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Tokenization of sukuk: Ethereum case study

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ABSTRACT

Sukuk is a financial instrument that provides returns similar to conventional bonds. It has served to cater to the capital requirements of big corporations and governments, while circumventing interest to adhere to the Shariah law. Sukuk can be touted as Shariah-compliant bonds that rank among the most successful and the fastest growing financial instrument in the Islamic economy. The sukuk research area is marked by a dearth of quantitative literature, compared to qualitative academic work. This paper seeks to fill this existing gap, and introduces a novel, exploratory analysis of sukuk tokenization based on a case study. The funding needs of small and medium enterprises remains largely unmet through sukuk on account of the high costs involved, among other reasons. As we show in this paper, blockchains can aid to lower the cost incurred through the tokenization of sukuk. We highlight some of the key challenges involved in the issuance of sukuk and discuss their resolution using blockchain. We also provide a taxonomy of blockchain applications in finance, with a particular focus on Islamic finance. Our paper reviews different blockchain architectures to assess their viability for tokenization. We conduct a novel case study on sukuk tokenization by implementing a basic smart contract for Sukuk al-Murabaha on Ethereum. The paper concludes by a conceptual analysis of feasibility concerns, based on a comparison of the conducted cost-benefit analysis of conventional sukuk issuance with tokenization.

1. Introduction

The Islamic finance (IF) market will be worth US 3.5 trillion by 2024 (Mohamed & Taitoon, 2019) and Moody estimations predict an increase in sovereign and supranational sukuk issuance to over $93 billion in 2020 (Moody's, 2019). There exists a strong demand for Shariah-compliant securities from IF institutions. Sukuk offers a stable methodology of financing to institutions looking to diversify their sources of financing. The various projections reinforce the strong foothold of this relatively nascent financial industry. The emergence of new technologies poses a threat to the finance industry and consequently the IF industry is also facing inevitable disruption by a storm of nascent technologies. Blockchain counts as the most potent to cause such a disruption, as the emerging academic literature in finance also argues (see (Yermack, 2017)). If the industry does not innovate and adopt to such disruptive trends, then there is a likelihood of a loss of existing client base. The conventional sector is using blockchain to create digital assets

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like stocks, bonds and land titles e.g. NASDAQ, Chain. The IF industry is also venturing in these areas by creating Sukuk or Islamic bonds on top of the blockchain. The IF sector has witnessed the rise of Sakkex (Sakkex, 2018) and SmartSukuk (https://blossom-finance.com/press/world-s-first-primary-sukuk-issuance-on-blockchain-closes, 2019), which are blockchain-based sukuk issuing platforms. Employment of emerging technologies, in this era of disruption, is an opportunity for the sector to reinvent the established methodologies by incorporating novel technologies to progress ahead of the financial technology startups.

Sukuk has immense potential to fund startups and small and medium enterprises (SMEs). However, sukuk issuance remains confined to large corporations and governments, with the primary target market being large investment funds. The smallest issue is still limited to millions with capital needs of SMEs and startups in the IF domain remaining largely unmet through sukuk. The employment of sukuk for funding SMEs can help to expand the Islamic economy and increase the user base. In (Solé, 2008), Solé describes sukuk issuance and SME financing using a concrete setup of Kuwait and in (Patel, 2014), Patel describes a similar setup for the French market. In these discussions the need for lower transaction costs, transparency and a lack of historic-track record is highlighted, which can be resolved using blockchain.

Sukuk issuance remains plagued with several challenges, the primary being the involvement of multiple intermediaries resulting in both high costs and an increase in the probability of human error. Tokenization of bonds is an application of blockchain technology to lower the various costs associated with the issuance process. Sukuk are Islamic bonds that can also benefit from tokenization by increasing the operational efficiency, cost reduction and enhancing transparency, which is one of the primary characteristics of blockchain. Transparency is also one of the essential attributes that would serve as validation of Shariah adherence for the masses. Notable organizations have tokenized bonds including World Bank, which launched *bond-i*, which was the world's first bond to be created, allocated, transferred and managed through Ethereum blockchain platform (The World Bank, 2018). In 2019 secondary bond trading was enabled on the *bond-i* platform, which was also a pioneer in the world. The Central Bank of China recently issued $2.8 billion of special bonds to fund small and micro-enterprise businesses, using their self-developed blockchain issuance system (Kuznetsov, 2019).

The IF domain is characterized by research on sukuk that is largely qualitative rather than quantitative and overall research in sukuk in IF is still underdeveloped (Zulkhibri, 2015). The present paper seeks to fill this gap. In this paper, we tokenize Sukuk al-Murabaha using Ethereum through smart contracts to program the necessary conditions like payment frequency, registering investors, automating the periodic payments to the investors while getting the deferred payment amount from the purchaser of the Murabaha asset. We do a cost-benefit analysis of sukuk tokenization with conventional sukuk issuance and conduct a feasibility analysis based on our results. This paper thus provides an impact-assessment approach for institutions, SMEs and even startups to support the adoption of blockchains for sukuk issuance. As a consequence, our analytical approach allows organizations to prepare for current market challenges in a systemically efficient manner, by understanding the cost and performance consequences of tokenization. Our paper is therefore a pioneer in the finance domain.

The rest of the paper is organised as follows. Related work is given in the paper in Section 2. The paper gives the requisite background on sukuk in Section 3.1, including the key challenges and circumvention of some of the challenges encountered during sukuk issuance. Relevant background on blockchain technology is given in Section 3.2 while a taxonomy of blockchain applications in the financial sector is given in Section 4. An assessment of the available blockchain platforms in the context of their viability for usage in tokenization is given in Section 5. Tokenization of Sukuk al-Murabaha by means of a basic smart contract is elaborated upon in Section 6. The cost-benefit analysis is discussed in Section 7. Feasibility of tokenization of sukuk is discussed in Section 8 while the conclusion is given in Section 9.

2. Related work

In (Schletz & Lee, 2020), Schletz et al. highlight that both debt and equity instruments can be managed by tokenization, which decreases transaction costs by disintermediation and automation, improves transparency, and thus shortens liquidity requirements. Nam and Yang in (Nam & Yang, 2017) observe that blockchain bonds convey information safely between the participating institutions, ensure access to the same distributed ledger through a smart contract and reduce the cost of processing complicated transaction information by absolving the need for a relay center. Uzsoki in (Uzsoki & Guerdat, 2019) highlights that the financial feasibility increases significantly by tokenizing debt instruments used for financing a project or diversifying a portfolio. Uzsoki also adds that tokenization absolves most of the financial, legal and regulatory intermediaries reducing transaction costs. Sukuk issuance involves compliance to the Shariah and investors request higher transparency depicting the adherence to the Shariah. Zaka and Shaikh postulate that blockchain-based sukuk can enable traceability of assets thereby increasing the investors' confidence (Zaka & Shaikh, 2019). Mohsin and Muneeza in (Mohsin & Muneeza, 2019) discuss a novel Waqf Sukuk model and emphasize on the usage of blockchain-based smart contracts to make the waqf collection process more efficient and transparent. Muneeza et al. conclude in (Muneeza, Arshad, & Tajul Arifin, 2018) that blockchain can enable fundraisers in crowdfunding platforms to issue their own shares as a blockchain-based issuance enhances efficiency and reduces costs. HSBC Centre of Sustainable Finance in collaboration with Sustainable Digital Finance Alliance published a report where they conduct a study on blockchain-based bonds, including a green bond, issued by banks up to Q3 2019 and demonstrated efficiency achieved and cost reduction spanning all bonds (HSBC, 2019). Blockchain energizes crowdfunding (Muneeza et al., 2018) and blockchain-based crowdfunding in conventional bonds is also a potential support to SMEs and startups. BNP Paribas along with six other European financial institutions has initiated a blockchain platform to permit SMEs to borrow money to their businesses through “mini-bonds” (Rizzo, 2016). The present paper differs in being a pioneer to conduct a case study on sukuk tokenization using Ethereum. The paper reviews blockchain platforms for their suitability for tokenization, provides a taxonomy of blockchain applications in IF, provides an algorithm and a basic smart contract for tokenization of Sukuk al-Murabaha on Ethereum. The paper also conducts a feasibility study based on a comparison of the cost-benefit analysis using conventional issuance and Ethereum sukuk tokenization.

3. Background

3.1. Sukuk

Sukuk represents the plural form of the Arabic word, Sakk, which means a certificate. Evidence of sukuk can be found as early as 1st century Hijri (Islamic Calendar) and in *Imam* Malik's ‘Muwatta’. In the Umayyad dynasty, the government issued sukuk to public servants and soldiers, which they could redeem at the end of the fixed-term period in exchange for food commodity or sell to others prior to maturity (Marifa Academy, 2015). In 1988, Islamic Fiqh Academy (IFA) passed a resolution 30 (3/4), which defined a sukuk, making it a recognized financial instrument in the IF industry. Accounting and Auditing Organization for Islamic Financial Institutions (AAOIFI) defined sukuk as certificates of equal value, representing an undivided share in ownership of tangible assets, usufructs or services (Marifa Academy, 2015).

Sukuk, sometimes referred to as Islamic bonds, are also described as Islamic Investment Certificates. However, it must be noted that a bond is a contractual obligation whereby the issuer is obliged to pay bond holders, on certain specified dates, interest and principal. In comparison, under a sukuk structure, the sukuk holders hold an undivided beneficial ownership in the underlying assets. Consequently sukuk holders are entitled to share in the revenue generated by the sukuk assets as well as share in the proceeds of the realization of the sukuk assets. Sukuk are Islamic bonds which behave in practice like any highly-rated conventional bond. However, sukuk should not simply be regarded as a substitute for conventional interest-based securities. The aim is not to engineer financial products that mimic fixed-rate bills and bonds, and floating-rate notes as is largely misunderstood by many, but rather to develop innovative types of assets that comply with Shariah.

A sukuk issuance comprises of an Obligor, asset and typically a Special Purpose Vehicle (SPV) to accumulate taxation benefits and solvency. Issuance of sukuk in global Islamic capital markets is predominantly structured as trust certificates, governed by English law, which generally requires the creation of an orphan offshore SPV in a suitable jurisdiction. This structuring involves the recognition of the concept of trust in the jurisdiction of the Obligor. In other jurisdictions, like those governed under the civil law, this is not the norm and sukuk structuring is being accomplished in accordance with local laws. A pertinent example is that of Turkey, which has legislated the creation of asset-leasing companies acting as SPV to enable the use of sukuk. The essential underlying concepts of sukuk are:

- Transparency and clarity of rights and obligations.
- Income from securities must be related to the purpose for which the funding is used, and not simply comprise interest.
- The securities should be backed by real underlying assets, rather than being simply paper derivatives.

Most commonly used sukuk structures replicate the cash flows of conventional bonds. Such structures are listed on exchanges, commonly Luxembourg Stock Exchange and London Stock Exchange in Europe, and made tradable through conventional organizations like Euroclear or Clearstream. Luxembourg Stock Exchange (LSE) is a principal European centre for listing sukuk, which can be done in the Regulated Market, the Euro MTF market or the LuxSE securities Official List (SOL). The securitization vehicles may be used to issue several classes of sukuk. A depiction of Sukuk issuances in Luxembourg since 2002 and their issue sizes can be seen in Fig. 1.

3.1.1. Key challenges in sukuk structuring

Some of the key challenges that are an obstacle to a greater adoption of this market are as follows:

1. **Slow process.** The documentation process of sukuk issuance is not as fast and efficient as the conventional bond market, resulting in higher costs.
2. **Decision of the Shariah scholars.** The decision of the Shariah scholars is crucial to any sukuk structuring process and the integration of the Shariah rulings increases the cost of the process.
3. **Lack of standardization.** There are no standards as in the conventional bond market and this slows down the structuring process, adds to the cost and makes the market deployment restricted.
4. **Globally acceptable Shariah standards.** There is a need for Shariah standards to different sukuk structures to have a unified view in the situation of differing Shariah opinions.
5. **Miscellaneous challenges.** There are other challenges like different tax treatments as compared to conventional bonds in different jurisdictions, requirement of a good credit rating and issues related to assets during the transaction life.

3.1.2. Circumvention of key challenges

A detailed discussion on the circumvention of all the listed challenges in Section 3.1.1 is outside the scope of this paper. We focus on the listed challenges that can be tackled utilizing emerging technologies like blockchain and highlight the circumvention possible. We sort the circumvention into the following four categories, where all except the last, are addressed in this paper:

1. **Tokenization.** Tokenization of sukuk using blockchain can help to generate more secure and immutable data while reducing the

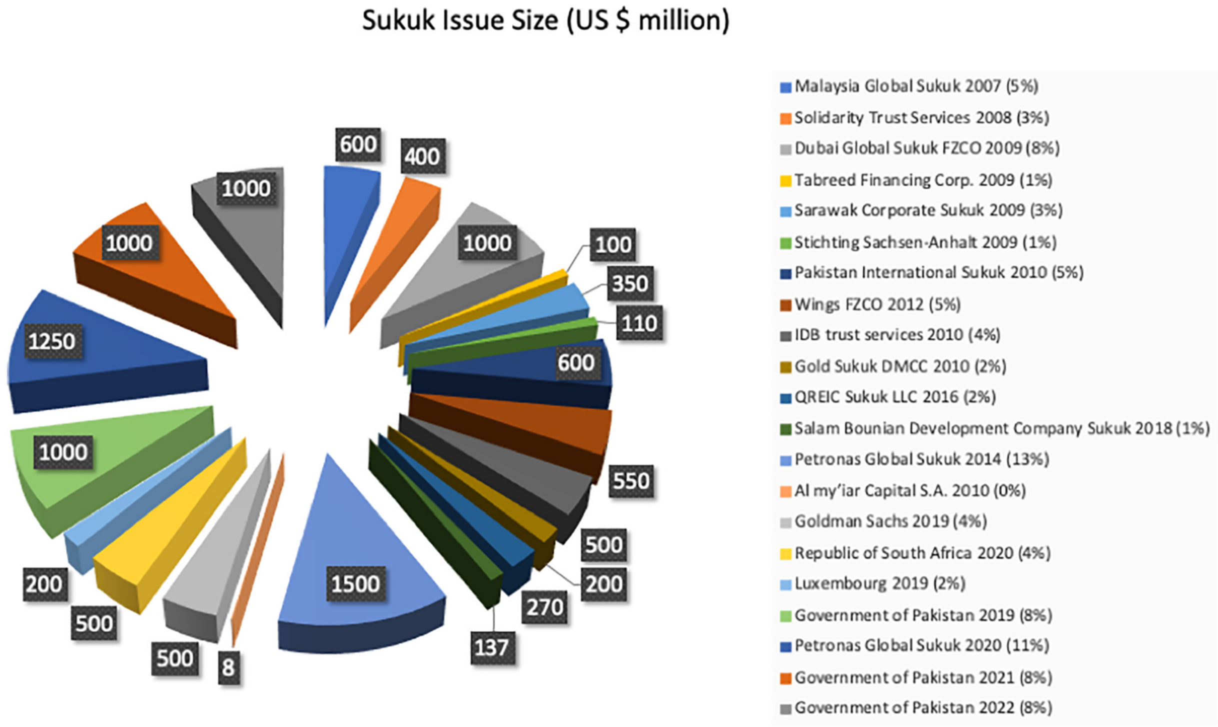

Fig. 1. Sukuk Listed on Luxembourg stock exchange since 2002.

number of intermediaries involved. Tokenization also facilitates smaller denominations in sukuk issuance potentially extending the benefits of the structure to SMEs.

2. **Smart contract template.** A smart contract template for usage on a blockchain can be provided for different sukuk structuring methodologies in consultation with prominent Shariah scholars. Once the basic template exists, developers can code the IF smart contract with the requisite terms required for a particular sukuk issuance. Validating an enhanced smart contract developed from a basic validated smart contract template, to see if it adheres to a specific protocol, is faster and easier than documenting a sukuk issuance catering to a specific IF smart contract from scratch.
3. **Automation.** A sukuk issuance involves two different contracts namely, between the Obligor and the SPV, and the SPV and the investors. Multiple smart contracts deployed by the SPV or a third party providing this service, can automate the process and make it more transparent. The automation of periodic payments to the SPV and the proceeds to the investors can make the procedure extremely efficient, transparent and in real time.
4. **Credit rating and market expansion.** Artificial intelligence can be used on the blockchain data relevant to sukuk issuances to develop alternate credit scoring methodologies and expand the market for more organizations to raise capital through sukuk issuance.

3.2. Blockchain

Blockchain is heralded as one of the most disruptive innovations of the fourth industrial revolution (Chuen & Lee, 2017). The technology absolves the need of intermediaries resulting in a reduction of transaction costs, while providing a decentralized, immutable database. It came into inception with Bitcoin (Nakamoto, 2008), which was the first blockchain-based payment platform that came into existence. This was followed by other blockchain platforms like Ethereum (Wood, 2015), Hyperledger (The Linux Foundation Projects, 2019) and Stellar (Stellar, 2019) among others. Blockchain can be described as a ledger of transactions that consists of a peer-to-peer network and a decentralized distributed database. A distributed ledger is a decentralized database, which is managed by multiple entities across multiple nodes (computing devices). Blockchain is a kind of distributed ledger, where transactions are stored immutably using cryptography. All blockchain platforms are distributed ledgers but not all distributed ledgers are blockchains as they might not have the underlying data structure present in blockchain platforms. Blockchain allows multiple parties to securely transact without the need of a trusted third party working as an intermediary. Further it allows all participants to see all the transactions that are taking place. Cryptography and pseudonyms can be used to hide some aspects of the transactions but even then the amount of information leaked is more than traditional centralised databases. So a blockchain permits all users in the blockchain network to read all publicly available data while writing to the blockchain is limited to a certain section of users known as validators (miners in Bitcoin and Ethereum). The validators are responsible for validating transactions by the users and once validated, a chosen validator writes the transaction to the distributed database of the blockchain network referred to as mining in Bitcoin

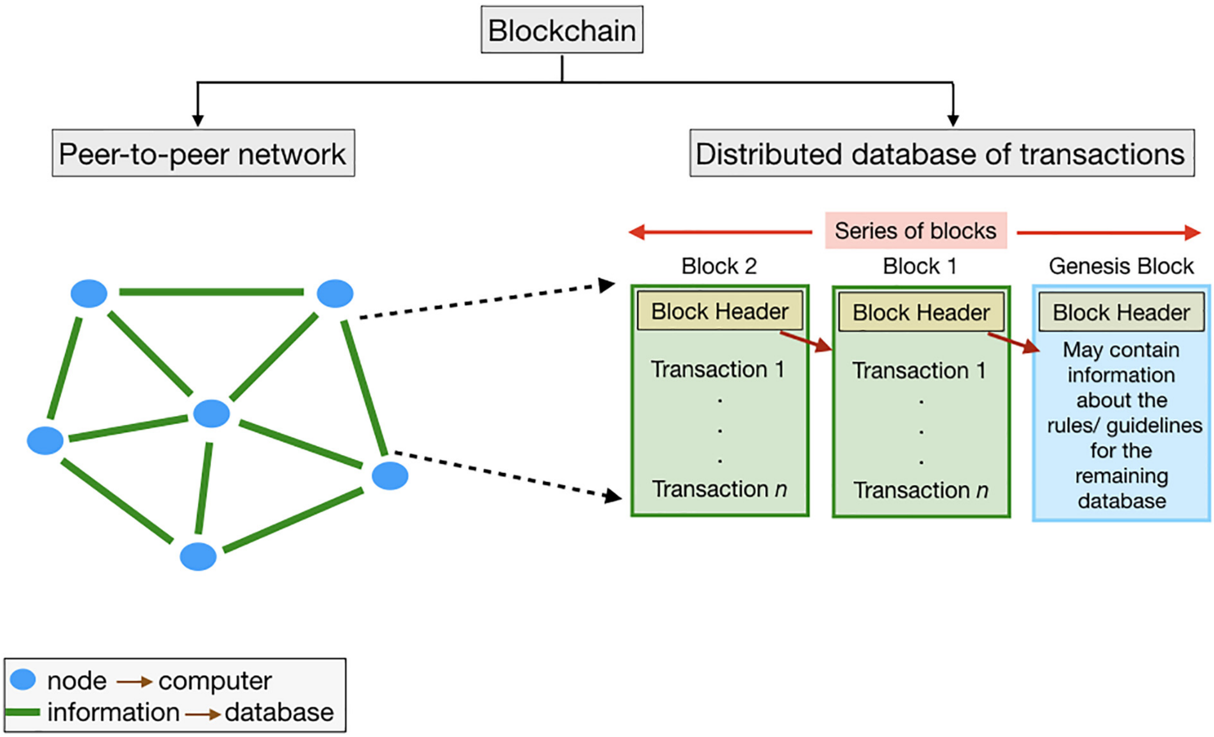

Fig. 2. Diagrammatic representation of blockchain.

and Ethereum. The new data record is then distributed in the entire blockchain network and thereafter verified by all the other validators. The choice of the validator to write the transactions to the blockchain is governed by different mechanisms based on the blockchain platform like proof of work (PoW) consensus mechanism determines the miner (validator) adding transactions to the Bitcoin blockchain. Blockchain thus transfers the power in the hands of the users creating not just transparency but inculcating a feeling of trust.

Fig. 2 represents a diagrammatic representation of the blockchain. The different blocks are linked to each other by way of references to the former, creating a chain of blocks. Each block contains a set of transactions verified by all the validators in the network. The ledger represented is ever expanding and is protected against revision, deletion and tampering. Any manipulation of data would be easily discovered as the original data would still exist on multiple other nodes. Blockchain adds transparency, enhances trust and can provide more security. The security is directly linked to the number of validators holding copies of the entire data of blockchain. In Bitcoin and Ethereum, the block header hash is computed by using only the block header and serves as a digital fingerprint of a block. A hash is a mathematical function that gives an output of a certain length, when given an input and it is irreversible. The block header contains a reference to the previous block, data related to the mining operation and information on all the transactions in the block (Khan, 2017a). Blockchain platforms can be categorized into public, private and consortium. In a public blockchain all users have equal rights to read and update the blockchain. A private blockchain has a single entity or a set of rules managing the access rights of the users in the network and it is controlled who can be a part of the private blockchain. Further a private blockchain can define roles for the network participants including restricting who can act as a validator while the data remains private to the participants of the network. A consortium blockchain usually represents a conglomerate of multiple organizations with the management restricted to the participating organizations. The right to be a validator is also usually restricted to the partnering organizations and the data can be private with the visibility restricted to the network participants. To summarise our overview above, the features of blockchain that make it beneficial for the IF industry are thus the following:

1. Transparency
2. Immutable data
3. Absolving the need for intermediaries
4. Smart contracts
5. Decentralized transaction settlement
6. No single point of failure

It is important to mention that blockchain technology is still in its early stages of commercial diffusion. The main underlying reason is that it still suffers from drawbacks, which we discuss in Section 8. It is a nascent technology and many providers have come

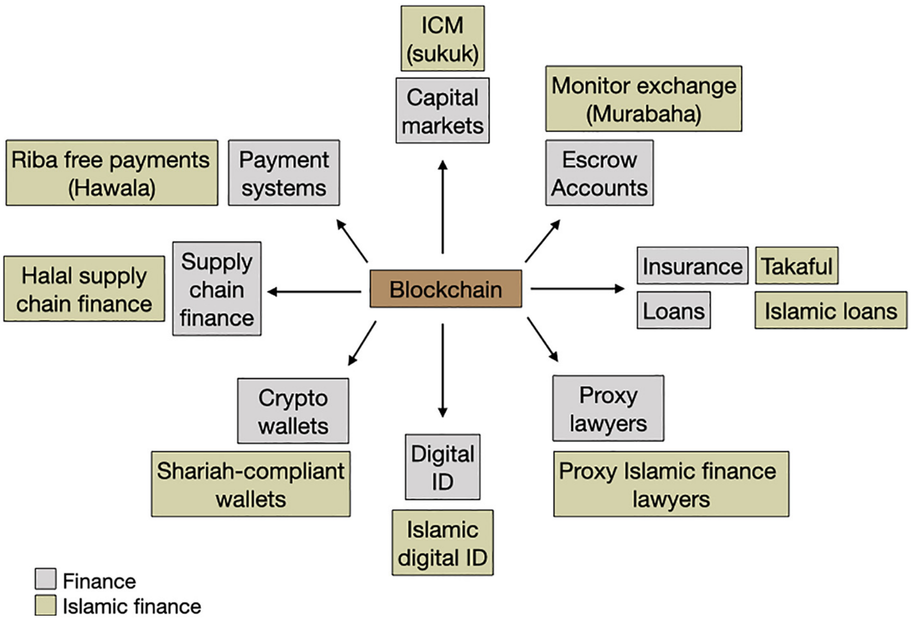

Fig. 3. Taxonomy of blockchain applications in finance and Islamic finance.

to the forefront offering a blockchain platform. The paper discusses the implementation of sukuk on Ethereum. Sakkex sukuk issuance is based on Stellar blockchain, whereas SmartSukuk uses public Ethereum. Wethaq's Sukuk platform is based on Corda blockchain platform (r3, 2019).

4. Applications of blockchain in the financial sector

Blockchain technology finds applications in diverse domains ranging from e-commerce for traceability of shipped physical assets (Hasan & Salah, 2018a; Salah & Hasan, 2018) to solutions catering to monetization of data exchanges between IoT devices (Suliman, Husain, Abououf, Alblooshi, & Salah, 2019). Mobile telecommunications using 5G can leverage upon blockchain technology to enable novel business models and services (Chaer, Salah, Lima, Ray, & Sheltami, 2019) while blockchain can also be employed to empower artificial intelligence (Salah, Rehman, Nizamuddin, & Al-Fuqaha, 2019). The healthcare industry too can benefit from the incorporation of blockchain in the domain (Agbo, Mahmoud, & Eklund, 2019). In this work, focusing on blockchain applications for finance, and in particular for Islamic Finance, we developed a taxonomy of pertinent financial applications that leverage on blockchains, characterized by their added value and by the markets they target. Fig. 3 depicts the resulting taxonomy, which classifies the applications into the following, nine domains:

1. **Capital markets.** Securities that are based on payments and rights, which are executed according to predefined rules can be coded as a smart contract in capital markets. Experiments are ongoing on the issuance of smart bonds and creation of digital assets like stocks, bonds and land titles (Davradakis & Santos, 2019). In Islamic capital markets (ICM), sukuk issuance follows a strict Shariah law together in conjunction with the principles followed in conventional bonds with the exception of riba, which can be coded by a smart contract.
2. **Escrow accounts.** Smart contracts can easily be utilized to set up escrow accounts monitoring the exchange between two parties. Real estate projects can use smart contract driven escrow account to facilitate the conditional transaction (Kirit & Sarkar, 2017). In Islamic finance, an application would be where in a Murabaha contract, the buyer would transfer funds to the smart contract account and post transfer of ownership, the smart contract would automatically release the funds to the seller.
3. **Insurance.** Blockchain-based smart contracts, when used in the insurance sector would reduce the operating costs, increase the speed of execution and enhance the efficiency in claims processing (Gatteschi, Lamberti, Demartini, Pranteda, & Santamaría, 2018). The transparency and lack of textual ambiguity in coded smart contracts can prevent legal disputes. There would also be less insurance fraud on account of the contract being pre-programmed according to some specific conditions. Takaful involves peer-to-peer insurance with policyholders supporting each other financially in critical times. Islamic insurance involves management by a takaful operator, where the operator can be replaced by a smart contract managing a pool of policyholders in a permissioned blockchain automating the process and enhancing the transparency.
4. **Loans.** Automating the lending process through the blockchain (Henriquez, Cohen, Bitan, & Tulbassiyev, n.d.) can result in cost reductions (Manda & Yamijala, 2019). Smart contracts can be used to provide and receive the periodic repayments of the loan together with information on the deposited collateral. In case the borrower misses a payment or a few designated payments, then the smart contract can initiate to revoke access to the collateral. Islamic finance mortgages can reap similar benefits by employing

the use of blockchain for granting loans.

5. **Proxy lawyers.** When considering routine financial transactions, lawyers are involved in repetitively processing mundane tasks and yet consumers have to spend a large amount on their fees to have them go through their wills or contracts. Theoretically smart contracts can do a greater portion of what the lawyers do and using them to support the legal system would reduce the costs associated with the process. The smart contracts could function as an intermediate layer between transacting and going to court by coding of legal rules to automate basic dispute resolution (De Filippi & Hassan, 2016). Islamic finance needs lawyers, who can resolve disputes in the Islamic finance domain in the light of the Shariah and similar to the conventional domain, many basic contractual regulations can be encoded in smart contracts with the violation automatically imposed in case of a deviation from the encoded terms.

7. **Digital ID.** The blockchain ID can be used to sign digital documents or sign in to websites. Banks can be set up for authentication of such blockchain ID's or they can partner with blockchain companies working on the same for facilitating instantaneous cross-border transactions. Blockchain-based identity management systems can be used in Islamic finance to make identification and record sharing easier. However privacy issues need to be tackled in this context (Haddouti & Ech-Cherif El Kettani, 2019).
8. **Crypto wallets.** Cryptocurrency wallets can be set up and controlled by smart contracts. These can include conditional clauses like daily withdrawal limits and restrictions like money that can be spent only on certain kinds of assets, in a certain geographical region or between two dates and likewise. The possibilities are endless and the savings would be huge considering the global reach of a blockchain platform. These can serve as an alternative to bank accounts for the unbanked and underbanked populations (Khan, Ahmad, & State, 2019). In Islamic finance there is a large percentage of Muslims not utilizing banking services on account of ethical reasons and this population can greatly benefit by the creation of customized cryptocurrency wallets adhering to the Shariah.
9. **Supply chain finance.** Supply chain management comprises of tracking the origin and movement of items which can suffer from counterfeiting and theft. The financially critical items like bills of lading or letters of credit can be tracked by a blockchain taking away the possibility of a group of users from corrupting the documents and end users would have more trust in what they receive paving the way for a smart supply chain finance (SCF) (Hofmann, Strewe, & Bosia, 2018). Examples of companies using this technology are *Skuchain* and *Wave*. The halal economy can benefit greatly by utilizing blockchain for non-repudiated data sharing between the suppliers and verification of halal certificates through the blockchain (Tieman & Darun, 2017). The digital platform can create opportunities for investors in the Islamic finance domain to invest in the halal supply chain.
10. **Payment systems.** Bitcoins are being used to send money to anyone across the world and merchants are accepting bitcoins as payments. The bitcoin transactions are recorded on the blockchain with transfer of ownership of bitcoin from one user to another, imitating the transfer of physical cash from one wallet to another person's wallet. The entire record of this movement is recorded in the blockchain e.g. *BitPay*. Islamic finance can develop their own payment systems on the blockchain (Zhong et al., 2019) and make it Shariah compliant to protect users from the interest associated with the available digital payment methods.

Our goal in this paper is to assess and to evaluate the employability of blockchains for sukuk issuance. Using our taxonomy above, this paper thus provides insights on application development for Islamic capital markets. We seek to answer important questions for organizational, i.e. commercial adoption of blockchain applications that are developed to support sukuk issuance. Issues, such as the emerging cost factors and their magnitude, and the benefits that blockchain would embrace for this particular financial instrument are equally important. Therefore, the rest of this paper is centered around a concrete tokenization exercise of sukuk using the Ethereum blockchain platform. The analysis of this exercise allows us to evaluate the potentials of tokenization both quantitatively (i.e. cost assessment) and qualitatively (i.e. benefits and concerns of commercialization), providing thus the answers we are seeking for.

5. Assessment of blockchain platforms for tokenization

In order to assess the feasibility of sukuk tokenization by measuring its performance, related costs and addressing its benefits, it is imperative to know that sukuk tokenization relies on employing smart contracts for execution. In this section, we review the blockchain platforms available that can support smart contracts. Smart contracts are heralded as the most important application of blockchain. A smart contract is a computer program that formalizes relationships over computer networks through a combination of protocols with user interfaces (Szabo, 1997). They form the base of blockchain-based decentralized applications, which might function as products or services for mass usage. Smart contracts reside and are executed on the blockchain, where the correct execution is enforced by the consensus protocol. It relies on a programming language provided by the blockchain platform to encode its operations and the ways to handle user transactions. It can implement a wide range of applications including gaming, financial, notary or computation (Bartoletti & Pompianu, 2017). The distinguishing feature in comparison to paper-based agreements is that smart contracts are computer programs with the capability of unilaterally applying strict rules and consequences on the basis of fresh data inputs. Further the blockchain assures that everyone is seeing the same thing without the reliance on having to trust each other.

Bitcoin, the first blockchain platform to be launched, does not support complex smart contracts. There is the availability of using simple smart contracts, but their execution is costly and designing is cumbersome (Das et al., 2019). The main platform for implementing smart contracts is Ethereum and its high level programming language Solidity (Ethereum, 2020) which is Turing complete and compiled into bytecode language. A programming language is said to be Turing complete if it can computationally solve a given problem with finite resources and a programming language that is not Turing complete cannot measure up to the Turing

Table 1
Comparison of smart contract-based blockchain platforms.

Blockchain platform	Turing complete	Programming language	Consensus algorithm	Execution environment	Wallet model	Public
Algorand	✗	TEAL[a]	PoS[b]	Stack	Account	✓
Bitcoin	✗	Script	PoW	Stack	UTXO[c]	✓
Ethereum	✓	Solidity	PoW	EVM	Account	✓
Hyperledger	✗	Go	FBA[d]	Docker	Account	✗
NEO	✓	Kotin, C++, VB.Net, F#, Java	dBFT[e]	NeoVM	UTXO, account	✓
Tezos	✓	Michelson	PoS	Michelson	Account	✓
Waves	✗	Ride	LPoS[f]	Docker	Account	✓
Corda	✓	Kotlin, Java	Pluggable[g]	JVM[h]	UTXO	✗

[a] Transaction Execution Application Language.
[b] Proof of stake.
[c] Unspent transaction outputs.
[d] Federated Byzantine Agreement.
[e] delegated Byzantine Fault Tolerance.
[f] Leased Proof of Stake.
[g] permitting the usage of the desired consensus algorithm.
[h] Java virtual machine.

complete programming language in terms of functionality. Each compiled smart contract is stored in the blockchain and executed by the Ethereum virtual machine (EVM) running on the network nodes. There are numerous other blockchain platforms that are providing the functionality of smart contracts and a comparison of the prominent platforms is given in Table 1. A review of the listed platforms indicates that only Ethereum, NEO and Tezos have smart contracts using programming languages that are Turing complete and can serve as feasible blockchain platforms for tokenization of sukuk in case a public blockchain platform is desired for issuance. We decided to conduct a case study on Ethereum on account of the above reasons. Ripple has invested in a smart contract platform, Flare (Ajiboye, 2020), which is still being tested and was therefore not in consideration for our discussion. Stellar is not a typical blockchain supporting smart contracts as it does not have a smart contract programming language or a virtual machine to support the execution of smart contract code and is hence not a part of the review process.

6. Tokenization of sukuk

The applications of smart contract technology are diverse but restricting it to the financial world, it can be conveniently said that any kind of business logic relying on data can be coded by way of smart contracts. Securities that are based on payments and rights, which are executed according to predefined rules can be coded as a smart contract in capital markets. Experiments are ongoing on the issuance of smart bonds. Sukuk issuance follows a strict Shariah law and other principles, many of which can be programmed to ensure both compliance to the Shariah and transparency for all involved increasing the mass appeal of the product among Muslims (Khan, 2017b).

Sukuk al-Murabaha is a possible structure to fulfill the capital requirements of an entity, when there is an absence of an identification of a tangible asset against which investment can be sought. It is heralded as a preference when other structures using Mudarabah, Ijarah or Musharakah are not possible, since it is debt-based. Hence, Sukuk al-Murabaha cannot be traded in the

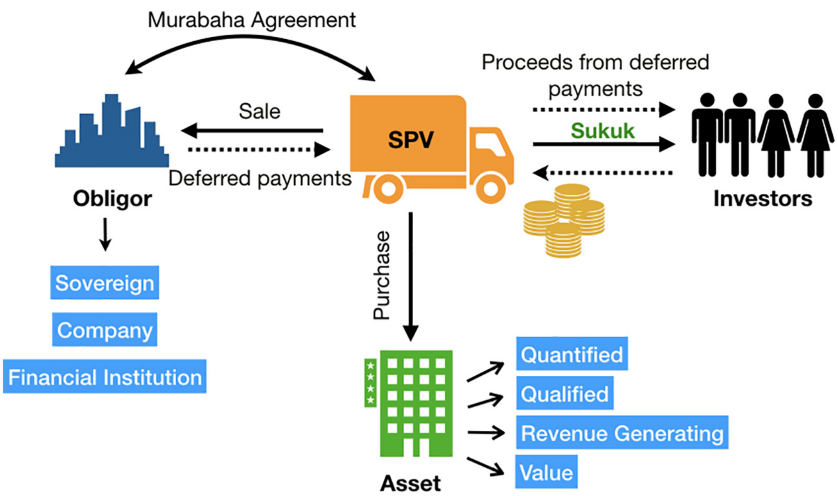

Fig. 4. A simplified representation of sukuk Al-Murabaha.

secondary market as per the Shariah prohibition of not trading debt except at par value. Fig. 4 is a diagrammatic representation of Sukuk al-Murabaha and the fundamental steps involved in the issuance process are given below:

- The Obligor creates a SPV to issue the sukuk. SPV is a separate legal entity with it's own assets, created by an organization to isolate financial risk, ensuring the survival of the entity even if the parent company goes bankrupt. Its role is to protect the underlying assets from investors in case of financial deficits.
- Investors agree on the sukuk and pay the principal amount to the SPV in return for sukuk certificates.
- SPV utilizes the proceeds in buying the required asset and resells the asset at a markup to the Obligor on deferred payment terms through a Murabaha contract.
- Obligor pays the installments as agreed to the SPV and the SPV transfers the requisite profit from the payment proceeds to the different investors.

Algorithm 1. Tokenization of sukuk al-Murabaha on Ethereum.

```
Require: Register the SPV and Obligor using their Ethereum address
Require: Initialize the payment frequency, number of sukuk coins, issue
    size, face value of the sukuk, maturity and profit rate
Require: Link to the Murabaha contract and relevant documentation is
    shared
Require: Register each investor using Ethereum address
Ensure: Obligor and investors buy sukuk coins to use in exchange for fiat
    currency.
Ensure: Obligor pays the periodic amounts for the asset
1: for entire period till sukuk maturity do
2:    if payment is due then
          pay fee to the SPV from Obligor's deferred payments and deduct
          the fee from the paid amount
3:    end if
4: end for
5: for entire period till sukuk maturity do
6:    while payment is due and number of investors ≠ 0 do
          pay each investor the profit based on his investment
7:    end while
8: end for
```

An algorithm to implement the Ethereum smart contract for Sukuk al-Murabaha is given in Algorithm 1. Sukuk al-Murabaha was chosen for our consideration since our case study involved a sukuk issuance involving the Murabaha contract (refer to Section 7). The algorithm indicates that it is essential to register the SPV and Obligor on the smart contract using their Ethereum address. Each investor, who intends to buy sukuk, should register through the smart contract using his Ethereum address. It is assumed that the SPV and the Obligor have entered into a Murabaha contract outside the smart contract. Notary services are not recognized online legally to the best of our knowledge and hence we excluded the purchase and sale of the sukuk asset from the smart contract. The SPV would however need to provide documentation relevant for the sukuk asset on the smart contract for the investors to see. The smart contract would collect the periodic payments from the Obligor, pay the fee to the SPV and the profit to the investors based on the payment frequency. Sukuk coins are a kind of token introduced through the smart contract.

The algorithm guided in the coding of the smart contract for Sukuk al-Murabaha. The smart contract was coded in Ethereum using the programming language, Solidity. Only basic functions required for sukuk issuance were coded and necessary control statements to check for identity verification, balance requirements, conversion from fiat to cryptocurrency, event notifications, security and privacy measures were not taken into account. The purpose of the smart contract was to code a proof of concept to determine the requirements for deploying a fully functional smart contract on Ethereum in terms of cost and development effort needed. The smart contract that was coded to analyze sukuk tokenization can be accessed from (Khan, 2019). The basic functions in Sukuk al-Murabaha smart contract with the objective of their usage is given in Table 2. The smart contract can be deployed and run on Remix for testing

Table 2
Basic functions in sukuk al-Murabaha Smart Contract.

Function	Objective
registerObligor	Registers the Ethereum address of the Obligor.
newInvestor	Registers a new investor by recording the Ethereum address, investor's name and initializing the sukuk coins owned as well as the owned sukuk as zero.
buyCoins	The registered investor buys sukuk coins.
investInSukuk	The registered investor uses sukuk coins to invest in sukuk.
enterProceeds	The Obligor pays the periodic deferred payment.
automaticPayment	The owner of the smart contract, the SPV, initiates the automatic payment for the investors from the payment proceeds collected from the Obligor.

purposes. Remix is a tool for writing Solidity smart contracts directly from the browser and aids in testing, debugging and deploying smart contracts (Remix, 2019). A decentralized application on the blockchain using the coded smart contract can be visualized in (OneClickDapp, 2019).

Listing 1 highlights the code for a function to distribute the profit accrued on the investment certificates (sukuk) on the basis of the payment frequency entered by the owner of the smart contract in the constructor passed during smart contract deployment. The function needs the payment frequency to execute and can be called only by the owner of the smart contract. The investors are accessed through their Ethereum addresses and the profit distributed to the investor depends upon the number of sukuk (equivalent to bonds) owned by him and the profit rate, which was 4.75% in our case study (see Section 7). The number of sukuk coins owned by the investor increases on the basis of the profit accrued. The sukuk coins are tokens introduced to function only for the users registered through the smart contract to ensure security of fiat money held outside the blockchain and validity of ownership of the same. The exchange rate should be specified on the website of the issuer of sukuk.

Listing 1. Tokenization of sukuk smart contract: function-Automatic Payment to Investors.

```
pragma solidity 0.6.1;
contract BlockSukukSPV {
//code preceding the function
  function automaticPayment()public {
     require(now >= paymentFrequency);
     if(msg.sender!=owner){revert();}
     uint track;
     uint counter=numInvestors;
     while(counter>0){
        address i= investorList[track];
        uint factor=investors[i].ownSukuk;
        uint profit = (factor*475*proceedsPayment)/100;
        investors[i].profitReceived=profit;
        investors[i].sukukCoin+=profit;
        proceedsPayment-=profit;
        Transaction storage t=transactions[numTransactions++];
        t.sender=msg.sender;
        t.receiverID=investors[i].investorID;
        t.ID=numTransactions++;
        t.amount=investors[i].profitReceived;
        transactionList.push(t.ID);
        t.time=now;
        track++;
        counter--;
       }
   }
//rest of the code
}
```

7. Cost-benefit analysis

After introducing and analysing the technicalities related to sukuk tokenization, this section turns our analytical angle towards concerns of commercial, i.e. organizational adoption. Socio-economic, in particular financial feasibility concerns are often bottlenecks of technology adoption, as it is also argued in (Gordijn & Akkermans, 2003). Therefore, we first revisit our implementation and address its cost consequences as follows. The costs of the transactions on Ethereum were computed by deploying the Sukuk al-Murabaha smart contract on Remix and executing the various functions. The tabulation of the various costs is given in Table 3. The transaction fee is computed by adding both the transaction cost and execution cost in terms of the gas used. In Ethereum, gas is a unit which helps to measure the amount of computational effort required to execute a certain operation on Ethereum. The exact price of the gas is determined by the miners and the price determines the speed with which the transaction is mined and recorded on the Ethereum blockchain. The calculations in Table 3 were done using average gas price of 1 gwei. The Ethereum cryptocurrency can be

Table 3
Transaction costs on Ethereum.

Transaction (Tx)	Gas used	Tx fee (ETH)	Costs ($)
Deploy Smart Contract on Ethereum	2,737,722	0.0027377	0.35043
registerObligor	63,336	0.0000633	0.0081
newInvestor	278,484	0.0002785	0.03565
buyCoins	406,430	0.0004064	0.05202
investInSukuk	389,826	0.0003898	0.04989
enterProceeds	77,130	0.0000771	0.00987
automaticPayment (1 investor)	371,594	0.0003716	0.04756
automaticPayment (5 investors)	1,650,610	0.0016506	0.21128

broken into smaller denominations like *wei* similar to a fiat currency being denominated into pennies. Wei is the smallest denomination for ETH, the cryptocurrency of Ethereum. 10^9 wei is equal to 1 gwei and is used to measure gas prices (ETH Gas Station, 2019). The cost is computed for a single investor for automatic payment of profit and thereafter for 5 investors and it is seen that the cost is simply 5 times the cost for a single investor. Reading data from Ethereum does not cost any gas unless it is through another contract, whereas writing to the blockchain incurs a cost and hence only the functions that involve a transaction fee have been listed in Table 3. It is also assumed that the total number of sukuk issued have been declared before contract deployment. However, the number can be changed and a function can be provided in the smart contract to increase the number of sukuk issued in case of over-subscription. Similarly a function to destroy the smart contract after maturity or at the will of the owner of the smart contract can be provided to prevent damage in case some error is discovered in the code after smart contract deployment. The costs have been calculated using the basic functions and should only be used for a theoretical assessment of cost-benefit analysis. Costs for the practical deployment of the full smart contract might vary, including the exchange rates causing a change in the transaction fee. The exchange rate utilized correspond to 28th December 2019.

We compare the cost of sukuk issuance the conventional way to a blockchain-based issuance. In blockchain, the issue price and profit per annum will not affect the transaction costs but the payment frequency, the number of investors and the number of sukuk issued will directly impact the cost incurred by the issuing organization. We use the data for the transaction fee from Table 3 and use the sukuk issued by Aldar as a reference (Islamic Markets, 2018). The details of the sukuk issuance are given below:

- Amount: $500,000,000
- SPV/Issuer: Aldar Sukuk
- Obligor: Aldar Investment Properties
- Minimum settlement amount: $200,000
- Par amount, integral multiple: $1000
- Issue date: 01/October/2018
- Maturity date: 29/September/2025
- Coupon frequency: Semiannual
- Issue price (% of face value): 99.718%
- Profit per annum: 4.75%
- Sukuk type: Hybrid involving Wakala and Murabaha

In order to compensate for the Wakala structure in our smart contract, we paid a fee to the SPV acting as a *wakeel* over the underlying assets. We did the following assumptions for the cost benefit analysis:

- Each investor bought the minimum number of sukuk defined in the prospectus of Aldar Sukuk.
- The Obligor, Aldar Investment Properties, also makes the periodic payment for the Murabaha contract semiannually.
- The sukuk tenor is 7 years, which would involve 14 transactions for the periodic payments by the Obligor and also profit accrued to the investors with regards to the coupon frequency.

We did the following calculations to do the cost-benefit analysis for tokenization of sukuk on Ethereum:

$$\begin{aligned}&\#\text{Investors} = \text{Amount}/\text{Minimum settlement amount}\\&= > 500000000/200000 = 2500\end{aligned} \tag{1}$$

$$\begin{aligned}&\#\text{sukuk each investor bought} = \text{Minimum settlement amount}/\text{Par amount}\\&= > 200000/1000 = 200\end{aligned} \tag{2}$$

Thereafter, we compute the total transaction costs referring to the transaction fees given in Table 3 for the basic functions as given below:

- ***registerObligor*** = 1∗0.0081 = $0.0081
- ***newInvestor*** = 2500∗0.03565 = $89.125
- ***buyCoins*** = 2500∗0.05202 = $130.05
- ***investInSukuk*** = 2500∗0.04989 = $124.725
- ***enterProceeds*** = 14∗0.00987 = $0.13818
- ***automaticPayment*** = 14∗2500∗0.04756 = $1664.6

We chose the case of Aldar Sukuk for our study because it is an average size issuance. The usual range of corporate sukuk issuance is between $100 M to $2B (International Islamic Financial Market, 2020). As per the financial statement of Aldar for 2019 (page 69 of (Aldar, 2020)) the total issuance cost of the mentioned bond was $7,165,532 or 1.43% from the total proceeds. Table 4 gives the cost components for tokenization on public Ethereum blockchain for a sukuk analogous to Aldar sukuk issuance. In Table 4 expenses mentioned refer to World Bank estimations for similar size and maturity bonds. The demarcation of the expenses was not given for Aldar and hence, we used the estimations from the World Bank for bond issuance (Patrick, van der Wansem, & Rivetti, 2019). According to an academician, the standard Shariah advisory fee is generally about one-quarter to one-half of a percent of the total

Table 4
Cost components for sukuk tokenization on public Ethereum.

Sukuk component	In quoted format	USD proceeds
Issuance	99.718%	$498,590,000
Smart contract deployment		$0.35
Fees: newInvestor & buyCoins		$102,130
Fee: investInSukuk		$124,725
Fee: enterProceeds		$0.14
Fee: automaticPayment		$16,646
Fee: registerObligor		$0.01
Independent advisor	0.020%	$99,718
Legal expenses	0.030%	$149,577
Bond rating	0.100%	$498,590
Rating costs	0.005%	$24,929.50
Shariah advisory fee	0.25%	$1,250,000
Total fees and expenses to be paid upfront	0.45%	$2,266,316
Total Proceeds to Obligor		$496,323,684
All-in price (proceeds/amount)	99.26%	

value (Rudnyckyj, 2018). In the absence of availability of the Shariah advisory fee paid by Aldar, we consider it one-quarter of a percent to the total value.

Table 5 gives the cost components for tokenization of sukuk on a private/consortium blockchain. The private blockchain and the consortium blockchain would be analogous in their cost components with the difference being in the number of nodes or computing devices employed as validators and distribution of profit accrued from the blockchain platform. In case of a consortium blockchain, the transactions for the distribution of the fee for the provided services as *wakeel* would be directly proportional to the number of partners whereas it would be a single transaction in case of a private blockchain. It is assumed that the partners in setting up this private/consortium blockchain would not be charging any fee for the transactions through their hosted blockchain and hence the transactions are all free and cost $0. We give a common Table 5 for the cost components of a private and a consortium blockchain highlighting the difference in the costs. We assume that the total number of nodes in the blockchain platform is equivalent to the number of partners in a consortium blockchain platform. The consortium consists of 3 partners based in Paris, Dubai and Malaysia. The private blockchain can be assumed to have 3 nodes located in Paris, Dubai and Malaysia.

The private/consortium blockchain uses Amazon Elastic Compute Cloud (Amazon EC2) to avail a secure and resizable compute capacity in the cloud (AWS, 2019) for hosting the nodes. The infrastructure costs for t3.large reserved instances in EC2 will be as follows (AWS, 2019b):

- EU (Paris) region for the blockchain node in Paris:

(a) Standard 3-Year Term: All upfront = $1096
(b) Standard 1-Year Term: All upfront = $545

Table 5
Cost components for sukuk tokenization on private/consortium Ethereum.

Sukuk component	In quoted format	USD proceeds
Issuance	99.718%	$498,590,000
Smart contract deployment		$0
Fees: newInvestor & buyCoins		$0
Fee: investInSukuk		$0
Fee: enterProceeds (private Ethereum)		$0
Fee: enterProceeds (consortium Ethereum)		$0
Fee: automaticPayment		$0
Fee: registerObligor		$0
Website Hosting		$2737
Blockchain Node Paris		$2737
Blockchain Node Dubai		$2856
Blockchain Node Malaysia		$2589
Independent advisor	0.020%	$99,718
Legal expenses	0.030%	$149,577
Bond rating	0.100%	$498,590
Rating costs	0.005%	$24,930
Shariah advisory fee	0.25%	$1,250,000
Total fees and expenses to be paid upfront	0.41%	$2,033,734
Total Proceeds to Obligor		$496,556,267
All-in price (proceeds/amount)	99.31%	

Table 6
Cost comparison for sukuk issuance vs tokenization.

Sukuk issuance type	Total Cost = Fees and Expenses paid upfront + Issue price
Conventional issuance	$7,165,532
Tokenization on public Ethereum	$3,676,316
Tokenization on consortium blockchain	$3,443,734

- Middle East (Bahrain) region for the blockchain node in Dubai:

(a) Standard 3-Year Term: All upfront = $1154
(b) Standard 1-Year Term: All upfront = $548

- Asia Pacific (Singapore) region for hosting the node in Malaysia:

(a) Standard 3-Year Term: All upfront = $1023
(b) Standard 1-Year Term: All upfront = $543

- Website Hosting from Paris: Price is similar to the hosting of blockchain node in Paris

The other cost assumptions remain the same in the cost-benefit analysis as they were in the case with sukuk tokenization on the public blockchain. The computed results for the cost-benefit analysis are given in Table 6.

8. Sukuk tokenization: feasibility analysis

The results of the performed cost-benefit analysis thus brings us closer to understand the commercial, i.e. financial consequences of sukuk tokenization. Combined with the findings of the concrete implementation exercise of a basic smart contract for tokenization, we articulated and assessed important feasibility concerns from the commercial, i.e. the financial market point of view, including implications for regulatory compliance. In the following, we report our findings and emphasize their significance:

1. **Issuance vs Tokenization cost comparison.** The cost incurred by Aldar for issuance was $7,165,532, while tokenization of a similar sukuk on public Ethereum involved a cost of $3,676,316. Private/consortium blockchain recorded the minimal cost incurred for tokenization with a value of $3,443,734. The cost ratio of conventional sukuk issuance to tokenization on public Ethereum is 1.95 whereas the cost ratio of conventional issuance to tokenization on private/consortium Ethereum is 2.10 indicating a significant reduction in expenses using Ethereum for tokenization.
2. **Role of Shariah advisors.** The role of the Shariah scholars will be paramount in tokenization and a common understanding of the programmed smart contract between the Shariah scholars, sukuk issuing organization and the technology team needs to exist to avoid potential incorrect Shariah adherence in tokenization to be legitimated as Shariah-compliant. The achievement of a common understanding is crucial for transparency and is a difficult process as it involves experts from three diverse domains to agree on a common outcome. This goal might entail the requirement of additional experts well versed in the Shariah law and technology, thus adding on to the costs. Industry exchanges on the subject give a comparatively lower Shariah advisory fee than we used but is undocumented preventing it's incorporation in our analysis. A higher limit, where the Shariah advisory fee is indicated to be in millions of dollars, also exists (SPEAR'S, 2012).
3. **Clearing and Settlement.** Clearing and settlement processes are more efficient by using blockchain, which ensures an automated delivery and payment mechanism in the absence of a central authority. This confines the settlement risk exposure significantly (Chiu & Koeppl, 2019).
4. **Counterparty Risk.** The counterparty risk is mitigated as the settlement is occurring in real time as a result of the automation of periodic payments.
5. **Smart contract evaluation.** The smart contract coded was with minimal functions to implement a Murabaha contract for sukuk issuance. A complete smart contract would involve more functions and events, that indicate to the owner of the smart contract when a stipulated action has happened in the smart contract like the payment by the Obligor. Thus the smart contract development and deployment on Ethereum would incur higher fees.
6. **Additional Costs.** The front-end development of the smart contract into a functional decentralized application would need to be accomplished and a payment gateway would need to be used to convert the fiat currency to ETH and buying of sukuk coins if the structure involves their usage. All this would increase the costs more.
7. **Know Your Customer** (**KYC**). KYC is a strict regulatory measure to assure institutional compliance regarding client verification, validation and transaction monitoring. Therefore, including digitalized tools to perform KYC related to sukuk tokenization is an essential part for investor validation. There exist numerous third-party solutions for KYC compliance. Alternatively, a tool needs to be developed in-house by the issuing organization. The detailed cost assessment of KYC clearance is out of the scope of this paper, nevertheless, raising awareness on this cost element is of high importance.

8. **Legal Issues.** Smart contracts are not considered to be legal in most jurisdictions and as such a legal contract would still need to be drawn up for the investors for their entitlement to a share in the underlying asset.
9. **Absence of an online notary.** The implemented smart contract focuses only on sukuk issuance to the investors whereas the Murabaha sale and purchase is conducted outside the blockchain network. This is primarily because the mechanism of online notary is not available in most jurisdictions as of now, to the best of our knowledge.
10. **Data privacy.** Privacy issues would need to be tackled when using blockchain and if available for this kind of a structure, privacy-preserving blockchain platforms should be employed. An alternative strategy would be to go for a hybrid of a traditional database for private data interoperable with a blockchain platform for recording transactions. The development skills needed to achieve either of the two is not easily available, thus adding on to the development costs.
11. **Scalability and throughput.** Blockchain is still in the early stages of development with scalability and performance bottlenecks impeding its mass scale usage (Chauhan, Malviya, Verma, & Singh Mor, 2018; Dinh et al., 2017).
12. **Key management.** Management of public-private key pairs associated with an Ethereum address and a more than basic technical awareness from the user is expected to engage with the blockchain platform.
13. **Vulnerabilities in smart contracts.** Post deployment on Ethereum, the smart contract cannot be updated to remove any potential coding errors and any undetected errors have the potential to be exploited like the DAO attack in which an anonymous hacker stole over $50 M worth of ETH (Mehar et al., 2019). Efforts should be made to adhere to a secure development process for smart contracts on the blockchain and deploy them post an optimum security analysis (Hasan & Salah, 2018b), otherwise their usage in tokenization can make them vulnerable to attacks causing major losses (Mense & Flatscher, 2018). It would be worthwhile to know the key aspects governing the security analysis, testing and implementation of smart contracts (Almadhoun, Kadadha, Alhemeiri, Alshehhi, & Salah, 2018) in other domains before using them to issue sukuk to help conceptualize a framework for their secure deployment in the Islamic finance sector.

The above analysis indicates that to ensure economic viability for tokenization of sukuk, the technology needs to be developed to a level where it can be aptly used in the market on a large scale and appropriate regulations have been framed by governments for recognition of an online notary. Additionally there should exist legalization of smart contracts in all the concerned jurisdictions to ensure dispute resolution and complaints redressal. It is recommended for organizations embarking on the initiative to conduct a cost-benefit analysis adding the costs listed above to the assessment conducted in this paper to come to a more just estimate of the process.

9. Conclusion

In this paper we evaluated the present challenges in sukuk issuance and discussed circumvention of some of them using blockchain. We discussed the blockchain platforms, in the light of their architecture, that can prove to be suitable for sukuk tokenization. We elaborated on a taxonomy for blockchain applications in finance and the Islamic finance domain in particular. We conducted a case study on tokenization of Sukuk al-Murabaha on Ethereum and coded a basic smart contract to gauge the contract development complexity and effort required. Developers with the requisite skills are not readily available and Islamic finance personnel should be trained to cater to this need in the sector. Our performed cost-benefit analysis of sukuk tokenization indicates that tokenization itself, leveraging on blockchain, incurs significantly less expenses when compared to conventional sukuk issuance. Furthermore, our more detailed analysis shows that sukuk issuance on the public Ethereum blockchain incurs a higher cost than tokenization on a private/consortium Ethereum blockchain platform. The results are, however, dependent on the concrete implementation characteristics and assumptions based on the particular application domain, such as the choice of the number of nodes, sukuk tenor, number of investors and other similar factors. Feasibility analysis of sukuk tokenization on Ethereum needs to be considered in the light of economic viability, when viewed from the broader perspective considered in Section 8, and the advantages it offers in terms of expanding the investor base and proving to be a solution for the funding needs of SMEs.

As an important contribution, this paper provides a step-wise, systematic approach to assess and to analyze fundamental elements of commercial feasibility of sukuk tokenization. By addressing the fundamental factors of cost-benefit analysis in Section 7, such as the cost factors of blockchain transactions, and by conceptualising the main findings and concerns of adoption in Section 8, we provide a solid assessment framework for organizations that intend to tokenize sukuk. However, it is crucial that the investors ensure that appropriate regulations are in place for sukuk tokenization to protect their interests before investing in blockchain-based sukuk. Technology is developing at a rapid pace and eventually regulations will follow to discipline its usage. Besides, technological advancements would result in more cost reductions in their employment with the passage of time. Therefore, hybrid arrangements which take into account the existing regulations and legacy systems should be integrated with blockchain to develop novel structuring methodologies for sukuk tokenization to leverage on the benefits of the technology.

CRediT authorship contribution statement

Nida Khan: Conceptualization, Methodology, Software, Writing - original draft, Visualization, Investigation, Data curation, Project administration, Resources, Formal analysis.**Bilal Kchouri:**Data curation, Writing - original draft, Investigation, Formal analysis.**Nissar Ahmad Yatoo:**Writing - review & editing.**Zsofia Kräussl:**Writing - review & editing.**Anass Patel:**Supervision, Funding acquisition.**Radu State:**Supervision.

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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