achieve the 2050 neutralisation target.

In addition, through the Just Transition Mechanism, which concerns financial and technical support for vulnerable Member States in their transition to the green economy due to the inability to decarbonise, the European Union will make available a minimum of €100 billion for the period 2021-2027.

On 4 March, the European Commission, in the framework of the Green Deal, published the so-called climate law legislative proposal to bring the 2050 climate neutrality objective into the European regulatory framework. Both the Commission and the Parliament emphasizes the importance of raising the 2030 climate target.
1.4 Blockchain

Over the last decades, information systems have become vital and ubiquitous in every organization. Rapid progress in combination with increasing dependence on technology has led to information systems with ever greater complexity. Today, a single application may contain multiple layers, microservices, APIs and so on.

Furthermore, new technologies are continually offering new opportunities and revenue streams for organizations and enterprises. However, these technologies allow for cyber-threats which exploit the vulnerabilities of information systems. Hence, with the rise of technology, both enterprises and cyber-attackers benefit as well. Over the last few years, the number of cyber threat agents, who steal all kinds of valuable data with new techniques, such as Distributed Denial of Service (DDoS) attacks, has been dramatically increasing. Thus, new approaches with regards to information security in various fields must be established. In addition, today's organizations need to collaborate with each other and share resources, such as devices, services, databases and every kind of information, in order to expand their productivity and keep them up-to-date on technological advancements. Therefore, these organizations require authorized access to the resources they share. For this reason, access control systems are used to regulate the access to valuable shared resources. The special requirements each organization imposes are reflected on their unique access control policies. These policies are constantly evaluated depending on the access request in order that a final authorization decision is made. However, interorganizational collaborations lead to more complicated access control systems across organizations. Although, traditional access control systems may be sufficient in protecting resources beyond organizational boundaries, they come with many drawbacks.

Blockchain was introduced with Bitcoin cryptocurrency by Satoshi Nakamoto, in 2008. Initially blockchain was designed to store the Bitcoin-related transactions in a decentralized and distributed ledger, which is immutable and updated not by a single-trusted authority but by the consensus among participants in a blockchain network (Nakamoto, 2008). As it was expected, blockchain is closely linked to cryptocurrencies and financial world. However, throughout the years, the blockchain technologies were enhanced with the ability to execute code snippets, namely, smart contracts that provide a blockchain network with business logic (Bashir, 2018). Thus, the benefits of such breakthrough technologies came to light and these technologies
were quickly adopted in plenty of applications of various fields. Hence, it became obvious that this emerging decentralized data sharing that allows a network of untrusted parties to interact with each other is not only useful to the financial sector (Dhillon et al., 2017).

The collaborations among different organizations result in complex systems with many shared components such as web services, APIs, databases, routers, printers etc. Although such systems are usually distributed, the access control systems protecting shared resources are implemented through centralized approaches. Each organization defines, stores and manages its own access control system. Therefore, for every access request a central authority is mediating in order to evaluate the request and to decide whether the access should be granted or denied. Thus, a centralized approach in access control systems comes with many drawbacks such as:

- A single point of failure (SPOF): In case the access control system fails then the whole system will be inaccessible. The systems are not tolerant to faults.

- A central authority: A central authority that intervenes in every request to enforce the authorization decision. This ultimately leads to performance issues as well as to absolute trust in the central authority.

- Low-scalability: The system cannot scale with the number of the growing participants.

- Security breach: A central server that stores the access control policies in a traditional database besides a SPOF, is the perfect “honey pot” for cyber-attacks which put these policies at risk. Also, the logs are saved in the same way as policies and are too vulnerable to breach and tampering.
2 AIM OF THE THESIS

This research aims to evaluate the efficiency of the blockchain technology on the carbon market. This is achieved through the examination of the scientific literature of blockchain and each main principles and its applicability on carbon markets.

Blockchain technology has emerged as an innovative technology during recent years with applications on nearly every aspect of life, since it can provide a secure, decentralized and transparent distributed ledger of actions, through the use of smart contracts.

Due to that, blockchain seems to be an ideal application for the carbon market since it can create a market with increased reliability, transparency through the whole process, which would be free of interference, intervention and manipulation.
The research can be divided in 4 research questions that help to fulfill its objectives. These questions are analyzed as follows:

1. **What is a carbon market?**

   To answer this question a description of the main mechanisms that characterize the carbon markets take place. In order to have a better understanding of the concept of carbon markets an analytical description of two of the most successful agreements that include carbon markets take place, the Kyoto Protocol and the European Union Emission Trading Scheme.

2. **What is blockchain? And what are its main components?**

   To answer this question a thorough research took place in order to determine the origins and incentives that lead to the creation of blockchain. The main issues that are answered under this question refer to definition and description of blockchain, its characteristics, the main types of blockchain systems that exist and the main platforms that are in use.

3. **What are the problems that are faced on carbon markets?**

   To answer this question the research that has already been done on the combination of blockchain and carbon markets was analyzed in order to determine the main issues that are sought to be solved through the application of blockchain.

4. **Is blockchain applicable to carbon markets?**

   To answer this question the framework of World Economic Forum entitled “Blockchain Beyond the Hype: A Practical Framework for Business Leaders” was used to evaluate the applicability of blockchain and analyze the methods that will be used for its application.
4 METHODOLOGY

The literature review methodology that was followed is an exhaustive review with selective citations (Randolph, 2008). The methodology for the identification and evaluation of the resources is based on the methodology that Scheepers et al (2014) uses and is also proposed from van Wee & Banister (2015).

We chose as our main source of data the search engines of:

- Google Scholar: Since it can provide access to a plethora of open access sources such as journals, articles and book and also elaborate to the verification of the sources.
- Science – Direct: due to its targeted recommendations and article metrics that enable more accurate evaluation of the data
- Scopus: Due to the fact that all of its content is reviewed for credibility before posted thus making it an inferior data source.

For the first three research questions there no limitation for the publication date was applied due to the fact that we are trying to present a historical review of the two subjects. On the other hand for the fourth research question only resources that were published after 2018 were used in order to ensure that we will use only the most up to dated data.

The language of the resources that were searched was mainly English with some exceptions of Greek academic books.

In order to evaluate the data extraction 5 criteria were used from which at least one should be met in order to ensure the credibility of the content

- Peer reviewed journal articles.
- Edited academic books.
- Articles in professional journals.
- Statistical data from government websites.
- Website material from professional associations

The resources that met at least one of the criteria were evaluated firstly according to their title in order to exclude either non-relevant resources of different topics either relevant resources that were not covering the research question that was intended to
be answered. After the title – check a summary check was taking place. If the summary was identified as relevant to the research question an evaluation of the full text would take place in order to make the final decision of inclusion or exclusion. Finally the resources that were going to be used in the thesis were input in tables divided in 3 columns. The first column is about the title of the resource and the publishing year, the second column is about the author and the third column is about the information of the resource that is going to be utilized in the thesis.

The key words that were used on the different search engines mentioned above were divided according to the research question.

For the first research question the key words that were used are:

- EU ETS
- Carbon Markets
- Carbon Trading
- ETS
- Emission Trading Schemes
- Paris Agreement

Which, had to be combined with at least one of the following keywords:

- Overview
- Analysis

For the second research question the key words that were used are:

And the keywords that were used to conduct the search:

- Blockchain
- Decentralized Ledger Technologies
- Ethereum
- Corda
- Hyperledger Fabric
- Decentralized Emission System

Which also had to be combined with at least one of the following keywords:

- Overview
- Analysis
For the third research question the key words that were used are:

- EU ETS
- Carbon Markets
- Carbon Trading
- ETS
- Emission Trading Schemes
- Paris Agreement

For this research question also the keyword “review” and “evaluation” was used in combination with all the above keywords in order to limit the research to sources who were performing a review and an evaluation of the above mentioned key words.

Finally for the fourth research question the following keywords were used:

- EU ETS
- Carbon Markets
- Carbon Trading
- ETS
- Emission Trading Schemes
- Paris Agreement

That had to be combined at least with one keyword of the following:

- Blockchain
- Decentralized Ledger Technologies
- Ethereum
- Corda
- Hyperledger Fabric
- Decentralized Emission System

The data that were gathered through the resources of 4\textsuperscript{th} research question were input into a framework developed by the World Economic Forum entitled “Blockchain Beyond the Hype A Practical Framework for Business Leaders” which enables the evaluation of the applicability of use-cases to the blockchain system in order to
evaluate the applicability of blockchain to the carbon markets while presenting the proposed methodologies of its application.

The overall search resulted more than 30,000 resources. Through the title and summary check the vast majority of these resources were eliminated due to being irrelevant with the topic and the research question which resulted a final number of 50 resources.
### 4.1 Literature review tables

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<td>Description of the stratospheric ozone regime which worked as a guide to the creation of the Kyoto Protocol</td>
<td><strong>Kanter, D., Mauzeroll, D. L., Ravishankara, A. R., Daniel, J. S., Portmann, R. W., Grabiel, P. M., Galloway, J. N.</strong></td>
</tr>
<tr>
<td><strong>The US acid rain program: Design, performance, and assessment. Environment and Planning (1998)</strong></td>
<td>Description of the US Acid rain program which worked as a guide to the creation of Kyoto protocol</td>
<td><strong>Svendsen, G. T.</strong></td>
</tr>
<tr>
<td><strong>The Kyoto Protocol. (2008)</strong></td>
<td>Description of the main principles that the Kyoto Protocol was based on and a criticism on the success or fail of its implementation</td>
<td><strong>Prins, G., &amp; Rayner, S</strong></td>
</tr>
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<td><strong>Climate change: The Kyoto Protocol and international actions (2007)</strong></td>
<td>Analysis and description of the regulation of the Kyoto Protocol</td>
<td><strong>Fletcher, S. R., &amp; Parker, L.</strong></td>
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<td><strong>NGO influence in the implementation of the Kyoto Protocol: Compliance, flexibility mechanisms, and sinks (2004)</strong></td>
<td>Description of the allowance allocation mechanism of the Kyoto Protocol</td>
<td><strong>Gulbrandsen, L. H., &amp; Andresen, S.</strong></td>
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<td><strong>Estimating the size of the potential market for all three flexibility mechanisms under the Kyoto Protocol (1999)</strong></td>
<td>Analysis of the CDM, JI and ETS mechanisms of the Kyoto Protocol</td>
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**Whitepaper of Corda**

**Corda: A distributed ledger**

**Christidis, K., De Caro, A., . . . Yellick, J.**

**Hearn, M.**

**Whitepaper of Corda**

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Propose a system where the relation to the trusted party is eliminated through the use of smart contracts.  

3 types of actors that require write access:  
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Proposed Consensus Mechanism: Byzantine Fault Tolerance  

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Proposed Consensus mechanism: Proof Of Work |
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5 RESULTS

5.1 Carbon Markets

In order to assist countries reduce their GHG emissions the agreements of the Kyoto protocol and the European Union Emission Trading system proposed three mechanisms, the Emission trading systems or Carbon markets, the Clean Development Mechanism and the Joint Implementation.

The utility of carbon markets is based on the principle of reducing the negative effects of the greenhouse effect through the reduction of the emissions created by certain activities. An important aspect of the scheme is the financial motivation that is communicated to the emitters that will eventually lead to reduce their emissions since it is the most financial efficient choice.

The principle that the schemes are based is the principle of “the polluter pays”. Emitters are obliged to buy the emission rights of the amount of the GHG that they have emitted. This fact increases significantly the operational costs forcing them to turn to more “green” methods.

According to the above, the trading schemes ensure that companies who emit GHG through their production process are supplied with emission rights. The supply of the emission rights can either be free or be bought.

Emissions trading schemes are divided into different categories based on characteristics such as the purpose they serve and the type and size of the measures they take.

The 2 main types are:

- **Cap and trade systems (cap and trade system)**: is the most flexible and popular emissions trading and control scheme. During its use, a regulator uses historical data to set a mandatory cap on emissions and creates emission allowances that are allocated to polluting units. The allowances are transferable and units that emit less than the allowances they hold can sell their allowances to units that emit more pollutants than the allowances they
hold. In the United States, such systems have been in action since 1990 to limit sulphur dioxide (SO2) and nitrogen oxides (NOx)

- **Trading offsets or credits:** in such a system the regulator imposes an emission limit on each unit and controls the emission of pollutants. If the unit's emissions are less than the limit imposed (which is often the historical level of emissions from a specified past year), then the unit acquires allowances—credits corresponding to the difference in emissions from the limit. These credits can then be sold to other units that exceed the imposed limit and need to produce additional emissions. This procedure is legally valid, but a percentage of the credits is withdrawn as a dividend to the environment.

The main features of an emission trading scheme are the following:

1) The creation of the credits. As mentioned above, allowances can be created through a credit programs or a cap-and-trade system.

2) Determination of the value of credits. Emission allowances can express quantities of a specific pollutant (for example, 1 tonne of carbon dioxide) or they can express a percentage of the total quantity allowed.

3) Identification of the overall target of the programme. In relation to what is considered environmentally safer, the regulator sets the final emission reduction target.

4) The initial allocation of allowances. The regulator may distribute the initial allowances by auction or distribute them free of charge based on each unit's past emissions. Although the efficiency of the system is the same, the compliance costs for companies are lower in the second case.

5.2 **Kyoto Protocol**

The Kyoto Protocol is mainly constructed by borrowing principals of three other treaty regimes. The Stratospheric Ozone Regime, which was proposed in 1981 on the Montreal conference and ratified in 1987 by 193 countries, lead to the discovery that chlorofluorocarbons or CFCs are the main factor for the ozone layer depletion (Kanter, et al., 2013). The US acid rain program (ARP) which was established in 1990 in the US and was the first action that used a trading scheme to reduce pollution
And finally the Strategic Arms Reduction Treaty also known as START which main purpose was to reduce the amount to nuclear warheads US and Soviet Union had on their armories (Prins & Rayner, 2008). Mavrakis & Konidiaris on the other side mentions that the principles and mechanisms that are applied to Kyoto Protocol are borrowed by the work of Crocker (1966) and Dales (1968) who were the first to suggest the emission trading as environmental management tool.

The Kyoto’s Protocol main purpose as mentioned before was to protect the environment through the reduction of certain greenhouse gases such as Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O), Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and Sulfur Hexafluoride (SF6). These greenhouse gases along with the sectors and sources that produce them are listed in annex A of the protocol’s framework.

In order to fulfill this purpose, the 39 parties that are listed in annex b must ensure that their overall emissions of greenhouse gases do not exceed the amount assigned to them. The target amount of overall GHG emissions was an average 5.2% reduction of the 1990 production and the amounts assigned to each country vary from 8% reduction to 10% increase and must be achieved during the first commitment period of 2008 to 2012 (Fletcher & Parker, 2007) and an overall 18% reduction of the 1990 production during the second commitment period 2013-2020. Countries not listed in the annex B should try to comply with the emission targets voluntarily (Gechev, 2020).

According to the protocol there are 3 flexibility mechanisms that can be used in order for annex B countries to achieve their emission targets. Those are:

5.2.1 Emission Trading system

Emission trading is established through the article 17 of the protocol. According to this article, countries that are listed in annex B are assigned greenhouse emission credits budgets which are called Assigned Amount Units (AAU) that will be used during the period of 2008-2012 and are calculated by a percentage reduction or, in some cases, increase of the 1990 emission levels of each country (Gulbrandsen & Andresen, 2004).

During the 2008-2012 period, countries that are determined that they will either exceed or deceed the amounts of greenhouse gases emission credits that are assigned to them are allowed through the article 17 to trade them with the other countries of
Annex B. This type of trading scheme is referred as “Cap and Trade” (Fletcher & Parker, 2007).

5.2.2 Clean development mechanism
Article 12 of the protocol provides for the establishment of Clean Development Mechanism (CDM).

CDM’s main purpose is to provide assistance to countries that are not listed in Annex B to create projects funded and assisted by countries of annex B in order to contribute to the overall greenhouse gases emission reductions through sustainable development (Zhang & Zhong Xiang, 1999).

In order to motivate countries of annex B to use the CDM, the protocol provides to them, for every successful project after the year 2000, Certified Emission Reduction (CER) credits. CERs can be used by annex B countries in order to comply with the amount of the greenhouse gases emissions budget assigned to them only when they exceed it.

The implementation of CDM projects is a win-win situation for both the annex b countries and non-annex b country. Most of the non-annex b countries are developing countries and the application of CDM project would help them build their sustainable development and also help the annex b countries gain CER cheaper than it would cost them to apply the same project in their land (Fletcher & Parker, 2007).

The purpose of these mechanisms is to fight and reduce the negative impacts caused by climate change. This is achieved by giving financial motives to annex B countries to reduce their or another country’s GHG emissions.

5.2.3 Joint implementation programs
According to article 6 JI has the same purpose as CDM that is mentioned below. The only differences between them are that JI is conducted between two countries of annex B and also that the credits, which in this case are called Emission Reduction Units (ERUs), are rewarded to countries for projects after 2008 (Zhang & Zhong Xiang, 1999).
5.2.4 REGULATION OF KYOTO PROTOCOL

The agreement on penalties for annex b countries that failed to comply with the protocol was a complex and time-consuming procedure that eventually resolved in 2001 during the COP-7 meeting in Marrakech (Fletcher & Parker, 2007).

According to the agreement non-complying countries will face a deduction of 30% of the allowed assigned greenhouse gases emissions credits and lose the ability to participate in the trading market. In order for the penalty to be applied the non-complying country must agree (Maamoun, 2019)

As stipulated in the Protocol, the European Union, one of the 39 Parties, committed to an 8% reduction in emissions compared to 1990 levels during the first period of implementation (2008-2012).

Article 25, paragraph 1, states that the rules for the entry into force of this Protocol will enter into force at the end of the three-month period following the ratification of at least 55 Parties, including industrialized Parties, responsible for 55% of total polluting emissions.

Currently, 192 Parties (191 States and the European Economic Community) have ratified the Protocol, including all EU Member States, as well as emerging economies such as China, India, Brazil and South Africa. However, the US is absent from the ratification of the Protocol and Canada withdrew at the end of 2012. The Protocol has been signed by 83 out of 192 Parties ("unfccc.int”)

The success or fail of the Kyoto Protocol is a matter of big argument through the years. Therefore no one can disagree with the fact that it was the first joint and international attempt against the climate change and that it acted as a guide for the establishment of many other emission trading scheme with the most successful of them being the European Union Emission Trading scheme (Wara, 2007, Prins & Rayner, 2008).
5.3 EU ETS

The Commission of the European Communities in 2001 had submitted a report to the Secretariat of the Convention on Climate Change on the forthcoming effects of climate change in Europe due to the increase in the average temperature of the earth caused by human activities. As mentioned on the report the result of this climate change, is that ecosystems are finding it difficult to adapt to the new climatic conditions and diseases are on the rise. Indeed, over the next years, extreme weather events take place on the continent and cause enormous destruction and loss of life. This is the environmental aspect of the problem of climate change.

However, European climate policy, part of the European Union's general policy on the environment, also depends on the security of energy supply. It seeks to achieve the greatest possible independence from fossil fuels, meet its energy needs from renewable energy sources (RES) and to reduce pollution of land, water and air. Since 1993, in the context of the pursuit of sustainability, the European Union has also sought ways to reduce other greenhouse gases (CH4, N2O, HFCs, PFCs, SF6), with climate policy becoming an integral part of the Union's environmental policy. The sectors of economic activity to which climate policy has been applied are energy production, domestic electricity consumption, agriculture, transport (air and waterborne), industry.

The Framework Convention on Climate Change entered into force in 1994, following the years of negotiations on the implementation of the Kyoto Protocol and the reduction of emissions of pollutants based on economic efficiency. In 2001, the European Union is pushing for the immediate implementation of the Kyoto Protocol, which is an attempt to address and tackle the climate change (Kuyper et al. 2018).

The European Union, in order to be ready for the implementation of the Kyoto protocol, has organised its environmental policy on the basis of the commitments and implementation periods arising from the Kyoto Protocol, incorporating the Protocol's mechanisms into its EU legislation. The "European Climate Change Programme" arose from the need to achieve the objectives undertaken by the European Union, to monitor the implementation of measures and the progress of the members' climate policies under the increasing trend of emissions, especially from the transport sector. When the European Union adopted the European Climate Change Program (ECCP), it sought to achieve both objectives: To limit the global temperature increase to 2°C and to reduce air pollutant emissions by 30% by 2020 (Convery, 2009).
The Greenhouse Gas Emission Trading Scheme (ETS) is one of the key tools of the European Union to reduce emissions, which wanted to pioneer the international environmental scene by setting up the first transnational emissions trading system (buying and selling of pollution rights) by interconnecting its member states initially and extending it to third countries subsequently.

The basic principles for the functioning of the Emissions Trading Scheme can be summarised as follows: a) the principle of emissions trading through maximum permitted prices, b) the mandatory participation of all industrial sectors, c) a strict compliance framework, d) the extension of the European market to other greenhouse gases and additional production sectors (Convery, 2009).

As Directive 2003/87/EC stresses, European policy to tackle climate change "should be based on a balance between the Community emissions trading scheme and other types of Community, domestic and international action".

The European Greenhouse Gas Emission Trading Scheme is considered as one milestone of European climate change policy and a particularly important weapon in its efforts to meet its carbon emission reduction targets that are set by the Kyoto Protocol.

The main objective of the ETS as set out in Article 1 of Directive 2003/87/EC is to promote the reduction of greenhouse gas emissions in a cost-effective and cost-efficient manner which means that the economic cost of the whole effort is lower than it would have been in the absence of trading.

The ETS is based on a "cap and trade" system. The whole idea of its operation is built on the ex ante imposition of a "cap" of the total amount of certain greenhouse gases that can be emitted by industries, power plants and other installations participating in the system. The quantities of emissions above or below the cap are converted into a trading product between installations to achieve a balance of emissions below the cap (Betz & Sato, 2006).

Today, the ETS is the largest internationally operating emissions trading mechanism in operation. It includes over 11,000 covered installations in the power generation industry and other energy-intensive industries among 31 countries (28 EU Member States, Norway, Liechtenstein and Iceland). It covers more than 45% of the European Union's total emissions and since 2012 the ETS also includes air transport.
5.3.1 Legislation

As mentioned above, the central principle underlying the operation of the ETS is that of "the polluter pays".

The EU, in support of the whole effort, is over-zealous and continues to commit itself by setting long-term emission reduction targets. Its weapon in this effort is Directive 2003/87 and the Emissions Trading Scheme (ETS). At the legislative level, the operation of the ETS is primarily covered by Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community (which amended and incorporated the original Directive 96/61/EC)(Convery, 2009). However, this Directive has been amended several times following market needs, individual Union commitments and the dictates of the international community.

The content of the Protocol predicted the creation of three flexible mechanisms which use market mechanisms to solve global environmental problems:

- The emissions trading system (Article 17)
- The clean development mechanism (Article 12)
- The joint implementation (Article 6).

Regarding emissions trading, the first example of the Commission's willingness to implement it was the Green Paper on Greenhouse Gas Emissions Trading within the European Union, which was the precursor to Directive 2003/87/EC41 (Ellerman et al., 2015). This Directive, although subsequently subject to significant revisions, can be considered the origin of the ETS.

As mentioned before according to this article 1, the target of the directive is to reduce carbon dioxide emissions in a cost-effective manner through the use of the emissions trading mechanism, with the scope targeting the industrial activities defined in Annex I of the Directive (Article 2). In particular, the Member States, through an established competent authority (Article 18), distribute (free of charge) emission permits to each owner of industrial installations and energy companies falling within the scope of the Directive. These permits include a certain number of allowances which the owner can sell on the internal market of the system, and at the end of each year he has to surrender a corresponding number of allowances (equal to the annual emissions of his installations, otherwise he would be subject to significant fines (Article 16).
During the first phase of operation (2005-2007), almost all of the allocation of allowances was carried out free of charge by the member states under the National Pollutant Allocation Plan (Articles 9, 11 and Annex III), subject to approval of this allocation by the European Commission (Article 9(3)) (Betz & Sato, 2009).

During the same period, an important regulatory addition was the amendment of the Directive (2003/87/EC) concerning the addition of the flexible mechanisms of the Kyoto Protocol (CDM, JI), known as "the Linking Directive" (2004/101/EC).

The amendment came to recognise the possibility for Member States to allow operators to use credits from Joint Implementation (JI) and Clean Development Mechanism (CDM) projects, excluding those generated by nuclear installations and those relating to land use, land use change and forestry project activities, within the Community scheme. Credits from Joint Implementation (JI) projects are called emission reduction units (ERUs) and credits from CDM are called Certified Emission Reductions (CERs). Arrangements have also been made so that ERUs and CERs are not counted twice when they are resulted from activities that also result in the reduction or limitation of emissions from covered installations pursuant to Directive 2003/87/EC.

The aim of the "Linking Directive" (Directive 2004/101/EC), was to strengthen the link between European and international practice by making the Kyoto Protocol project mechanisms (Joint Implementation and Clean Development Mechanism) compatible with the ETS. In this way, operators will be able to use these two mechanisms under the ETS in order to comply with their respective obligations. The main advantage for covered installations is the reduction of compliance costs for them.

The next important milestone in the regulatory development of the ETS was Directive 2009/29/EC which marked the second phase of the ETS. A significant event of that period was the entry of new states into the system (Norway, Iceland and Liechtenstein) and the consequent need to harmonize the procedures for the control and establishment of emission registries for non-EU countries. The third phase of the ETS (2013-2020) was based on a number of important rearrangements of the regulatory framework through the revision of the base Directive (2003/87) and in particular Article 10 which concerns free allocation by Member States. The main purpose of these amendments was to centralise the management of the system in
terms of emission registries, to introduce a pan-European emission reduction limit (1.74 % per year) and to implement a harmonised system for the benchmarking of free allocation of allowances. At the same time, Member States for which the financial pressures of the scheme were considered to be a barrier to modernising their energy sector were allowed to receive further free allowances (Article 10c).

The issue of oversupply of allowances is also being addressed through the Market Stability Reserve Mechanism, which aims to temporarily withdraw reserved allowances from the system in the event of low allowance prices. The evolution of the legal framework of the system so far outlines an attempt to centralise the parameters and mechanisms.

In the fourth stage of the ETS (2021-2030), the influence of the Paris Agreement (2016), and in particular the contents of Article 6, which concerns the evolution of emissions trading schemes, becomes clear. In particular, the Agreement places particular emphasis on international cooperation on the transfer of external offsets, effective monitoring to avoid double counting and the evaluation of the flexible mechanisms of the Kyoto Protocol (Sato et al, 2015) At the same time, commitments for further emission reductions appear to have an impact on the targets of the Directive, through an increase in the limit reduction rate from 1.74% to 2.2% per year, resulting in an overall reduction of 43% compared to 2005 levels (Stulmacher et al., 2019). In addition, funds for the promotion and implementation of renewable energy technologies are being set up, for the industrial and energy sectors of the Member States. Exceptionally, the provision of free permits to the energy sector of MS falling under Article 10 (paragraph 3) will continue to apply in the fourth phase of the scheme. Special reference should be made to the maintenance of free allowances in the industrial sector due to the risk of carbon leakage, despite the lack of data to support the existence of this phenomenon.

5.3.2 Structural and Functional Structure

Each covered facility needs a permit to emit greenhouse gases. Subsequently, permit holders purchase or receive free of charge 'emission allowances' expressed in tonnes of CO2 equivalent, which will allow them to emit the corresponding volume of greenhouse gases for a specified period of time. If, at the end of the period, emissions exceed the "allowances" of the installation concerned, then "allowances" must be
obtained from the market, mainly through the auctioning system, for the additional quantities of emissions, otherwise a fine is imposed. As regards the price of tradable emission allowances, this is not subject to regulatory pricing rules but is determined by the law of supply and demand.

5.3.3 Emission cap
Each year, the EU sets a cap on total emissions. Within this limit, the companies can buy and sell emission allowances depending on their emissions and their needs. The emissions cap is reduced over time, so that there is a reduction of emissions in overall emissions.

Over the last few years the EU has been trying to reduce the levels of the emissions cap. To this end, from 2013 onwards, it was decided to reduce the total number of allowances by applying a Linear Reduction Factor of 1.74% per year, averaged over the period 2008-2012. In the long term, the current linear reduction factor will lead to an emission reduction in the ETS-EU system of about 71% in 2050 compared to 2005 for all countries participating in the system. An increased linear reduction factor would result in even larger emission reductions. In order to meet the target of a 40% reduction in 2030, compared to 1990, EU ETS emissions would need to be reduced by 43% compared to 2005 and the overall emissions cap would need to be reduced each year by a linear reduction factor of 2.2% from 2021 onwards. This would result in an 84% reduction in EU ETS emissions in 2050 compared to 2005 (Stulmacher et al., 2019).

However, in recent years, the economic crisis has contributed to a reduction in emissions and demand for emission allowances. Combined with other potential factors, this has resulted in a decline in the carbon price and the accumulation of a large surplus of allowances in the system, with the result that there is a visible risk that the ETS no longer provides an incentive to reduce emissions in a cost-effective manner or to innovate in low-carbon technologies (Hintermayer & Martin, 2020).

For the EU to achieve the above-mentioned objectives, it will need to ensure that its main instrument for achieving them, the ETS, continues to function properly. As a first step in this direction, the EU, following a temporary freeze on the auctioning of certain CO₂ allowances ("backloading") during the first years of the 3rd period, decided to create a Market Stability Reserve for the ETS. With the surplus of
allowances reaching 2.1 billion in 2013, the purpose of the reserve is to correct the accumulation of the large volume of surplus allowances and to increase the robustness of the ETS against imbalances between supply and demand (Convery, 2019).

This development was a precursor to a comprehensive Commission strategy. Thus, on 15 July 2015, as already mentioned above, the Commission presented a proposal for a broader review of the ETS. The aim of the proposal is to give legal force to the European Council's guidelines on the role of the ETS in meeting the EU’s 2030 greenhouse gas targets. The proposed changes also aim to encourage innovation and the use of low-carbon technologies to create new employment and growth opportunities while maintaining safeguards for the competitiveness of European industry.

5.3.4 Allowances distribution
During the first and second period of emission trading, almost all allowances were distributed free of charge. Allocation was based on National Allocation Plans (NAPs), under which each Member State determined both the number of allowances to be received by each installation and a limit the use of CDM and JI emission credits to meet their obligations (Betz & Sato, 2006). The benchmark for the allocation of allowances during the first two phases of the ETS was historical emissions, i.e. the level of emissions that covered installations had in the past. All national allocation plans were submitted to the Commission for evaluation and Member States were entitled to auction up to 5% of their total allowances in the pilot phase and up to 10% in the second phase. In reality, this option was not used by Member States (Betz et al, 2004).

From the third period, auctioning (from the primary market) became the default method for the allocation of rights. However, the element of free allocation still exists, mainly to protect the internationally competitive industry from carbon leakage. During this period, free allocation of allowances is carried out on the basis of fully harmonised rules and benchmarks.

The national allocation plans used in the first two periods were abandoned due to their complexity, non-harmonisation and lack of transparency (Convery, 2009). What is now required of Member States is to communicate the quantity of allowances to be allocated to each installation within their territory by notifying the Commission of
National Implementation Measures (NIMs). Member States remain responsible for the collection of data and the final decision on the allocation of allowances, while the Commission is required to approve all or part of the national implementation measures submitted to it and to request changes where necessary.

5.3.5  **Auction of allowances**
Auctioning is a transparent method of allocating allowances that allows participants to acquire allowances at market conditions (price and supply). The basic starting point of the auctioning system is the 'polluter pays' principle.

According to Directive 2009/29/EC, the auctioning of allowances begins from the third trading period (2013-2020) onwards (and in the case of aviation, from 2012 onwards) is the norm for the allocation of allowances within the EU. As already mentioned, during the first two periods of the ETS, although auctioning of allowances was possible, this alternative was not preferred and only 4% of the total allowances allocated were auctioned in the second phase.

5.3.6  **Allocation of Auction Rights for NER**
Before the determination of the total number of allowances to be auctioned within the EU, a 5% of the total quantity is reserved to be allocated free of charge to New Entrant Reserve (NER) installations. If these allowances are not ultimately allocated to New Entrant installations or other eligible purposes as defined in the Directive (Article 10a(7) of the ETS Directive), they are also allocated to Member States to be auctioned.

The allocation of auctioning rights between Member States in Phase 3 is defined in Article 10 (2) of the ETS Directive:

- 88% of the allowances auctioned are distributed to EU Member States on the basis on their share of verified emissions installations in 2005.
- 10% is allocated to the less wealthy EU Member States as an additional source of income to help their economies invest in emission reductions and adapt to climate change.
• The remaining 2% is given as a "Kyoto bonus" to nine EU Member States that by 2005 had reduced their greenhouse gas emissions by at least 20% of the levels in their Kyoto Protocol base year or Protocol period. These are Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, the Czech Republic, Estonia, Latvia, Lithuania, Poland, Romania and Slovakia.

5.3.7 Auctioning Platform

Another provision of the directives for the third ETS period is the operation of a common platform for the auctioning of allowances on behalf of Member States. The idea of creating a common auction platform was inspired by the principles of non-discrimination and transparency in order to provide guarantees for full, adequate and fair access for all companies covered by the ETS with the ultimate aim of reducing the risk of market abuse.

As mentioned before the operation of the emissions trading system over time increasingly limits free allocation, strengthening the auctioning process, which is carried out within organised market structures, the so-called Emissions Exchanges. The market function of the emission exchange is similar to that of the others. In the auction process, individual sellers make a purchase declaration, known as bids, and the buyers submit an offer for the product in question, thus investing in current or future projects and business activities. All greenhouse gases included in the Protocol are tradable on the basis of their greenhouse gas contribution index, which determines their price in terms of tonnes of carbon equivalent.

Emissions trading products can be divided into 4 main categories related to the directives:

• Spot trades: refer to products for immediate delivery, for which the terms are clarified on the day of the transaction and payment is initiated within a short time frame.

• Options: members either buy and sell options or set a future strike date on which the agreed purchase and sale will take place.

• Futures contracts, also known as "futures": which involve agreements to buy and sell, of an impersonal nature, between two parties, with predetermined terms at the time of purchase and sale concerning price, quantity and date.
- Forward settlement: transactions similar to spot settlement, but for which a subsequent payment date is set at the time of the transaction.

The auctions take place on two markets: the European Energy Exchange (EEX) based in Leipzig and the Inter Continental Exchange (ICE), based in London, for the UK auctions, following the request of UK request for self-exclusion. The European Union's first Transitional Common Auction Platform (EU TCAP) was abandoned and moved to the European Energy Exchange AG (EEX) as the common auction infrastructure and operates at (EEX), following a decision by the European Commission and the participating Member States. It is the largest primary and secondary carbon market platform in the world. In this venue, common contract auctions are held for the members of the European system, with Poland participating provisionally, following a request for an exemption from the common contract procedures and pending its own auction venue. Germany operates on the EEX under the self-exclusion procedure.

5.3.8 Auctions Process
EEX conducts weekly primary auctions of the Spot Market - EUA:

- On behalf of the 25 Member States and the 3 EEA EFTA States participating in the common auction platform, every Monday, Tuesday and Thursday from 9.00-11.00 am,

- on behalf of the Federal Republic of Germany, every Friday from 9.00 to 11.00 a.m., under the code Spot Market - EU Primary Auction CAP4 - EUA.

- On behalf of Poland, every second Wednesday at the same time as the previous two Wednesdays, under the code Spot Market - Polish Primary Auction CAP4 - EUA.

During this two-hour period the collection of orders is processed, the validity of the individual orders is checked and at 11.00 and the auction process starts. The last one to bid is based on the 'black box' method, which consists of blind bidding by the interested party, with reference to the bids of the other bidders. All bids are submitted during a specific bidding frame. At the end of the auction, the distribution of allowances is carried out on the basis of the time of entry of individual orders and the
price. All successful bidders will be required to pay the same clearing price for the auction.

Each individual bid must indicate three basic elements, firstly the identity of the bidder, the price for each licence, expressed to two decimal places, and the quantity expressed as a multiple of a batch of 500 allowances, as defined in the Regulation. The participants have the right to make any change in the quantity auctioned and cancel the whole process.

The Spot Market Primary Auctions - EUAAs for states participating in the common auction platform are held every two months, starting in March, on Wednesday at 15.00. The auctions of EUAAs for Poland and the Federal Republic of Germany, on the other hand, shall take place once a year for each of them, at the same time. The product code of these auctions is EAA4.

5.3.9 Funding Programs Funded By the EU ETS
The profits of allowances are contributing to the Innovation Fund, the Modernisation Fund and the NER 300 Programme, which provide financing for many green actions and are recognised in the European Green Deal Investment Plan as the main financial instruments contributing to the objectives of the European Green Deal.

• NER300

The EU's NER 300 Programme is the world's largest programme for financing innovative renewable energy and carbon capture storage projects in the EU territory, as a key strategic environmental financing instrument of the Union (50% contribution).

It owes its name to the 300 million emission allowances that contribute to the funding of the fiancé program, as referred to in Article 10 of Directive 2009/29/EC. The CCS projects financed are mainly in the power generation and industrial sectors of refineries, steel and iron and steelworks. The categories of renewable energy projects relate to hydroelectricity, photovoltaic systems, solar, wind, geothermal and ocean energy, bioenergy, and smart grids for automatic monitoring of energy flows. According to the data provided, in the first funding cycle, starting in December 2012, €1.1 billion was offered for the implementation of renewable energy projects and
subsequently in the second cycle, in July 2014, €1 billion was distributed to one CCS project and 18 renewable energy projects, respectively. This funding, led to the leveraging of private capital of €1.9 billion in the first cycle and €860 million in the second cycle (Marcantonini et al, 2017).

• The Innovation Fund

This fund also draws its funding from the European Emissions Trading Scheme, as well as from undisbursed NER 300 funds. It is the continuation of the NER300, due to its flexibility in terms of funding and the simplification of the selection process, thus improving risk-sharing. This fund supports carbon capture and utilisation (CCU), carbon capture and storage (CCS) projects, renewable energy projects, innovative technology projects from energy-intensive industries, and energy storage projects. It is estimated that, based on the projected carbon price, the fund's revenues would amount to 10 billion (Marcantonini et al, 2017, Borghesi et al, 2016).

• The Modernisation Fund

It is a special programme that provides financial support to the 10 economically weakest Member States in their attempt for transition to climate neutrality to modernise their energy systems and improve their energy efficiency.

According to European Union figures, the total amount to be distributed to the beneficiaries of the programme for the period 2021-2030 is the profit of 643,232,888 allowances. The investments supported by the Fund concern energy storage, energy efficiency, renewable energy production and use, restructuring of energy systems in coal-dependent regions, as well as energy network modernisation projects, including district heating, pipelines and grids (Marcantonini et al, 2017).

The financing of this fund comes from the profits of the auctioning revenues of 2% of the European emissions trading scheme for the period 2021-2030.
5.3.10 EU ETS Phases

Phase 1 (2005-2007)

The first phase covers the three-year period 2005-2007. It included around 12,000 installations, responsible for 50% of emissions on EU territory. It followed a learning-by-doing approach and, due to a lack of reliable data, was based mainly on empirical estimates.

It was considered a pilot phase, preparatory in nature since it preceded the implementation of the Kyoto Protocol, which had a starting year of 2008. It was used by the European Union as a readiness test under Directive 2003/87/EC, with the aim of gaining experience, improving infrastructure and monitoring individual procedures in order to ensure compliance with the Protocol (Martino & Trotignon, 2013).

As mentioned above the calculation of the cap was carried out with a decentralised organisation structure, thanks to the National Allocation Plans (NAPs), where each Member State holds the quotas by sector and number of installations. In 2005, the cap was set at 2,096 MtCO2eq. (Betz & Sato, 2006) No binding targets were foreseen and 95% of the allowances were allocated free of charge on the basis of historical emissions data (grandfathering) with the remaining 5% to be auctioned (Hintermann, 2010).

Under the grandfathering method, the free allocation of allowances to installations is based on the estimated quantity of emissions, according to previous levels of average annual emissions. (Martino & Trotignon, 2013) The installation holding the emission allowance, after calculating the quantities of its actual emissions produced, proceeds to purchase other allowances if the ones it holds are not sufficient or sells them in case of surplus or, if it is more advantageous, intervenes in its structures in order to reduce the level of CO2 emissions produced to reach the limit of the allowances it already holds.

The choice of individual practices is determined by the cost-effectiveness of buying the necessary shares, rather than by the investment of an energy rebalancing. The ease of adopting or not adopting an emissions reduction solution depends on the cost to this adoption compared to the market price of CO2.
The scheme covered power plants > 20MW and heavy industry (oil refineries, steel, cement, lime plants) and paper mills, to which free allowances were granted.

The penalty for non-compliance was €40 per tonne of coal equivalent.

The achievements of this period were the creation of a price for carbon, the construction of the infrastructure for monitoring, reporting and verifying emissions, and the implementation of trade within the Community. (Martino & Trotignon, 2013) On the other hand, the total number of allowances issued as supply exceeded demand, which resulted to the price in 2007 to be zero, as the use of allowances would not be valid in the second implementation period.

Furthermore the first phase of eu ets lead to a 1.9% increase of the total emissions.

Phase 2 (2008-2012)

The second phase of the European emissions trading scheme was the same as the initial period of the Kyoto Protocol (2008-2012). The emissions target was reduced to 6.5% compared to the 2005 level, thanks to the verified data available from the first period. The experience gained from the first trial phase led to a doubling of the number of permits auctioned (10%), with a consequent reduction of the free allocation to 90%. The penalty clause rose from €40 to €100. As in the first phase, it was the national allocation plans that would determine the overall per-country emission limits. In 2009, the cap was set at 2,049 MtCO2eq (Sanin et al, 2015).

From the beginning of the period, EU ETS installations were allowed to use carbon credits in respect of the other two mechanisms proposed by the Protocol, JI and CDM, with the exception of activities related to the agricultural sector and nuclear power, which were not used in the first period, in accordance with Directive 2004/101/EC. In this phase, the use of these credits provided installations with a total capacity of 1.4 billion tonnes of carbon, which gave a boost to the European system, increasing its competitiveness and making it the world's largest source of demand for allowances (Betz & Sato, 2009).

In the second phase, three additional countries, Iceland, Norway and Liechtenstein (01/01/2008) entered the scheme from the group of countries belonging to the so-called European Free Trade Association (EFTA) and on 01/01/2012, the aviation
sector was added to the scheme by Directive 2008/101/EC, but with a different calculation of the emission cap compared to that of stationary installations. The newly introduced sector was in turn included in the Single EU Registry, which was implemented from 4 May 2013 and came to replace the individual national registries, consisting of more than 30,000 accounts.

The inclusion of emissions of polluting gases also includes nitrous oxides (from the production of nitric acid).

Phase 3 (2013-2020)

In 2013, the ETS is entering its main phase, after the first two phases, which helped to acquire the necessary knowledge and acted as a guide to collective European action through the adoption of reciprocal measures.

In the current phase, all the Member States of the previous period continue to participate in the system, with the addition of Croatia (01/01/2013). A series of innovative changes and harmonised rules among the participants characterise this period, with the aim of achieving the common environmental goal.

The first key change is in the distribution system, which is moving from the national free allocation based on historical emissions data that took place during the two previous phases (grandfathering) to a single allocation based on the emissions of benchmark installations per industrial sector (Danchev & Maniatis, 2014).

The benchmark, is a comparison factor, obtained by an ex ante calculation conducted by the Commission, through which the amount of emissions emitted for the production of one product is calculated, based on the principle that a product unit should be equal to a benchmark. This factor is then multiplied by the forecast level of production to obtain the quantity of free allowances distributed per unit of industry. Installations that meet the criteria will receive annually the quantity of allowances required for their production while those that fall short of the benchmarks will have to purchase additional allowances to cover their emissions.

The financial crisis of 2009 created a decline in carbon prices, with a consequent weakening of the motive to reduce emissions. The surplus of allowances as a result of
weak demand reached 2.1bn in 2013, making the need for change urgent due to the serious short and long-term impacts on the system.

In 2014, the Commission redefined the plan regarding auctions, implementing a "back-loading" system, which consisted of retiring allowances, with refeeding later. This system seemed ideal, as it changed the allocation of allowances without reducing their volume, which could lead to a balancing of supply and demand, and therefore to a balancing of the price.

In 2014, 400 million allowances were withdrawn, in 2015 300 million, and in 2016, 200, i.e. a total of 900 million allowances over three years, which, while initially to be auctioned in 2019-2020, were decided to act as a reserve.

The MSR (Market Stability Reserve) started operating in to secure In addition to the retired allowances mentioned above, it was also decided to include all unallocated allowances in it.

In addition, the method of auctioning was adopted as a basic tool for distribution, which aimed to improve the efficiency of the system. Although auctioning is not a perfect distribution method, it is an efficient way of distributing as it generates public revenue and provides incentives for early action against climate change. During that time the auctioning of allowances would be carried out through EU TCAP, until the launch of the Common Platform, which currently involves 24 out of 27 European Member States.

Directive 2009/29/EC outlines the guidelines for the regulatory measures in the field of rights distribution at this stage. According to it for the year 2013, a single pan-European cap of 2,084,301,856 allowances was established for fixed installations. The linear reduction factor was calculated on the basis of overall emission reduction targets of 21% in 2020, taking 2005 as the base year or 20% taking 1990 as the base year.

The 2009 Directive also dictates additional sectors that will be included to the EU ETS, as well as more greenhouse gases, are introduced into the scheme to update those defined by Directive 2003/87 /EC34. It is important to mention, due to their responsibility for 3% of total polluting emissions, the inclusion of aviation, covering flights within the European Union, as well as those operators whose flights are served by at least one airport in European territories. For this sector, a different limit is set.
compared to that of installations, which will apply in the years of phase 3 and will correspond to 5% less than the annual average emission limit for the period 2004-2006.

Phase 4

For the period after 2020, the "20-20-20" target was set in the framework of the European Climate Change and Energy Policy, which includes a) a 20% reduction in greenhouse gas emissions, b) a 20% reduction in energy use by achieving energy efficiency, c) a 20% increase in the use of renewable energy sources for energy production. Subsequent Community actions launched the implementation of the Energy Charter 2050 and the reduction of gas emissions by 80-95% by 2050, compared to 1990 levels.
5.4 BLOCKCHAIN AND DISTRIBUTED LEDGER TECHNOLOGIES

Distributed Ledger Technology (DLT) is one of the achievements that were created by the reshaping and evolving of existing technologies into an innovative idea. The key idea behind DLT systems is the ledger which consists of a collection of all kinds of data, a bookkeeping or a complete archive of transactions in order to record information and group each piece logically.

Information on the whole has been valuable and of great importance to everyone since antiquity. The earliest ledger of human history dates back to four thousand years ago, when people from a Sumerian city called Uruk used to record their everyday taxation and payment transactions on clay tablets which could only be validated by a central authority. Throughout the years, almost every ancient empire had been deploying their own ledger. In modern times though, the ledger has been in the center of modern civilizations, including not only financial records like taxes and payments but a broader spectrum of assets. In the middle of 20th century, when the computer revolution began, paper became byte and physical data was replaced by the digital ones. As it was expected, the ledgers were affected by the rise in the use of computers and adapted themselves to the digital world (Mingxing et al., 2018). Despite the technological evolution, the fundamental principle remains the same, that is, ledgers are controlled and managed by a central authority.

In order to define the Distributed Ledger Technology, there are some technologies that need to be further explained.

5.4.1 Centralized Systems
Centralization refers to a system where all actions, operations, computation and storage are controlled, managed and applied by a single central authority. Every participant in this system is connected to and dependent on a single entity (Singhal et al., 2018).

According to the centralized approach, a system is created, maintained and managed by a central authority. A single trusted authority controls the system, its data and is responsible for all operations taking place in it. All users must be connected to this
authority in order to interact with the system. This approach is a common means to
develop information systems and store data today while providing an easy way of
designing, maintaining and controlling. However, there are serious risks and
limitations in production. In a centralized system, users depend on a single point of
control and a single point of failure, which means that every participant must trust the
single authority. Also, there is a reduction in the performance, stability and scalability
of the system

5.4.2 Distributed Systems
The term “distributed” refers to the technical characteristics of a system. In a
distributed system, all the computational power and data are distributed among nodes
which are in arbitrary physical locations (Singhal et al., 2018). Nodes are sharing
resources and functioning together in order to achieve the same goal and although
they appear as a single “machine”, they are in fact independent on each other. One of
the main characteristics in a distributed system is that the time required for the
communication between the nodes is comparable to the time required for a complete
operation in a centralized system. Finally, in a distributed system the computational
power and data may be shared thus increasing the functionality of a system but a
central authority still exists and manages the entire system.

5.4.3 Decentralized Systems
The need for the removal of a central authority led to a different type of system
control, the so-called decentralized system. This is a form of system where all
participants are not dependent on a single trusted authority but the control is shared
among them. All participants have equal privileges in decision making in the system.
This consequently provides the decentralized systems with more democratic and fair
characteristics
5.4.4 Distributed Ledger Technologies
Distributed Ledger Technology (DLT) is a general term that refers to a decentralized and distributed ledger between participants of a network. The ledger constitutes a collection of transactions which functions as a special kind of database which can be replicated and distributed throughout the network. Furthermore, there is neither a single point of failure nor a central authority and thus the participants control, maintain and update the ledger themselves while being equal to each other.

The trust among participants is achieved by protocols that are based on cryptography. In this way, participants may not trust each other but they are certain that the content of ledger is valid. A copy of the ledger can be stored locally by every participant and the stored data is immutable, complete, consistent and always available on request. Since the main feature of DLT is a distributed network that depends both on participants being in arbitrary physical locations and protocols that following cryptography principles, it provides tolerance to crash faults and is considered a complex and difficult cyber attack target (Mingxing et al., 2018).

5.4.5 Blockchain

Blockchain is the most common type of Distributed Ledger Technologies. The concept of blockchain was introduced in Satoshi Nakamotos’ white paper “Bitcoin: A
Peer-To-Peer (P2P) Electronic Cash System”. This described a digital currency, which allows participants of a peer-to-peer network to transact directly without, however, having to deal with a trusted third party (TTP). In fact, the first blockchain implementation dates back to 2009, when the genesis block of bitcoin was originally released (Nakatomo, 2008).

Although the first implementation of blockchain was initially about a decentralized digital currency, this breakthrough technology has been quickly adopted by the computer science community, due to the special characteristics and benefits it can provide. Nowadays, blockchain technology has not only been used in the financial world but its usage has spread in various sectors including supply chain, health care, identity management or even in video-games (Singhal et al., 2018).

Blockchain is a cryptographically secure distributed and shared ledger that is immutable and append-only. However, it can only be updated via consensus mechanisms among peers in a peer-to-peer system. Blockchain is generally regarded as a complex system that combines different technologies in order to achieve its purpose. Each blockchain implementation is quite different but the major components at its core are peer-to-peer networks, cryptography, consensus and smart contracts (Bashir, 2018).

The ledger of the Blockchain is a chain of blocks which contain all kinds of data and it is distributed among participants. Technically, it is a database that stores data in a form of transactions. A transaction is a recording in the block and a block contains a bunch of transactions which are organized logically. The blockchain can store millions of transactions but it must guarantee their integrity. Transactions in a block are linked to each other through the use of the Merkle tree. A Merkle tree is a binary tree where every non-leaf node contains a hash value of its child nodes and every leaf node contains a hash of a specific transaction data (Mingxing et al., 2018).

Every block is unique and identified by a hash function while it is also cryptographically linked with the previous block hash. The hash function of each block is produced by the previous block hash, the hash of the merkle tree root, the timestamp and other meta-data. In this way the data of a block is immutable, since a change to data leads to completely different hash functions and consequently to different chains of hashes. Block 0 is a special block that contains the initial configuration of the network (Bashir, 2018).
Consensus is vital for blockchain and represents the center of decentralization. Since there is no central authority to control the network and all participants have equal privileges there is one main problem known as “Byzantine Generals Problem”. Byzantine Generals Problem is about the fact that all participants must agree on a common behaviour pattern or action but they cannot trust each other. The consensus is ultimately achieved when the order and results of transactions in a block have satisfied all the predetermined rules that defined in the blockchain network and every participant has the same copy of ledger. Consensus protocols aim at eliminating the trust problem among unknown participants as well as at ensuring that every transaction which have been added to the ledger is valid. Therefore, every participant can be certain about the validity of each block (Mingxing et al., 2018).

One major element of blockchain is the smart contracts. Smart contracts define both the business processes and the shared data in the blockchain network. Smart contracts are not just computer programs that facilitate the exchange of data that is stored in the blockchain but constitute an agreement among participants as well. Smart contracts are embedded in the blockchain and executed through transactions. The execution of smart contacts must be deterministic and the peers that execute a smart contract according to the same ledger must come up with the same result.

![Blockchain structure](https://www.zdnet.com/article/cryptocurrency-101-what-every-business-needs-to-know/)

5.4.6 Blockchain Characteristics
Some of the main functional characteristics of the Blockchain technology are:
• Decentralization: Blockchain is an effective mechanism for the building of decentralized systems. Since blockchain uses a distributed network there are no central points of computation and thus there are no single points of failure. Furthermore, in blockchain systems the data is replicated among nodes and maintained by trust mechanisms. Every node has a copy of the data while it is ensuring the data quality. A trusted third-party is unnecessary, since all nodes are equal to each other in terms of decision making for the system and a distributed consensus mechanism is applied. This further provides a fully decentralized system with democratic and fair characteristics and high efficiency in performance as well.

• Transparency: As every transaction and data are shared among the nodes of the network, the network becomes highly transparent and trustworthy. Everyone may access all the transactions that have been carried out and verify the state of the ledger at any given time. Also, transparency prevents all kind of counterfeiting and integrity problems that can be caused in a decentralized system.

• Immutability: Once a transaction has been recorded in the block and the block has been added to the blockchain, it cannot be altered or removed by any participant. Thus, an immutable ledger, that provides high data integrity, is created. This however comes in contrast with traditional databases in which data can be edited or removed at any time.

• Consensus Driven: A transaction is considered valid and recorded in the blockchain on condition that there is mutual agreement among participants. Consensus provide an way of validating the transactions according to the existing rules. If a transaction violates a rule, it is considered invalid and thus it is not added to the blockchain. In this way, the blockchain network is consensus driven. (Mingxing et al.2018, Bashir, 2018).
5.5 PROBLEMS WITH EXISTING CARBON MARKETS

Interconnection of the markets

Seong-Kyu Kim and Jun-Ho Huh (2020) mention that a big problem with existing carbon markets is that they lack of an efficient way to interconnect the existing carbon markets together in order for them to cooperate for their common goal on reducing GHG. They locate the problem to the inability of the existing markets to be ruled under the same one central authority. The same issue is also mentioned by Richardson & Xu (2020) who are elaborating to the formulation of the problem by adding that the need for a common carbon market is also stressed by Article 6 of the 2018 Paris agreement, they argue that due to the fact that carbon markets are not interconnected other issues immerge such as fraudulent activities. Jackson et al. (2018) also support this opinion by mentioning that a solution to this problem will lead to the creation of a common and more sustainable carbon price (Sadawi et al., 2021), motivation to the stakeholders to implement innovative technologies in order to reduce their emission, incentives for carbon mitigation project funds, transparency and better monitoring.

Double-Spending

Another problem that is cited in multiple resources is the issue of double-spending (Mandaroux et al., 2021, Schneider et al., 2015). Double spending refers to the act of selling or using carbon credits that are either non-existent either not belonging to the seller either using or selling the same carbon credit to multiple parties (Scheltz et al., 2020). An interesting statistic about the problem of double spending is referred to an illustration of INTERPOL which mentions that the carbon credits that where generated by reforestation project resulted an 70.000.000 € fraud in 2010. The reason for this is that carbon credits are not in a physical form thus making the detection and monitoring of such actions very difficult.

Transparency

Transparency is an issue that is creating many problems to the implementation of the market mechanisms. Scheltz et al. at 2020 believe that the inability for proper information transmission between the interested parties of the Kyoto Protocol, such as auditors, regulators and stakeholders, has led to a decline of the success of the target
emissions. According to Schneider et al. 2015 and La Hoz et al., 2017 this problem originates to the asymmetry of information that is caused due to lack of proper monitoring and reporting systems. This is also stressed by Franke et al, 2020 who argues that the solution to this problem would be either equal data accessibility either a way to monitor the actions and project proponents of all participants effectively.

**Carbon price & Carbon Surplus**

Another frequently cited issue of carbon markets is the determination of the carbon prices and the surplus of carbon credits. Two issues that are related to each other. According to EEX the prince of the EU ETS carbon allowance for the years of 2013-2022 fluctuates between the prices of 10-87 € per mtCO₂. Liss (2018) mentions that in order to create pressure and motivate the stakeholders to reduce their emission this price should above 110 € per mtCO₂. According to Koch et al (2014) the problem with the carbon prices originates from their surplus. A good example that supports this view it the surplus of emissions of the EU ETs. The issue was first observed during the economic crisis of 2008. Industries were either stockpiling either selling their emission allowances due to reduced production and demand or due to closing due to bankruptcy respectively. From 2014 and onwards about 200 million allowances were stored by stakeholders each year (Richardson & Xu, 2020) which resulted about 900 million of allowances at 2016 a number close to the half of total emissions of the market.

**Administrative Costs**

Administrative costs are the problem that prevents smaller enterprises and less developed countries to join the carbon markets (Richardson & Xu, 2020). Franke et al (2020) emphasize that the administrative costs for transaction fees and participation to CDM and JI projects of the Kyoto protocol are so high that in Holland one fourth of the emission allowance price is the transaction fee and seventy eight percent of the total cost for CDM and JI projects of New Zealand is consisted of administrative cost. Michaelov et al (2020) express the opinion that the main reason for the high administrative costs is the need for centralized authentication of actions. (Leonard, 2020)
**Fraudulent Activities**

Probably one of the most important problems that carbon markets face is the problem of fraudulent activities. Fraudulent activities refer to a plethora of illegal activities that are conducted by either stakeholders or criminals who seek to gain profit by exploiting loopholes of the systems. The most important activities of this category are the tax fraud, hacking and misuse of the weak law of the markets (Mandaroux et al., 2021).

The most well-known occurrence of the vat fraud was observed in the EU ETS. Sellers were taking advantage of the EU ETS policy that dictated that carbon allowances that were bought from other EU countries were VAT free (Frunza, 2013) (Nield & Pereira, 2016). Sellers were buying such allowances from platform markets and sell them to their countries with the VAT applied and after several transactions they were disappearing stealing the profits from the VAT. This activity was first observed in 2009 in the French trading carbon platform of BlueNext. This actions resulted a loss of 5,000,000,000 € according to INTERPOL. In order to stop this phenomenon the commission created the reverse VAT mechanism by which the VAT should be paid by the party that received the allowance. However this directive was not mandatory for the members of the EU ETS thus according to ECA in 2015 one third of the members were not following this directive (Mandaroux, 2021).

The second type of fraudulent activities refers to hacking activities that take place in order to steal carbon credits. Such activities occurred in the beginning of 2010 and resulted more than 3 million carbon credits being stolen from countries such as Romania, Italy, Austria, Czech Republic and Greece with only one third of them being retrieved (Mandaroux, 2021).

The third type of fraudulent activities refers to the exploitation of the weak legislation of the EU ETS and the heterogeneity of the system. Stakeholders seek for loopholes due to the combination of the EU ETS legislation and their national legislation in order to operate in a less regulated environment.

**Monitoring**

Finally another issue that emerged from the literature review is the lack of existence of a proper mechanism that is able to monitor transactions and data. Even though
there is a central datacenter that operates under the jurisdiction of the commission the access to this data is restricted thus raising trusting issues. (Pan et al., 2018) (Zhao & Chan, 2020)
As presented on the previous chapters the carbon markets seem as very promising system in the attempt to tackle the climate change. As we can understand these systems are not flawless and face several problems which are created mainly due to the short life of the markets. Blockchain as an innovative technology is capable of contributing to the improvement of the markets according to literature through various methods. On this chapter the utilization of a framework developed by the world economy forum entitled “Blockchain Beyond the Hype A Practical Framework for Business Leaders” (World Economic Forum, 2018) takes place in order to assess the applicability of the blockchain technology to the carbon markets and to present in each criteria of the framework the method that blockchain can be applied. The Framework is consisted of 12 yes or no question that enables the evaluation of applicability of various use-cases to the blockchain technology.
1. Are you trying to remove intermediaries or brokers?

In most carbon markets there is a small amount of official bodies that act either as regulators or as technical experts for the smooth operation of the market. A good example of this is the CDM registry of the Paris Agreement that is run under the jurisdiction of the United Nations Framework Convention on Climate Change. Despite the fact that those bodies are generally trusted their utility will always be
followed by concerns. The application of blockchain technology to these criteria could ease the actions of monitoring, reporting and verification through automating most of the procedures via the utility of smart contracts and distribution of the data to all interested parties eventually creating transparency. (Franke et al. 2020, Richardson & Xu 2020)

Another case of intermediaries in the carbon markets is the existence of carbon traders like EEX. Through the application of blockchain to carbon markets the existence of carbon traders will not be needed since all of the transactions will be made decentralized and peer to peer (Khaqqi et al. 2018, Karakott & Skwarek 2020).

2. Are you working with digital assets?

The nature of carbon markets is based on digital assets. In most carbon markets despite the name that is used to describe an allowance/credit/token etc. they represent a digital tradable asset that expresses a certain amount of emission (in most cases as mentioned before 1 Mtn CO₂).

The motive behind the application of a blockchain solution to trade carbon credits is that due to the technology of blockchain the transactions will become faster, since there will be no intermediaries, more transparent and easily traceable. Each credit will bare its whole transaction history and every user of the system will have access to the common ledger. The logic that is described in most of the literature is that each credit can be owned only by one user which is more or less already happening but there are issues, as mentioned before, concerning the ways they are monitored. This will be monitored by an immutable database that will be on every user’s node thus making actions such as double spending or fraudulent activities nearly impossible. (Khaqqi et al., Kim & Huh, 2020, Franke et al., 2020)

3. Can you create a permanent authoritative record of the digital asset in question?

One of the principles of carbon markets is the existence of central database that contains the information about transactions, CDM and JI projects. The application of blockchain technology to such databases will increase the transparency,
traceability, monitoring and evaluation since blockchain creates immutable ledgers that are distributed to every user’s node.

4. Do you require high performance, rapid (~millisecond) transactions?

The need for high performance rapid transaction is an issue of discussion. According to Franke et al. (2020) the market that is run under the Paris agreement is expected to treble its transactions leading to a transaction volume of 1.2 Billion transactions per year.

A big drawback of blockchain system is their reduced transactions speed which called “Scalability Issue”. According though to literature if the transaction volume reaches the amount that Franke et al. (2020) mention blockchain can still offer an efficient solutions. But even if in the worst case scenario that transactions increase above the limit that blockchain can be an efficient solutions the method of outsourcing data to external cloud databases connected to the blockchain is possible (Mandaroux et al., 2021, Richardson & Xu, 2020).

5. Do you intend to store large amounts of non-transactional data as part of your solution?

Through the literature review no evidence was found for the need to save non-transactional data on the proposed systems.

6. Do you want/need to rely on a trusted party? (e.g., for compliance or liability reasons)

According to literature the main motive of applying a blockchain solution to carbon markets is to remove central authority, automate and decentralize the procedures of monitoring, reporting and verification. Of course there will always be a need for a trusted party with increased rights on the system in cases when rules have to been changed. (Zhao & Chan 2020, Mandaroux et al. 2021)

A good example presented in a plethora of papers is that through blockchain and especially through the utility of smart contracts the actions for not complying with the regulation of the system can be automated and be more accurate. (Franke et al. 2020, Leonard 2020).
7. Are you managing contractual relationships or value exchange?

The nature of carbon markets is based upon value exchange and contractual relationships.

8. Do you require shared write access?

In most carbon markets 3 types of actors that require write access exist.

- The General Authority that are responsible for monitoring and validating transaction and regulating the markets
- Technical experts that are required for the validation of CDM and JI projects
- Users that execute transactions

(Kim & Huh, 2020, Richardson & Xu, 2020, Franke et al., 2020, Mandaroux et al., 2021, Zhao & Chan, 2020)

9. Do contributors know and trust each other?

An important element of the carbon markets is the need for trust between users. Since users must account their own emissions and buy/sell carbon credits. The need for the establishment of a trust mechanism is also strong because the interest of the participating parties is not common but it can rather be characterized as competitional. The lesson that has been learnt during the implementation of the carbon markets is that strong motives for either fraudulent activities either false claims appear due to the absence of strong monitoring tools. Thus the application of a blockchain system can contribute to the solution of this problem through the various consensus mechanisms that exist on its technology. According to literature the most suitable and most cited mechanisms are the Proof-Of-Work (PoW) (Alkawasmi et al., 2012, Alkawasmi et al., 2015, Kim & Huh, 2020, Leonard, 2019, Kakarot & Skwarek, 2020) and the Byzantine Fault Tolerance (BFT)(Mandaroux et al., 2021, Franke et al., 2019, Scheltz et al., 2020)
10. Do you need to be able to control functionality?

The functionality refers to the ability of the regulator to make changes i.e. set price caps, set methods for allocation without the obligation of getting approved by the users of the system. That is something that is needed in most carbon markets.
6 DISCUSSION

Evaluating the framework of the World Economic Forum entitled “Blockchain Beyond the Hype A Practical Framework for Business Leaders” we understand that the case of carbon markets seems suitable for the blockchain technology on the common attempt to tackle the climate change, since it provides all the necessary infrastructure to increase its efficiency.

If we attempt to combine the results of the research question 2 concerning blockchain and its components with research question 4 about the applicability of blockchain to carbon markets we manage to come up with solutions about the problems of the carbon markets that were set on research question 3.

The chapter regarding the problems with existing carbon markets identifies 6 main problems.

- The lack of the ability of the existing carbon markets to be interconnected.
  Taking into consideration that the majority of the carbon markets are governed from the same principles, we can understand that the digitization and automation of the procedures, that is enabled through the application of blockchain, cultivates a breeding ground for at least a preliminary linkage between the different markets

- Double spending
  As it was stated in the framework the digital asset of carbon markets are the carbon credits. Through the application of a blockchain system a common and immutable database will be created which will be updating through the various transactions. In order for someone to manage to get away with double spending he should be able to control more than the half of the nodes that are participating to the market.

- Transparency
  As stated above through blockchain the database containing the transactions will be available to all users’ nodes thus creating transparency on every transaction
- **Administrative costs**
  Through the removal of intermediaries and the automation of most of the processes the administrative costs will be reduced. An exception to this might be the utilization of Ethereum platform because Ethereum creates transaction costs in order to offset the amount of energy used for the system.

- **Fraudulent activities**
  Fraudulent activities are divided in 3 categories tax fraud, hacking and misuse of the weak legislation.
  Through the uniqueness that blockchain provides for each credit every transaction can be traced back to the beginning thus even if the seller disappears he still be able to be traced.
  The effect of hacking falls to the same category as double spending so its more or less impossible to happen unless the hacker somehow manager to control more than half of the nodes of the system

- **Exploitation of weak legislation**
  The phenomenon of exploitation of weak legislation and how can blockchain can elaborate to the reduction of this phenomenon is a matter of discussion.
  Smart contracts provided by the Ethereum platform can act as a turnoff of this phenomenon but certainly there are aspects of the legislation that can’t be regulated through smart contracts

- **Monitoring**
  As mentioned previously on this chapter through blockchain every transaction is transferred to a common database which is also saved to every node of the system thus increasing the monitoring of transactions. On the subject of monitoring the emissions a part of the literature mentions that smart IoT devices should be applied on the production lines of industries in order to monitor their operation and automatically extract the amount of emissions.
7 Conclusion

As we can understand from the previous chapters blockchain can surely be combined with carbon markets to assist them in their common goal of tackling the climate change since they can offer efficient solutions to the majority of the problems that were identified.

But consideration should also be taken to the fact that blockchain technology is not a panacea and its application can be also followed with problems such as:

- The scalability issue
- High energy consumption
- High cost of implantation
- Need for specialized knowledge

In conclusion blockchain is an innovative newly emerging technology with applications in a really vast plethora of fields. It can contribute to the improvement of carbon markets through solving a lot of the identified problems but since it is still a new technology there are a lot of aspects that needs to be researched before deciding to apply it to something as big and important as carbon markets.


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