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Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application

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HIGHLIGHTS

- A blockchain-enabled system is proposed for emissions trading application.
- The objective is to improve management and increase abatement investment.
- Financial incentive is used to motivate industry participants.
- Multi-criteria analysis emphasizes the benefit of the system against established ETS.

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ABSTRACT

Emission Trading Scheme (ETS) has dual aims to reduce emission production and stimulate adoption of long-term abatement technology. Whilst it has generally achieved its first aim, its issues are hindering the accomplishment of the second. Several solutions have been proposed to improve ETS's efficacy, yet none of them have considered the advancement of Industry 4.0. This paper proposes a novel ETS model customised for Industry 4.0 integration. It incorporates blockchain technology to address ETS's management and fraud issues whilst it utilizes a reputation system in a new approach to improve ETS efficacy. Specific design of how the blockchain technology and reputation system are used to achieve these objectives is showed within this paper. The case study demonstrates the inner working of reputation-based trading system—in which reputation signifies participants performance and commitment toward emission reduction effort. Multi-criteria analysis is used to evaluate the proposed scheme against conventional ETS model. The result shows that the proposed model is a feasible scheme and that the benefits of its implementation will outweigh its drawback.

1. Introduction

Energy consumption is the main contributor to global emission. About 76% of world emissions in 2010 arose from the need to generate energy, mainly for electricity and industrial processes [1]. From 2015 to 2040, an increase of 16% is predicted for energy-related CO_2 emissions worldwide [2]. Carbon dioxide made for 75% of the global greenhouse gas emission in 2010 and will continue to rise at an average of 0.6% per year between 2015 and 2040—most of it stems from fossil fuel combustion [1,2]. Considering the effect of greenhouse gas emissions to climate change [3], various studies have been conducted and several solutions have been proposed; including converting CO_2 to valuable products, adjusting operational procedure to lower CO_2 production, and capturing the CO_2 for storage. However, there are little initiatives in the implementation of these solutions, most of the time due to the financial burden that these solutions incur.

Imposing a price to emission products is believed to be an effective method to lower the reluctance in reducing emission production. One option to do that is through Emission trading scheme (ETS) or cap-and-trade scheme. In 2016, 17 ETSs were active worldwide and more governmental bodies were considering its implementation [4]. Each of them differs in their specific regulations. Whilst this policy measure has been able to reduce emission production, it still has several problems that undermine its effectiveness [5,6]. Furthermore, it is yet to make significant progress in encouraging investment in technologies that provide long term abatement effects [7,8]. Therefore, a complementary measure is needed to increase the policy effectiveness, encourage adoption of these technologies and thereby support a long term solution [9].

Previous studies has proposed and studied several options in

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improving the efficiency of Emission Trading Scheme (ETS). Perino and Willner [10] discusses the EU-ETS options to postpone the introduction of new permits when there is a surplus in the market in order to bolster the price of the permits. The proposal to create a central authority that adjust the supply of permits to stabilize the price of the permits is presented in [11]. The possibility of introducing a carbon floor price to guarantee a minimum price of permits is explored in [12]. A different allowance allocation methods that involves the adjustment of the pre-allocation based on the enterprises' actual output and carbon intensity is applied in Shenzen's ETS—the first regional level of ETS in China—to avoid oversupply of permits and windfall profits [13–15]. All previous proposals share a similarity in their objective to control the price of the permit by decreasing the supply or introducing a minimum price; the ultimate purpose being to increase the global price of the permits to a certain level, so that purchasing more permits becomes the less attractive option. However, these solutions will not be able to fully accomplish their objective while the integrity of the entire policy is still an issue. Furthermore, none of these proposals customise their solution to suit the change Industry 4.0 may cause to the way the industries will operate in the future.

The fourth industrial revolution, Industry 4.0 is characterized by high degree of process automation and digitisation that will increase flexibility and efficiency for manufacturing and service industries [16–20]. Integrating the concept of Industry 4.0 with established systems leads to the realization of a smart system. Amongst them is integration with Eco-Industrial Park (EIP) to realise a smart EIP. As part of J-Park Simulator (JPS) project that intends to showcase a realised smart EIP [21–24], we try to customise a novel ETS model that is thoroughly supported by the smart EIP's intelligent and automated systems and devices, and is able to take a full advantage of that support. Furthermore, the model is expected to construct a different approach in solving ETS issues by leveraging that support.

The paper propose a novel ETS model that is supported by the digitisation and automation of Industry 4.0 that has also provided the foundations for machine-to-machine (M2M) transaction. For such transaction, reliable and secure system is a vital requirement to manage the complexity of the new paradigms [20]. Blockchain technology is chosen as the tools to accomplish that and utilized to solve ETS's inefficient management and fraud issues. On the other hand, the use of blockchain technology also made it possible to apply a different approach to discourage participant from purchasing more permits. Instead of introducing a price control measure, it introduces a new approach to encourage the adoption of more sustainable and long-term solutions. Previous study [25] have found reputation system to be an effective method to secure participants' good behaviour and to improve market quality. Integration of reputation system to trading mechanism—in which the reputation indicates participant performance and commitment to emission reduction effort—is used to achieve this aim. However, reputation-based trading system cannot be easily realised in a current ETS environment. The issue will be the integrity of each reputation-based transaction being executed. But, with the support of blockchain technology, transactional integrity can be preserved by applying a specific trading algorithm as part of the blockchain transaction procedure.

Thus, the first objective is to show the use of blockchain technology to solve ETS's management and fraud issues whilst the second objective is to show the use of reputation system to encourage investment in long-term abatement technology. The system showed in this paper is applied to a basic ETS policy that accepts carbon credits generated through the Clean Development (CDM) and Joint Implementation (JI) programmes. The customisation's focus is the trading mechanism and the monitoring and reporting procedure, therefore, the system is expected to be able to accommodate any modification in permits issuance and distribution method as well as other separate areas.

The paper is organized as follows: Section 2 provides the background on emissions trading schemes and blockchain technology. Section 3 presents the methodology in designing the new ETS model. Section 4 shows a case study that exhibits the inner workings of the reputation-based trading system and the applications. Section 5 shows the evaluation of the proposed scheme against a conventional emission trading scheme using a multi-criteria analysis. Finally, Section 6 provides the conclusion and future work plan regarding the application.

2. Background

2.1. Emission trading

Two recognized methods to levy a price for producing emissions are carbon taxes and tradable permits [26,27]. The difference between the two lies in the price generation method: in taxes case, the price is fixed and determined by policy makers; in tradable permits case, the price is the result of supply and demand. Both policy options have been analysed and compared many times in different aspects and situations with mixed results; some researchers find both equally effective, whilst other favours one over the other [27–31].

The tradable permits policy is also known as ETS or cap-and-trade scheme. It sets a limit or a cap to the type and amount of GHG that the sectors under its jurisdiction are allowed to produce. Equal number of permits that allows participants to emit GHG are then created and distributed at the start of the period, either through free allocation or auction. At the end of the period, all participants are required to surrender the relevant amount of permits along with a report on the amount of emission produced during that period.

Permits are tradable between participants. Entities with excess permits may sell them to others who have produced more emissions than they have permits for. Depending on the policy, in the event an entity cannot source enough allowance to comply with the regulation, sanctioned offset may be used to counterbalance the excess [26]. This offset is emission reduction that is done in a different location, with the aim of achieving carbon neutrality. Carbon neutrality means the amount of emission produced, in carbon dioxide equivalent (CO_2e) unit, is the same as the amount of emission reduced or sequestered.

The advantage of emissions trading is that there is a clear emission reduction target to be achieved. In addition, the scheme is also cost efficient. This is due to the fact that the cost of reducing emission may well vary between firms and this method provides flexibility for the participant to meet their obligation using the most cost efficient method [32,33]. The scheme also provides an opportunity for a concerned party to tighten the limit by buying and surrendering the allowances [32]. Another point in favour of tradable permits policies relates to the global emission abatement effort. With this scheme, it is possible to link the individual systems in order to create a larger and more stable market and to motivate developing countries' involvement [26,34].

There are several key elements to be considered in designing an ETS policy [26]. Those elements are:

- Scope, it includes the decision of economic and industrial sectors and the type of gases to be covered.
- Cap allocation, it determine emission reduction goals and the limit of emissions—and therefore the amount of permits—to be issued. It also includes period to specify the length of time the limit and the permits stay relevant. Flexibility refers to the options to keep unused permit relevant in the following periods. It is included under cap allocation due to its effect on the future cap if permits issued in a period stay relevant after the end of that period.
- Allowances or permits distribution. Permits can be distributed through free allocation, auction, or the combination of the two.
- Offset policy. It specifies whether an offset can be used in the scheme, what type of offset is allowed, its acceptable source and the limit of the amount.
- Trading mechanism specifies the rules of emission trading.
- Monitoring, Reporting and Verification (MRV) procedure. It defines

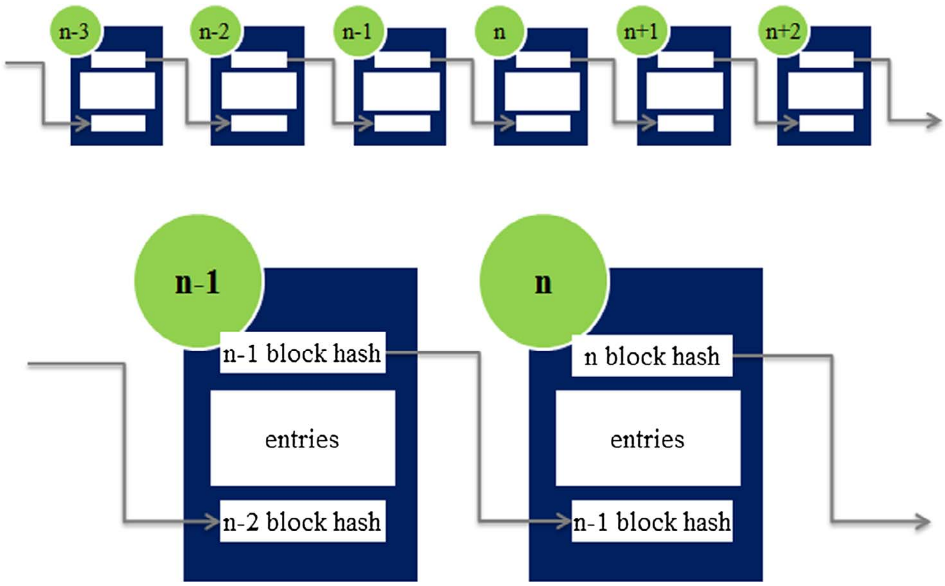

Fig. 1. Illustration of blockchain and contents of a block.

the methods to oversee and ensure the compliance of all participants.

- Expansion potentials. It considers the flexibility of the policy to cover additional sector or gas in the future as well as the possibility of linking the ETS with other ETSs.

2.2. Blockchain technology

Blockchain's largest application is as the underlying technology of Bitcoin in which it provides security and credibility to the crypto-currency. Blockchain is an electronic ledger hosted by many different participants (or nodes) in the network. Each copy of the ledger that any node holds is identical to the others. The only events deemed valid (and therefore recorded on the blockchain) are the one acknowledged by the majority. Therefore, an entry in a blockchain will be accessible to all nodes and cannot be added to without agreement from the majority.

An illustration of the structure of a blockchain is provided in Fig. 1, in which the blockchain is represented as a series of blocks chained to each other in a sequential manner. If the blockchain is equated to a ledger book, a block is equivalent to a page in the book; in it a collection of events that happen in a certain timeframe are written [35].

The contents of a block are used to produce the hash (a fixed sized data which are the result of data mapping by a hash function) of that block. The subsequent block will then take this hash as one of its entries. This is to indicate the sequence of the blocks. Any change in block content will cause an unpredictable change in the hash. Therefore, for a change in the earlier block to be accepted and considered valid, all following blocks in the sequence need to be recreated to reflect that one change. This way an entry in blockchain will be immutable and irrevocable.

These characteristics of blockchain—decentralized, transparent, immutable, and irrevocable—are favourable characteristics in various applications. For that reason, many industries in many different sectors (including financial service, the food industry and the military) are looking into the application of the blockchain in their area of business [36–39]. People with climate change concern have also been attracted by the possibilities of the technology. Recently, a number of individuals have proposed ideas on application of blockchain in carbon pricing mechanisms—especially as variants to cap-and-trade scheme—in order to support the efforts to reduce climate change effects [40–45]. Some of the proposals present worthy ideas to be explored, yet almost all of them lack some elements to make a feasible and practical implementation.

3. Methodology

This paper proposes a novel ETS model supported by blockchain technology and with reputation-based trading system for trading mechanism, blockchain-enabled reputation-based emission trading scheme (referred to as BCRB hereafter). The approach in creating the ETS model and it relations to ETS policy's elements (as described in Section 2.1) is presented in Fig. 2 with shaded area identifies BCRB model's elements. Blockchain technology and smart devices are used to support one element of the ETS policy, the Monitoring, Reporting, and Verification procedure. At the same time, both technologies also support the reputation system that acts as the foundation for the reputation-based trading system. Reputation-based trading system consists of two mechanisms, market segmentation mechanism and priority-value-order mechanism.

The proposed BCRB model does not fundamentally change the conventional schemes; rather, it complements them. Thus, it will be easier to implement in any environment, established or otherwise. The reputation system inside the scheme provides a twofold motivation—direct financial incentive and improved public perception. The financial incentives will act as a motivator inside the scheme whilst a boost in public perception works outside the scheme to attract consumers or investors. This effect is aided by the transparency of the blockchain. It hinders any attempt by the institution to obfuscate or misrepresent their commitment to emissions reduction.

Reputation in the BCRB system is a function of past emission rates and participant's strategy to achieve the emissions reduction. The evaluation of past emission rates is quite straightforward, the less ratio of emissions per product an enterprise produce in the past, the better the reputation. For strategy in reducing emissions, the evaluation follows CDM's guideline for "additionality"; the more "additional" the strategy is, the better the reputation. Participant's reputation determines the perceived value of the credits offered or demanded by the participants. The index for reputation is called the Reputation Point (RP).

3.1. Blockchain-enabled emission trading scheme

Blockchain technology supports the MRV element of ETS policy and the reputation system by providing an immutable and transparent record of permits and reputations. Simultaneously, it supports the reputation-based trading system by integrating the trading rules—heavily influenced by reputation—to the algorithm that regulates how a

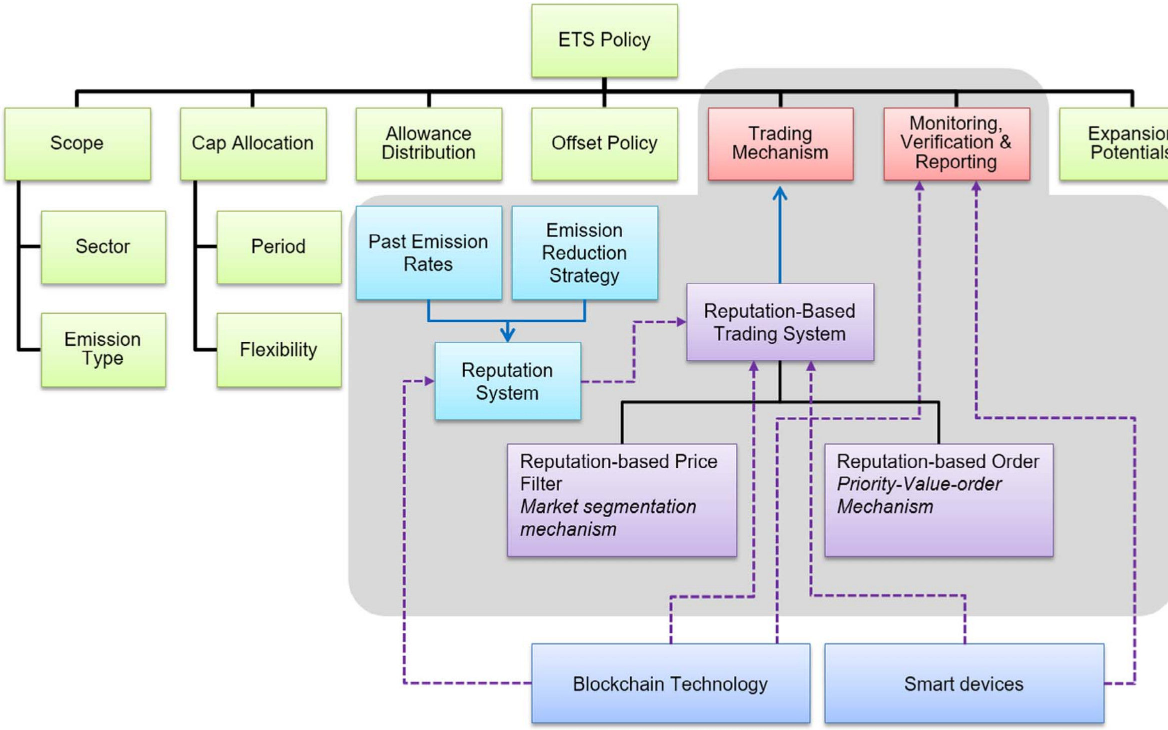

Fig. 2. ETS policy's elements and the approach of the proposed model.

transaction is conducted in the blockchain environment. Thus, there will be no change in the process of issuing, distributing and surrendering allowances; only that the process is conducted through the blockchain. The surrendering process uses emissions rate as a base. Since blockchain can only ensure the immutability of the data recorded and not the credibility of the data entered, tamper-resistant smart meters are necessary to obtain accurate input data and to make sure that a correct amount of permits are surrendered.

In the proposed BCRB model, there are four main roles that represent the actors inside an ETS system; the Authority, the Firm, the Project and the Auditor. Each is independent from the others and has different capacities and limitations. First, the Authority will be an appropriate government body that enforces and regulates the scheme. The Authority has the right to issue the permits and the equivalent assets (labelled as CC in blockchain environment) and distribute them. Secondly, the Firm is the business institutions involved in the scheme. The Firm acts as seller and buyer in the emission markets. The Project represents CDM projects or other sanctioned projects aim at generating and selling certified emission reduction units. Finally, the Auditor is the rating agent. The Auditor evaluates Firm's emissions rates and strategies to reduce emissions and determine the reputation in RPs. A full comparison between four roles is shown in Table 1.

There are several benefits in the use of blockchain for the ETS policy. The first is transparency which will lead to accountability. With all information accessible for scrutiny, participants are forced to conduct themselves in a responsible and accountable manner. Blockchain provides this transparency whilst maintaining information credibility and a certain level of privacy. The other benefit comes from the credible information. It helps in the monitoring and verification of the credit source and ownership. This, in turn, will help protect the system from fraud and other problems such as double counting issues [46].

The drawbacks of the blockchain-enabled ETS are equal to the drawbacks of the blockchain technology itself. Among them are the resource to retain multiple copy of comprehensive and extensive records. The fact that blockchain technology can be considered as a nascent technology can also pose a few problems along the way. Other issue include the shift in paradigm that the technology caused and how will the actor involved in the system accept this shift.

3.2. Reputation-based trading system

The principal modification in the BCRB system from that of the conventional ETS is in the trading mechanism. Two separate factors drive this change in the trading mechanism. One is a deliberate change that is the addition of reputation system, the other is a change that is caused by decentralized characteristic of the blockchain. As a consequence, whilst conventional ETS only requires an agreement in selling and buying prices to execute a trade, BCRB system requires more.

The consequence of decentralized characteristic of blockchain technology are the absence of central organization that manages, sorts, and matches the bids and offers. Thus, a participant will have to

Table 1
Description of roles and its function in the BCRB system.

Role	Holder	Capacity		Responsibility
		Issuance	Transaction	
Authority	Government body or equivalent	Issue the assets (CC)	Distribute CCs	Create and enforce the policy
Firm	Business institution	–	Send or receive CCs as seller or buyer	Report emissions and surrender relevant amount of CCs
Project	CDM project or equivalent	–	Send or receive CCs mainly as seller	Report emissions to receive CCs
Auditor	Independent evaluator or equivalent	Issue reputation points	–	Evaluate firms and projects to assign RPs

independently select a satisfactory offer out of all offers presented by the opposite parties. In order to do that, each participant must first collect all bids/offers they need. This, in turn, divides the participant into two categories based on their level of participation in the trading process: active participation and passive participation. Active participation is when a buyer or seller actively searches for an offer or bid to satisfy their demand and carry out the trading process to completion. Passive participation is when a buyer or seller publishes an offer to buy or sell then wait for the transaction to be completed when an active participant of the opposite party select their offer.

The change in trading mechanism that is caused by the addition of reputation system is applied in the offer collection and selection process. In collecting the bids and offers, Reputation Points will be used to decide participants' access: the better the reputation, the better the access. Market segmentation mechanism is describe as this distribution of access. The mechanism determines how many offers participants can collect and from which group. It withholds some better offers from buyers/sellers with lesser reputation. This is one of the reasons why executing a trade in BCRB 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 the other's offer.

In the selection process, BCRB sorts the collected offers for buyer differently. It considers not only the asking price—as in the conventional ETS—but also the reputation of the publisher of the offer. The sorting method is called priority-value-order mechanism. Offers with lower prices will not necessarily be placed at the top of the list; instead, offers with a lower priority will. The priority is quantified through an index called Priority Value (PV) (see Eq. (1)). However, Priority Value is not applicable for bids. Price is used to sort the bids. The reason for this is that generally sellers have better reputation than buyers. Using price to sort bids, sellers have the opportunity to choose the highest bids available to them.

$$PV = \frac{askingprice}{reputation-basedfactor} \tag{1}$$

The denominator in the Priority Value equation is derived from the reputation index, Reputation Points. There are several ways to derive this factor; each affects price competitiveness differently. As an example, a large ratio of factor range to the factor may cause the market to favour the good participant too strongly. Thus, the price competition is reduced or destroyed entirely when the price variation is small. The system is more effective when the variation of price is of a same magnitude with the factor.

3.3. Trading procedure

Fig. 3 shows a typical procedure for buying process in BCRB scheme. It starts with the buyer collecting sellers' offers that they have the access to. Buyer reputation is verified by the system to determine the access and the group of offers. After that the offers are sorted based on the PVs. Offers at the top of the list must be selected first. If the top offer cannot fully satisfy buyer demands, the next offer on the list may be selected along with the first one. This process continues until the demand is fully satisfied (with or without excess from the offer) or until the end of the list is reached.

Should the buyer not find any of the offers acceptable, they can wait or publish their own bid. Any offer or bid published is binding; once it is selected and accepted by another participant the publisher cannot pull back their offer. The typical selling process follows the same lines, but with a difference in the method of bid sorting. Both market segmentation and priority value order are part of the application's built-in protocol. Any bid/offer enquiry into the system will be subjected to this protocol.

In publishing a bid or offer, price is an important consideration. The publisher needs to consider the offer's priority as well as visibility. Priority refers to the offer position on the final list of the opposite party. Visibility refers to the number of opposite parties that are able to see the offer. When an offer is a good offer from the perspective of the opposite party (low price for offer, high for bid), it is considered a privileged offer that can only be accessed by few; thus, the offer has low visibility. On the other hand, a highly visible offer is one that is not the most favourable for the opposite party and can be seen by all.

Fig. 4 shows the effect of price and reputation on priority and visibility for a passive seller. The buyer considers a low priced offer favourable; therefore, it is a privileged offer that has low visibility. When the passive seller has good reputation, either low or high priced offers can have low PVs and be boosted to the top; this is not so when the reputation is bad. Thus, a passive seller with a better reputation has flexibility in determining their asking price. A passive seller with a bad reputation, however, needs to consider the conflicting effect of visibility and priority.

For a passive buyer, the decision is less complicated. A high price means less visibility but higher priority, while low price means more visibility with low priority. The reputation of the passive buyer has little to nothing in the selection of bids by an active seller.

4. Case study

The case study shown in this paper is built on the open blockchain platform, Multichain. Multichain has a feature that restricts the action that the nodes connected to the blockchain can perform. Unless they are specifically given the permission to do so by the blockchain administrator, they will not be able to perform any action in the blockchain environment. This feature is the one that is used to limit the action that can be performed by the four roles specified in Section 3.1.

The stream feature of Multichain [47] is used as the trading platform of the scheme in which bids and offers are published. Participants can then collect, review and select bids and offers for a trade from this stream. Information published to this stream is limited to the trading-related info, such as size, price, and publisher's identity. An offer can be voided when it is deactivated or executed. The record of the exchange and reputation is, however, still registered in the main platform.

The detailed fundamental implementation of blockchain for a free trading market has been illustrated by [48] with electricity market as an example. The cases presented in this paper have a similar basic transaction process whilst emphasizing the reputation-based trading system proposed in this paper.

The specific system used in the case study is as follows: the detailed market segmentation mechanism is given in Table 2, the offers are sorted based on the Priority Value and the bids are sorted based on the asking price. The market segmentation mechanism gives a buyer 100%, 50% or 25% access to all offers based on their reputation. Meanwhile, 100%, 75% or 50% access is given to a seller with high, average, and low reputation respectively.

All available offers and bids for this case are shown in Tables 3 and 4. There are 18 offers with asking price range from USD 1.11 to 1.40 per carbon credit. These are published by sellers with various reputation points range from 2 to 4. For bids, there are 14 bids with the offered price of USD 1.24–1.39 per carbon credit. Buyers and sellers will collect some or all of these bids and offers based on the market segmentation mechanism.

The case will involve three participants that differ in reputation: companies A, B, and C. All produce more emissions than permitted with business-as-usual operation. In order to comply with the regulations, each employed a different strategy to reduce their emissions. Company A decided to use cleaner fuel for operation. Companies B and C decided to use the same method, but also employed some additional measures. Company B replaced some of their old equipment with a new piece that utilizes energy more efficiently. Meanwhile, company C chose to concentrate more effort on reducing emissions by reconfiguring their operation and replacing some units to greatly improve energy efficiency.

As the result, whilst companies A and B still need to acquire some

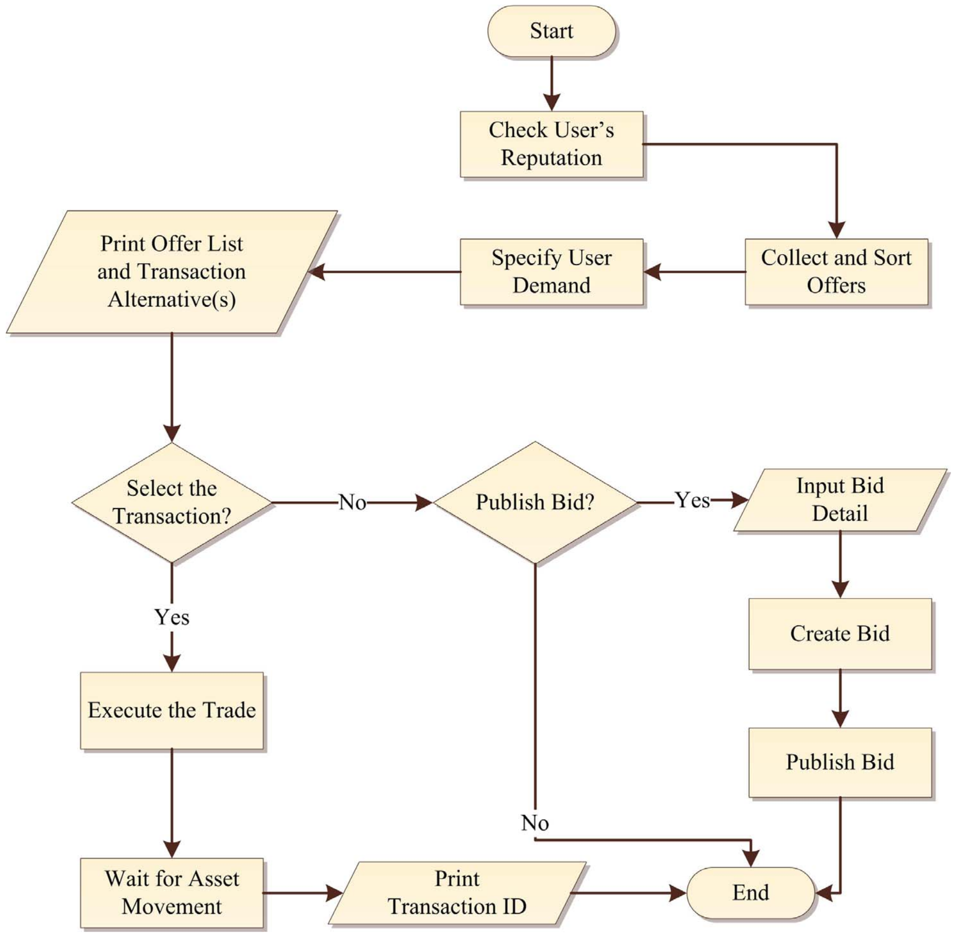

Fig. 3. Typical buying process in blockchain application for emission trading.

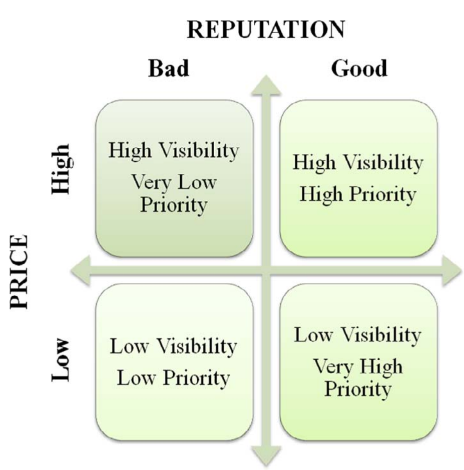

Fig. 4. The effect of seller asking price and reputation points to offer visibility and priority.

Table 2
Classification of reputation and market segmentation of the case study.

Seller/Buyer reputation	Reputation Points (RP)	Offer access (for buyer)	Bid access (for seller)
High	More than 3.5	100%	100%
Average	2–3.5	Most expensive 50%	Cheapest 75%
Low	Less than 3.5	Most expensive 25%	Cheapest 50%

Table 3
Available offer in case study.

Seller	Individual price, USD/carbon credit	Seller reputation point	Offer priority value	Bid size, carbon credit
F	1.33	2	0.665	30
G	1.28	2	0.640	15
H	1.39	2	0.695	37
J	1.25	2	0.625	29
K	1.36	4	0.340	38
L	1.37	4	0.343	20
M	1.40	4	0.350	19
N	1.35	4	0.338	30
P	1.35	3	0.450	25
Q	1.27	3	0.423	25
R	1.34	3	0.447	37
S	1.30	3	0.433	23
T	1.38	3	0.460	27
V	1.28	3	0.427	33
W	1.30	3	0.433	38
X	1.31	2	0.655	35
Y	1.11	2	0.555	19
Z	1.29	2	0.645	28

carbon credits to offset their emissions, company C have more permits than they need. Audit of the companies' strategy and emission rates gives different reputation points for A, B and C. Currently, Companies A, B and C have 2, 3 and 4 reputation points respectively. At present, companies A and B need an additional 87 and 48 CCs respectively to cover their emissions with same price limit of USD 1.37/CC.

Company A calculates the cost of implementing technology that will further reduce their emission at approximately USD 1.36 per permit. The decided limit of USD 1.37 is due to the risk of changing the

Table 4
Available bid in case study.

Buyer	Individual price, USD/carbon credit	Buyer reputation point	Bid size, carbon credit
G	1.30	3	24
H	1.24	3	37
J	1.32	3	33
K	1.35	3	27
L	1.32	2	25
M	1.33	2	32
N	1.36	2	33
P	1.29	2	36
Q	1.28	2	27
R	1.34	2	23
S	1.38	4	19
T	1.39	4	18
V	1.31	3	21
W	1.33	3	33

production process. For company B, further modification will cost approximately the same as company A. Therefore, they decide that as long as they can purchase their CC for less than USD 1.37, this option is considered the best course of action.

Fig. 5 shows the process of collecting and selecting relevant offers that are able to fulfil the demands of A and B. There is a difference in the amount of offers that A and B collect due to the market segmentation mechanism. Based on A's reputation (RP = 2; low reputation), they can only access the most expensive 25% of all available offers. Therefore, out of 18 offers, they can only see four offers with asking price range from USD 1.37 to 1.40/CC (the offers from sellers L, M, T, and H). The offers are displayed sorted based on priority value with the lowest as the top priority.

An inexact match between offers and demands often makes supplementing an offer with another necessary. Table 5 shows the possible combinations of offers that are able to satisfy A's demand. The average price per credit of the combined offers and the relative balance between

Table 5
Possible offer combinations that can fulfil company A demand.

Alt	Seller ID(s)	Average price, USD/CC	Balance, CC
1	L	1.37	−67
2	L & M	1.3846	−48
3	L, M, & T	1.2327	−21
4	L, M, T, & H	1.3853	+16

Table 6
Possible offer combinations that can fulfil company B demand.

Alt	Seller ID(s)	Average price, USD/CC	Balance, CC
1	N	1.35	−18
2	N & K	1.3555	+20

the offers and the demand are shown.

Company B (which have an average reputation, 3 RP) can review 50% (nine offers) of the most expensive offers. The asking price ranges from USD 1.33 to 1.4/CC. The top priority offer for company B is from seller N which offers 30 CCs with asking price of USD 1.35/CC. With seller N supplying 30 of the required CCs, the remaining 18 can be purchased from seller K which offers 38 CC at a price of USD 1.36/CC. This combination is shown in Table 6.

The price limit for both companies is USD 1.37/CC. According to Tables 5 and 6, company B can immediately satisfy their demand (with a 20 CCs excess) for a price under that limit. Company A, however, can only purchase 20 CCs under the price limit. They either have to compromise their price limit or publish their own bid and wait for some sellers to supply their demand. With the latter option, delivery timeframe is the main issue. Waiting time will lengthen if the bid price is at the lower end of the price spectrum.

Subsequently, company B take offers N and K and complete the trade. This trade is executed in the blockchain network. Fig. 6 shows the output of the company B trade process while Fig. 7 shows the record of

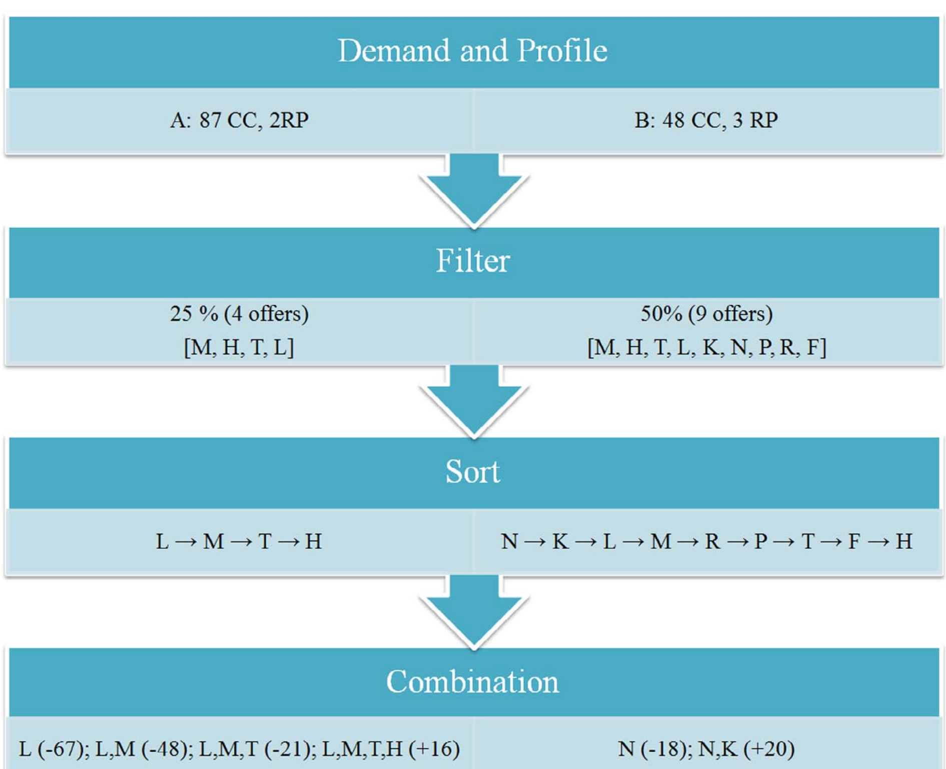

Fig. 5. The process of collecting, selecting and combining offers that are able to fulfil the demand of companies A and B.

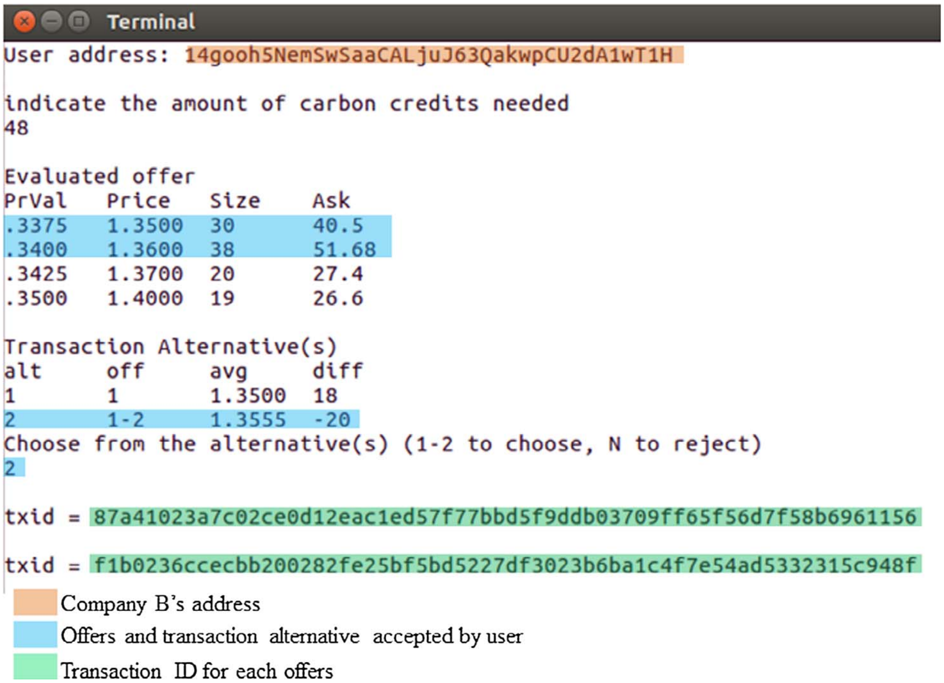

Fig. 6. Terminal window showing the output of company B buying process in which 68 CCs are being purchased.

Fig. 7. Terminal window showing the detail of one of company B's transaction as recorded in the blockchain.

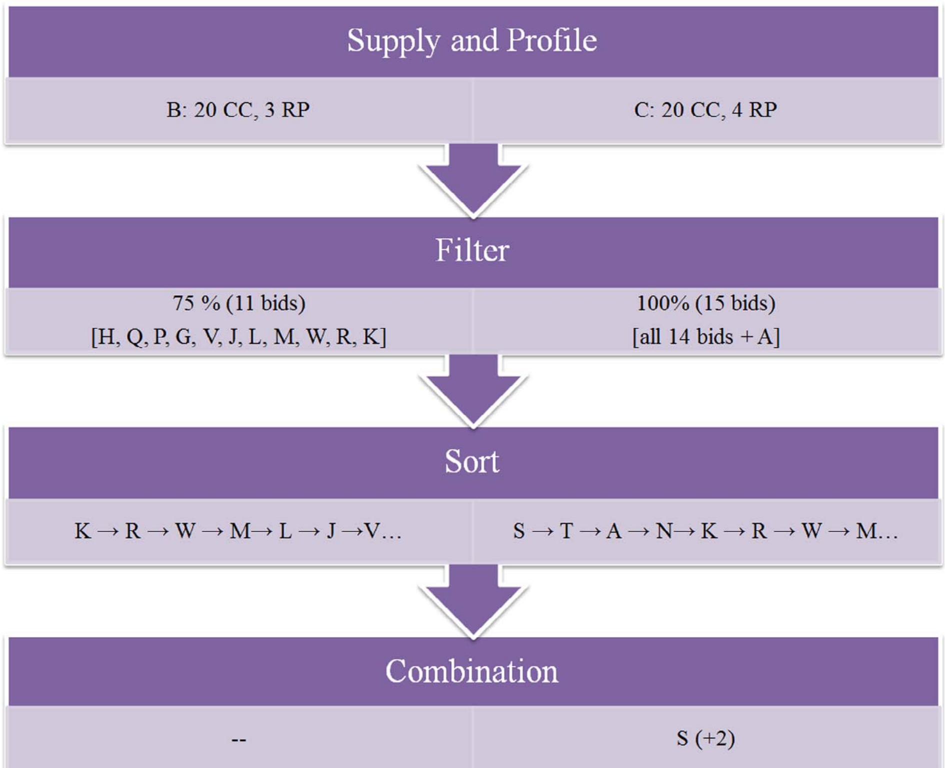

Fig. 8. The process of collecting, selecting and combining buyer bids in which companies B and C can sell their carbon credits.

one of the transaction in the blockchain. The corresponding transaction id is shown in both pictures. The transaction record is shown from the company B point of view. The CCs are assets received by company B (a plus sign for assets gained) while the asking prices paid are the assets sent (negative sign for assets lost).

Meanwhile company A's demand cannot be fully satisfied. Company A purchase only 20 CCs from seller L. The remaining 30 CCs (out of the required 67 CCs) are demanded through a bid at a total offered price of USD 41.1. The other 37 CCs, however, will be purchased at a later time.

After buying 68 CCs, company B decide to sell the excess 20 CCs. At the same time, company C also decide to sell some of their CCs that they will not need. Fig. 8 shows the bid selection process for companies B and C. As a seller that has high reputation (4 RP), company C are given the access to all of the available bids. Therefore, the 14 bids shown in Table 4 and the one additional bid by company A are shown to company C.

As shown in Fig. 8, the highest bid that company B receives is for USD 1.35/CC from buyer K, far below the USD 1.39/CC that company C received from buyer S. Company B cannot accept any bid due to the insufficient amount of CCs that they offer. But, even when they have sufficient credits, considering the CCs they want to sell were bought at higher price than the bid that they received, they are still unlikely to accept.

In the bid lists that companies B and C receive, company A's bid is third in company C's list, but does not make it onto company B's list. Therefore, it may take some time before a seller fulfils company A's demand. In the meantime, they still have more credits to purchase. This difficulty in acquiring CCs is likely to force company A to further reduce their emissions rate.

In conventional ETS, company A will be able to purchase CCs more easily and at lower prices. Therefore, they have no reason to reconsider the implementation of abatement technology. When all offer prices are beyond the price limit there is a pressure to further reduce emissions and implement long-term abatement technologies. Using this proposed mechanism, however, a few sellers with good reputation demanding a high price can provide the necessary pressure.

This example shows the implementation of the system. We demonstrate the impact of good reputation on the quality of bids or offers a participant receives and the ease of demand fulfilment. We observe the two types of participation (active and passive participation) from the case study. Active participation is exhibited by companies A, B and C as they find a bid or offer that can satisfy their demand. Passive participation is exhibited by company A when they publish their bid along with all enterprises listed in Tables 3 and 4. In both types of participation, the participants with the better reputation have a clear advantage over the others.

In the first case between companies A and B, company B have the advantage as the active participant who has more reputation points. Between the passive participants who had their offer reviewed, it also apparent that the top offers are the ones from enterprises that have more reputation points. A case in point is the company B transaction, where a more expensive offer (USD 1.35/CC) is prioritised over cheaper ones (USD 1.33 and 1.34/CC) due to the seller's reputation.

In the second case between companies B and C, again the advantage is given to company C which have more reputation points. For passive participants in this case, however, enterprises with better reputations have no apparent advantages over others. This is due to the fact that the bids are sorted based on price first and buyer reputation second instead of a combination of the two. Therefore, a seller will have the advantage in both capacities as an active or passive participant; but a buyer only in their capacity as an active participant.

The case study utilizes the reputation index as a direct factor. It will work well in cases with large price deviation. For cases with small price deviation, as in this case, it is advisable to add a constant to the reputation. This way, the market will be more competitive and not completely dominated by the participant with the best reputation.

5. Multi-criteria analysis

The BCRB system described in Section 3 introduces a few new mechanisms to the conventional ETS. As the mechanism will change the implementation of the scheme, an evaluation is deemed necessary to

Table 7
Criteria and weight coefficient developed in [49].

Criteria	Weight coefficient
1. Environmental performance	**0.168**
1.1. Direct contribution to GHG emission reduction	0.833
1.2. Indirect environmental effects	0.167
2. Political acceptability	**0.738**
2.1. Cost efficiency	0.474
2.2. Dynamic cost efficiency	0.183
2.3. Competitiveness	0.085
2.4. Equity	0.175
2.5. Flexibility	0.051
2.6. Stringency for non-compliance	0.032
3. Feasibility of implementation	**0.094**
3.1. Implementation network capacity	0.309
3.2. Administrative feasibility	0.581
3.3. Financial feasibility	0.110

Table 8
Grade scale for the assessment of the sub-criterion adopted from [49] with modification.

Assessment	Grade
Null	0.0–0.5
Slightly more than null, less than very bad	0.5–1.5
Very bad	1.5–2.5
Bad	2.5–3.5
More than bad less than moderate	3.5–4.5
Moderate	4.5–5.5
More than moderate less than good	5.5–6.5
Good	6.5–7.5
More than good less than very good	7.5–8.5
Very good	8.5–9.5
Excellent	9.5–10.0

measure the benefits against the drawbacks. As these mechanisms are used to regulate the interaction between participants involved in the scheme, these mechanisms will then be considered as a policy that will support the ETS and evaluated as such.

Multi-criteria analysis (MCA) is an acceptable evaluation method of an environmental or climate change policy instrument [50–53]. The environmental performance, cost assessment, feasibility and acceptability are some of the key criteria that will be assessed in the evaluation. A comprehensive set of criteria have been proposed by [49] and used with slight modification to evaluate various policy options expected to improve EU-ETS performance and efficiency in [51]. The criteria and weight coefficients are presented in Table 7 while the grade scales, adopted from [49] with modification, are provided in Table 8. The conventional ETS will receive middle grade for each assessment while the BCRB will receive grades in a range to account for the uncertainty in future implementation.

5.1. Evaluation of the environmental performance

The *direct contribution to GHG reduction* criterion examines the direct effect of the mechanism under evaluation in reducing the amount of GHG emission. For this sub-criterion, the conventional ETS will provide the reduction due to the limit/cap (*assessment: good, grade: 7*) while the BCRB will have the additional reduction due to the obstruction imposed on participants with bad reputations (*more than good less than very good, 7.8–8.5*). The *indirect environmental effects*, however, are the additional outcome of the mechanism. Both criteria can be measured using the same performance indicator—such as the energy intensity and consumption as well as renewable energy source ratio—and are assumed to be proportional to each other. Therefore, the grade for the *indirect environmental effects* is equal to the *direct contribution* sub-criterion.

5.2. Evaluation of the political acceptability

The first sub-criterion for the *political acceptability* criterion is *cost efficiency*. It measures the ability of the mechanism to achieve its goal without creating an undue financial burden. It compares the cost of reducing the emission with and without the mechanism. A *good* grade is given as the base score for the conventional ETS. Compared to that, the BCRB will probably have higher cost of permit. However, that cost is on a suitable level to inspire technology adoption, the type of scheme notwithstanding. Furthermore, any participant under the BCRB will still have the choice to comply using any method that will give them the least financial burden. Therefore the grade for the BCRB is similar to the base grade, *good (6.8–7)*.

The second sub-criterion is *dynamic cost efficiency*. The criterion evaluates the mechanism's ability to support any research, development, investment and adoption of the technology that will reduce emissions, either incrementally or radically. The BCRB is designed to promote this effect (*very good, 8.6–9*). The conventional ETS, however, cannot effectively engender this effect (*more than moderate less than good*) [7,8].

The third, *competitiveness*, evaluates the cost to comply with the regulation and how the mechanism affects participants' production cost. Both schemes will have an adverse effect on production cost. But, the additional mechanism in BCRB will probably raise it to a higher level. Therefore, the base grade assigned to the conventional ETS is *moderate*, while *more than bad less than moderate (4–4.5)* is assigned to BCRB.

The *equity* sub-criterion assesses the fairness of the distribution of permits, compliance cost and reduction responsibility. The BCRB does not have a specific way of distributing the permits; it is the same as the conventional ETS. Reduction responsibility is the impact of the permit distribution; thus, it will also stay the same. The compliance cost between entities, however, will differ based on the participant's reputation in BCRB. In effect, some participants will not be able to comply at the lowest possible cost. The base grade for *equity* assigned to conventional ETS is *good*, while *more than moderate less than good (6–6.5)* is assigned to the BCRB.

Flexibility is defined as the ability to support different choices on how participants may comply with the regulations. Both schemes still allow participants to choose any options to comply with the regulation that best suited them. However, there is a stricter limitation placed on participants in the BCRB. Therefore, even though *good* grade is assigned to both, *6.7–7* are given to the BCRB for its limitation.

The last sub-criterion in this criterion is *stringency for non-compliance*. It addresses the mechanism's ability to deter non-compliance and non-participation and to provide an effective way of monitoring, validating, and verifying (MVV) the emissions being produced or reduced. For this sub-criterion, conventional ETS receives a *moderate* grade because it has insufficiency that enable problems such as double-counting to occur. Consistent method of tracking and recording the units is one approach that will address this issue [46]. Blockchain application in the BCRB will provide this function. Furthermore, an additional MVV procedure exists in BCRB due to the transparency and the requirement for majority acknowledgement for validation that is native to the blockchain application. The reputation and the limitation it causes in BCRB also provide additional motivation that will deter non-compliance and non-participation. Therefore, the BCRB is assigned a *very good (9–9.5)* grade.

5.3. Evaluation of the feasibility of implementation

The *feasibility of implementation* criterion deals with the required infrastructure and legal framework that is needed to support the proposed mechanism in part and the scheme as a whole. It assesses whether all relevant entities involved in the scheme are able to accomplish all the requirements necessary for the success of the scheme.

Table 9
Result of multi-criteria analysis comparison between BCRB scheme and conventional ETS.

Criteria	Conventional ETS	Blockchain-enabled reputation-based ETS	
		Low	High
1. Environmental performance			
1.1. Direct contribution to GHG emission reduction	7	7.8	8.5
1.2. Indirect environmental effects	7	7.8	8.5
2. Political acceptability			
2.1. Cost efficiency	7	6.8	7
2.2. Dynamic cost efficiency	6	8.5	9
2.3. Competitiveness	5	4	4.5
2.4. Equity	7	6	6.5
2.5. Flexibility	7	6.7	7
2.6. Stringency for non-compliance	5	9	9.5
3. Feasibility of implementation			
3.1. Implementation network capacity	7	6.9	7
3.2. Administrative feasibility	7	6.8	7.2
3.3. Financial feasibility	7	6.7	7
Weighted Total	**6.69**	**6.97**	**7.37**

The first sub-criterion is *implementation network capacity*. It evaluates the competency of relevant public authorities and/or private institutions to design, support and implement the scheme. Four indicators assessed in this sub-criterion are technological infrastructure, trained personnel, data credibility and information transparency. The proposed mechanism in BCRB needs additional support in technological infrastructure, but less in personnel. However, there is little to no doubt that the relevant authorities would be able to provide the infrastructure that the scheme needs. Thus, both schemes are given *good* grade with the score *6.9–7* for BCRB.

Administrative feasibility, the second sub-criterion evaluates the amount of work needed in order to enforce the mechanism and the entities that perform those works. Both schemes need similar amount of work to ensure compliance. This work, however, is executed differently. Conventional ETS relies on the relevant entities performing this work in an efficient and timely manner. BCRB relies on the machines and its algorithms to do the work. This means that there are less entities needed or less effort for the relevant entities. Therefore, both are assigned *good* grade with the score *6.8–7.2* for BCRB.

The *financial feasibility* sub-criterion assesses the cost of implementation, included are costs of preparation, administration, reporting and operation. The BCRB will incur higher costs in setting up the infrastructure for implementation, but the process automation will lower the cost of administration, reporting and operation. Therefore, both mechanisms are given *good* grade, with *6.7–7* grade range given to the BCRB.

The grade summary of the evaluation is presented in Table 9. It shows that, considering all the criteria that determined the viability of a climate change policy, the benefit of the BCRB exceeds the drawback; even after considering the uncertainties that may impede its merit. The analysis demonstrates the advantage that the proposed scheme has over the conventional scheme.

6. Conclusion

The paper proposes a novel ETS model customised for Industry 4.0 integration. It uses blockchain technology and smart devices to improve compliance measure of ETS policy. Taking advantage of the blockchain characteristics, such as transparency and immutability, the accuracy of data essential for the scheme can be ensured. Thus, the functionality, consistency, and credibility of the scheme can be improved. At the same time, due to the support of blockchain technology, a new approach to solve ETS inefficiency can be implemented. Reputation-based trading system offers a novel approach by directly encouraging the participants to adopt a long-term solution in emission reduction. Its implementation also gives more leverage to the participants that adopt long term solutions to determine the market price of the permits. Since these participants have more incentive to set a higher permit price to compensate their emission reduction strategy, the global price of permit may increase even without a shortage of supply or a price floor.

One consequence of the reputation system is financial incentives. Participants with better reputation are given the opportunity to choose a better trade offer and to conclude the trade faster. Two added reputation-based mechanisms that facilitate these incentives are the market segmentation mechanism and the priority-value-order mechanism. The market segmentation mechanism is a filter based on reputation. It gives a buyer or seller with better reputation access to more and better offers. The priority-value-order mechanism is a sorting method that considers reputation along with price as opposed to only price.

The case study shows the inner workings of the scheme and its application. In the case study, we observed two types of participation in the trading process: active and passive. Active buyers and sellers are benefitted by the market segmentation mechanism while passive sellers benefit from the priority value order. Passive buyers, however, receive no benefit or restriction as a consequence of their reputation. Their offers are evaluated purely based on merit. These benefits are expected to shape participants' attitudes in support of solutions that promote long-term abatement effect.

The scheme described in this paper did not deviate too much from the conventional emissions trading scheme. Instead, it adds complementary measures to enhance it. Thus, it can be implemented more easily and quickly than other proposals that ask for complete alteration of the scheme. The evaluation using multi-criteria analysis shows that this scheme is a feasible scheme which benefits outweigh drawbacks.

This work is a part of a larger work package to realise virtual smart EIP, J-Park Simulator. Future works will include the integration of the proposed ETS model to JPS platform and a test of its performance under a larger setting with multiple agents and multiple contrasting objectives deployed on that platform.

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