Blockchain enabled carbon emission trading in India

Dibyajyoti Dash, Student, University of Petroleum and Energy Studies (corresponding author)
djdashsrm230@gmail.com
(+91) 797 - 808 - 5352
University of Petroleum and Energy Studies
Knowledge Acres, Kandoli,
Dehradun, Uttarakhand-248007, India
Atul Rawat, Professor, University of Petroleum and Energy Studies
Ashish Ranjan, Student, University of Petroleum and Energy Studies

Abstract:

In today's scenario, every green environmentalist aims to promote policy and business that works for the environment. Carbon dioxide has become a cause of global panic as its concentration is increasing alarmingly in the earth's atmosphere leading to global warming. An opportunity for the trade of carbon credits both within and outside the regulated area was created leading to the formation of a global carbon market. Blockchain technology is represented as a series of blocks chained to each other, which provides credibility and security in various applications. Trading using blockchain would ensure enhanced security, improved transparency and optimized efficiency. Reputation based Blockchain (BCRB) system acts as the foundation for the entire process of carbon emission trading. Reputation based transaction system improves performance and commits to emission reduction effort by setting a trade algorithm. This paper discusses how the blockchain technology and reputation based trading system would affect the carbon emission trading in India and help the participants adopt a long term solution in emission reduction.

Introduction:

Blockchain is a concept that has attracted a lot of attention from various sectors. It is an incorruptible digital ledger technology which is decentralized, distributed and open, capable of storing any information (Zheng *et al*. 2017, 557). It became popular with Bitcoin, which was the first ever blockchain application. A couple of years after the release of Bitcoin in 2009, blockchain technology attracted a lot of attention from various sectors. Several organizations realized that blockchain technology could be used for more than just simple currencies. Global establishments such as the United Nations Framework Convention on Climate Change (UNFCCC) secretariat has also recognized the general capability of blockchain technology. Developed nations such as US, UK and Canada have paid close attention to the development of blockchain technology and its applications in various fields such as financial services, smart contracts in healthcare and music, and smart property. Specifically, transparency, cost-effectiveness, traceability and efficiency of the technology are viewed as the principle potential benefits. Besides, India has also progressively initiated research on blockchain technology.

Hailed as a disruptive innovation of the Internet era, this technology is expected to bring about a major breakthrough in data storage and information transmission. The unique characteristics of blockchain can lead to a major disruption in the climate change. It might also transform the existing models of carbon emissions trading leading to technological innovation and industrial transformation.

The global focus on climate change has shifted dramatically in the recent past. Renewable energy has responded well to the climate change challenge but it remains too expensive, resulting in a slow impact. A quicker reduction of carbon emissions is required to address this alarming issue of climate change at a price less than that of renewable energy and fossil fuels. Blockchain can place a significant impact on its potential to enhance the process of carbon trading.

Review:

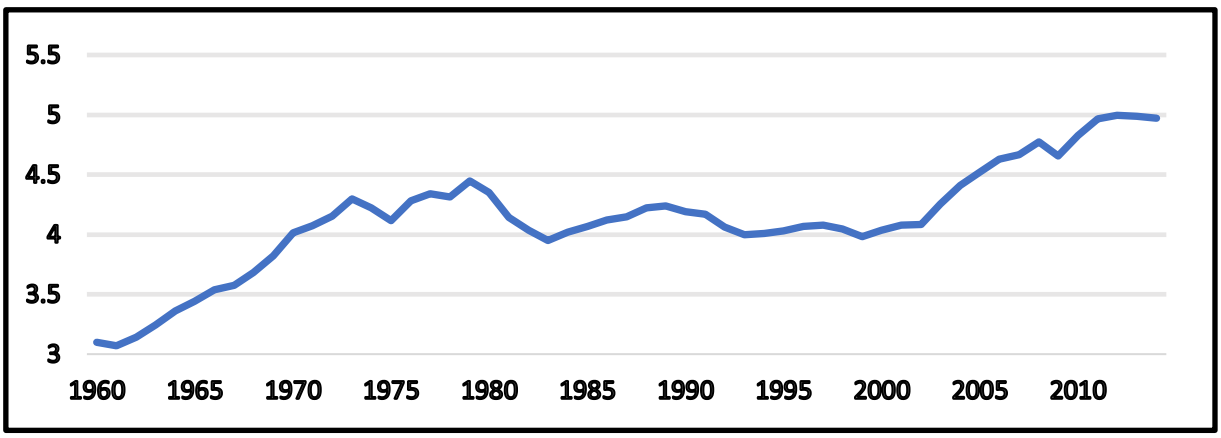
Blockchain, in itself, is a revolution. The first major innovation of blockchain was bitcoin. The current market cap of bitcoin is around $10-$20 billion dollars (Gupta 2017). The second innovation was known as the 'smart contract' embodied on the Ethereum platform. It allowed financial instruments such as bonds and loans, to be represented as separate entities. The Ethereum smart contract platform now has a market cap of around a billion dollars (Gupta 2017). The third major innovation, the current cutting edge of blockchain technology is known as 'proof of stake'. A group with the largest total computing power, known as miners, operate data centres and make the decisions. These innovations represent ten years of work. As the full potential of these innovations hits society, blockchain will gain traction and broad acceptance will eventually come about.

Two important parameters affecting a nascent technology and its business use cases are its novelty and complexity. The more novel it is, the more effort will be needed to ensure that users understand what problems it solves (Iansiti 2017). Complexity is represented by the number of parties that are needed to work together to create value. The scale and impact of blockchain technology will increase with time, and its adoption will require a significant institutional change (Iansiti 2017).

Blockchain technology in energy and commodity trading can transform the existing market space. This would result in high market efficiencies and significant cost savings for traders. Trading and risk management in the financial services sector has led much of the development so far. Still, in the early stages of development, the potential of blockchain technology in trading are broad and promising. Distributed Ledger Technology (DLT) helps a digital system for recording the transactions and their details at multiple places at the same time. Cryptographic proofs lock in the transaction order chain in perpetuity, eliminating any disputes over the sequence of events (Goldberg 2017). Through the application of blockchain technology, there is an opportunity to streamline internal processes and processes shared with external market participants. This can change the landscape of energy and commodity trading. (EY, n.d.).

Carbon dioxide emission in India has been increasing at a rapid rate in recent years. If we monitor the situation closely, India's carbon emission has jumped by a significant margin in the last four decades. **Figure 1** represents the increase in global carbon dioxide emissions represented as metric tonnes per capita. In 2015, the world emitted a total of 32.3 gigatons of carbon dioxide, out of which India accounted for 2 gigatons making it the third largest emitter after China and USA respectively (Andrew 2018). The study titled 'Carbon Dioxide Emissions from Fuel Combustion 2018' by International Energy Agency (IEA) also revealed that India's CO_2 emissions from fuel combustion increased by 292.6 % from 1990-2016.

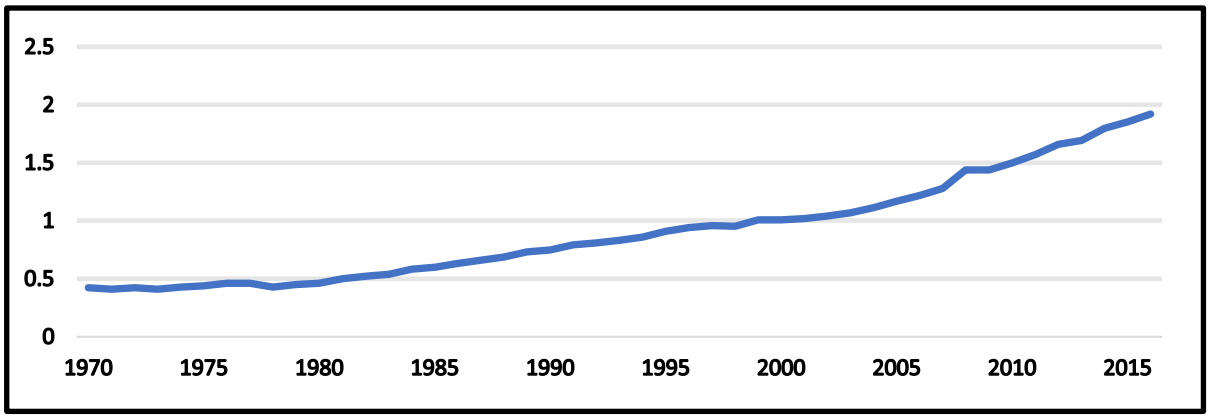
Figure 1: Global CO_2 emissions (metric tonnes per capita)



(Source: World Bank)

If we look at the per capita carbon dioxide emission in India from 1971 to 2016, there has been a significant increase. The per capita emission in 1971 was 0.32 tonnes which increased to 1.57 tonnes in 2016 (IEA 2018). **Figure 2** represents a steady increase in the carbon dioxide emissions measured per capita in India. The curve is slowly accelerating over time. A strong per-capita growth has been observed in recent years however, it has come at a cost of almost doubling up the carbon dioxide emissions.

Figure 2: India's CO_2 emissions (metric tonnes per capita)



(Source: World Bank)

The study also looks at the major sources of emissions that include coal, oil and natural gas. In India, carbon dioxide emissions from these sources are quite alarming. The quality of Indian coal being subpar, more than a third of India's emissions are directly linked to coal. Emissions from coal rose from 127.2 metric tonnes in 1971 to 1468.1 metric tonnes in 2016 (IEA 2018). This proves that, despite an increase in the share of renewables, India still heavily relies on combustion of coal to produce their electricity. The oil and gas industry has also contributed significantly. The emissions have increased rapidly from 1971 to 2016. Emissions from oil rose from 52.8 metric tonnes in 1971 to 544.3 metric tonnes in 2016 (IEA 2018). If we look at the emissions coming from natural gas, it was 1 metric tonne in 1971 which increased to 95.7 metric tonnes till 2010. However, it declined to 53.6 metric tonnes in 2015 and again rose to 63 metric tonnes in 2016 (IEA 2018). This is mostly due to lack of built-up pipeline infrastructure.

According to the BP Statistical Review in 2019, India's primary energy consumption rose by 7.9% in 2018, the highest growth rate since 2007. India, being the fourth largest producer of coal in the world in 2018, consumption of coal increased by 8.7%. This contributed to 60% of the total increase in primary energy. Oil and gas consumption increased by 5.3% and 8.1% respectively. This led to a 7% increase in carbon emissions. In 2018, India accounts for almost 25% of the total increase in global CO_2 emissions. This represents 7% of global CO_2 emissions (BP Stats Review 2019).

Carbon Tax and Carbon Emission Trading:

Carbon pricing is defined as a tool that establishes a link between the external costs of greenhouse gas emissions with their sources through a price. It acts as an economic signal to the emitters, which allows them to either transform their operations or continue emitting and paying for it. There are various carbon pricing approaches like emission trading system (ETS), carbon tax, results-based climate finance (RBCF) and internal carbon pricing. A carbon tax directly sets a price on carbon by defining an explicit tax rate on GHG emissions (World Bank, n.d.). The carbon emission reduction outcome in case of a carbon tax is not pre-defined, but the carbon price is. An emissions trading system (ETS) provides certainty about the environmental impact, but the price remains flexible. ETS is classified into two types: Cap and Trade System & Baseline and Credit System.

In 1990, European nations like Poland and Finland started to impose a carbon tax in their country. In 1991, Norway and Sweden followed their footsteps. Denmark, Estonia, and Latvia introduced it in 1992, 2000, and 2004 respectively, before the introduction of ETS (Emission Trading System). In 2005, ETS was introduced and it was implemented in the entire European Union and some parts of South America, excluding those nations where Carbon Tax had already been imposed. In 2008, CCIR (Carbon Competitiveness Incentive Regulation) and Carbon Tax were introduced in Alberta and Columbia respectively. New Zealand also had its ETS by the end of 2008. In 2009, RGGI (Regional Greenhouse Gas Initiative) was introduced in Virginia, US. Consequently, more nations followed this trend and introduced/modified their carbon pricing system year by year.

In basic terms, under carbon emission trading, a nation/industry having more outflows of carbon can buy the right to emit progressively, and the nation/industry having fewer emissions sells the right to emit carbon to different nations/industries. The nations/industries producing more carbon in this manner fulfil their carbon emission requirements, and the exchanging market results in the most cost-effective carbon reduction strategies being exploited first. The process of carbon emission trading would be facilitated by the sale and purchase of carbon credits or CER. Carbon credits is defined as the unit related to reduction of 1 tonne of carbon dioxide emission from the baseline of the project activity. This vibrant market has attracted a lot of attention due to significant global governmental involvement. The biggest reason behind the emergence of the carbon emission trading market was the successful collaboration of various regulatory bodies with the governments of various nations to design a framework for emission trading around the world. Opportunities for this market is expected to rise with the European Union member nations taking initiative to reduce their greenhouse gas emissions.

India's efforts to curb the emission hasn't been successful lately. The Kyoto Protocol was signed and ratified by India in August, 2002. The main purpose of the protocol was to make developed nations pay for their ways with emissions while in the meantime, monetarily compensate nations with good behaviour in this regard. The protocol worked out three major mechanisms for emission reduction that is, International Emissions Trading (IET), Clean Development Mechanism (CDM) and Joint Implementation (JI). India has mostly relied on the Clean Development Mechanism to reduce the greenhouse gases in the past few years.

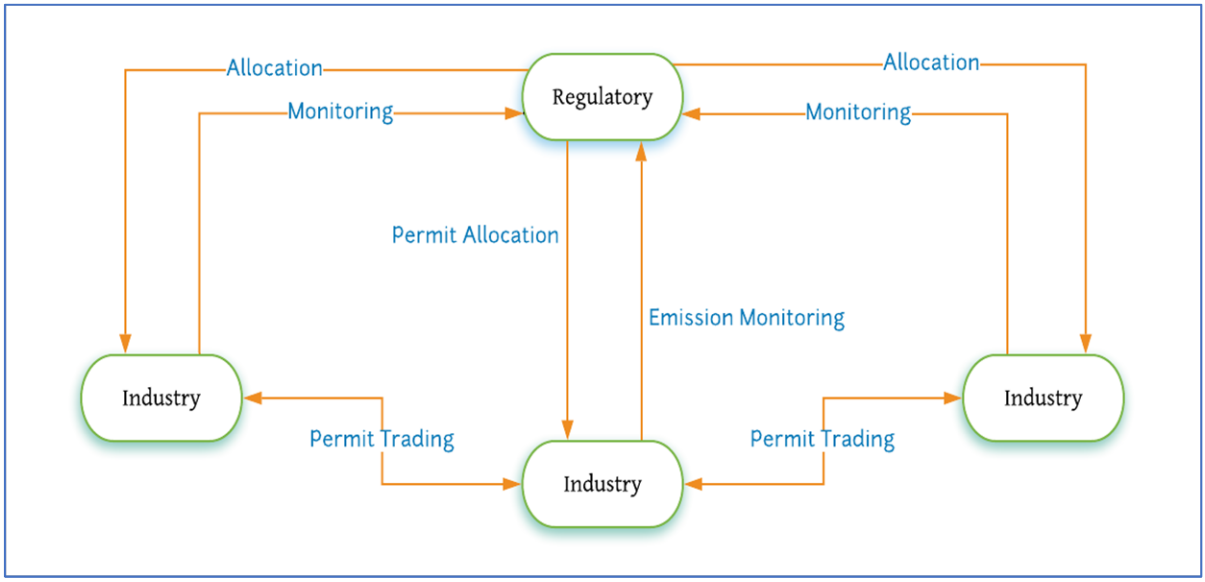
European Union Emission Trading Scheme (EU-ETS):

The International Emissions Trading takes place by the European Union Emission Trading Scheme System which is the largest carbon trading market in the world. The main objective of this system is to reduce greenhouse gas emissions in industrial sectors. It works on the basis of 'cap and trade' principle. A cap is determined for certain greenhouse gases that can be emitted by the establishments (Wikipedia Contributors, n.d.). The cap is decreased with time such that the total emissions also decrease (Burtraw *et al*. 2001, 11). The cap allows the organizations to sell or purchase emission allowances which they can exchange with each other as required. They can likewise purchase a limited amount of international credits from emission-saving projects worldwide. The limit on the maximum number of allowances accessible guarantees that they have a value and after each year, a company must surrender its allowances to cover all its emissions. Failure to abide by the rules would result in imposition of heavy fines. **Figure 3** represents the framework of emission trading scheme which involves four major aspects like Allocation, Trading, Monitoring and Compliance control (Sohail 2015). In the event that an organization diminishes its emissions, it can keep the extra allowances to cover its future needs or else sell them to another organization that is shy of allowances. Trading brings adaptability that guarantees emissions are sliced where it costs least to do so.

Launched in 2005, the system covers about 27 member states of European Union (EU) including the European Economic Area (EEA) which includes countries like Norway, Iceland and Liechtenstein. The targeted point of regulation were energy-intensive user sectors and energy generation sectors. But the EU-ETS is not delivering the carbon dioxide cuts. A number of loopholes have rendered the system ineffective. Policymakers should bring about major

improvements to the way the EU-ETS functions. Some of them include ceasing free permits to polluters, setting a tight cap and preventing the utilization of banked permits from earlier phases of the plan. These can be achieved by incorporating blockchain technology to the system. The future of trading can be revolutionized by the use of blockchain technology. If transactions took place on a blockchain network, settlement times could drop from days to minutes, thereby improving efficiency and reducing errors. Since the blockchain would be transparent to all parties, the need for audits would be dramatically reduced. The cost of doing business is lowered significantly. These savings could be passed on to traders in the form of lower commissions and fees (Bohl n.d.).

Figure: 3 Framework of European Union-Emission Trading Scheme



Blockchain Reputation Based (BCRB) System:

Reputation based trading system consists of an algorithm that influences how a transaction is being conducted in the block chain environment. The entire process will be carried out by blockchain keeping in mind that there is no change in the process of issuing, distributing and surrendering allowances. Allocation of credits would follow the process of Grandfathering, Benchmarking, and Auctioning. Tamper-resistant smart metres are required to obtain accurate input data and to ensure that correct amount of permits are surrendered. It should be noted that block chain can only ensure the immutability of the data entered and not the credibility of the data.

The reputation of an enterprise is a function of its past emission rates and its strategy to achieve emissions reduction. Past emission rates are evaluated by determining the ratio of emissions per product produced by the enterprise. For strategy in reducing emissions, the evaluation follows CDM's guideline for 'additionality' (Khaqqi *et al.* 2017, 12) Reputation points will play a key role in the allocation of credits by the central authority.

There are four important aspects in the Reputation based carbon emission trading known as the Authority, the Firm, the Project and the Auditor. Authority is the government body that has the right to issue permits and equivalent assets and distribute them. The firm acts as seller and buyer in the emission markets which includes CDM projects or any other sanctioned projects aimed at buying and selling Certified Emission Reduction (CER) units. The main aim of the auditor is to issue reputation points to these firms.

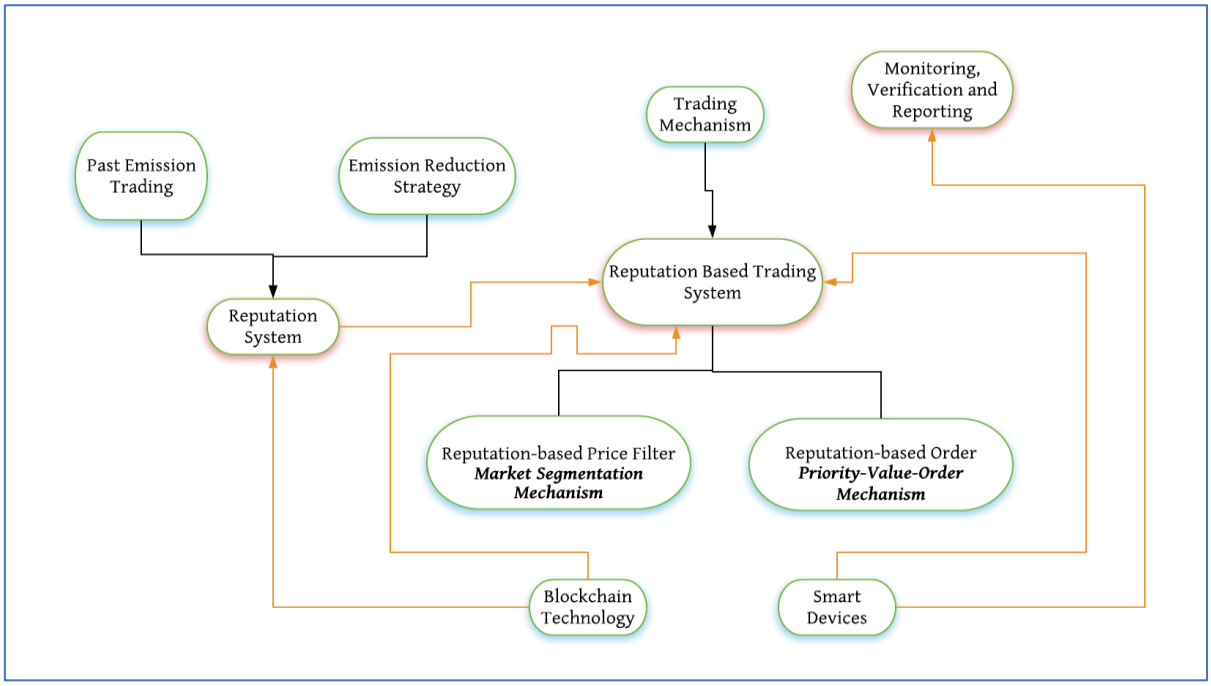
The outcome of the decentralized characteristic of blockchain technology is the absence of a central organization that oversees, sorts, and coordinates the bids and offers. As a result, a member should independently choose an acceptable offer out of all offers exhibited by the

opposite parties. In order to do that, every member should first gather all bids or offers they require.

The change in exchanging mechanism that is caused by the expansion of reputation system is connected in the offer collection and gathering process. In gathering the bids and offers, Reputation Points will be utilized to choose member's access: the better the reputation, the better the access. The system decides the number of offers participants can gather and from which group. It withholds some better offers from buyers or sellers with lesser reputation. This is one reason why trading through this system requires more than an agreement on price. Even when a buyer and a seller agree on price, they do not necessarily have the access to each other's offer.

In the selection procedure, the system sorts the gathered offers for the buyer in a unique way. It considers not just the asking price as in the customary ETS, it also takes into consideration the reputation of the publisher of the offer. This sorting technique is called Priority Value Order mechanism. Offers with lower prices won't really be set at the highest priority on the rundown, whereas offers with a lower need will. The need is measured through an index called Priority Value (Khaqqi *et al.* 2017, 12). Priority Value is a ratio of asking price to that of the reputation point.

Figure: 4 BCRB Model Elements



Priority Value isn't relevant for the bids. Price is utilized to sort the bids. The purpose behind this is, by and large sellers have a better reputation over buyers. Utilizing price to sort bids, sellers have the chance to pick the highest bids accessible to them.

It begins with the buyer gathering seller's offers that they have the access to. Buyer reputation is confirmed by the framework to determine the access. Once it's completed, the offers are sorted by their priority value. Offers at the highest priority on the list must be chosen first. In the event that the best offer can't completely fulfil purchaser requests, the next offer on the list might be chosen. This procedure proceeds until the demand is completely fulfilled or until the end of the list is reached.

In publishing a bid or an offer, the price is an important element. The publisher needs to think about the offer's need and in addition the visibility. Priority alludes to the offer position on the

final list of the contrary party. Visibility alludes to the number of opposite parties that can see the offer.

When an offer is a decent offer from the perspective of the opposite party (low price for the offer, high for bid), it is viewed as a favoured offer that can be accessed by a few but the offer has low visibility. Then again, a profoundly visible offer is one that isn't the greatest for the contrary party and can be seen by all.

Figure 4 represents BCRB Model's Elements. Blockchain technology and Smart devices support the Monitoring, Verification and Reporting procedure. Simultaneously, they also support the reputation system that acts as the foundation for Reputation based Trading System. Reputation is a function of past emission rates and participant's strategy to achieve the emissions reduction. The system consists of two mechanisms, market segmentation mechanism and priority value order mechanism.

Exploiting the characteristics of blockchain such as transparency and immutability, the accuracy of information obtained can be guaranteed. In this way, the usefulness, consistency, and validity of the scheme can be improved. In the meantime, because of blockchain technology, inefficiency in the conventional ETS system can also be dealt with. The reputation-based trading system offers a novel approach by directly encouraging the members to adopt a long-term solution for emission reduction.

Moreover, the scheme does not deviate much from the conventional ETS, instead it adds complementary measures to enhance it. It can be implemented easily and quickly than other proposals that ask for complete alteration of the ETS system.

Carbon Trading in India:

India, currently has the command and control approach to pollution regulation, which has resulted in high levels of non-compliance, lack of high-quality information, transparency, etc. There are two cap and trade markets in India. The first is a Renewable Energy Certificate Scheme and the second is Perform, Achieve and Trade (PAT) Scheme. Both of them have several loopholes and are ineffective in delivering emission cuts.

In recent years, Online Emission Monitoring Technology has received attention and interest in the context of providing accurate and continuous information on the particulate matter or gaseous emission from stacks. There are already commercially available systems for monitoring various parameters. Central Pollution Control Board (CPCB) being an apex environmental regulatory agency, has an important role to play in the preparation of a strategic plan and get required support from the MoEF&CC for implementation. The enforcement of the Continuous Emission Monitoring System (CEMS) guidelines will be affected if these requirements are not fulfilled. While implementation is the key, blockchain is essential for its real success.

Recently, Gujarat launched a market-based particulate pollution regulation system as a pilot project. It is designed to provide economic incentives to industrial units that are successful in controlling their emission. The government will allow to buy and sell permits by setting a cap (Tripathi 2019). Gujarat Pollution Control Board (GPCB) will obtain the readings from the Continuous Emission Monitoring System (CEMS) installed in various industries. CEMS sends live readings of stack pollution through a network of sensors on a minute to minute basis. The cap will guarantee that the total level of pollution across all industries does not supersede the defined levels of allowed particulate emissions in the region. Once the cap is set, the government will convey the overall emission reductions to the industries. Rest, the system would ensure that the industries cut their particulate pollution in a less effective manner. It would also reduce the cost of compliance for industries.

The major flaw in CEMS is the credibility of data obtained. Calibration of devices plays an important role in determining the exact amount of emission. So, the industries not interested in spending money to abate pollution would want to calibrate it in a particular way or tamper with the data.

Through this system, Gujarat will be largely successful in abating pollution but it won't be able to achieve the desired emission cuts. This issue can only be addressed with the help of blockchain. Blockchain will force the participants to conduct themselves in a responsible manner with all the information accessible for scrutiny. The proposed BCRB model does not change the cap and trade mechanism adopted in Gujarat. Rather, it complements them making it easier to implement in any given situation. The reputation factor provides both financial incentives and improved public perception. This effect can only be aided by the transparency of the blockchain. Moreover, it also prevents any organisation or institution from violating their commitment to emissions reduction.

Gujarat's Cap and Trade System vs BCRB System

Following the footsteps of China, the Gujarat government in India launched the cap and trade system in Surat to set an overall cap on the permitted particulate matter emissions. Surat's industrial belt consists of a lot of textile, dye and cotton mills. Residents run the risk of serious health hazards due to the industrial emissions and noxious fumes from these mills. Though economically efficient, the cap and trade system will face a lot of implementation challenges.

One of the major challenges would be the balancing of economic competitiveness with the reduction of emissions. If a low cap is set, it could affect the economic competitiveness of the industrial state. With fears of unemployment rising, this would be a major setback. However, the setting of a high cap would render the system ineffective. This was one of the major flaws in the European Union - Emission Trading System (EU-ETS). Over-allocation of permits would enable the industries to easily pay and pollute. Therefore, it becomes necessary for the Gujarat government to supplement the cap and trade scheme by facilitating technological sharing.

The current system targets a particular set of industries such as textile and dyeing. In order to effectively tackle air pollution, it needs to expand to other highly polluting industries like cement factories and thermal power plants. This can be accomplished by developing a new nationwide carbon market. Blockchain reputation based scheme can be implemented as a complementary measure to enhance the emission trading scheme implemented in Gujarat. It will improve the functionality, consistency, and credibility of the scheme.

Cap and Trade system can become an important tool in India's fight against climate change, but its implementation in India's complex political economy is likely to be messy (Goel 2019).

Conclusion:

In a nutshell, carbon pricing involves imposing a cost on greenhouse gas emissions to hold emitters responsible and help drive reductions. Given the imminence of a climate catastrophe and the fact that the world devotes more attention to the issue than ever, there has never been a better time for governments to introduce a carbon pricing system.

Implementation of Emission Trading System (ETS) especially in developing countries like India, will be a tedious task. Establishing the financial market needed for Emission Trading System is a complicated process. India needs to embrace the blockchain technology to address this issue. Taking into consideration its distributed nature, blockchain can enhance administration and sustainability for tackling climate change. A sense of transparency and traceability is fostered as the technology helps to record transactions openly and permanently which prevents a monopolistic control over the framework. The United Nations Climate Change (UNFCCC) secretariat has recognized the capability of blockchain technology.

India intends to reduce its emissions by 33 – 35% below 2005 levels by 2030 under the Paris climate agreement (Climate Action Tracker, n.d.). This can only be accomplished by developing a new nationwide carbon market.

Reference list:

Andrew, Robbie. 2018. "Guest Post: Why India's CO_2 Emissions Grew Strongly in 2017." *Carbon Brief*, March 28, 2018. https://www.carbonbrief.org/guest-post-why-indias-co2-emissions-grew-strongly-in-2017.

BP Statistical Review. 2019. "India's Energy Market in 2018." Accessed July 17, 2019. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-india-insights.pdf#page46

Bohl, Lee. n.d. "What is Blockchain and How Will it Affect the Future of Trading." *Charles Schwab*. Accessed July 13, 2019. https://www.schwab.com/active-trader/insights/content/what-is-blockchain-and-how-will-it-affect-future-trading

Burtraw, Dallas, Karen Palmer, Ranjit Bharvirkar, and Anthony Paul. 2001. "The Effect of Allowance Allocation on the Cost of Carbon Emission Trading." *AgEcon Search*, (August): 1-30. https://ageconsearch.umn.edu/record/10536/.

Climate Action Tracker. n.d. "Pledges and Targets." Accessed July 3, 2019. https://climateactiontracker.org/countries/india/pledges-and-targets/

EY. n.d. "Overview of blockchain for energy and commodity trading." Accessed July 17, 2019. https://www.ey.com/Publication/vwLUAssets/ey-overview-of-blockchain-for-energy-and-commodity-trading/%24FILE/ey-overview-of-blockchain-for-energy-and-commodity-trading.pdf

Goel, Siddharth. 2019. "Gujarat's Emission Trading Scheme is India's First Real battle in War Against Air Pollution." *The Wire*, June 14, 2019. https://thewire.in/environment/gujarat-air-pollution-emission-trading-cap-trade

Goldberg, Shelley. 2017. "How Blockchain could revolutionize commodity markets." *The Quint*, December 22, 2017. https://www.bloombergquint.com/view/how-blockchain-could-revolutionize-commodity-markets

Gupta, Vinay. 2017. "A Brief History of Blockchain." *Harvard Business Review*, February 28, 2017. https://hbr.org/2017/02/a-brief-history-of-blockchain

Iansiti, Marco and Karim Lakhani. 2017. "The Truth About Blockchain." *Harvard Business Review*, February 28, 2017. https://hbr.org/2017/01/the-truth-about-blockchain

International Energy Agency. 2018. "Statistics: Global energy data at your fingertips." Accessed July 3, 2019. https://www.iea.org/statistics/?country=WORLD&year=2016&category=Energy%20supply&indicator=TPESbySource&mode=chart&dataTable=BALANCES

Khaqqi, Khamila Nurul, Janusz Sikorski, Kunn Hadinoto, and Markus Kraft. 2017. "Incorporating Seller/buyer Reputation-based System in Blockchain-enabled Emission Trading Application." *Applied Energy,* (October): 8-19, https://doi.org/10.1016/j.apenergy.2017.10.070

Sohail, Sadia. 2015. "Emissions Trading in Particulate Matter Takes off." *Down To Earth,* July 4, 2015. https://www.downtoearth.org.in/news/emissions-trading-in-particulate-matter-takes-off---38793.

Tripathi, Bhasker. 2019. “Surat's Emission Trading Project Can Be A Powerful Tool To Reduce Air Pollution." *IndiaSpend*, June 5, 2019. https://www.indiaspend.com/surats-emission-trading-project-can-be-a-powerful-tool-to-reduce-air-pollution/.

World Bank. n.d. “What We Do: Pricing Carbon.” Accessed June 27, 2019. https://www.worldbank.org/en/programs/pricing-carbon

Zheng, Zibin, Shaoan Xie, Hongning Dai, Xiangping Chen, and Huaimin Wang. 2017. "An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends," *2017 IEEE International Congress on Big Data*. (June): 557-64. https://doi.org/10.1109/BigDataCongress.2017.85