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Assessing blockchain technology adoption in the Norwegian oil and gas industry using Bayesian Best Worst Method

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ABSTRACT

Despite the promising features of blockchain, such as enhancing efficiency, transparency, immutability, cost savings, and traceability, the technology is still not widely adopted across industries. The oil and gas industry uses state-of-the-art engineering solutions for oil and gas exploration but substantially lags behind in using innovative digital technologies that can improve operational excellence. This study proposes a multi-criteria decision-making (MCDM) framework for assessing blockchain adoption strategies. The framework builds on critical factors for blockchain adoption and four adoption strategies — single use, localization, substitution, and transformation. Data were collected from ten experts in the Norwegian oil and gas industry using a structured web survey. The Bayesian Best Worst Method (BWM), a probabilistic MCDM method, was used for analysis. The results suggest that three sub-criteria, which are lack of expertise about technology, lack of supply chain partner collaboration, and reducing operation cost, have the most impact on the adoption process. As for blockchain adoption alternatives, the fourth phase, that is, transformation, is the most preferred in the context of the Norwegian oil and gas industry. The proposed framework lays the foundation for companies to understand the critical elements that need improvement to accelerate the blockchain technology adoption process.

1. Introduction

As science and technology improve every day, there is more significance for oil and gas resources to assist economic and social progress around the world [33]. British Petroleum [66] reported that 57% of total energy consumed is oil and natural gas alone, with an expansion of 1.8% global oil consumption and a 3% increase in natural gas consumption. Despite substantial publicity towards new energy, oil and gas will have over 50% share of the global energy industry as of 2040 [67]. Such developments encourage the oil and gas industry to progress swiftly technologically, such as adopting innovative drilling technology, 3-D seismic, intelligent oilfield and refinery, hydraulic fracturing, and intelligent pipeline [30, 33,68]. These innovations suggest that the industry is advancing towards intellectualization, digitalization, and automation [33].

Meanwhile, due to the enormous fall in oil prices in the last decade, the oil and gas industry has struggled [69]. This downfall also led to massive layoffs in the companies as a means of saving costs, which in turn, the employment rate of the industry has plummeted [70]. Therefore, the structure of the oil and gas industry is no longer stable [71]. The profits of oil and gas companies have remarkably come down [68]. This adds to the problems of the administration, which already is so conventional and is known for less efficiency and more expensive solutions [33]. When the companies were making huge profits in the last decade, they were not bothered much with their ineffective operations [68]. The oil and gas industry is notorious for sitting back and watching things happen when they should lead the way [13], and only a few companies take risks in adopting new technologies [33]. Meanwhile, digitalization of the supply chain can facilitate companies in achieving higher efficiency while meeting expectations of both customers and suppliers [24].

For the data-intensive industry, such as the oil and gas industry, blockchain technology, one of the supply chain digitalization tools, can

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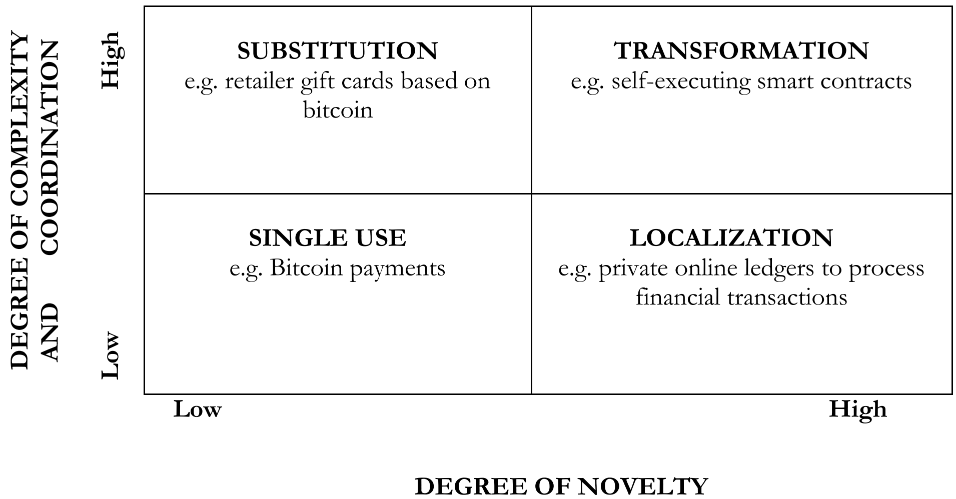


Fig. 1. A blockchain adoption stages (Iansiti & Lakhani, 2017)

significantly assist the industry in several ways [30]. Blockchain is a rising technology that has numerous application areas in the oil and gas industry, which in turn can improve the efficiency of the industry [14, 30]. Blockchain can be used for trading, management and decision making, supervision and cyber security by securing data and increasing transparency during any transaction in the industry along with a significant reduction in paperwork [33]. Blockchain can also record transactions and data for accounting directly, which will be extremely effective for the industry that utilizes a tremendous amount of sensor technology, which in turn drastically decreases process time [14]. Niazi [42] pointed out that whenever crude oil is inexpensive, the exploration and development cost for upstream oil becomes very expensive. He argued that with the addition of the challenges faced in downstream efficiency rate, companies are forced to decrease their costs dramatically. Blockchain could be a gamechanger in how these companies carry out business transactions and can increase their profitability [42].

The Norwegian oil and gas industry is the biggest sector in Norway in terms of government revenues and added value [72]. Norwegian gas industry is the third biggest exporter globally, and its crude market covers 2% of the global demand [73]. The Norwegian oil and gas industry is well known for its innovativeness and its intensive technological nature, which also served several industries in Norway [74]. The stable Norwegian political system encourages new technology advancements, and the Norwegian oil and gas industry is always looking for ways to innovate its technology [75]. The industry heavily invests in research and development and is very collaborative with research communities, suppliers and other companies [76]. However, the industry lacks technological advancement in the areas of the supply chain, procurement and finance [28].

Despite an assertion that blockchain will be highly rewarding for oil and gas industry, success stories in the industry are rare. Integration attempts of the blockchain technology into business process management systems are also limited [59]. Majority of the previous studies focused on the development and architecture of blockchains, while little attention has been paid to the adoption of the technology by industry players. Hence, industry players are largely ignorant of where and how the blockchain technology is effectively relevant and which strategy to adopt [12]. Therefore, this study explores the types of motivators and drivers to identify the factors influencing the adoption of blockchain technology in the context of the Norwegian oil and gas industry. Further, incorporating the motivators and barriers with four blockchain adoption stages in a multi-criteria decision-making (MCDM) framework, this study investigates the most preferred blockchain adoption strategy in the context of the Norwegian oil and gas companies. Hence, the following two research questions (RQs) are addressed:

- (RQ1) What are the most important factors that influence the adoption of blockchain technology in Norwegian oil and gas companies?
- (RQ2) Which adoption stage is the most preferred stage in Norwegian oil and gas companies for blockchain adoption?

The rest of the study continues as follows: Section 2 explores the literature review that includes the basics of blockchain technology, blockchain adoption stages, blockchain in the oil and gas industry, and the motivators and barriers to blockchain adoption. Section 3 presents the data collection process and the six steps for data analysis. Section 4 provides the results covers the factors that influence the adoption of blockchain and the priority blockchain adoption stage alternatives. Section 5 discusses the findings along with their practical implications. Section 6 underlines the most important findings and provides recommendations for future research.

2. Literature review

2.1. Blockchain

Blockchain is a shared, distributed ledger which is to assist in recording the transaction and in trailing assets in a business network [19]. An asset could be either tangible such as a car, a house, and land or intangible such as copyrights and patents. Any value can be virtually monitored and exchanged in a blockchain network, decreasing costs and risks [19]. Blockchain can record such transactions efficiently among two parties in a traceable and immutable manner, preventing fraud and data falsification [20]. Bitcoin is the most well-known example that is strongly associated with blockchain technology [9]. Blockchain is a foundational technology that has the ability to lay new foundations for the economy, although it could take years for the technology to affect the infrastructure of the economy [20]. Also, successful blockchain implementation requires integration of several technologies such as big data and cloud computing, which is much more complex than simply combining multiple technologies [61]. Hence, the adoption will be slow but surely gaining momentum.

2.2. Blockchain adoption alternatives

There are two dimensions that influence the development of a foundational technology and its business application [20]. One is the novelty, and the other is complexity. Novelty is how much newness the application brings. For example, if some application is very new, then extra efforts are needed to provide a better understanding of how it is helpful to the users. Complexity is the degree of the participation of environment coordination, and it is measured by the number of parties that collaborate to make an impact. For instance, when only one member is signed on the social network, it provides not much value, but it does provide more when numerous contacts use it. For all the participants to obtain value, other users need to be convinced to utilize blockchain. This phenomenon is best described through the network effect theory which argues that the more users join a platform, the more value can be obtained from the platform [77]. Based on the degree of novelty and complexity, four quadrants classify the stages in blockchain technology adoption — single use, localization, substitution, and transformation [12].

Yang [61] discussed two versions of blockchains, Blockchain 1.0 and Blockchain 2.0. Blockchain 1.0 focuses on the financial and cryptocurrency applications, while Blockchain 2.0 expands the application to smart contracts and digital automation. The most recent and comprehensive version of blockchains is Blockchain 3.0, which builds upon the two previous versions and highlights the enterprise and institutional applications of blockchains in real-life business scenarios [78]. Supply chain management is a sample application of Blockchain 3.0. that uses various features of blockchains to create transparency, resiliency, and automation in supply chains. Blockchain adoption in the oil and gas industry can mostly be associated with Blockchain 3.0, which focuses on the enterprise and business applications of this technology. Single use and localization usually come under the financial applications of Blockchain 1.0, and substitution and transformation can mostly be associated with the smart contracts and Blockchain 2.0. However, the four stages in Fig. 1 can all be associated with Blockchain 3.0 version classifications.

2.2.1. Single use

Single use falls in the first quadrant in Fig. 1, where both dimensions novelty and coordination are low. Single use applications make better, cheaper and very specialized solutions by adjusting already existing applications [21]. Bitcoin being used as an alternate currency is an application of single use stage for blockchain [20]. When compared to other stages, single use can be implemented without much difficulty since it does not require a high degree of coordination and involves fewer risks [79]. Even though it is relatively easy to do trial and error for single use applications, companies may hesitate to implement if the desired results are not met [80]. This stage is best suited for testing the applications on a small scale due to the low-risk factor, and when they are effective, it will further interest the stakeholders to start investing in localization [12].

2.2.2. Localization

Localization falls in the second quadrant, which is comparatively high in novelty and low in coordination. Therefore, value is created instantly by these localized applications in the business, which essentially assists the adoption [20, 21]. Due to the easy maintenance purpose and the requirement of only limited parties in the network, permission blockchain or consortium blockchain is beneficial for localization applications [81]. With any of the two blockchains, local networks can be developed by engaging numerous organizations through a distributed ledger to meet the requirements [20]. This essentially makes any transaction easy in this local network [79]. From the supply chain perspective, for a shipment to arrive from one continent to another, a lot of paperwork for approval and many interactions such as with customs are needed along the way, which not only consume time but also almost half of the cost of the transport [82, 83]. To counter that issue, companies IBM and Maersk introduced blockchain in their supply chain to integrate the whole value chain, and therefore, transparency and security increased by digitalization [84].

2.2.3. Substitution

The substitution stage lies in the third quadrant, where the degree of coordination is high and the level of novelty is low. The reasons for that are in terms of coordination, the substitution applications need to reach the public extensively to adopt while in terms of novelty, these applications are developed on the basis of already established single use and localized blockchain applications [20]. The methods to do business could be completely changed by using the substitution applications [21]. However, Dobrovnik et al., [12] argued that more caution is necessary for designing these substitute applications because if they substitute the entire way of doing business, then the adoption for these applications would be difficult. These applications should be presented to the customers in a way that they substitute the methods that are costly, and their performances are far better than the existing applications [12]. One example for this stage is cryptocurrency based new payment systems that came out based on bitcoin. They also argued that the issue with the cryptocurrency is that every party in the network needs to use that for it to be effective, and customers need to grasp the system as well. The significant difference between substitution and localization is that substitution applications are to be used broadly among the public for it to be effective, while localization applications are to be used among particular private parties [81].

2.2.4. Transformation

The transformation stage lies in the last quadrant, where the applications are highly novel and require high degree of coordination. To adopt this stage in organizations, coordination must be there among several parties, such as business partners, stakeholders, and even competitors [12]. It is not possible to reach this stage without significant changes in social, legal, and political systems. According to Iansiti and Lakhani [20], now the complete transformative application of blockchain is smart contracts. Such transformative application could transfer a payment automatically once the delivery is done as agreed. Due to the requirement of a high degree of coordination and challenges in security, the transformation phase will take many years to attract the market even though its advantages can be revolutionary [20, 21].

2.3. Blockchain in the oil and gas industry

Even though the oil and gas industry is known for its innovations technologically, such as 3-D seismic, hydraulic fracturing, seismic imaging, and geosteering, the management has always been very traditionally slow in its approach towards adoption [30]. The oil and gas industry is majorly classified into three sectors: upstream, midstream and downstream [85]. According to Khan et al. [86], the upstream sector denotes exploration and development of oil and gas include drilling and production. The midstream sector denotes the transportation and marketing of oil and gas. The downstream sector denotes the refining, storing, and sales of oil and gas [86]. Dutta and Banerjee [13] highlighted that in upstream, there are too many equipment that are in daily use, which is very hard to keep track of and in consequence, there is a huge loss of time and money. In midstream, there is a threat for faking transactions and contracts among third parties. In downstream, there is a cause for concern regarding data security and integrity [13].

Besides, due to the nature of the data-intense oil and gas industry, loads of paperwork cause a significant loss in money and time. With too many parties involved in the business, transactions become slower apart from the issue of trusting that many parties as well [33]. Implementing blockchain in the industry promises to solve all these problems [13]. For instance, a smart contract could significantly reduce the necessity of a third party's trust among two transaction parties and the chance of fraudulent activities [87]. After the confirmation of the exchange of either data or money, it cannot be altered or forged, which tends to be the case in the complex and big oil and gas industry [33]. The digital way of not only tracking but also keeping trade-related records such as purchase order, change order and receipts make the supply chain very stable and eventually streamline the terms of the contract [28].

Koeppen et al. [28] highlighted another important application of blockchain that can be in the places where smart sensors are being used. Smart sensors are able to provide offshore oilfield operations even in real-time, but the sensors are susceptible to hacking apart from the competitors who are waiting to obtain the information as well. To get a competitive edge by having blockchain in the oil and gas trade, BP is working with the major Italian oil company Eni and Wien Energie of Austria [88]. The pilot program they are working on is to prevent cyberattacks and to save money over time [89]. Despite the potential, this pilot program appears to stall at the pilot stage, with no evidence of further development.

Lu, Huang, et al. [33] highlighted that cross border payment is another great blockchain application for transactions. They pointed out that the oil and gas industry often trade its products internationally, and the number of transactions is also large along with the quantity of the product. When paying with cryptocurrencies such as bitcoin and ethereum, it not only saves the time for transfer but also decreases the time required for verification and liquidation [33]. In order to enhance the compliance of the oil and gas business, blockchain, with its transparency, can avoid problems that come during bidding, such as invalid bidding and not willing to sign the contract even after winning the bid [33], [90].

A famous blockchain project in the oil and gas industry is Vakt, which is a commodity trading company that is building the world's first enterprise-level blockchain platform for the industry. The project has users such as BP, Equinor, Shell, Gunvor, Koch, Mercuria, ING, Chevron, Reliance and Total. The purpose of their project is to enhance security and speed [91]. Another blockchain consortium is formed by U.S. oil company groups including Chevron and Exxon to explore the potential benefits and standardize the adoption of blockchains for the oil and gas industry [92]. One of the emergent fields in the oil and gas industry relates to achieving the Environmental, Social, and Governance (ESG) goals and building a more sustainable environment with the use of new technologies like blockchains. To combat with the climate change, the European Union (EU) has recently developed several regulations to emphasize the need for carbon neutrality in the industry [93]. This transition will require massive disruptions in the industry with the support of technological advancements.

Although the applications of blockchain in the oil and gas industry have been promising, the actual implementation rate has remained low. Most of the applications stayed at the pilot and planning stage, far from full implementation. This can emphasize the existence of the barriers and challenges that impede the implementation of blockchain technology in the oil and gas industry.

2.4. Motivators and barriers to blockchain adoption

The most significant factors for integrating blockchain technology in the supply chain of an organization are motivators and barriers [50]. According to Saberi et al. [50], influencing factors in blockchain adoption include two motivators and three barriers, and each criterion has three sub-criteria. The motivators inspire organizations in adopting blockchain technology, which are pressures and drivers. Barriers hinder organizations from adopting blockchain, which can be organizational, supply chain related and technological.

2.4.1. Pressures

This refers to the pressures that come from customers, the market and the need to collaborate with partners.

The Need for Collaborating with Supply Chain Partners. The pressures come due to the necessity of working together towards a shared goal of implementing blockchain. Saberi et al. [50] highlighted that the most influential pressure in the supply chain is the need for collaborating with supply chain partners. They argued that blockchain adoption influences more collaboration to make full use of the technology in the supply chain.

Customer Pressures. The pressures come from the customer to implement the technology. Customers are significantly been influenced by sustainability in the past few years. Customers prefer their products that are sustainable, and they want to verify that themselves on their products [43]. This condition has brought pressure to the companies to implement blockchain technology through which the credibility and validity of the product can be verified throughout the supply chain [4, 25, 94].

Market Pressures. The pressures come from the market to adopt the technology. To practice sustainability through blockchain, the supply chain market would be forcing the organizations since the oil and gas sector is often under the pump for its lack of intent towards sustainability [95,96]. Blockchain can significantly decrease carbon emission starting right from the product design, manufacture, and shipment. Due to the market pressures, organizations need to reassess and change their tactics which eventually satisfies the customers as well in terms of sustainability [50, 97].

2.4.2. Drivers

They refer to the influence factors such as information security, cost reduction and information traceability.

Increases in Information Security. It refers to the motivating factors such as information security while using the technology. Rahmadika et al. [45] pointed out that in order to prevent the information from any potential attacker, the technology uses timestamps in its digital documents. To keep information secure, blockchain has several consensus protocols such as proof of work and proof of stake [45]. Boireau [6] highlighted that only people who have the private key could have access to the token that has digital assets in blockchain applications.

Reducing Operations Cost. It refers to the cost reduction in operations when using the technology. Rahmadika et al. [45] argued that a decentralized blockchain system does not require a third party to take care of payment processes, unlike centralized financial infrastructures. So the transaction speed is increased, and in turn, the cost is significantly reduced. Carter and Rogers [98] pointed out that if there is any potentially illegal activity that can be performed by supply chain partners, companies tend to be suspicious. Therefore they often conduct audits that are naturally expensive, and they are forced to establish standard systems such as contracts and mandatory reporting [98]. But when the transparency is always present because of blockchain, those costs are significantly reduced, and costs for a lot of agents in between the process are cut as well [9].

Increases in Information Traceability. It refers to the tracking feature, such as shipments. Traceability plays a vital role in the supply chain, and it gives a tremendous competitive edge [99]. There is a significant increase in traceability and transparency of information when blockchain is integrated [100]. This largely captivates customers who can check various information regarding the products they buy. The companies may implement blockchain because offering traceability and transparency feature solves the problems of sustainability of customers since customers can check all the relevant information themselves that gives them satisfaction [25, 50].

2.4.3. Organizational barriers

It refers to the barriers that come within an organization, such as lack of expertise about technology, lack of tools to implement the technology, etc.

Lack of Expertise about Technology. It refers to the lack of skills to use the technology in an organization. It is also the lack of thorough understanding of the technology that is largely stopping the growth [39]. Glaser [16] argued that only a handful of people completely understand the basics of the technology even though there are a lot of discussions and media releases about blockchain. Even though the technology has attracted many in the industry, the availability of only a few designers of the technology and a few applications is of concern [39].

Lack of Tools for Blockchain Technology Implementation. It refers to the lack of tools within an organization to use the technology. The tools could be necessary hardware and software to run the technology along with the maintenance. To implement widely, it could be expensive to invest in the companies [34, 39]. To unlock the full advantage, users in various geographical areas should access blockchains to record and trace information [101]. Information should be available in real-time where needed to run smooth operations. Specific tools are also needed to integrate blockchains with the supporting devices such as Geographic information system (GIS) and Radio Frequency Identification (RFID) for automatic collection of the data. In order to conduct computations for the "proof-of-work" consensus mechanism, specialized hardware is essential [8]. However, the-proof-of-work mechanism is widely used in the Bitcoin and cryptocurrency applications to make the network highly secured when wide range of users interact with the system [102]. In the enterprise and business applications of blockchain including supply chain management, a private network obtains permissions to join and interact with the platform. Therefore, there is a lower need for specialized hardware and computational power to maintain the integrity of information [104].

Lack of Benchmarking Data for Blockchain Technology Implementation. It refers to the lack of any standards to compare with during the implementation of technology. There are no successful business models to emulate, and the lack of standard methods and benchmarks are impeding the growth of the technology [39, 105].

2.4.4. Supply chain-related barriers

It refers to the barriers that come due to the supply chain, such as lack of customer awareness about the technology, lack of collaboration, and coordination with supply chain partners.

Lack of Customer Awareness about Blockchain Technology. It refers to the lack of knowledge of the customer about blockchain applications. Due to poor communication between the supply chain partners and major differences in their choices, customers tend not to be aware of what they are dealing with [106,107]. Organizations already do not follow sustainable activities due to their insufficient knowledge, and the complex blockchain technology only adds further confusion to the customers [108].

Lack of Supply Chain Partner Collaboration. It refers to the lack of ability to work together with supply chain partners towards a shared goal of implementing blockchain newly. To maintain a healthy relationship with supply chain partners is complicated yet necessary to add value for the stakeholders, particularly in terms of sharing information [109,110]. There is though hesitancy in sharing information because a few partners may think that other companies could get a competitive advantage when they share important information [111,112]. This lack of collaboration from partners obstructs the dissemination of technology, which is mainly based on transparency and testability [50, 110].

Lack of Supply Chain Partner Coordination. It refers to the lack of ability to exchange information and resources with supply chain partners in order to implement blockchain. This lack of coordination is considered as a major barrier in the implementation of blockchain [50]. Coordination is also about who does what, when, why, and how [113]. It is mostly hierarchical based, and every individual may well not be aware of the overall goal (Macfadden, 2018). The lack of coordination in sharing information and having different priorities can also restrict blockchain adoption [94,106,107]. Coordinating even the little things to make the process efficient makes a huge difference in implementing blockchain [12].

2.4.5. Technological barriers

It refers to the barriers that come from a technical perspective, such as limited infrastructure of information technology, security concerns, and immaturity of the technology.

Immaturity of the Technology. It refers to the part where the technology has not been used for some time and still has flaws. Blockchain technology is immature, and this immaturity causes technical difficulties such as scalability, usability, and interoperability [7]. There are still latency and throughput problems especially in the public or permissionless blockchain environment where anyone can join the platform [55, 118]. The technology needs to be developed even further due to increased latency and decreased throughput rate [35]. These limitations are of a temporary nature and are expected to be settled [16]. It is already recommended to increase the size of blocks so that the scalability issue can be solved [11].

Limited Information Technology Infrastructure. It refers to the restrictions that exist in the infrastructure of the technology. Cocco et al. [8] highlighted that it includes the money needed to run the technology, which might be more than the buying price of the technology and manpower to run. They also argued that the other limitations being the requirement of more computational power to blocks involved in blockchain, a smaller number of transactions, and a limit in the size of the block. If the block size is limited, there will be an increase in energy consumption per transaction. When the volumes of the transaction are tremendous, there is a huge concern about how to reduce the consequential wasted mining resources [8].

Security Concerns. It refers to the concerns that arise due to unauthorised access or attacks. Yli-Huumo et al. [62] highlighted that the technology cannot be easily hacked, especially with numerous computational algorithms. With the unique feature of the decentralized structure, blockchain technology is known to be a secured one. But doubts have been raised about the vulnerable nature of blockchain because of several hacks that happened particularly in the cryptocurrency field [62]. Boireau [6] pointed out that security issues are predominant among other issues that are hindering the process of mainstream blockchain adoption. The most vulnerable link in the blockchain is third party applications such as wallets, decentralized apps (Dapps), and exchanges [11]. Moreover, the infamous 'dark web' hinders the growth of the technology in a notable way [50]. The initial growth of bitcoin was driven by dark web applications for underground enterprises where anonymous users engage in criminal activities and drug trading [119]. Due to the lack of central authority, the blockchain environment has been ideal for such activities. The cryptocurrencies, especially bitcoin, are still used for payments in the dark web marketplaces where privacy and identity of users are highly protected from the surveillance of authorities and governments. Although over the past few years, the commercial applications of blockchain have outweighed the nefarious applications, some users and organizations may still hesitate to adopt blockchain technology to avoid legal complications [120,121].

3. Research methodology

3.1. Best-Worst method

This study employed a multi-criteria decision-making (MCDM) method for analysis, particularly the Best Worst Method (BWM), which is a newly developed MCDM method. There exist several variants of the BWM method already. Ahmad et al. [1] applied the original BWM for assessing the sustainability of the oil and gas supply chains. Mostafaeipour et al. [38] used the fuzzy BWM to analyze the barriers to solar energy adoption. Applications of BWM in combination with other approaches are also evident, for example, hybrid BWM application with Z numbers and zero-sum game for emergency relief situations [31]. More recently, applications of the Bayesian BWM is getting more attention, a probabilistic BWM method for group decision making [36]. For instance, the Bayesian BWM has been used by Bai et al. [5] for guiding organization through a decision support system model for selecting the appropriate blockchain service provider.

This study applies the Bayesian BWM. To find out the most preferred stage for adopting blockchain for Norwegian oil and gas companies, five criteria their corresponding fifteen sub-criteria were considered. In BWM, the decision-maker primarily determines the best (i.e., most important, most desirable) and the worst (i.e., least important, least

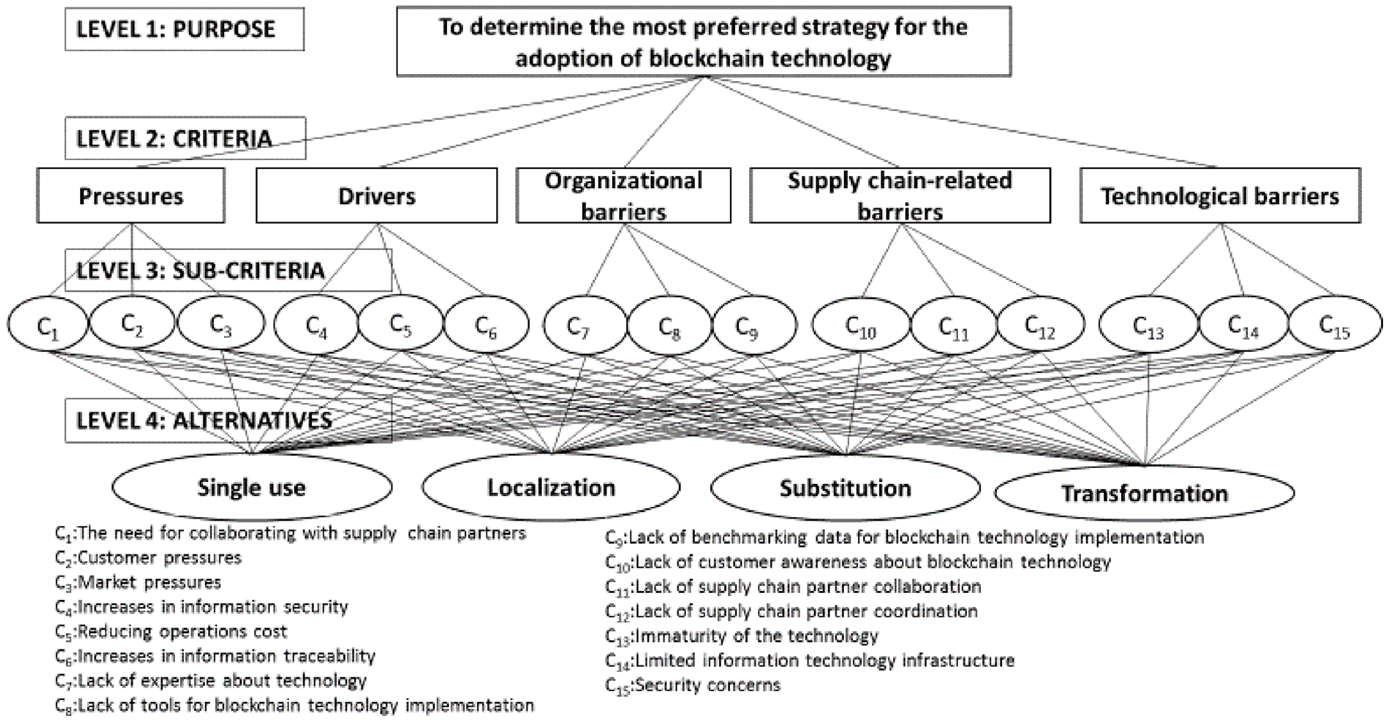


Fig. 2. A MCDM framework for the adoption of blockchain technology

desirable) criteria [46]. Among each of these two criteria (best and worst) and the other criteria, pairwise comparisons are then carried out. To check the reliability of the comparisons, a consistency ratio is assigned for the BWM [46].

There are numerous MCDM methods; each of them has benefits and drawbacks. In comparison to widely used MCDM methods such as Analytic Hierarchy Process (AHP), BWM offers a lesser number of pairwise comparisons leading to better consistency ratios. Only [2n−3] comparisons are needed for BWM, while AHP needs $[n(n-1)/2]$ comparisons. At the same time, the obtained final weights from BWM are extremely reliable because it offers more consistent comparisons of criteria and sub-criteria. The Bayesian BWM can be applied following six steps.

Step 1. Identification of decision criteria and sub-criteria

In this step, as mentioned earlier, based on the existing literature, five criteria and fifteen sub- criteria were identified to investigate the most preferred strategy in blockchain adoption among four alternatives. The four alternatives were single use, localization, substitution, and transformation. The five criteria were pressures, drivers, organizational barriers, supply chain-related barriers, and technological barriers. Three sub-criteria were identified for each criterion, and therefore in total, there were fifteen sub-criteria determined. The sub-criteria were the need for collaborating with supply chain partners (C_1), customer pressures (C_2), market pressures (C_3), increases in information security (C_4), reducing operations cost (C_5), increases in information traceability (C_6), lack of expertise about technology (C_7), lack of tools for blockchain technology implementation (C_8), lack of benchmarking data for blockchain technology implementation (C_9), lack of customer awareness about blockchain technology (C_{10}), lack of supply chain partner collaboration (C_{11}), lack of supply chain coordination (C_{12}), immaturity of the technology (C_{13}), limited information technology infrastructure (C_{14}) and security concerns (C_{15}).

The four stages of blockchain adoption are associated with the five criteria and their respective sub-criteria. For instance, the pressures from C_1 to C_3 can have an influence over the choice of blockchain stage of a company. The need for collaborating with supply chain partners cannot be achieved with the adoption of single use strategy, but with localization and substitution, it can be achieved to a limited extent. While transformation stage opens the possibility of achieving maximum collaboration among the stakeholders in the oil and gas supply chain, it also has several barriers. The degree of organizational, supply chain-related, and technological barriers are expected to be higher as companies' blockchain adoption strategy moves from single use to transformation stage. Overall, the lowers the novelty and collaboration required for the adoption stage, the lower the barriers but also the lower capability of achieving the pressures and drivers; and vice-versa. The proposed framework for blockchain adoption is depicted in Fig. 2.

Step 2. Identification of the best (B) and the worst (W) decision criterion and sub-criterion

To identify the best and worst criterion or sub-criterion, we ask the respondents, "Which criterion or sub-criterion is the most important and the least important for the adoption of blockchain technology for Norwegian oil and gas companies?".

Step 3. Comparison of the best criterion (B) against other criteria (j)

Once the best criterion (B) has been identified, the respondents are asked to compare (B) with the rest of the criterion on a 9-point scale, where 1 represented equally important compared to the other criterion and 9 represented absolutely more important than the other criterion. The outcome of this step is the best-to-others (BO) vector as follows:

$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$, where a_{Bj} illustrates the preference of the best criterion B over criterion j, and $a_{BB}=1$.

The same approach was applied for the identification of the preference of the best decision sub- criterion (B) against all the other decision sub-criteria.

Step 4. Comparison of other criteria (j) with the worst criterion (W)

After identifying the worst criterion (W), the respondents are asked to compare the rest of the other criteria with the (W) on a 9-point scale, where 1 represented equally important compared to the (W), and 9 represented absolutely more important than the (W). The outcome was the others-to-worst (OW) vector in the following manner:

$A_w = (a_{1W}, a_{2W}, \ldots, a_{nW})^T$, where a_{jW} illustrates the priority of j over the worst criterion W, and $a_{WW} = 1$.

Table 1
Overview of the 10 respondents

Respondent	Type of Organization	Experience (years)	Area of expertise	Education
1	Private	12	Digital technology and Operations/asset development	PhD
2	Public	21	Competence Management	Master
3	Public	10	Supply Chain - Procurement & Inventory and Warehouse Management	Bachelor
4	Private	10	Supply Chain	Master
5	Private	13	Project and technology management	PhD
6	Private	9	Senior analyst procurement	Bachelor
7	Private	25	Business models	Master
8	Private	15	IT, Oil & Gas	Master
9	Private	4	Blockchain architectures and usage	Master
10	Private	7	Supply Chain	Bachelor

The same method was applied for the identification of the preference of all the decision sub- criteria against the worst sub-criterion (W).

Step 5. Estimate the weight for each respondents wˆk,k=1,…,10 and the aggregate weights of all respondents wˆ*=w_1ˆ*,w_1ˆ*,…,w_nˆ* utilizing the Bayesian BWM as follows:

$$A_B^k \mid w^k \sim multinomial\left(\frac{1}{w^k}\right),\ \forall k = 1, \ldots, k$$

$$A_w^k \mid w^k \sim multinomial\left(w^k\right),\ \forall k = 1, \ldots, k$$

$$w^k \mid w^* \sim Dir(\gamma \times w^*),\ \forall k = 1, \ldots, k$$

$$\gamma \sim gamma(0.1, 0.1)$$

$$w^* \sim Dir(1) \tag{1}$$

Here, multinomial and Dir denotes a multinomial and Dirichlet distribution, respectively. Gamma (0.1,0.1) denotes a gamma distribution with the shape parameters of 0.1. A Markov-chain Monte Carlo (MCMC) sampling [15] is required to estimate the solution of the probabilistic model in equations (1). The Bayesian BWM has been applied using *JAGS: Just Another Gibbs Sampler* [44] and is freely available at https://github.com/Majeed7/BayesianBWM. By taking advantage of the samples obtained from JAGS, Mohammadi and Rezaei [36] proposed creedal ranking, an approach for probabilistic comparison of a set of criteria that can be visualized using directed graphs. By multiplying the estimated aggregate criteria level weights with their respective sub-criteria level weights, global weights for the sub-criteria are calculated.

Step 6. Final priority scores of blockchain adoption stages

To estimate the priority scores of each blockchain stage, respondents were asked to rate each blockchain stage under the fifteen sub-criteria on a scale of 1 to 9, where 1 referred to "no influential at all", and 9 referred to "extremely influential". The priority scores were normalized by dividing each of the values by its respective column's maximum value. These normalized values for each sub-criterion for all four stages were multiplied by its respective global weights. The final priority scores for each alternative were obtained in the following way:

n

$$Z_i = \sum w_j{}^* x_{ij}{}^{nor}$$

Table 2
The most important to others vector

Respondent	Criteria level Motivators and Barriers						Sub-criteria level Pressures				Drivers				Organizational barriers				Supply chain-related barriers				Technological barriers			
	Best	P	D	OB	SCB	TB	Best	NCS	CP	MP	Best	IIS	ROC	IIT	Best	LE	LT	LB	Best	LCA	LSCB	LSCO	Best	IT	LI	SC
1	**P**	1	2	2	2	5	**NCS**	1	3	9	**ROC**	3	1	9	**LB**	3	6	1	**LCA**	1	2	3	**IT**	1	3	2
2	**SCB**	3	5	7	1	2	**MP**	4	7	1	**ROC**	4	1	9	**LE**	1	5	9	**LCA**	1	4	7	**LI**	4	1	9
3	**TB**	2	3	4	5	1	**MP**	9	3	1	**ROC**	3	1	8	**LE**	1	3	8	**LSCB**	3	1	8	**IT**	1	8	3
4	**TB**	8	8	7	2	1	**NCS**	1	7	5	**IIT**	2	4	1	**LB**	6	3	1	**LSCB**	4	1	2	**IT**	1	3	5
5	**D**	9	1	3	7	3	**MP**	3	9	1	**IIS**	1	3	9	**LE**	1	6	6	**LCA**	1	4	7	**LI**	4	1	7
6	**OB**	7	8	1	6	8	**MP**	3	6	1	**IIS**	1	3	8	**LB**	3	8	1	**LSCO**	7	3	1	**SC**	8	4	1
7	**SCB**	9	3	2	1	9	**NCS**	1	9	4	**IIT**	4	9	1	**LB**	2	8	1	**LSCO**	8	2	1	**LI**	4	1	2
8	**P**	1	2	3	3	5	**CP**	2	1	3	**IIT**	3	2	1	**LE**	1	2	4	**LCA**	1	3	4	**LI**	2	1	2
9	**TB**	4	3	2	2	1	**NCS**	1	5	3	**ROC**	7	1	2	**LT**	4	1	4	**LSCB**	6	1	2	**IT**	1	2	4
10	**OB**	3	2	1	2	2	**CP**	3	1	3	**IIT**	4	2	1	**LE**	1	2	3	**LSCB**	3	1	4	**LI**	5	1	3

P: Pressures D: Drivers OB: Organizational barriers SCB: Supply chain-related barriers TB: Technological barriers NCS: The need for collaborating with supply chain partners CP: Customer pressures MP: Market pressures IIS: Increases in information security ROC: Reducing operations cost IIT: Increases in information traceability LE: Lack of expertise about technology LT: Lack of tools for blockchain technology implementation LB: Lack of benchmarking data for blockchain technology implementation LCA: Lack of customer awareness about blockchain technology LSCB: Lack of supply chain partner collaboration LSCO: Lack of supply chain partner co-ordination IT: Immaturity of the technology LI: Limited information technology infrastructure SC: Security concerns

Table 3
Others to the least important vector

Respondent	Criteria level						Sub-criteria level																			
	Motivators and Barriers						Pressures				Drivers				Organizational barriers				Supply chain-related barriers				Technological barriers			
	Worst	P	D	OB	SCB	TB	Worst	NCS	CP	MP	Worst	IIS	ROC	IIT	Worst	LE	LT	LB	Worst	LCA	LSCB	LSCO	Worst	IT	LI	SC
1	TB	9	8	8	8	1	MP	9	5	1	IIT	8	9	1	LT	5	1	6	LSCO	5	3	1	LI	3	1	5
2	TB	6	5	8	7	1	CP	5	1	7	IIT	7	9	1	LB	9	6	1	LSCO	7	4	1	IT	1	4	2
3	SCB	8	7	6	1	9	NCS	1	7	9	IIT	8	9	1	LB	9	8	1	LSCO	8	9	1	LI	9	1	8
4	OB	5	3	1	8	9	MP	8	3	1	ROC	5	1	5	LE	1	4	6	LCA	1	4	6	SC	5	4	1
5	P	1	9	7	3	7	CP	8	1	9	IIT	9	7	1	LB	9	4	1	LSCO	7	4	1	SC	6	7	1
6	TB	3	2	8	4	1	CP	4	1	6	IIT	8	5	1	LT	6	1	9	LCA	1	7	7	IT	1	7	8
7	TB	5	5	9	8	1	CP	9	1	7	ROC	7	1	9	LT	8	1	8	LCA	1	7	7	IT	1	4	6
8	TB	5	4	3	3	1	MP	3	3	1	IIS	1	3	2	LB	2	3	1	LSCO	4	3	1	IT	1	2	2
9	P	1	3	2	5	8	CP	5	1	5	IIS	1	5	6	LB	3	4	1	LCA	1	6	6	SC	3	3	1
10	SCB	2	3	5	1	4	NCS	1	5	3	IIS	1	3	5	LB	3	3	1	LSCO	2	4	1	IT	1	4	3

P: Pressures D: Drivers OB: Organizational barriers SCB: Supply chain-related barriers TB: Technological barriers NCS: The need for collaborating with supply chain partners CP: Customer pressures MP: Market pressures IIS: Increases in information security ROC: Reducing operation cost IIT: Increases in information traceability LE: Lack of expertise about technology LT: Lack of tools for blockchain technology implementation LB: Lack of benchmarking data for blockchain technology implementation LCA: Lack of customer awareness about blockchain technology LSCB: Lack of supply chain partner collaboration LSCO: Lack of supply chain partner co-ordination IT: Immaturity of the technology LI: Limited information technology infrastructure SC: Security concern

$j = 1$

Here, Z_i is the final priority score for each alternative i and x_{ij} is the normalized value for criterion j of each alternative i.

3.2. Data collection

Data was collected from respondents working at various departments at four Norwegian oil and gas companies. The survey was distributed to potential respondents at Aker BP, Equinor, BW Offshore, GE oil and gas Offshore, Schlumberger Limited, and DNV. The structured web-survey was hosted in Nettskjema.no (available upon request) and distributed via LinkedIn and email during the period of April to October 2020. Eleven respondents completed the survey, but one was removed due to straight-lining. The sample of 10 respondnets represent Aker BP (four), Equinor (two), BW offshore (two) and DNV (two). Out of these four companies, one has initiated a blockchain project in 2018 and suspended in 2020.

A sample of 10 respondents is sufficient for MCDM studies as they do not rely on statistical inference. On the sample size requirement of MCDM studies, Munim et al., [40] stated that "the quality of the information or observations is more important than the quantity" (p. 326). Using sensitivity analysis, they also showed that data saturation in MCDM studies can be achieved using 8 to 10 expert respondents. The demographic overview of the ten survey respondents is reported in Table 1. Since the information from the survey does not directly or indirectly recognize any individual from an organization, The Norwegian centre for Research Data (NSD) stated that this study does not require registration of the survey in their system.

4. Results

4.1. The most and least important criterion for blockchain adoption

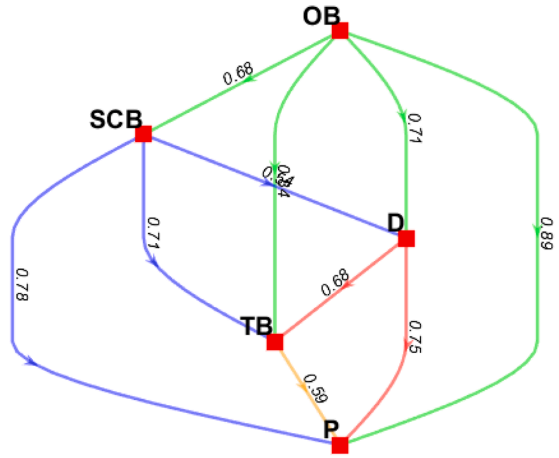
We present the most important to other criteria (or sub-criteria) and other criteria (or sub-criteria) to least important vectors in Table 2 and 3, respectively. On the criteria level, it is not possible to clearly identify the most important criteria as the respondents have selected the five criteria rather uniformly. Three out of ten respondents reported that *Technological barriers* are the most important criteria, whereas each two respondents reported that *Pressures, Supply chain-related barriers* and *Organizational barriers* are the most important criteria. Only one responded *Drivers* as the most important criteria. However, it is rather clear that *Technological barriers* are the least important criteria as reported by five out of ten respondents. *Pressures* and *Supply chain-related barriers* are reported as the least important criteria each by two respondents. Only one responded *Organizational barriers* as the least important criteria.

4.2. Aggregate weights of sub-criteria

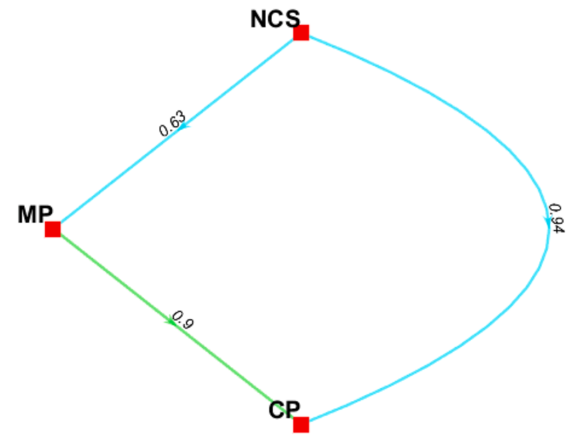
The aggregate criteria and sub-criteria level weights estimated using the Bayesian BWM are reported in Fig. 3, where the nodes in each graph represent the average weight of the criteria. On the criteria level, *organizational barriers (0.233)* is the most important, and *pressure (0.173)* is the least important for blockchain adoption in the Norwegian oil and gas industry. The values on the edges of the credal ranking graph in Fig. 3 indicates the relative degree of confidence of one node over another. One can say with 0.68, 0.84, 0.71 and 0.89 confidence that *organizational barriers* are more important than *supply-chain related barriers, technological barriers, drivers, and pressures, respectively*. Similarly, Fig. 3 (b-f) can be interpreted.

4.3. Priority of blockchain adoption stages

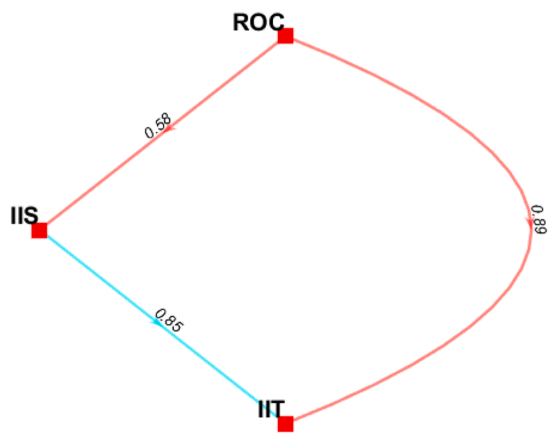
The calculation of priorities for blockchain adoption stages is



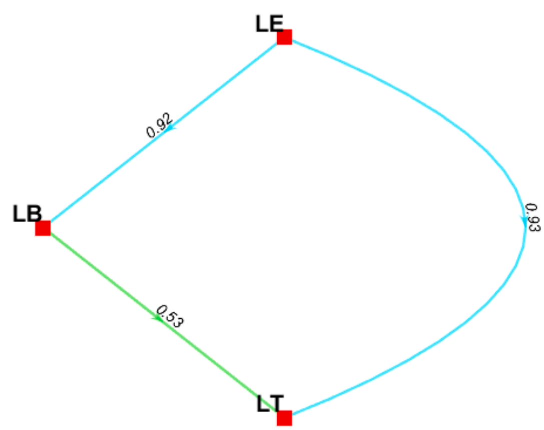
(a) Criteria level



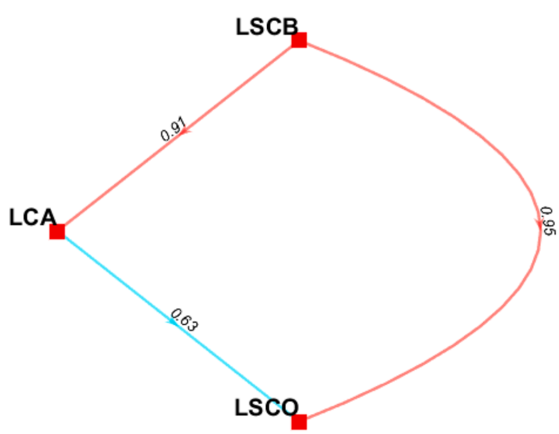
(b) Sub-criteria level: Pressures



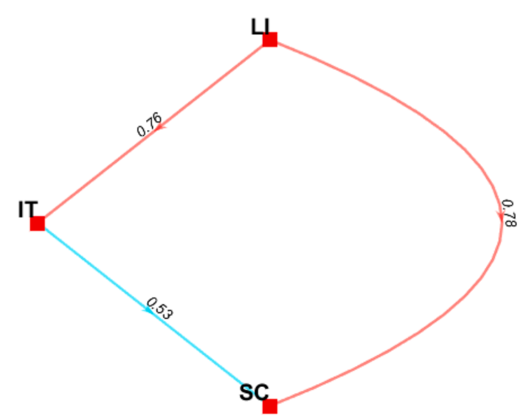
(c) Sub-criteria level: *Drivers*



(d) Sub-criteria level: *Organizational barriers*



(e) Sub-criteria level: Supply chain related barriers



(f) Sub-criteria level: *Technological barriers*

Fig. 3. Credal ranking of criteria and sub-criteria (P: Pressures D: Drivers OB: Organizational barriers SCB: Supply chain-related barriers TB: Technological barriers NCS: The need for collaborating with supply chain partners CP: Customer pressures MP: Market pressures IIS: Increases in information security ROC: Reducing operations cost IIT: Increases in information traceability LE: Lack of expertise about technology LT: Lack of tools for blockchain technology implementation LB: Lack of benchmarking data for blockchain technology implementation LCA: Lack of customer awareness about blockchain technology LSCB: Lack of supply chain partner collaboration LSCO: Lack of supply chain partner coordination IT: Immaturity of the technology LI: Limited information technology infrastructure SC: Security concerns)

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Table 4
Priority of blockchain adoption stages under each criterion (respondent 02 example)

Blockchain adoption stages	NCS	CP	MP	IIS	ROC	IIT	LE	LT	LB	LCA	LSCB	LSCO	IT	LI	SC
Single use	5.00	2.00	2.00	7.00	7.00	7.00	4.00	4.00	6.00	3.00	6.00	7.00	7.00	2.00	9.00
Localization	9.00	2.00	2.00	9.00	9.00	6.00	6.00	5.00	6.00	2.00	2.00	7.00	7.00	6.00	9.00
Substitution	6.00	4.00	6.00	7.00	8.00	8.00	4.00	4.00	3.00	3.00	3.00	2.00	6.00	7.00	9.00
Transformation	6.00	3.00	3.00	3.00	8.00	2.00	5.00	4.00	5.00	2.00	2.00	2.00	7.00	6.00	9.00

Table 5
Normalized value (respondent 02 example)

Blockchain adoption stages	NCS	CP	MP	IIS	ROC	IIT	LE	LT	LB	LCA	LSCB	LSCO	IT	LI	SC
Single use	0.556	0.500	0.333	0.778	0.778	0.875	0.667	0.800	1.000	1.000	1.000	1.000	1.000	0.286	1.000
Localization	1.000	0.500	0.333	1.000	1.000	0.750	1.000	1.000	1.000	0.667	0.333	1.000	1.000	0.857	1.000
Substitution	0.667	1.000	1.000	0.778	0.889	1.000	0.667	0.800	0.500	1.000	0.500	0.286	0.857	1.000	1.000
Transformation	0.667	0.750	0.500	0.333	0.889	0.250	0.833	0.800	0.833	0.667	0.333	0.286	1.000	0.857	1.000

Table 6
Priority of alternatives (respondent 02 example)

Blockchain adoption stages	NCS	CP	MP	IIS	ROC	IIT	LE	LT	LB	LCA	LSCB	LSCO	IT	LI	SC	Sum
Local weights*	**0.395**	**0.245**	**0.360**	**0.360**	**0.380**	**0.260**	**0.431**	**0.281**	**0.288**	**0.298**	**0.433**	**0.269**	**0.313**	**0.380**	**0.307**	
Global weights*	**0.068**	**0.042**	**0.062**	**0.073**	**0.077**	**0.053**	**0.100**	**0.065**	**0.067**	**0.062**	**0.090**	**0.056**	**0.057**	**0.069**	**0.056**	
Single use	0.038	0.021	0.021	0.057	0.060	0.046	0.067	0.052	0.067	0.062	0.090	0.056	0.057	0.020	0.056	0.771
Localization	0.068	0.021	0.021	0.073	0.077	0.040	0.100	0.065	0.067	0.041	0.030	0.056	0.057	0.059	0.056	**0.833**
Substitution	0.045	0.042	0.062	0.057	0.069	0.053	0.067	0.052	0.033	0.062	0.045	0.016	0.049	0.069	0.056	0.779
Transformation	0.045	0.032	0.031	0.024	0.069	0.013	0.084	0.052	0.056	0.041	0.030	0.016	0.057	0.059	0.056	0.667

Criteria level weight are (see Fig. 3a): Pressures (0.173), Drivers (0.204), Organizational barriers (0.233), Supply chain-related barriers (0.209), and Technological barriers (0.182). Global weights are calculated by multiplying the sub-criteria level weights with their respective criteria level weight. For example, global weights of NCS was calculated as (0.173 × 0.395= 0.068).

Table 7
Priority of alternatives (total sample aggregate level)

Blockchain adoption stages	NCS	CP	MP	IIS	ROC	IIT	LE	LT	LB	LCA	LSCB	LSCO	IT	LI	SC	Overall
Single use	0.039	0.027	0.033	0.057	0.061	0.046	0.069	0.047	0.052	0.049	0.066	0.037	0.040	0.042	0.039	0.706
Localization	0.045	0.032	0.043	0.061	0.066	0.039	0.073	0.044	0.053	0.049	0.063	0.043	0.045	0.054	0.048	0.758
Substitution	0.057	0.040	0.055	0.067	0.068	0.047	0.086	0.056	0.056	0.048	0.070	0.042	0.050	0.065	0.050	0.858
Transformation	0.061	0.039	0.054	0.066	0.076	0.045	0.089	0.058	0.058	0.052	0.080	0.049	0.052	0.063	0.055	**0.898**

NCS: The need for collaborating with supply chain partners CP: Customer pressures MP: Market pressures IIS: Increases in information security ROC: Reducing operations cost IIT: Increases in information traceability LE: Lack of expertise about technology LT: Lack of tools for blockchain technology implementation LB: Lack of benchmarking data for blockchain technology implementation LCA: Lack of customer awareness about blockchain technology LSCB: Lack of supply chain partner collaboration LSCO: Lack of supply chain partner coordination IT: Immaturity of the technology LI: Limited information technology infrastructure SC: Security concerns. *Weights are based on full sample estimation.

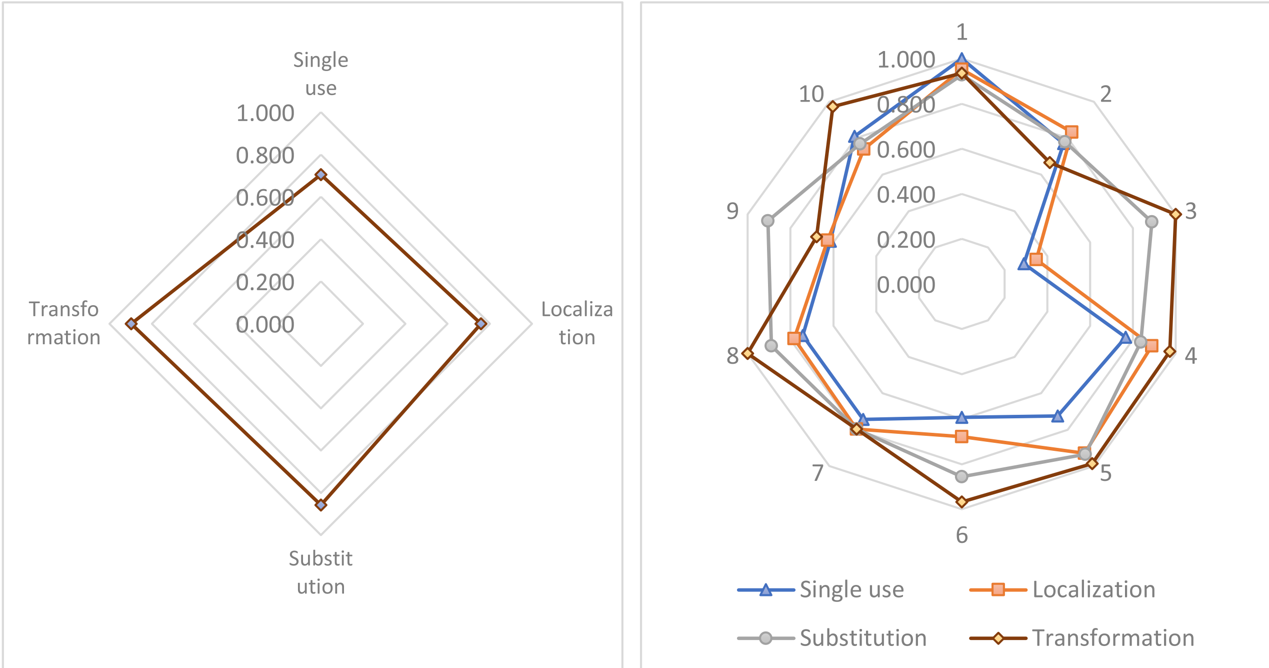
reported in Table 4, 5, 6 using the example of respondent 02. Global weights of the sub-criteria in Table 6 are calculated by multiplying the sub-criteria level weights with their respective criteria level weight. In order to find out the priority scores for each alternative stage, normalized values for each sub-criterion were multiplied by corresponding global weights, as shown in Table 6. For each alternative, the sum of the global weights for each sub-criteria indicates their priority. To calculate the aggregate priorities for the full sample, the average priorities of each respondent are calculated (reported in Table 7). On the aggregate level, transformation (0.898) is the most preferred blockchain adoption alternative followed by substitution (0.858), localization (0.758) and single use (0.706).

5. Discussion

This study assesses the most preferred strategy for the adoption of blockchain technology for Norwegian oil and gas companies (RQ1) and the most influential factors for blockchain adoption (RQ2). The global weights of the sub-criteria (see Table 6) indicates that sub-criteria such as *lack of expertise about technology (0.100), lack of supply chain partner collaboration (0.090),* and *reducing operating costs (0.077)* are the most crucial factors for the adoption of blockchain technology. The results of this study are in line with the past studies [50, 33, 22, 3].

Lack of expertise about technology is the biggest obstacle for companies to implement blockchain, especially comprehending the technical aspects of the technology. Experts who can design blockchain applications by understanding every intricate nature of blockchain elements are very few [16, 39]. Therefore, it is imperative that the management realizes this and makes sure that their personnel understands the blockchain extensively in order to speed up the adoption before investing in the infrastructure of the blockchain [20, 22].

Lack of supply chain partner collaboration is the second influential factor for blockchain adoption. It seems the supply chain partners are insecure in sharing information [111,112]. There is a big difference in privacy policies regarding data sharing in traditional supply chains and supply chains with blockchain. There is not much clarity in the rules, which ultimately affects the adoption of blockchain, so the rules should be established [112,122]. The communication gap is a concern,



(a) Aggregate priority *(b) Individual respondent priority*

Fig. 4. Priority of blockchain adoption stages

especially when there is a diversified workforce [123]. Effective communication, along with the understanding that they are working towards the same goal, are instrumental towards blockchain implementation [105]. In order to make the implementation profitable, having suitable collaborators is pivotal, and in turn, solid organizational structure is developed [124]. Trust is the main element in collaboration with supply chain partners, and the lack of trust can stop the dissemination of blockchain [125].

Reducing operations cost is the third most important factor driving blockchain adoption among industries. It is expected that blockchain implementations are likely to reduce operations cost of companies by automating regular administrative tasks, including payment processes [45, 3]. Such applications will increase transaction speed at the same time reducing potential errors. Hence, the cost for regular quality control or audits would be saved as well [98]. Due to transparency and traceability possibilities, the cost of legal services that were used to solve disputes among supply chain partners, including customers, is likely to reduce too [9]. Reducing operations cost has been one of the major drivers for blockchain adoption, and it will be in the future. However, how much could be saved in terms of overall organizational expenses, considering the investment required in blockchain technology, needs further exploration.

The aggregate and individual level priorities are depicted in a radar diagram in Fig. 4. The most preferred blockchain adoption stage is *transformation* (0.898), whereas the least preferred blockchain adoption stage is *single use* (0.706). The second most preferred stage is the *substitution stage* (mean 0.859), and the third most preferred stage being *localization* (mean 0.752). On the individual level, six out of ten respondents prioritize the *transformation* stage for blockchain adoption, while one prioritizes single use, one substitution, one localization, and one prioritize localization, substitution and transformation equally. Iansiti and Lakhani [20] argued that even though the transformative applications got a long way to go, it would be logical to assess their chances for investing in how to develop blockchain technology. They [20] claimed that as much as it is difficult to adopt, this stage will be most influential when it is implemented through a new business model, which will have a significant value. It would be difficult to enjoy the benefits of this stage without coordination among several parties and the proactive changes in social, political, and legal systems [12, 20]. This kind of applications not only will redesign the business model in an organization but also could cut out the third party, such as lawyers and brokers, completely. The complexity of high degree of coordination necessity and challenges in security in the application will delay the adoption even though this stage has tremendous potential [20, 21].

In the context of the oil and gas industry, Lu et al. [33] point out four main areas for blockchain application: trading, security, supervision, and decision making. Due to the large number of parties involved in the supply chain, a large number of contracts have to be handled associated with a large volume of transactions involving international parties. Handling of those transactions can be more secured and faster through blockchains. A single use blockchain can facilitate such transactions. However, supply chain actors may not be willing to use a public blockchain for their transactions due to security concerns and hence, demand a private or consortium-based blockchain. Localization or transformation can solve that issue as substitution is typically a public blockchain too. Meanwhile, localization has scalability issues, making transformation the best alternative. Similarly, transformation is deemed as the best alternative for executing smart contracts, tracking oil and gas products throughout the supply chain, and recording data with improved cyber security.

6. Conclusions and future research

Even though there are enough published studies on the blockchain, literature on the adoption of blockchain in the oil and gas industry is rare. This study provides an MCDM framework for assessing blockchain adoption drivers, pressures, barriers, and strategy. Analysing data from respondents representing Norwegian oil and gas industries, this study found that the most preferred blockchain adoption stage as *transformation* and the study also found the most influential factors in adopting blockchain are *lack of expertise in the technology* followed by *lack of supply chain partner collaboration* and *reducing operations cost*.

While the first two factors are *barriers* that need attention, the third factor is a *driver*. The proposed framework can be used to evaluate the blockchain adoption readiness. One of the reasons for failure of previous blockchain projects could be that they started with the aim of a transformation blockchain adoption without evaluating their readiness. As the transformation blockchain will require coordination among all the parties involves in a supply chain including international ones, their implementation needs further development in standardization of reporting processes, interoperability, regulations, and adoption of blockchains by involved parties. Companies can use the proposed framework to identify where they stand and how they should go forward in developing their organizational capabilities. Future research is needed on the architecture design and requirements mapping for adoption of the transformation blockchain in the oil and gas industry.

Since this research was conducted only for the Norwegian oil and gas company context, research that involves oil and gas companies from other countries could be conducted to recognize any difference in influencing factors or the preference in the stage in adopting blockchain. The criteria considered for this study were limited to develop the proposed framework. A framework that considers other aspects such as environmental factors to expand the study could be developed in the future. The respondents were asked which adoption stage is most preferred at one point in time. Nevertheless, the relative importance of determinants could vary with time and influence other results, which could lead to a change in the preference of the adoption stage. Hence, an exciting path for further research could be longitudinal research that tracks blockchain technology for a period of time to see if anything changes over time. Despite the benefits of blockchain technologies, reliability analysis [63] of the blockchain platforms needs attention. Further, this study found the reducing operations cost is one of the driving factors for blockchain adoption. However, the expected operations cost reduction might not be sufficient to justify adoption due to initial capital requirements. Studies on in-depth cost-benefit analysis should be conducted in the future.

CRediT authorship contribution statement

Ziaul Haque Munim: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Srinivasan Balasubramaniyan:** Data curation, Formal analysis, Writing – original draft. **Mahtab Kouhizadeh:** Writing – original draft, Writing – review & editing. **Niamat Ullah Ibne Hossain:** Writing – original draft, Validation.

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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Further reading

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