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Applying blockchain technology for building energy performance measurement, reporting, and verification (MRV) and the carbon credit market: A review of the literature

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ABSTRACT

The threats posed by climate change to Earth's ecosystems, human health, and the global economy are self-evident, and the building sector has contributed significantly to the creation of this problem. For two decades, the construction industry has attempted to mitigate its environmental impact by adopting green building strategies. However, due to a lack of a secure and accurate measurement, reporting, and verification (MRV) system, lowering the industry's carbon footprint has not been embraced by building owners. The building industry has not been able to participate in the carbon credit markets as well. Several factors are contributing to this failure. The primary issue is the complicated and insecure accounting system for accurately tracking energy consumption and carbon emissions. Although there are several building energy performance (BEP) audit schemes, these programs do not provide a suitable structure for a secure and accurate carbon emission MRV. Some climate action groups have navigated an overview of Blockchain for climate actions, especially in registries and tracking solutions, digital MRV, decentralized environment of clean energies, and climate finance. Moreover, there are several attempts to adopt blockchain MRV systems in the climate action projects, and blockchain carbon credit markets were already in place since Blockchain technology can offer a transparent, reliable, and affordable MRV system. This research walked through the literature of the BEP audit programs, the carbon credit market for the building sector, the possibility of adopting Blockchain technology to a digital BEP MRV. The study found that the digital MRV system, which climate action projects require, can be applied to the building sector with the adoption of Blockchain technology. Next, because a few blockchain carbon credit markets are already running, a blockchain digital MRV system needs to be developed to help the building sector participate in the carbon credit markets.

1. Introduction

It is evident that human activities have accelerated climate change since the Industrial Revolution. The anthropogenic carbon dioxide concentration in the atmosphere has increased to about 50 % higher than preindustrial levels. The main cause has been the consumption of fossil fuels for energy generation, transportation systems, and industrial applications [1]. The building and construction sectors are primary sources of energy consumption. In 2018, the built environment accounted for about 40 % of world energy usage and 40 % of greenhouse gas (GHG) emissions. Annual emissions from the building sector increased 2 % in 2018, over 2017, to a record high. It occurred while final energy consumption grew 1 % more than in 2017 and 7 % more than in 2010. These alarming figures are due, to a considerable extent, to the growth of both global building floor area and population. Although energy-efficiency strategies in buildings continue to be implemented, they are not enough to outpace the growth in energy demand [2]. Therefore, energy-efficiency strategies for buildings and their management schemes are crucial to climate change mitigation.

The building sector implemented several energy-audit programs to monitor energy consumption. Examples include the American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE)

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Guideline 14, the International Performance Measurement and Verification Protocol (IPMVP), the Federal Energy Management Program (FEMP), and the Department of Energy (DOE) Uniform Methods Project (UMP). These audit processes are outlined in-depth due to their influence on the energy consumption scheme. They provide rules for measuring energy utilization, energy demand, and water use [3]. However, these programs do not address metrics related to climate change mitigation. If the building sector were to convert energy savings to emission reductions, it could be a game-changer. It could be accomplished by virtue of identifying an accepted method agreed to by the stakeholders that could deliver reliable and auditable reporting and verification.

The measurement, reporting, and verification (MRV) system is critical to the carbon credit market [4]. MRV is also pivotal to building energy performance (BEP) measurement. However, the current BEP MRV cannot deliver a trustworthy solution to the problems. The trustworthy attribute for this system can be developed by adopting Blockchain technology: Blockchain is a database shared immediately by a network of all players. Once data are recorded in a blockchain system, they are immutable, sharable, traceable. These characteristics of Blockchain enable the BEP MRV system to have transparent, traceable, and affordable features. Therefore, It has excellent potential for Emissions Trading System (ETS) design features and a suitable MRV for carbon emissions [5].

This study presents a review of the three types of papers that address: (1) the carbon credit market and the building sector; (2) BEP and its measurement and verification (M&V); and (3) digital BEP MRV and Blockchain technology. Through the literature review, this study delivers the reasons why the building sector cannot participate in the carbon credit market, the readiness of BEP M&V programs for climate mitigation actions, the plausibility of a blockchain digital BEP MRV. On top of that, this study pursues the characteristics of a potential blockchain MRV application for BEP and climate actions. Ultimately, this study focuses on finding a pathway for the building sector's participation in the carbon credit market.

2. Background

2.1. Carbon credit markets

A carbon credit is a security that can be tradeable. It grants the owner the permission to release one ton of carbon dioxide (CO2) or greenhouse gas equivalent (CO2e). There are two types of credits: a permit and a certificate. A permit grants the right to an entity to emit a specific mass of greenhouse gases (GHG) into the atmosphere. A certificate means the verification by the third party that some organizations or individuals removed or avoided the emission of one ton of CO2e. The Kyoto Protocol launched the Emission Trading System (ETS) to encourage nations to participate in climate change mitigation through credit trading [6]. If participants have extra credits, they can trade them with other players in the market. This mechanism allows market participants to meet their carbon allowance allocated by the government or regional jurisdiction. Many countries have ratified the international carbon trading treaty to provide the ETS system for their country [7]. Recently, the United States targets 100 % renewable energy production in the power supply system by 2035 [8]. On top of that, the Paris Agreement's 2 °C scenario requires the adoption of high-efficiency and low-carbon systems for the building industry, which means the building sector needs to decrease 85 % of current GHG emission levels [9]. It seems too ambitious for the building sector to reduce its carbon emission to meet these goals. Therefore, they should be monitored by proper MRV systems. If not, there is a high chance that the plans will remain just plans. By participating in the ETS, the building sector is going to have another pressure of reducing their emission and a way to benefit from their emission MRV in the carbon credit markets.

Carbon credit markets fall into three groupings: mandatory vs. voluntary, allocation vs. offset, and international vs. regional markets. Fig. 1 shows the categories of the market and credits [10]. While the mandatory market is regulated by the law or mandatory GHG reduction target, the voluntary market is based on the voluntary climate actions of corporates and individuals. The allocation market is the market that trades emission allowances allocated by the government to industrial facilities, fuel suppliers, electricity importers, and so forth. The offset market is about providing companies or projects with opportunities to finance carbon reduction or climate action projects to offset their GHG emissions. Finally, in an international market, carbon credit trade occurs over the countries, while in a regional market, transactions are limited to the nation's inner boundary.

The main sectors covered by the ETS include industry, energy, power generation, transportation, and waste. Only Japan allows the building to trade its credits in the market [11–13]. The Paris Agreement focuses on suppressing warming by 1.5–2° Celsius above the temperature level of the industrial revolution. The essence of the Paris Agreement is the Nationally Determined Contributions (NDCs) for climate mitigation action. The signatories of the agreement attempted to include the building sector within their NDCs. As of 2018, 136 NDCs contain the building sector as their covered sector. However, despite these efforts, most participants of the Paris Agreement still do not adopt supportive policies for the building sector to carry out to reduce carbon emissions from it [14].

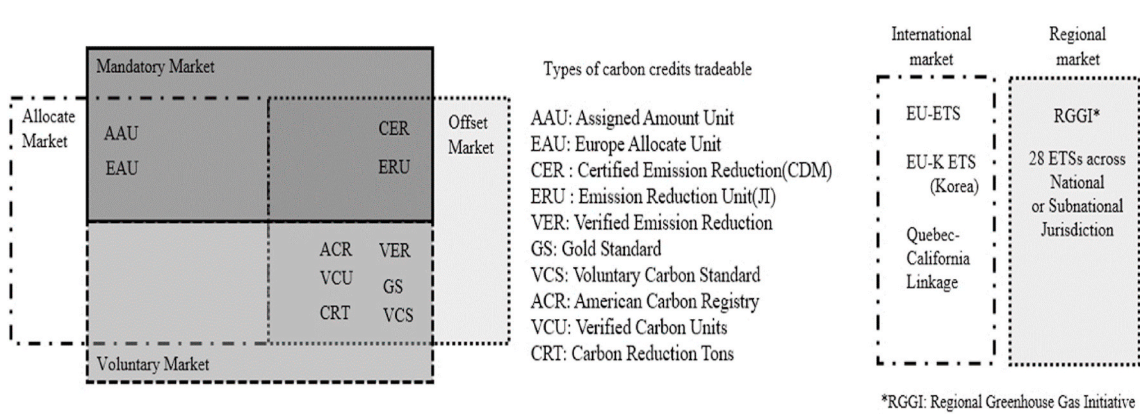

Fig. 1. Types of the carbon credit markets and credits. Adapted from Ref. [10].

2.2. BEP audit

BEP auditing can be determined as a process to assess where a building or facility consumes energy and detect changes to lower energy consumption [15]. The structured energy audit is the foundation of BEP measurement and carbon credit accounting since robust and reliable audit processes provide accountable data for financial purposes. While Thumann et al. (2010) categorize the energy audit processes into three groups: (1) walk-through, (2) standard, and (3) computer simulation [15], Krati (2011) divided them into four groups: (1) walk-through, (2) utility cost, (3) standard, and (4) detailed. A walk-through audit means a short tour of a building or facility to inspect the energy systems visually. A utility cost audit analyses the cost of the facility operation. It focuses on energy consumption trends, peak demand, weather data, and energy savings opportunities. The standard audit provides a comprehensive energy assessment of the building's energy structure. In addition to walk-through and utility cost audits, it includes establishing a baseline for energy use and assessing energy savings and energy conservation measures (ECMs). The detailed energy audit is the most extensive, time-consuming energy audit, including adopting tools to measure energy consumption for the facility, such as meters, submeters, and computer simulations [16].

For building energy auditing, several energy-auditing programs are utilized; ASHRAE Guideline 14, IPMVP, FEMP M&V, ISO 50000 series, DOE UMP are representative energy audit programs in place around the world. These guidelines or protocols have a lot in common in measuring energy consumption, uncertainty, and savings. However, they do not focus on carbon emission reduction, just on energy performance. A few climate action projects, such as fuel switch, energy efficiency, and renewable energy that the building sector joins in, are based on the renovation of building energy mix, the reduction of building energy consumption or the surplus production of renewable energy on-site or off-site. Thus, these guidelines or protocols deliver methodologies to calculate energy savings and carbon emission based on energy consumption. Therefore, the BEP improvement is significant both in the BEP auditing and carbon trading. Moreover, these guidelines or protocols can be combined with new technologies such as Blockchain, IoT, 5G, and/or Artificial Intelligent (AI), which leads to a data-driven environment, saving cost and time and reducing human errors [17].

2.3. Blockchain

In 2008, Satoshi Nakamoto, perhaps using a pen name, released a paper titled "Bitcoin: A Peer-to-Peer Electronic Cash System [18]." In his article, he suggests a new electronic cash allowing online payment systems without intermediaries such as banks, insurance companies, and other financial institutions. Blockchain technologies are being developed from cryptocurrency to supply chain management tools, and their applications are increasing across a broad range of sectors. The data is secured cryptographically by public and private keys in the network [19]. Since it runs without authority, it organizes procedures with less cost and time, making it possible to be more efficient. These features are gaining momentum, continuing the tendency of autonomous headquarters, such as NASDAQ, and enabling the trading of both physical and non-physical resources [20]. The transparent, immutable, accountable, sharable characteristics of Blockchain have great potential for financial and non-financial trades.

3. Methodology

This study tried to conduct systematic searches for the terms "carbon credit and building energy performance," "MRV and carbon credit or building energy performance," "Blockchain and building energy performance" with a few databases for studies from January 2008 to December 2020. The major databases were Web of Science, ScienceDirect, and ProQuest. The searches were delivered on the keywords, abstract, and title of articles. The results fell into three categories: technical papers, scientific publications, and reports on special topics published by a particular organization. Significant articles on BEP or MRV systems were indicated in the literature. However, studies that have a combined subject such as the carbon credit market, building sector, Blockchain, and MRV, were not found in significant numbers. Since this research's main purpose is to identify the carbon credit market, the BEP, and the potential blockchain MRV application, the focus was on papers written later than 2008.

The publication search for the carbon credit and the building energy performance has two main categories utilizing specific clusters of keywords. The first cluster of keywords is connected to carbon emission, carbon credit, carbon credit market (carbon credit terms). The second keyword cluster for the building energy performance, building energy (building energy performance terms) screen publications. Furthermore, the publication search for MRV and carbon credit or building energy performance comprises two major classes employing specific keyword groupings. The first set of keywords is intended to uncover MRV, measurement, reporting, and verification (MRV terms). The second category of keywords for carbon credit or building energy performance is carbon emission, carbon credit, carbon credit market (carbon credit terms), the building energy performance, building energy (building energy performance terms) filters publications. Moreover, Blockchain and building energy performance, the search was conducted with two groups of keywords. The first is Blockchain and Blockchain technology (Blockchain term). The other is BEP (building energy performance terms). For each search phrase, general keywords (such as performance*, consumption*, or efficiency*) are used. To discover articles or papers that had all three of the requested phrases, the "AND" command was used.

The publishing review was divided into two sections. The initial step was to gather all relevant articles based on the research terms. The articles' titles and abstracts were scrutinized in order to select those that were most relevant to the carbon credit market, BEP, MRV, and Blockchain. The second stage was composed of a more detailed examination of all the chosen papers. Double-counted articles from each database were eliminated, and only papers that reviewed, enhanced, or applied the three categories above were taken. The search identified 57 relevant papers out of 561 papers of the initial search. The authors read the titles and abstracts of them and selected the papers related to the study.

4. Carbon credit market and the building sector

4.1. Building sector's contribution to climate change

According to Zaid (2013), the construction industry accounts for around 40 % of worldwide energy consumption and carbon emissions. It uses approximately 60 % of worldwide power, with 80–90 % consumed during the operational phase. The operational phase utilizes 50 % of electricity for space heating or cooling. As for greenhouse gas (GHG) emissions, residential buildings are responsible for two-thirds of the global building, carbon emissions, and commercial buildings account for one-third. Also, 80–90 % of emissions occur during building operations. Table 1 shows that the building sector has the potential for 75 % energy savings and 35 % emission reductions [21]. The energy performance potential of the building sector means the maximum reduction rate of the present energy consumption-related activity from the buildings.

4.2. Energy-efficiency and green building certificates for carbon reductions

The building sector has great potential for energy consumption reductions and CO2 emissions reductions. Green building certification systems such as Green Globes and Leadership in Energy and Environmental Design (LEED), Living Building Challenge urge the building industry to decrease the high potential impact on global warming with an energy-saving and carbon-emission reduction approach. According to

Table 1
Building sector's global energy responsibility for climate change. Adapted from Ref. [18].

•Building sector's energy responsibility				
40 %	of global energy consumption	Accounts for 60 % of global electricity	80–90 % consumed in the operational phase	50 % consumed for space heating or cooling 10–20 % utilized for water heating
			10–20 % consumed for embedded energy and demolition/deconstruction	
40 %	of global GHG emissions	65 % from the residential sector 35 % from the commercial sector	80–90 % emitted in the operational phase	
•The energy performance potential of the building sector				
75 %	Reduction in energy consumption			
35 %	Reduction in carbon emissions			
40 %	Reduction in water consumption			
70 %	Reduction in waste output			

the Green Globes Assessment Protocol for Commercial Building (2019), it includes a reduction scheme in building carbon dioxide equivalent emissions as one of three paths for measuring energy performance. When the building reduces 50 % of CO2e emissions of the baseline building in its region, the reduction formula is as follows (1).

$$\text{Percent reduction in } CO_{2e} = 100 \ X(1 - PER/BER) \tag{1}$$

where BER represents the baseline equivalent emission rate based on the baseline building's CO2e emission rate, and PER represents the proposed building's CO2e emission rate [22].

Under the LEED program, in the Energy and Atmosphere section, optimization of energy performance can be achieved by mitigating environmental and economic damages from aggressive energy utilization. Option 1 of this section requests calculation of the Performance Cost Index (PCI), the Performance Cost Index Target (PCIt), and rate improvement utilizing cost and greenhouse gas (GHG) emissions. Furthermore, renewable energy regulations call for on-site renewable energy generation as well as off-site renewable energy purchase or offsetting credit for GHG emissions in order to minimize the entire or a portion of the yearly building energy consumption [23].

Living Building Challenge suggests two international energy-saving-related certifications: zero-energy certification and zero-carbon certification. The former focuses on delivering net-zero energy building by adopting on-site renewable energy production. The latter is for projects that reduce climate impacts from energy and material consumption. It asks the project to stick to use operational energy based on carbon offset and renewable energy from off-site. On top of that, it requires setting up a challenging energy efficiency level and lowering embodied carbon level [24].

4.3. Countries' strategies to reduce the building sector's carbon emission

The Chinese Ministry of Housing and Urban-Rural Development (MOHURD) was one of the pioneers in introducing carbon trading schemes to the building sector. The original concept was designed to place a ceiling or a cap on the energy consumption of a building in line with China's mitigation actions on climate change. The strategy of using subsidies to support energy efficiency has been successful in achieving the carbon emissions caps, and, as a result, China is still searching for a comprehensive solution. In their first ETS system, MOHURD set limits on energy consumption and focused on actual emissions levels. The ETS can provide accountability for emissions and supplement the deficiencies of the existing reduction policy. The MOHURD project showed that an ETS can provide several benefits: efficiency, selective limitation of emissions, responsibility, monitoring of emission levels, and continuous incentives to improve. MOHURD implements three emission reduction schemes: cap-and-trade for commercial buildings, subsidies for the renovation of current residential buildings in hot climate zone, and a regulated increase in emissions from thermal supply facilities. The MOHURD initiative zeroes in on the building sector, which has thus far failed to reap the benefits of carbon trading. If China succeeds in utilizing the ETS in an efficient way for the building sector, it would be a milestone with respect to controlling the carbon emissions from buildings [25].

The Tokyo Cap-and-Trade was the first cap-and-trade market in the world to target the building sector. Tokyo ETS accounts for 40 % of both industrial and commercial carbon emissions. It is equivalent to 20 % of all Tokyo City's carbon emissions [26]. The primary characteristic of Tokyo ETS is that it regulates emissions at the facility level. Nishida et al. (2011) showed that the success key factors are a mandatory reporting process and an open communication process among the stakeholders [27]. The commercial sector is the major source of urban carbon emissions [28]. Most of the measured emissions from the commercial sector stem from buildings. Policies aimed at big existing buildings must be implemented to decrease significant energy use in the sector. These policies targeted approximately 1000 commercial buildings and 300 industrial facilities, including government buildings. A quarter below carbon emission levels in 2000 by 2020 is the target cap. The reduction target is 8 % for commercial buildings and 6 % for industrial buildings. The baseline emissions of the individual building are determined by the use of the building owners of the preceding program for an average of any three years of emissions in a row (2002–2007). Independent parties verify all reports about the emissions and reductions. By utilizing a licensed auditing program, the Tokyo Metropolitan Government (TMG) works together with verifiers and auditing organizations. In the TMG policy, the key success factors for program design are as follows: a mandatory program, an effective cap and allowance distribution, fairness for players, stabilization of the carbon price in a closed market, and simplicity. For the success of program execution, the mandatory reporting program is crucial, and collecting detailed data for the government is pivotal in that it can encourage the energy efficiency of buildings, enabling high-level policy development [27].

Local law 97 to support the Climate Mobilization Act was enacted by The New York City Council in 2019. It demands that buildings in New York with a floor area greater than 25,000 SF reduce their carbon emissions by 40 % by 2030 and up to 80 % by 2050. According to Danielle Spiegel-Feld (2019), the concept of applying an ETS for the building sector is emerging only recently, and Tokyo is the sole example. The Tokyo ETS includes around 1300 buildings, while New York Local Law 97 embraces about 50,000 facilities. It requires buildings that have larger than 25,000 SF to satisfy NY's carbon reduction goal. As such, New York City delivers a new framework for ETS for the buildings. The buildings have a wider range of categories than any other classes regulated by traditional ETS. Moreover, the owners of the buildings usually do not have full control over the energy used in their facilities. Between 40 % and 60 % of the building, energy utilization in commercial buildings is in spaces controlled by the tenants [29]. The various types and numbers of buildings present a high administrative load on local government for energy auditing and verification. Small properties have difficulty measuring emissions, counting reduction costs, catching up with the trends of carbon prices, and having partners to trade the credits [30]. The lessons learned from the Tokyo ETS show that there are a few reasons for the stagnation of carbon trading from the buildings, including a lack of a public trading platform for the building sector and the various options available to building owners for lowering their energy consumption. The former increases transaction costs, the latter decreases the demand to buy allowances.

The Internal Revenue Service (IRS) of the United States released a regulation under Internal Revenue Code (IRC) regarding CO2 sequestering. Section 45Q enables taxpayers to claim a tax of $20 per ton for CO2 geologic storage and $10 per ton for CO2 used for enhanced oil recovery or enhanced natural gas recovery. In 2026 these tax credits will increase from $20 to $50 per ton and $10 to $35 per tonne, respectively. The New IRS Codes will broaden the availability of the tax credit of Section 45Q and provide for the recapturing of carbon emissions. To get the tax credit, applicants should provide an LCA analysis or assessment of GHG emissions stemming from their projects. The background of this code is that according to Treasury Inspector General for Tax Administration (TIGTA), in 2020, only ten taxpayers accounted for 99.86 % of the entire credits of Section 45Q. The investigation on their tax return data shows that approximately 90 % of the tax credits claimed have been inappropriate because the Environmental Protection Agency (EPA) could not provide them with a monitoring, reporting, and verification (MRV) system to prove their credit authenticity [31].

4.4. Barriers to participating in the carbon credit market by the building sector

The barriers of the building industry against climate change mitigation action fall into four folds: the insignificant energy saving amount of a single building, a wide range of energy-efficient schemes, the fractured incentives, and various interests of building stakeholders. To tackle these obstacles, Lam et al. (2014) argue that an ETS should enable its players to combine energy savings of each building, ease the depth of MRV procedures, and provide owners and occupants with advantages from ETS [32].

China has seven pilot ETS projects, but there are several critical issues hindering carbon trading from developing in China: lack of quality of historical emission data, the higher local GDP or industrial productivity than the Chinese average, the grandfathering of permit allocation methods, and the MRV system. Therefore, the following important ideas should be considered in ETS: 1) establishing a national reporting and monitoring system for greenhouse gas (GHG) emissions at the facility level, 2) integrating the carbon trading schemes with a carbon tax scheme to include enterprises with fewer emissions, and 3) considering the linkage between carbon trading and pollution trading. Chinese ETS systems consider MRV to be pivotal for the effectiveness of the ETS system. It encouraged players to have electronic reporting and verification. Although it was in the initial stage, these measures made it possible to culminate in provisional guidelines for MRV of CO2 emissions, especially in Shanghai and Shenzhen [33].

Song et al. (2017) argue that the building sector's unique characteristics make it more challenging due to financial, technological, infrastructural, and administrative obstacles stemming from the building sector's unique characteristics. The authors found the following elements influencing ETS implementation in the Chinese building sector: government, emitters, distributed energy use, CO2 emissions in buildings, and decentralization of building asset rights [34]. First, as a policymaker, the government provides the infrastructure to monitor and verify the emissions; provides financial support for emission reduction schemes; assigns the allowance to carbon emitters; and governs the ETS market. Thus, the government should enhance the significant ETS market for the construction industry [35]. Second, emitters are the primary players that decide on selecting technical equipment for the building and the carbon credit trading strategy. Since these factors are connected to each other, emitters' decisions on minimizing the credit losses through the ETS system are critical to carbon reduction. Finally, the distributed energy consumption and decentralized rights are particular characteristics of the buildings. These characteristics should be handled as primary concerns in developing the ETS in the Chinese building industry [34].

5. BEP and MRV

5.1. BEP M&V

The primary goal of the BEP M&V is to measure the energy savings of the building for evaluating and verifying the project's energy-saving target. The energy savings can be defined in equation (2) [36].

$$\begin{aligned}\text{Savings} = {} & (\text{Baseline Energy Consumption} - \text{Reporting Period Energy}) \\ & \pm \text{Routine Adjustments} \pm \text{Non}-\text{Routine Adjustments}\end{aligned} \tag{2}$$

Among several BEP M&V programs, FEMP M&V guide delivers processes and guidelines for auditing the building energy savings stemmed from energy-efficient strategies such as energy-efficient equipment, water-saving measures, operational improvement, adopting renewable energy generation, and performance-based energy-saving contracts. It embraces particular methodologies that IPMVP developed. It provides details about delivering M&V approaches, assessing M&V strategies and result reporting, and payment based on the energy-saving result in the project contract. So, these processes are aligned with the IPMVP. ASHRAE Guideline 14 offers how to calculate energy savings connected with performance contracts utilizing measurements. Furthermore, it provides device and data management guidelines and provides uncertainty calculation approaches using models and assessments. However, it does not have an approach related to retrofit isolation with critical parameter measurement (Option A), which FEMP and IPMVP provide. Retrofit isolation is an M&V technique that considers only the affected equipment or system independence of the rest of the facility. The UMP is a protocol for measuring energy savings with energy efficiency schemes. It presents methodologies to determine energy savings for building types such as residential, commercial, and industrial buildings. It is in accordance with the IPMVP's options as well as has more detailed processes required to calculate the savings from each project to assess the program-wide impact [37]. ISO 50000 series, Energy Management Standard, consists of six categories: 500,001, 50,002, 50,003, 50,004, 50,006, and 50,015. These standards provide a framework of energy strategy requirements for organizations. ISO 50001 also has no practice about option A of the FEMP and IPMVP, and it does not require an independent third-party audit. It is because ISO consultants play a role in third-party auditors [38].

These energy M&V programs require a wide range of processes of BEP accounting. Table 2 shows the criteria that the programs request. First of all, they separate the measurement boundaries as retrofit isolation, whole facility, and simulation. The subjects to audit are energy and water. They usually ask for data about meteorological data and occupancy data to calculate the relation between energy consumption, weather, and occupant's behavior. Energy savings definitions are the same as FEMA has, like equation (1). Most of the programs require a baseline period and a post-installed period as a minimum of 12 months. When they calculate the energy savings, they adjust routine and non-routine events. They request a lot of data, such as equipment, Occupancy, HAVC operating schedules and setpoints, energy use and load profiles, etc. They usually calculate savings uncertainty on auditing. They do not require climate change mitigation action.

Granderson et al. (2017) argue that automated measurement with M&V 2.0 tools of BEP takes less time than conventional cases. Previously, M&V operations were done manually, and it took a few days to access the savings using normal ways to screen the data and develop altered baseline models for each building. It implies that the use of an autonomous system has the ability to minimize the number of human resources required to attain project energy savings [39]. Also, M&V tools are utilized to measure performance-based measurement. This manner enables the building to acquire more robust results than the current simulation-based estimation approaches [40]. Ye et al. (2016) introduced the Metering Cost Minimization (MCM) model to aid in the

Table 2
Comparison of BEP M&V programs.

Item	Contents	ASHRAE 14 (14′)	IPMVP (12′)	FEMP M&V (15′)	ISO50000 Series M&V (14′)	DOE UMP (18′)
Measurement Boundary	Retrofit Isolation (Key parameter) Retrofit Isolation (All parameter) Whole Facility Simulation	X			X	
Subjects to audit	Energy Water					
Required independent variables	Meteorological data Occupancy					
Energy Savings Definition	E (Baseline) - E (ECMs installed) ± Adjustments					
Data required to set up the Baseline	Equipment list, Performance data, Occupancy, etc.					
Savings Uncertainty Calculation						
Third-party Independent Audit					X	
Climate Change Mitigation Action		X	X	X	X	X

Legend: X-Not dealt with, O-dealt with.

construction of optimal M&V metering designs that minimize metering costs while achieving measurement accuracy requirements. The authors used the lighting retrofit project as a case study to show how the methodology may be applied to different projects. A hybrid spatial and longitudinal MCM model is used to create the best M&V metering approach. They also employed sample approaches, sample size determination techniques, and decay models for the light population for the MCM model. The suggested methodology lowers the cost of M&V by up to 94% when the confidence and accuracy levels in various lighting categories are optimized during the course of the project [41]. The FEMP M&V approach was used for 172 projects, according to an Oak Ridge National Laboratory (ORNL) study on energy and cost reductions from the DOE energy savings performance contract (ESPC) program in 2018. The projects have estimated energy-saving, and actual reporting on real energy consumption as well as have projected cost savings from saved energy and utility bills and decreased maintenance and repair costs. In the summation of all data, actual cost savings showed a 107.9 % achievement on the proposed cost savings. In the pool of 156 projects (16 projects out of 172 have failed to reduce energy consumption), the ORNL report reveals that around 70 % of the measured yearly cost savings were due to decreased utility expenses, and 30 % stemmed from operational expenses and repair cost savings [42].

Financial incentives of utility subsidies and energy performance contracts also require a countable measurement and verification (M&V) that can deliver tangible evidence of energy savings related to energy conservation measures (ECMs). M&V 2.0 provides a more cost-effective alternative to energy consumption sub-metering or the installation of specialized device data collectors. Recently, performance-based incentives have required post-installation M&V to provide proof of savings. As a result, the accuracy of the M&V is critical to financial incentives for both utility companies and their customers. Energy service companies (ESCos) save a lot of energy for a variety of enterprises. And the performance is delivered by these ESCos using M&V data. Consequently, M&V is pivotal in demonstrating energy savings and negotiating energy-saving contracts [43].

5.2. Building carbon emission accounting

However, currently, these energy audit programs focus only on energy savings. They do not provide a way to derive carbon emission reduction from energy savings. Despite the fact that the ultimate purpose of energy savings is to reduce environmental impact and climate change, the energy audit program cannot give information on carbon emission reduction. While M&V is essential to building energy audits since it is usually for commissioning, energy certification, and green building certification, MRV is critical to carbon emission reduction. Paris agreement offers MRV of GHG emissions that is carried out at national, institutional, individual level to measure the carbon footprint and deliver a report it by means of an emission inventory [4].

UNEP proposes a Common Carbon Metric (CCM) for evaluating energy savings and estimating GHG emissions for MRV of carbon emissions in the construction industry. It is necessary to measure the building's operational energy consumption and subsequent carbon emissions since the building releases around 80–90 % of its overall emissions during the operational stage. The weight of CO2e per square meter per year (kgCO2e/m2/year) with building type and climatic zone should be reported. But it requires MRV data not for an individual building but for representative samples building. These samples enable the buildings to be categorized by area and address. CCM has three scopes of emissions: scope 1 (GHG directly from the building), scope 2 (indirectly from the building, purchased energy out of the building), scope 3 (building materials have upstream and downstream emissions). This study focuses on scope one since scope one accounts for the building operational phase. The carbon emissions reduction formula has the same as the energy savings definition, comparing to formula 1 of energy savings calculation. So, the accounting processes are very similar to one of the energy savings. According to the GHG protocol (2005), GHG accounting has six principles: relevance, completeness, consistency, transparency, accuracy, conservativeness [44]. Fig. 2 shows what GHG reductions are. The formula for calculating carbon emission reduction is almost the same as the energy savings calculation formula of energy audit programs. Because emission calculation is based on energy savings, energy-saving MRV is crucial to emission reduction. As Granderson and Newsham argue, M&V 2.0, automated measurement, and digital MRV increasingly become more and more important to measurement and verification.

6. Digital BEP MRV and blockchain

6.1. Digital BEP MRV

6.1.1. Smart meter

Smart meters are critical and fundamental features of digital BEP MRV. Recently, clients requested their energy usage patterns in order to monitor and audit the real savings amounts and values obtained as a result of the behavioral modifications they implemented. Lima et al. (2012) proposed an automated metering and submetering system for water and electricity, and the system is incorporated into the energy management tool. The program provides customers and utility providers with energy profiles that include historical consumption, daily and hourly energy predictions, and predicted energy savings as a result of

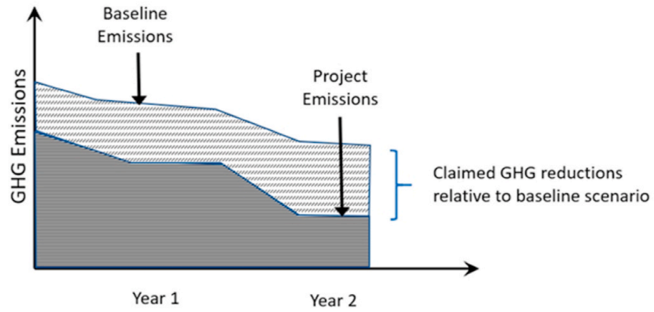

Fig. 2. Comparison against a baseline scenario for project accounting. Adapted from Ref. [44].

changing energy consumption patterns and implementing energy-efficient equipment. The Smart Grids principles are connected with smart devices that measure water and power use. Clients actively respond to changes in the Smart Grid system, knowing the effects of their energy use on society and the environment. The system consists of three folds: meter and submetering devices, a network of communication, data management/analysis system. The proposed system enables efficient energy control for conscious users as well as provides a business opportunity with regard to energy performance information infrastructure. The reliable data collected from the network allow the clients to change their lifestyle. Furthermore, data availability delivers clear advice on governmental energy-saving policy [45].

6.1.2. Digital BEP MRV

Digital BEP MRV transforms the current manual BEP MRV processes with smart meters, smart sensors, IoT, cloud computing, and other state-of-the-art technologies. Ke et al. (2016) propose using smart sensors and cloud computing to measure and verify energy performance in real-time. The system proposed consists of three folds: on-the-spot monitoring, cloud computing, client tiers. The on-the-spot monitoring layer has smart sensors, a data communication gateway, and data collection recorders. The cloud computing tier has an M&V database, Google app engine, router, and browser. The client tier provides users with the analyzed energy data [46]. With Blockchain technology, digital BEP MRV uses all the smart sensors, M&V database in a secure, transparent, just-in-time manner.

6.2. Blockchain

Before going any further, it is substantial to discuss Blockchain technology's characteristics and the potential and impact on digital BEP MRV. Blockchain is on the basis of distributed ledgers. A distributed ledger is a sort of database all players have simultaneously in the system. When a user has their own credentials, they can access this system from remote or multiple places. Because all participants in a distributed ledger system have the same copy of the ledger, they will always have their ledger updated in a short period. The ledger can contain economic, social, and environmental components, among other things. The public and private keys are used to protect the data cryptographically [19]. It ensures security and authenticity. The distributed ledgers are transferred to distributed "nodes" within systems. Node saving is secured by all players, with their verification executed by shared codes. This computational code provides the veracity of the transaction[47].

When Blockchain was introduced in the market, it mostly generated and traded cryptocurrency. For example, Bitcoin, Ethereum, Ripple are representative cryptocurrencies in place in the market. The consensus algorithm is critical to cryptocurrency. Blockchain networks use several consensus algorithms by their developed circumstances: Proof of Work (PoW), Proof of Stake (PoS), Practical Byzantine Fault Tolerance (PBFT), Delegated Proof of Stake (DPOS) and Stella. Through these consensus algorithms, a blockchain network eliminates intermediaries for oversight and saves cost and time efficiently. All network players must show that they have the authority to conduct a transaction, being pursuant to consensus; all participants accept before a new block is generated. Then, all players have copies of the block that is immutable and transparent. Once an agreement is executed, cyber-peers generate blocks and hash cryptography [48]. According to its purpose, the Blockchain network has three network features: public, private, and consortium (permissioned) networks. The public network opens to every participant having no conditions. Everyone can access the network. However, private networks provide access credentials to qualified members beforehand. A consortium blockchain unites public and private network characteristics, but approval is still required [20].

A smart contract is an automated predefined code execution by a trigger of particular conditions. The smart contract does not have any intermediary needed to run predefined requirements. Thus, the whole procedure is featured by automation and enforceability. Smart contracts can use various rules such as administrative, financial, contractual rules. For a smart contract, a few computer languages are utilized: Java, Go, and Python [48].

Tokenization means converting legal rights or valuable information into a simple digital piece of data "token." It facilitates transactions of non-financial assets. For example, chips in the casino represent a specific amount of money but are not money. Also, Blockchain carbon credit markets such as Veridium, Nori, Poseidon use two token systems to facilitate the transactions of carbon emissions reduction and monetization of carbon emission reduction. They use carbon tokens such as NRT, Carbon, Carbon credit to represent a reduction of a ton of carbon dioxide and utilize payment tokens such as NORI, VERDE, OCEAN. These types of cyber-symbolism have facilitated development in digital coinage overall [49]. On top of that, as explained above, it recently expands its horizons to non-current asset trades. The tokenization helps the network accelerate transparent and immutable transactions.

According to Herian (2018), the Blockchain promises better decentralization of the network, enabling simultaneity in data exchanging between participants, improving the methods of the registry. Blockchain networks deliver multi-national and cross-jurisdictional means of carrying out the transaction in autonomous manners by tokens and smart contracts. Blockchain, combined with IoT, AI, and other technologies, can reinforce Blockchain's autonomous features [50].

There are lots of controversies over the blockchain drawbacks on energy consumption used for coin mining, which utilizes as much poser annually as Ireland [51]. The energy intensity is determined by which consensus algorithm is chosen for a blockchain system. As mentioned before, there are many consensus algorithms actively used in the market. According to Bach et al. (2018), the PoW algorithm uses 653.22 kWh and emits 311 kg of CO_2 per coin mining. Pos follows PoW with 34 kWh electricity consumption and 21.1 kg emission [52]. Table 3 shows the environmental impacts of typical consensus algorithms. As seen in Table 3, PBFT, Ripple, and Stella algorithms require relatively low energy consumption and emit less CO_2 into the environment. Therefore, when using PBFT, Ripple, or Stella as an algorithm for a blockchain digital MRV, it can avoid the pitfall of energy consumption discussion of Blockchain.

6.3. Blockchain digital MRV

MRV requires data transparency, accountability, immutability. Blockchain has specific characteristics suitable to the MRV system. Thus, there are a few cases to adopt a blockchain MRV to energy-related projects. According to Gold Standard, Blockchain digital MRV has potential in that digital MRV collects data automatically with hash function in a safe, secure, accurate manner [53]. According to Fuessler et al. (2018), digital blockchain MRV procedures can significantly decrease existing barriers and increase the quality of data. The blockchain system can diminish the time and cost of data fetching with IoT sensors,

Table 3
Environmental impact of typical consensus algorithms. Adapted from Ref. [52].

Property	PoW	PoS	PBFT	DPOS	Ripple	Stella
Energy saving	no	partial	yes	partial	yes	yes
Platform	Bitcoin	Ethereum	Hyperledger Fabric	Bitshares	Ripple	Stellar
Carbon market adopted		NORI				Veridium Poseidon
Energy consumption	653.22 kWh	34 kWh	–	1.8 kWh	0.0113 Wh	0.03 Wh
CO2 emission	311 kg	21.1 kg	–	0.51 kg	0.00004 kg	0.000015 kg

eliminating human errors. A smart contract in Blockchain enhances the data quantification and reporting process. Verification includes the review of data gathered, accuracy, and conformity. Blockchain systems can facilitate in-time third-party verification by uploading data and being checked constantly. AI can help Blockchain find data anomalies immediately. Finally, climate impact data can be readily converted into the issuance of carbon credits. Tokenization by Blockchain enables MRV to get a seamless connection between credit buyers and sellers without intermediaries [54]. Khaqqi et al. (2018) proposed a reputation-based blockchain network. This blockchain technology enhances the MRV system for ETS and the reputation system by delivering transparent and untampered data of permits and reputations. They argue that the primary benefit is transparency, which will result in accountability. The other advantage is the credible data. It improves credit and ownership auditing and verification, protecting the network against fraud and double counting [55].

6.4. Blockchain carbon credit trading

Blockchain was invented for cryptocurrency transactions without an intermediary such as a bank. Furthermore, tokenization enables players to trade any assets under a blockchain platform. Climate finance for the building sector is one of the areas that are starting to adopt a platform based on a blockchain cryptocurrency. Li et al. (2011) argued that an integrated climate finance system could improve building energy consumption efficiency and energy delivery enhancement. The local government will establish standards, regulations and implement rigorous technical monitoring methods and emission reduction measures. They also propose that carbon credits produced for energy-saving initiatives be aggregated and deposited in a single depository overseen by the local government. The local government can support energy-efficient projects, including the extra cost support for energy savings schemes. By this climate finance, the building sector can upgrade the building codes related to energy efficiency, spread the best practices, establish the value chain, and deliver green-building associated jobs and skills [56].

Recently, as mentioned above, Nori, Veridium, Poseidon, blockchain carbon credit markets have developed. These markets do not assess carbon emission amounts but provide only carbon credits transactions. The systems apply carbon credit tokenization. They have two token tiers representing the reduction amount of carbon emission and payment tools in a blockchain carbon market. For their platform, while Nori utilizes the Ethreum platform, Veridium and Poseidon employ the Stellar platform. They all are a public blockchain system. In 2019, Poseidon already had carried out its initial coin offering (ICO), and the others are getting ready for ICO in 2020. Table 4 shows the attributes of Blockchain carbon credit markets. Nori and Veridium made a partnership with carbon credit registries such as Climate Action Reserve, The American Carbon Registry, IHS Markit Registry [57].

Leonhard (2017) suggested a conceptual carbon market, taking an example for the university wants to trade carbon credit through digital tokens. The blockchain system can back these tokens with its immutable features, using the Initial Coin Offering (ICO) process. The procedures he suggested are as follows: (1) The blockchain system enables a university to make a carbon credit trading based on the carbon offset project; (2) The university makes a contract with another university to monitor and verify their project; (3) The first university conducts an ICO; (4) When the ICO executes successfully, the funds move into a virtual banking system, which can only redraw with the verification from both the first and second universities; (5) The first university conducted projects, and with the completion of projects, the second university measures the carbon offset amount; (6) Both universities verify their results, and the first university gets the carbon offset by exchanging tokens they have got; (7) The first university exchange the carbon offset for the money in the virtual baking system by retiring their carbon offset. With the proposed blockchain carbon credit market, Leonhard argues that it will have an auditing system in place to eliminate the potential frauds and that the market delivers players an easier and securer way to trade their carbon credits generated by the projects [58].

According to UNFCCC (2017), blockchain technology can contribute to climate action in the following ways: improvement on carbon credit trading, renewable energy trade from peer to peer, transparent climate finance circumstance, enhanced tracking and reporting on GHG emissions reductions, and prevention of double accounting [59]. Chen (2018) argues that although Blockchain delivers a significant opportunity to enhance financial responsibility in carbon trading, facilitating renewable energy micro-grids, macro-level economic strategies, regal frameworks should be combined to provide the Blockchain with the full potential [60].

According to Andoni et al. (2019), Small energy providers are excluded from the carbon credit market due to the high costs associated with complex certification processes because carbon credit markets are scattered and convoluted. Furthermore, auditing is performed manually under the supervision of an organization, making it vulnerable to mistakes and fraud. Blockchain technologies can automate the issue of

Table 4
Blockchain carbon credit markets. Adapted from Ref. [57].

Item	Nori	Veridium	Poseidon
Organization in charge	NORI LLC	Veridium Foundation/ InfiniteEarth	Poseidon Foundation
Platform	Ethereum	Stellar	Stellar
Consensus Algorithm Behind	POS (Proof of Stakes)	Stellar Decentralized Consensus	Stellar Decentralized Consensus
Type of Blockchain	Public	Public	Public
Initial Coin Offering (ICO) year	2020	2020	2019
ICO country	U.S.A.	Hong Kong	USA, Canada
Carbon Token (One Ton of CO2e represented)	NRT	One Tonne of CO_2e	Carbon Credit
Payment Token	NORI	VERDE	OCEAN
Market size	500 million tokens ($10/ token)	25 million tokens ($10)	36 billion tokens ($2.3 million)
Co-up Registry	Climate Action Reserve, The American Carbon Registry, and Verra	IHS Markit Registry, APX Registry	

green or energy-efficient certificates, reduce transaction costs, and, in the end, create a worldwide carbon credit market. Furthermore, it helps improve market transparency and avoid double accounting. According to the authors, several entrepreneurs are developing blockchain technology for renewable energy and carbon reduction certificates, as well as their autonomous issuance and market trading. In 2016, Nasdaq launched a green certificates trading pilot utilizing blockchain technology. There are several blockchain carbon credit platforms: Veridium, Poseidon, DAO IPCI, to name but a few. And Carbon X presents incentives on the eco-friendly behavior of consumers by Blockchain. Energy-Blockchain Lab in China presented a carbon credit management system using Hyperledger Fabric. The reduction of Chinese carbon credit transaction cost by 30 % is the primary target of the system. Grid Singularity, an Austrian company, tries to deliver a platform to trade green certificates [61].

Ahl et al. (2019) conducted research on a review of a blockchain-based distributed energy system. They present a holistic approach to the issues of P2P microgrids embedding blockchain technology. From their research, they find that it is important to bridge the gap between technological advances and organizational acceptability. The authors used the TESEI framework to extract technological, economic, social, environmental, and institutional elements of Blockchain's potential in the energy sector. First, Blockchain is useful for energy management, power grid, and p2p network. It may be used for energy market mechanisms, prosumer business models, and smart contracts in terms of economics. It is useful for socioeconomic incentives, stakeholder benefit management, and community commitment from a social standpoint. For the environmental aspect, it can reduce carbon emissions, increase sustainability, and track the life-cycle impact. Finally, for the organizational realm, it boosts market policy for energy-efficiency, grid, and P2P [62].

Richardson et al. (2020) researched the potential applicability of the blockchain carbon trading system. They present that there is a significant possibility of Blockchain to improve the accessibility to the current ETS. However, there are more basic concerns with the ETS, such as a lack of connectivity between multiple ETS systems, a lack of smart contract regulations, and the MRV system not being sufficient to support the ETS. Thus, a holistic approach is needed to deliver an applicable blockchain system to the real carbon market [63]. In terms of programmability, operational cost, and security, they believe Ethereum and Hyperledger Fabric are the most feasible blockchain platforms.

Kim et al. (2020) conducted research on carbon credit trading based on Blockchain to verify the rights of carbon emissions among 17 UN-SDG projects. On top of that, they also investigated the combination of big data and AI in mobile circumstances [64]]. Fig. 3 shows the steps of Blockchain for MRV and carbon emission.

6.5. *Potentials of blockchain for climate change mitigation action*

Although Blockchain is not a cure-all for climate change, it can play an essential role in reducing carbon emissions in buildings. When we consider a Blockchain as a potential technology that can address climate change impacts from the building sector, the three features below should be taken into account: reducing intermediaries, simplification of verification, and continual reporting and compliance. An effective, measurable, reportable, and verifiable system is pivotal in assessing the climate action of the building sector. MRV is a core instrument of executing the Nationally Determined Contributions (NDCs) to each country that commits to climate mitigation targets. Especially when combined with IoT and AI, MRV can be much more improved in automation and verification [65].

There are several Blockchain platforms such as Bitcoin, Ethereum, EOS, and Hyperledger Fabric, etc. The former three platforms feature cryptocurrency. The latter focus runs without mining reward and transaction fees. Braden (2019) assessed these platforms for climate strategies on the basis of five criteria: programmability, running costs,

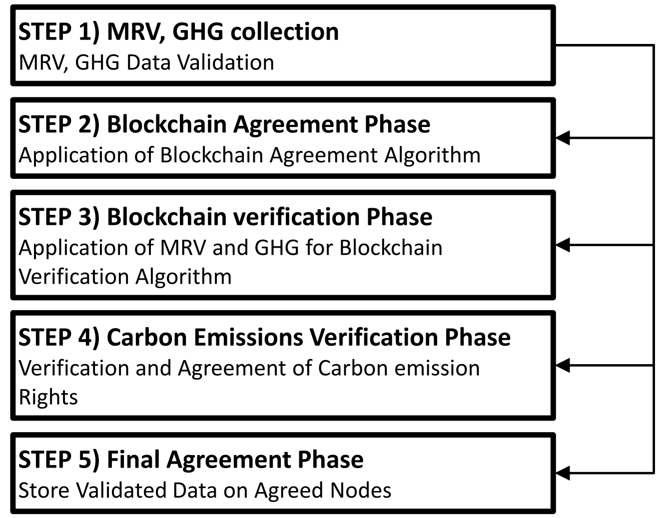

Fig. 3. Verification blockchain for MRV and carbon emission. Adapted from Ref. [64].

security, usability, and countability. It found that Ethereum is the best platform in that it has good programmability and operating costs. Hyperledger Fabric comes next. And Bitcoin is the worst platform because it consumes a lot of energy when it runs [66]. He also discovered Blockchain's potential for ETS design, MRV of emissions, and mitigation action. Table 5 reveals the results of his investigation.

The potential for Blockchain for ETS primarily stems from its characteristics such as transparency, immutability, smart contract, no need for an intermediary. On top of that, the potential for digital MRV of emissions and mitigation activity is based on data transparency, smart contracts, a combination of IoT, MRV databases. A blockchain digital MRV should be dealt with as a data infrastructure. The building sector's climate action strategies such as joining a smart grid, renewable energy generation, CO_2 sequestration tax credit, energy efficiency projects, and even participating in the carbon credit market require transparent, reliable energy consumption data management. Some blockchain systems such as Hyperledger Fabric, Ripple, Stellar can provide a transparent, affordable digital MRV with much less environmental impact.

7. Conclusion

The threat of climate change is self-evident. Instead of mitigating its causes, the building sector has exacerbated the problem. This is largely due to the complicated characteristics of the energy performance. This paper has reviewed publications that are related to the carbon credit market, BEP, and Blockchain technology. The goal has been an analysis of the applicability of a digital blockchain BEP MRV for the building sector's participating in the carbon credit market.

The authors of this paper acknowledge that the building sector is increasingly recognizing its contribution to the climate issue. A primary means for doing this has been the adoption of energy-efficient building certificates. However, this has not been high enough to reverse the trend of carbon emissions from the built environment. Furthermore, barriers are preventing the building sector from participating in the carbon credit market. These obstacles include persistent construction practices that cannot generate sufficient energy savings, many varieties of savings strategies, and fragmented incentives. All this creates a dynamic that diminishes stakeholder support.

It has been proposed in this research that ETS could act as a remedy. That system could be successfully applied to the problems detailed by this review. Unfortunately, as illustrated by analysis of MRV metrics, strict ETS protocol discourages the building sector from joining the credit market. As researchers have pointed out, this is due to a lack of

Table 5
Blockchain potential for ETS design features. Adapted from Ref. [66].

ETS features	Challenge	Potential for Blockchain
Boundary	Narrow boundary, with only a few industrial areas involved owing to expensive costs for trades	Broadened edge with lower operation cost aligned with Blockchain-based autonomous ETS procedures
Emission Cap	Emission caps fluctuate following political situation, which may negatively impact planning over time.	An open Blockchain system offers self-allocating rules and allowance numbers. A smart contract could improve ETS frameworks.
Allocation of allowance	Allocation of allowances through bidding is not transparent	Blockchain-based bidding could play a role in a portal-connected national bidding system.
Offset measures	Double counting matter	A country operated blockchain registry will ensure that created offsets are recorded in the Blockchain and retired with the registries.
Trading system	Securities fraud, insider scooping, black money, manipulating of prices, and cybercrime	Risks may be diminished with permissioned Blockchains.

immutability, agility, and transparency. Consequently, any union of such metrics with stringent auditing procedures is doomed to failure. The credit market is beset with inadequate accounting procedures. Therefore, although there are several auditing programs used in conjunction with MRV, ETS requires results to be rigorously defined. These demands use a standard consistent with the exactitude of a financial report. This is where Blockchain technology can play a significant role. The technology is able to provide MRV-based monetary data in an affordable, fast and transparent manner. Such certainty could lead the building sector to acquire confidence in the carbon market. It would occur because the financial impact of the credits upon a project could be accurately determined. Released from this burden of guesswork, the industry could well take responsibility for its energy consumption and carbon emissions.

It goes without saying that further studies will be needed to develop a viable Blockchain-based digital MRV application. That research could focus upon several key factors. For example, ready access to information concerning the scope of energy consumption and carbon emissions in a project would be crucial. Also, the fuel mix should be taken into consideration according to various regions and situations, which gets a more precise calculation of energy savings and carbon emissions [67]. Most important would be the reliability of connection to ETS. In sum total, that research would culminate with a streamlined carbon registry MRV, centered upon a blockchain system. The aim would be to encourage the construction industry to adopt an optimistic perspective regarding credits.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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