Potential Use of Renewable Energy for Rural Electrification in Pakistan by Incorporating Blockchain Technology

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Abstract

Background: Significant innovations in technology and progressing use of renewable energy sources (RES) reinforce the demand for the sustainable, continuous and abundant supply of energy to every consumer. Blockchain, as an emerging technology promises to provide temper proof, secure, transparent and decentralized energy trading mechanisms that help to provide sustainable environmental solutions by circulating economy to empower both consumers and prosumers. The rapid development of blockchain technology has gained interest from energy start-ups, innovation developers, finance suppliers, academic institutions and government.

Results: This study outlines potential significance, benefits and application of blockchain technology and analyses how Pakistan can integrate blockchain technology into its distribution system to cope with current challenges. Although the substantial renewable potential of Pakistan is an opportunity to implement blockchain technology but financial management, innovative technology development and acceptance of decentralized technology are the biggest obstacles. After a detailed discussion of Pakistan's current financial position, digital market structure, energy policy and technology situation for the implication of blockchain technology, Photographic Geographical Information System (PVGIS-5) data base tool is used to estimate solar power generation capacity from prosumer community in potential areas of country like Baluchistan.

Conclusion: This study recommended feasible site for solar power generation according to PVGIS tool. Then introduces a street scenario about domestic power generation and blockchain based distribution into Pakistan's energy sector like Brooklyn energy system by regulating laws, revising energy polices and suitable development subsidies.

1 Introduction

World gross domestic product (GDP) has been increasing rapidly with the continuous growth of the economy across the globe. According to the World Bank report of 2019, global GDP increased from $30.6 trillion in 2000 to $85.8 trillion in 2018. As per Accenture (2016) estimate, the contribution of the digital economy in the global GDP was 22.5% in 2015, and it might be increased up to 25.5% approximately in 2020 because many developed countries are increasing digital share in their economies and paving a way towards more digitized energy production and distribution.

Such ongoing development requires an abundant supply of energy to compensate residential, industrial and commercial energy needs. Global primary energy consumption reached to 580 EJ in 2018 and from past 40 years, its significant portion was covered by fossil fuels which led towards unmanageable CO_2 emission increment, which was up to 33.7 bn tons in 2018 [1]. These detrimental environmental consequences give rise to the use of renewable energy sources (RES). Nevertheless, predicting RES is challenging because it depends upon weather conditions, and thus the variable nature of RES commence new challenges in operation and management of continuous energy supply [2]. Modernization of existing infrastructure and entering into the digital era proves massively successful to cope with the energy system challenges. The transformation of energy systems has a long-term impact and involves extraordinary costs at a social level. Energy policymakers should therefore develop programmes to ensure social acceptance of energy policy efforts over a more extended time through appropriate training and information tools. The acceptance of higher costs for alternatives is not automatic. Like it is forecasted that in the United States, $2 trillion might be required for up-gradation of electricity network up till 2030 [3].

To the best of author's knowledge, this is the first study aiming at the implementation of blockchain technology in Pakistan to provide an alternative way of energy distribution mostly for the distant areas with the help of small setups.

In this study, first, we provide an insight into the growing need for renewable energy at the global level due to continuously increasing industrialization and technology-dependent lifestyle (Electrification). The clean & green, secure and substantial amount of energy has become the foremost requirement of the time. A lot of smart and innovative, initiatives and strategies are formulated from time to time to cope with energy challenges, so blockchain is one of those technologies. Its simplified technical structure, with its core function, is explained in this section. Second, we discuss the in-depth understanding of blockchain technology infrastructure and its practical importance, the general classification of its implementation areas and its overall application scenarios. Third, we turn attention mainly towards blockchain technology in the energy sector and highlight its potential attributes to the energy sector. Then we review practical used case applications of blockchain technology in the energy sector in the world and contoured global experience for the development of blockchain technology in Pakistan's energy sector. Fourth, we discuss in detail, Pakistan's current

energy generation, transmission and distribution system, demand and supply structure, digital market situation and outlined position and adoption potential of blockchain technology in Pakistan's energy sector. Then with the help of Photographic Geographical Information System (PVGIS-5) data base tool we identified the most suitable peripheral area of the country, which is Baluchistan. Proper applicable scenario is suggested with real time implementation strategies. Finally, we analyse barriers related to the implementation of blockchain technology with facts and figures and clarify its function mechanism and make an in-depth discussion on, possible ways, current risks and future scope of integration of blockchain technology into Pakistan's energy sector.

2 Background

2.1 Blockchain technology

In the world of internet, blockchain is a secure distributed data storage application along with the point-to-point transmission, encryption algorithm, consensus mechanism and many other computer application [4]. Information is stored in sets of data called blocks and verified using cryptographic hashes. Participants can join or leave the blockchain network at any moment without impacting the operation of the system significantly, and it is challenging for external attackers to gain control of the blockchain [5]. Blockchain is a computing paradigm whose core attributes are decentralization of shared database, higher-order distribution and co maintenance. From a technical viewpoint, it is a higher-order background database, maintaining a public distributed ledger. Blockchain framework realizes a transfer of value and asset between individuals without any intermediate; that is why it replaces the traditional transaction confirmation systems [5].

Blockchain technology is a peer to peer (P2P) process, in which records are not kept/updated by a single authority but distributed across the whole network so that all computer nodes have the same information. In this configuration, new record added as a new block of information explains why this technology is called "blockchain". The addition of a new block of information in the distributed ledger requires cryptographic validation. Hence a particular key labelled as "hash algorithm" is associated with validating the new transaction and information is sent to the all nodes of the network.

Briefly, on each transaction, two programs are executed, one generates the new block, and the other algorithm validates this newly added block. The whole record is accessible to all members in blockchain-based technology, but no one can exchange or alter the recording process, so this immutable feature leads to remove corruption and can help to empower the community through sustainable infrastructure.

Blockchain technology is categorized into three main types: private blockchain, public blockchain and consortium blockchain based on architecture. Zheng et al. compared their specific attributes [6], as shown in Table 1. Different types of architectures are used for specifically different need and according to technical feasibility level.

Table 1
Types of blockchain architecture

Characteristics	Private blockchain	Public blockchain	Consortium blockchain
Network type	Centralized	Decentralized	Partially centralized
Participation approval	Permissioned	Permission less	Permissioned
Agreement information	Central authority	All nodes	Decision making nodes
Authority to read	Limited to authorized users	Public	Limited to authorized users
Efficiency	High	Low	High

The innovative functionality of blockchain technology is rapidly applied to an increasing number of process. Figure 1 highlights the major application areas of blockchain technology.

The first application of blockchain was the decentralized payment of instruments [7] then this application expanded from one currency to multiple assets. Since blockchain technology has transparency and reliability, so attempted to decentralize the entire market by transaction recording, smart contracts and decentralized autonomous enterprises. Similarly, when blockchain technology

is applied to distributed energy resources, distributed energy resources system becomes more responsive, efficient and less costly in energy supply services [8]. Blockchain technology applications in the energy distribution system automatically provide promising rectifications in the energy market [9]. Blockchain provoked an essential change in the energy market in which clients can control, convey and sell of utilities. So prosumers can easily refer to their excessive essential to other customers inside their framework. In this way, blockchain bloomed the economic and social advantageous in the energy system with better energy generation, accurate energy consumption and transparent data tracking.

The existing literature gave an insight on how the implementation of blockchain technology influencing every process. Use of blockchain technology gaining attention day by day because this technology is still under- investigation. Blockchain is being used to improve the health care system by providing a supportive digital health care environment and keeping centralized records of reports and data. Blockchain technology is equally important in the agricultural sector and leading towards more efficient and optimized management in precision agriculture. Several blockchain-based model and algorithm are developed to extend the cross country e-commerce supply chain.

After many successful developments in technical industries by blockchain technology, encourage its significant influence in the tourism industry as well. Blockchain technology's several aspects like the breakthrough business model, cash transfer, security, trust and exceptional performance, offer good opportunity to adopt into tourism business model [10].

A wide range of blockchain implementation process has been conducted all over the word like, asset registry, inventory, electronic voting, land exchange, patents, judicial decision storage, criminal record, marital status, tax record, ideas, information, money tracing, passport, digital identity and many more. Table 2 summarises the overall categories of blockchain technology applications and their respective beneficial utilizations.

Table 2
Major categories of blockchain applications

Types	Description of activity and impetus	Authorization	Source
Governments	E-invoices, E-licenses, Poverty relief, corruption curtailment	Government policies and services	[11]
Industries	Marketing, Consumption accountability, smart contracts, self-governance, data integrity, revenue growth	Innovation and development of industries	[12]
Financial sector	Transnational payments, supply chain management	Stable and circular economic growth	[13] [14] [15] [16]
Health care	Medical insurance, E-record, Medicine traceability	Health care data	[17]
Copyright & legislation	Law and order mechanism, Ecertification, Notarization, copyrights verification	Copyrights management	[18]
Agriculture	Local markets, livestock grazing, food supply chain	Food safety and security	[19] [20]
Commerce	Product traceability, cross-border exchange	Supply chain	[21]

2.2 Blockchain technology in the energy sector

Growing renewable energy generation promoted the decentralization of energy system by inclusion of the smart grids and the microgrid. In the forthcoming distributed energy system, power buyer and seller can contact directly in P2P enabled framework of blockchain technology [22].

Blockchain is a game-changer technology with diverse applications in various grey areas; having several built-in essential features that can augment several traditional and imminent applications in the energy sector. Blockchain has enormous energy system applications due to its socio-economic and consumer-centric influences. Table 3 illustrates the potential applications of blockchain

technology in the energy sector. Till the middle of 2017, 3% share of blockchain technologies use was only in the energy-related areas [23]. Blockchain can reinforce three major energy trends digitalization, decarbonization and electrification [24].

2.2.1 Blockchain potential attributes in energy system operations

There are numerous energy system use cases where blockchain technology is applicable. Potential application and aspects in which blockchain technology might affect the operation and management of the energy system are listed below:

- **Resource Sharing**: Blockchain offers common source sharing among multiple users like sharing of charging unit for e-vehicle, energy packaging information for energy commodity trading and many more.
- **Transparency**: Unchangeable record and the transparent procedure is one of the utmost best features of blockchain technology. Further, it assists in auditing and regulation of the system.
- **Billing**: Smart metering of blockchain assures automated billing for consumers and prosumers. The smart contract provides convenience in instalment invoices to the utility companies.
- **Competitive nature**: Smart contracts enhance trouble-free and secure switching of energy suppliers that mobilize market with increasing competition which ultimately reduces energy tariffs.
- **Trading**: Blockchain-based trading platforms have tremendous potential to shake typical market infrastructure due to inclusion of green certification, commodity trading transaction, risk management and trading without intermediators.
- **Market estimation**: Energy market depends upon supply and demand profile. The market fluctuates according to, consumer's preferences, environmental concerns and individual's energy practices. Blockchain technology identifies demand patterns and stimulates the market to provide a specific product.
- **Security**: Cryptographic techniques safeguard transaction process. Blockchain secures confidential data, maintain privacy and reliable for identity management.
- **Automatic control**: Decentralized distribution significantly improves control of the energy grid. Behind the meter activities based on blockchain notably, speed up the system.
- **Grid management**: Blockchain could potentially manage a decentralized grid network efficiently. Blockchain could assist in optimizing flexible alternative sources which as, a result, and affect revenue for network use.
- **Swift communication & data transfer**: Blockchain could be used for data transmission and storage through intelligent devices. Apart from data transfer, data standardization is also enabled in blockchain technology.

2.3 Current applications use cases

E-Vehicle trading

The excellent blockchain application is in the energy-related topics the vehicle to vehicle electricity trading mechanism [25]. The aggregation based electricity transaction blockchain with much pertinent suggestion including billing is introduced in [26] and discrete charging pile is reported in [27], providing a unified payment channel and varying charging conditions in public for the e-vehicles. Germany is robustly following adaptation of e-vehicles and relegating gasoline vehicles. In 2017 Germany energy and gas supplier RWE (Rheinisch-Westfälisches Elektrizitätswerk) provides a subsidy to launch, Share & Charge blockchain-based project to provide sufficient charging piles for development of e-vehicles [28].

Carbon emission trading

Carbon emission trading is another vital application of blockchain in the energy sector. Blockchain technology serves as a distributed framework for the storage of emission, verification of emission transactions and unmodifiable reporting of transparent records [29], [30], [31].

Green certification

Consensus blockchain is designed to trace and secure energy transaction. To keep check and balance for managing environmental certificates and emission permits to track at which threshold these certificates are granted and which services are included in it.

Blockchain-based technology guarantees of origin (GoOs) is already working in the European energy market with a direct link between consumer and renewable energy producer [32], [33].

Energy commodity trading

Energy product's information is encased into a block. Digital trading is done on the common market mechanism. Digitalization provides an opportunity to more and more energy commodity traders to enter into the blockchain field. For example, oil trading generally conducted through producers, provider, contractor, sub-contractor, refiner and retailer. Blockchain technology helps to achieve efficiency in energy trading and also reduces risks [34].

Blockchain-based energy material trading platform VAKT established in 2018 with broad banks and trading companies such as BP, Shell and Equinor. This platform is a very transparent, more convenient and safest electronic model for oil and gas trading. Soon after its launch, Chevron (second-largest oil company of United States), French oil giant, Reliance and Total joined the VAKT platform.

Blockchain amenity to track renewable energy

Spanish multinational energy company Iberdrola used blockchain technology in the first pilot project to track renewable energy with the cooperation of Kutxa Bank. In this successful test project, Iberdrola technically transferred and monitored energy from two wind power plant and one power plant to the two different bank offices locations [35].

Potential of connected devices:

Filament Company integrated blockchain technology with IoT first time to maximize the potential of connected devices as reports [36], but Filament start up closed its business. IoT may help in grid maintenance. Usually in the large, wilderness, if a pole knockdown it is difficult to find that from where electricity connection is cut off. Filament solution was equipping each pole with a tap and connect this mesh network with blockchain. Then if one pole downed, a detector notifies the next one because all devices are connected with each other due to the blockchain mechanism. Hence blockchain updates this fault information to the concerned authority as well. Recently the VeChain and IOTA are reported as part of the top IoT-blockchain projects [37].

Brooklyn microgrid:

Brooklyn project is first blockchain-based applied engineering program [9]. In the start, ten families were involved in this P2P energy trading. Five families were producers, equipped with a solar panel, and the remaining five were consumers. In this way, suppliers can supply surplus energy to their neighbours without any traditional electric utility company. In the near future, this distributed power generation may be able to provide an opportunity for everyone to sell their surplus electricity.

While in traditional power system, only utility company deals with consumers and prosumers. Possibility of charging high amount of bill to the consumer and provide less profit to the producer is obvious.

Table 3
Blockchain application scenarios in the energy sector

Energy Industry	Energy Trading	Energy Certification	Power Grid Management	E-mobility
1) Energy management system: automatic decentralized distribution management [35] **2) Smart metering**: self-regulation, billing [38] **3) Energy security**: secure [39] and reliable [40], cybersecurity [41] **4) Sustainable behaviour**: secure, focused consumer & prosumer behaviour [9]	**1) Energy market mechanism**: competition, concurrent prices [42] **2) Prosumer business model**: locality and participation willingness [43], co-development [44] **3) Socio-economic incentive**: emission reduction, higher renewable share [45] **4) Market policy**: selling & purchase strategies, marketing model support, **5) Emission trading**: emission trading platforms	**1) E-licenses**: prosumers licenses, authorization development **2) Green certification:** astute mechanism of green certificate allocation [46]	**1) Smart contracts**: smart utility contract, consensus mechanism **2) Self-sufficiency**: lower line losses **3) Automation and control: a**utomatic tracking and management	**1) E-vehicle trading** **2) Evehicle charging station**: charging station piles [47] **3) E-wallet** **4) Community engagement:** community building,

3 Research Approach

Qualitative research approached is being used for the fundamental theoretical understanding of how blockchain is integrated into the energy system of any developing country. By gradually revealing diverse factors, two questions "why" and "how" are imposed.

The first question offers a reminder that blockchain has emerged as a promising technology by unfolding literature. Inherently, blockchain is "a mathematical model for sorting data in such a way that is nearly impossible to forge" [48]. Second, this study provides a new case study affirmation that directly accelerates the adoption of blockchain technology. Influencing factors like market, technology and finance are discussed in detail with facts and figures. Data for this case study is collected from multiple definite and supportive sources to evidence the subject of the study and make it reasonably reflective.

At present, not much practical work on blockchain, mainly in the energy sector, has been done in our targeted country (Pakistan). So keeping in mind sustainable development, the potential solar power source location is highlighted and solar power generation is estimated with Photographic Geographical Information System (PVGIS-5). An adaptable strategy is proposed for decentralized local power generation and distribution by blockchain. Moreover, this qualitative research-based case study can help to establish validated findings (when a close relationship is composed, then qualitative data most often provide leading understanding). The case study method is a preferred strategy for pre-implantation scrutinization.

4 Case Study On Pakistan

Pakistan, being a developing country in the green energy generation sector, have much room for progressive technologies to be implemented in upcoming projects. Subsequent sections discuss a detailed review of the influence of blockchain on Pakistan's energy supply, demand and market. Execution of this technology in the current distribution system and its performance is forecasted in technical, economic and social aspects.

4.1 Supply and demand structure of energy

Pakistan is 5th largest country by population around the world. According to United Nations Population Division Estimates, the current population of the Pakistan is 220,892,340, among which only 35% lives in urban areas. Out of this total population 51,000,000 people do not have access to the electricity.

According to State of Industry Report, 2020 [49] total installed power generation capacity of Pakistan is 38.7 GW and it is generating 13.2 GW electricity despite 18.5 GW average demand. That is why a significant shortfall of 5 000 MW to 6 000 MW is present as a massive obstacle in the economic growth of the country [50]. The reason behind this shortfall is the reduction of power production by Independent power producers (IPPs) due to lack of oil and gas supplies. Figure 2 shows the energy consumption by various sectors [51].

Current scenario of primary sources contributions is as fossil fuel 65.2% (oil 35.2% and gas 30 %) of total, hydro 25.47% of the total, nuclear 3.79% of total and renewable energy (wind solar and bagasse) as 5.5%. It is obvious that principal portion of current power generation is based on oil and gas. So this non-sustainable status quo forces to ponder overutilization of other resources like coal, biomass, solar, wind and other sources. Luckily, Pakistan has vast potential for alternate energy sources like the estimated potential for solar power is more than 100 GW and for wind energy is almost 10–50 GW at most feasible recommended places like Jhampir, Gharo, Keti Bandar and Bin Qasim Karachi [52].

Alternative Energy Development Board of Pakistan (AEDB) collaborated with international organizations from the USA, Germany and Denmark to estimate electricity generation potential in Pakistan by using bagasse and waste. It is estimated that the vast potential of 1.8 GW from bagasse and 500 MW from waste is present [53]. Generally, total renewable energy potential is about 167.7 GW which is almost eight times more than the total current demand of the country [54].

Table 4
Installed Capacity (MW) in Pakistan till 2020 [49]

Source type	Amount in MW	Percentage share
Hydel	9861	25.4 %
Thermal	25244	65.2 %
Nuclear	1467	3.7 %
Renewable Energy	2147	5.5 %
Wind power plant	1248	
Solar power plant	530	
Bagasse power plant	369	
Total	38719	100 %

Renewable energy is playing a successful role by providing 2147 MW electricity to the national grid. Moreover, 856 MW solar, 1 140 MW wind, 297 MW bagasse and 2 638 MW micro-hydro projects are under project development stages [55]. The Pakistan Council of Renewable Energy Technology has installed 5 357 biogas plants with an accumulated generation capacity of 12–16 million m^3/day [56].

Electrification rate of Pakistan was 74% during 2016, which accounts electrification rate for urban population as 90% and for rural population as 63% [57].

Pakistan Ministry of Finance reported that the growth rate of the energy sector is 5.8% in the financial year of 2017–2018 [58]. Consumer base electricity demand increases with a growth rate of 85% during the last 15 years due to rapid urbanization. The electricity demand triples till 2050 while in the supply increment is not following this rate [51].

4.2 The digital market in Pakistan

Today's numerous blockchain functions are performed by mobile phone. So general access to mobile and internet significantly enhances the usefulness of blockchain technology conveniently. According to Pakistan Advertiser Society report of 2018, more than 72 % of the Pakistani people uses smartphones. Android is typical; almost 62 % population uses android smartphones. Easy access

to 4G internet network across the whole country, the escalating number of mobile internet users. Almost 60 % of users use more than one cell phone in Pakistan [59]. Most of the daily work and life tasks are conducted with mobile phones. This rapid adoption of mobile technology is growing at the same level as some developed countries. Though with the increasing role of information technology (IT), the overall economy of a country grows via the production of digital services and goods.

IT shares 2.5 to 4.5 % of the total GDP of Pakistan. Moreover, the country is striving hard for adopting and utilizing digital technology. To endorse the digitalization an initiative with the catchword "Digital Pakistan" is launched by country's Prime Minister at 5th December 2019. Government is very optimistic to certainly provide the convenient access of internet technology to every citizen, so they can perform the routine task through smartphones usage and help to reduce corruption and other social evils [60].

So, this digital development technically provides a solid starting point for the implementation of blockchain technology in any sector. The blockchain-based solution to eradicate line losses is proposed to update the energy system of Pakistan. Different and detailed techniques are suggested by integrating blockchain and IoT technologies to avoid power loss. The prototype implementation of the system shows complete feasibility and results collected from algorithm validate this approach to identify line losses during transmission [61].

Because blockchain technology is equally important in both perspectives, government and business, that is why the number of blockchain-based proposal for public/private industries are under consideration. The growing popularity of blockchain technology gained attention from many entrepreneurs. Financing events, investment opportunities significantly reflect the development trend in various sector. Blockchain technology due to its explicit nature and the vast array of attributes come by rank one along with and used with big data and IoT (Inter of Things) [62] and AI (artificial intelligence) [63].

4.3 Blockchain in Pakistani distributed system

Thermal, hydro and nuclear are the significant resources for power generation in Pakistan. Water and Power Development Authority (WAPDA), Pakistan Atomic Energy Commission (PAEC) and Karachi Electric Supply Company (KESC) are major electricity suppliers throughout the country. Moreover, there are 42 IPPs that help to accomplish the energy needs of the country.

Pakistan Electric Power Company (PEPCO) and KESC control Pakistan's power grid at the distribution level. PEPCO administratively control ten public sector power Distribution Companies (DISCOs) which are responsible for supplying power on the national level to the whole country except Karachi city, which is supplied by KESC. National Transmission and Dispatch Company (NTDC) manages transmission grid all over the country except Karachi city. National Electric Power Regulatory Authority (NEPRA) is responsible for issuing the license to IPPs and monitoring performance standards along with controlling tariff rates of power generation and distribution.

Precisely, Pakistan has a centralized energy system and currently facing many challenges like poor structural transformation, unstable prices, transmission loses and many more. This traditional energy supply system is more producer oriented. In this context, the blockchain technology is more consumer-centric by its inherent features (decentralization, automation, immutability, irreversibility, security, public facility) and flexible energy production rate. So that amount of energy can be adjusted with consumer need and provided with assured security even in the rural areas.

While in the currently installed system, a considerable amount of power is stolen every year, which results in the form of high rates as a penalty to the paying consumers. Among the other technical losses, there are 10–40 % non-technical losses like power theft, faulty meters, billing error and line losses are reported [64]. In the smart contract of blockchain automated billing [65], micropayments and pay-as-you-go for pre-paid meters [66] facilities are available to provide security and transparency of system that helps in the auditing process.

In a community, public service energy blockchain projects, different, distributed clean power producers are connected, subject to supply energy. Users by choice can command transaction from any power source. They can check real-time information about possible supply sources and do a transaction through a mobile application. When a user makes a purchase, at once blockchain generates a smart contract that matches a P2P transaction between the user and the supplier.

5 Implementation Perspective

5.1 Energy blockchain a not mature technology

Still, the energy sector decision-makers [67] are taking great interest in the integration of blockchain technology into energy sector at the global level and claims that this technology has tremendous potential of transformational change, can trigger development and improve the efficiency of current energy system practices.

Undoubtedly blockchain technology has enormous inherent features, but few risks are also present in this technology. However, the latest consensus algorithms are trying to overcome those risks. Like, if any person can run the smart contract by writing own distributed application, then chances of code vulnerability are more [68]. Another sensitive matter is that the security key must be treated carefully and remain confidential. Since any authority does not control blockchain technology, if somehow the private key is stolen, then it is challenging to track and recover. In the latest blockchain technologies, many alternate solutions are provided to handle such compromised or lost private keys issues. Currently, by using best practices, this security issue is resolved, but still, the risk factor is present as a challenge in blockchain technology.

Blockchain technology primary attribute is it maintains anonymity, from this attribute attacker took advantage and use it for criminal activity. Attackers could trace the IP address and do transactions [69]. Continuous transactions in blockchain proliferate size of the block, which leads to longer download time and take more memory space [70]. Mini blockchain is a solution to reduce energy consumption [71]. Hence the proof of space [72] and proof of stack [73] algorithm are good choices to minimize the energy consumption problem. Blockchain forking [74] is also a problematic technical issue which is almost sorted out in all well-known protocols of blockchain. Many formal structural designs are proposed to reduce the risk of occurring blockchain forking.

Blockchain is a digital technology that requires a lot of software and hardware support. Though, it is not completely mature technology even in developed countries right now. It has many sensitive areas like extra storage space issue which consume more energy, unnecessary transaction time and cost, cyber-attack issues. For a country like Pakistan with current digital development level handling of cyber-crime in the energy sector opens another challenge.

5.2 Technology and policy issues

Implementation of blockchain technology into the energy sector is a straight away contrary process as compared to an already installed structure that is why it demands acute leniency into the energy regulatory framework. Because developing countries like Pakistan, the energy industry is closely associated with the national economy of the country.

Undoubtedly blockchain technology is technically feasibly but to attain social sustainability, and energy policies need to be reconsidered, license provision practices should be well managed to avoid unfair and larceny of electricity supply. Without license electricity supply based on blockchain is illegal. Energy policies amendments require astute reforms to acquire environment and economic sustainability because, in the early nineties, the shift from cheap hydel to imported oil by government policies plunged the country into the worst ever energy crises. The government should involve to promote blockchain technology and appreciate private investors with the right incentives to make this system active.

5.3 Financial problems

Genuinely energy plays a vital role to achieve development goals, sustainable growth and economic prosperity of any country. Further, due to the technology-based lifestyle of people, the energy production process is not just requisite, but its consumption pattern is equally important. Therefore, the energy supply system is the backbone of the world economy. Implementation cost is one of the most significant constraints in developing countries because a detailed economic feasibility report is required to calculate the ratio between national GDP and cost of development. Such calculations mostly include the capacity of a country to pay the development price per consumer that is going to be served. Cost of electricity production highly depends on the price of fuel, generation means and transmission structure. Simply, the difference between the price of electricity generation and final price imposed on consumers is payable by the government as a subsidy.

Still, the government of Pakistan is not paying due to economic crises. So, this failure of government not to provide subsidy to power generation companies results in circular debt. Whereas, it was 480 billion PKR in 2013 [75] and reached about 600 billion PKR in 2018 [76]. Despite being paid massive amount by the government to address the issue of circular debt still, there is 10–12 hours load shedding in urban areas of the country [77]. Another issue is the shortage of oil and gas supply which results in reduced electricity

generation by IPPs. This shortage is due to non-payment of funds to oil and gas supply companies which needs to pay as a subsidy. Electricity demand is growing 10 % annually while electricity production rate is 7% only [78]. However, all these issues can be sorted out with outstanding financial management, realistic planning and strong partnership with private producer, international agencies. The government of Pakistan had paid around 9 billion dollars to the USA during 2008-09 to help meet its energy demand [79].

6 Applicable Scenario

Briefly, the merits and demerits of real-time application of blockchain technology are explained above with the current status of power generation, distribution strategies and its impact on the digital market. Unfortunately, Pakistan lagging in the field of energy, to address this shortfall every favourable effort is worthwhile. So keeping in mind demand of the time, authors propose a feasible yet straightforward scenario for the decentralized energy distribution for RES in rural areas. The suggested method is similar to Brooklyn energy distribution as Fig. 3 shows. Mainly peripheral areas of Baluchistan province, which are very far from the main grid line but have a tremendous opportunity for domestic solar power generation. Theoretically addressed its impact on digital market system because energy utilization approach and energy market are strongly coupled with each other. This is a simple proposed case for solar power but can be applicable for any renewable power, vast room for further research is available according to opportunities and possibilities. Many neighbouring Asian countries like India, Japan, Thailand, South Korea, Singapore, and Malaysia have started blockchain-based digital energy trading [80].

6.1 Resources potential

Abundant renewable energy resources encourage the implementation of blockchain technology with local power generation, mainly in remote areas. Pakistan, being on the Sun Belt have almost average 26–28 C annual temperature in more than 300 sunshine days with 1900–2200 kWh/m^2 [81] Southwestern areas of Baluchistan province are rich in solar energy, and annual mean sunshine duration is 8-8.5 hours [82], these values are among the highest mean sunshine in the world. The map on Fig. 4 shows the solar energy (Direct Normal Irradiance, DNI) of Baluchistan [83].

PVGIS-5 database tool was used to estimate solar electricity generation potentials of Baluchistan, Pakistan. As per standard test conditions which are in Table 4 yearly and monthly in plan irradiation for a fixed angle and energy output is calculated for 1kWp. Yearly energy production for 1kWp installed PV is 1856 kWh with 2507 kWh/m^2 yearly in-plane irradiation. Monthly data for energy production and irradiation for a given system are elaborated in Table 5.

Table 4. Basic considerations in estimating PV capacity of Baluchistan.

PVGIS-5 estimates of solar electricity generation:

Provided inputs:		Simulation outputs	
Latitude/Longitude:	28.479, 65.644	Slope angle:	35 °
Horizon:	Calculated	Azimuth angle:	0 °
Database used:	PVGIS-SARAH	Yearly PV energy production:	1855.93 kWh
PV technology:	Crystalline silicon	Yearly in-plane irradiation:	2507.41 kWh/m²
PV installed:	1 kWp	Year-to-year variability:	38.80 kWh
System loss:	14 %	Changes in output due to:	
		Angle of incidence:	-2.55 %
		Spectral effects:	-1.02 %
		Temperature and low irradiance:	-10.78 %
		Total loss:	-25.98 %

Table 5
Monthly PV energy and solar irradiation.

Month	E_m (kWh)	H(i)_m (kWh/m²)	SD_m (kWh)
January	149.2	186.0	16.4
February	140.9	179.4	15.5
March	162.9	217.3	9.5
April	156.2	215.6	4.3
May	152.2	219.1	3.2
June	143.1	204.5	8.0
July	145.5	208.1	4.1
August	155.2	217.1	5.2
September	161.9	225.8	5.3
October	173.6	233.9	4.0
November	160.0	206.1	8.0
December	155.3	194.4	14.0

E_m: the average monthly electricity production, H(i)_m: the average monthly sum of global irradiation per square meter received by the modules, SD_m: the standard deviation of the monthly electricity production due to year-to-year variation.

Moreover, average electricity production per month from the given system is 154.6 kWh. Average monthly sum of global irradiation per square meter received by the modules of the given system is 211.4 kWh/m^2, and the standard deviation of the monthly electricity production due to year-to-year variation is 8.1 kWh. As shown in Table 5, the maximum PV power generated by 1kW solar panel is 173.6 kWh in October with 233.9 kWh/m^2 irradiation. Due to such substantial RES scope, Government of Pakistan is also encouraging solar power generation. Secondly, electricity demand for such rural areas is very low, almost 100W because the lighting is the only need for such small houses [84]. Local power generation alternatives are more suitable according to statistics because the extension of grid lines proven significantly less economical for such peripheral areas. Generally the average cost of a solar PV system without battery backup is around 280 to 330 PKR/Wp in Pakistan [85]. It should be mentioned that the micro-credit system may also help in developing these areas.

6.2 Household distributed power generation

According to the World Bank 2019 report, almost 63% of the population of Pakistan lives in villages and each village is consist of 200–250 houses. Suppose we consider each village as a local grid so that each local grid consist of multiple houses, part of which are equipped with PV source and act as prosumer and supply their surplus energy to their neighbours. All houses of each local grid are interconnected by P2P blockchain distribution like the Brooklyn system. For the simplicity of the system, energy storage units cover only the prosumer own needs, and surplus energy is directly transferred to the neighbours. Technical help and support, of course, is needed for maintaining the local grids in operation, but the aggregated cost for the particular rural areas would be considerably less than the extension of the national grid on that areas.

6.3 Digitalization of energy market system model

The building of a conceptual, theoretical framework for the development of digital energy market is relevant to organization transformation to adopt new technologies and realignment of process. New technology is not solely responsible for the transformation of any industry. However, to investigate market transformation, especially in the digital era requires valid conceptual foundation that cuts across the industry along with academia to interpret digital developments. Several authors carry through the organizational strategy to attain digital market transformation [86], [87].

However, digitalization of markets is still in the evolutionary stage for developing countries like Pakistan. Though many frameworks for digital business transformation are available selection is made on the basis of the current state of market and strategies are adopted according to the mission.

To design a simple system of the local energy market, consider the same proposed model, which is explained above for the south-western area of Pakistan. If we consider there are N households. Almost all of them or at least half are equipped with solar energy and produce their own energy. Excess energy is sold to the neighbours if there is demand otherwise sell it to the local grid.

Energy is exchanged by double auction mechanism and bought and sold by matching bids to make energy more tradeable. Billing is done precisely according to data of smart meters which are mounted on each household. The hardware security module is installed on the smart meter, which communicates with the blockchain network and posts about the actual amount of energy consumed from and sold to the local grid.

7 Conclusion And Policy Implications

Integration of blockchain into the energy market enhances its capabilities into the main six dimensions that are, economic gadgets, reliable governance, deft environment, more mobility, effective dwelling and smart human being. Keeping in view all outstanding feature of blockchain this study attempted to suggest its integration in Pakistan's energy sector, especially for the development and electrification of the rural areas. Currently, the centralized energy system of the country faces many challenges which might be addressed and alleviated by blockchain technology. Presently all circumstances like the growing use of renewable sources, promotion of distributed power generation, sustainable development goals, circular economy, secure and error-free energy transactions procedure, are in favour of the successful implementation of blockchain technology in the energy sector, similar to health, finance, market, agriculture and many more sectors. Figure 5 presents an overview of the major drivers and barriers of blockchain. Apart from its development into various sectors, blockchain technology in the energy sector is still in the exploratory phase. However, the major barrier is not just technology but maybe the energy policy.

To estimate real time solar power generation potential data base tool PVGIS-5 is used to calculate exact monthly PV energy and solar irradiation for Baluchistan province of Pakistan. However, 211.4 KW/m^2 average monthly sum of global irradiation per square meter received by the modules of the given system is quite suitable for local power generation. So, an implementation strategy like Brooklyn energy system is proposed for decentralised domestic power project with detailed site allocation according to demand. Hence this study paved a way towards new sustainable development of RES for Pakistan. This case study hopefully will provide a huge room for developers to explore this research domain and encourage real time implementation of local energy generation and decentralised distribution to gain double advantage. However, such latest smart technologies are not common in practice not just in Pakistan but around the globe. Few suggestions for the development of Pakistan's energy system are provided after a detailed analysis of current facts and figures.

- **Policy**: presently outdated system govern the energy sector, which does not seem going to encourage the blockchain technology in the energy sector. So policies should be revised, more flexible rules for certification and licenses should be regularised.
- **Individual production**: license provision system should be more prompt and simplified. Distributed power generation should be promoted to adjust the domestic energy need by mutual power assistance among household users.
- **Institutional framework**: government should support educational framework and research institutions to focus on relevant research. Domestic talent should train and upgrade to cope with real-time problems and their ultimate solutions.
- **Management**: energy management system itself should be simple as well as improved and efficient.
- **Incentive mechanism**: current practices are not perfect to attract new users. More subsidies should provide to encourage new investors. Relevant regulation should be more convenient.

8 Declarations

- **Ethics approval and consent to participate:** Not applicable.
- **Consent for publication:** Not applicable.

- **Availability of data and materials:** Not applicable, because all the respective data sources are publicly available and mentioned accordingly reference list.
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- **Competing interests:** The authors declare that they don't have any known competing financial or personal relationships that could have appeared to influence the work reported in this paper.
- **Authors' contributions:** The whole study is done by just two authors mentioned above with mutual cooperation and through discussion.
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Figures

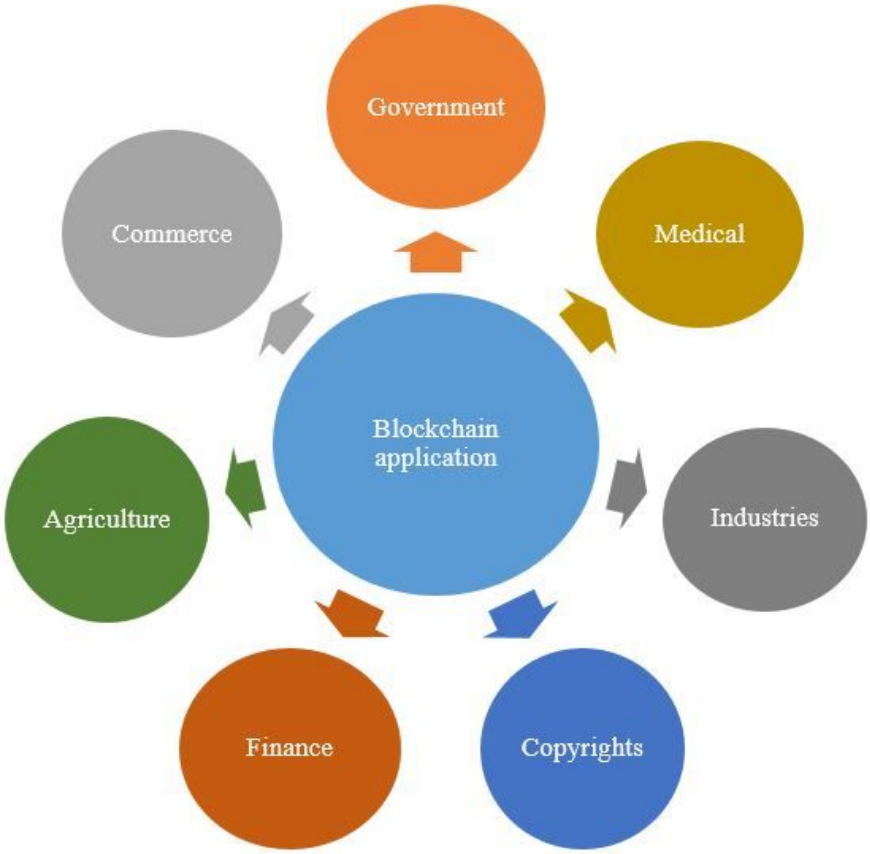

Figure 1

Major application areas of blockchain technology.

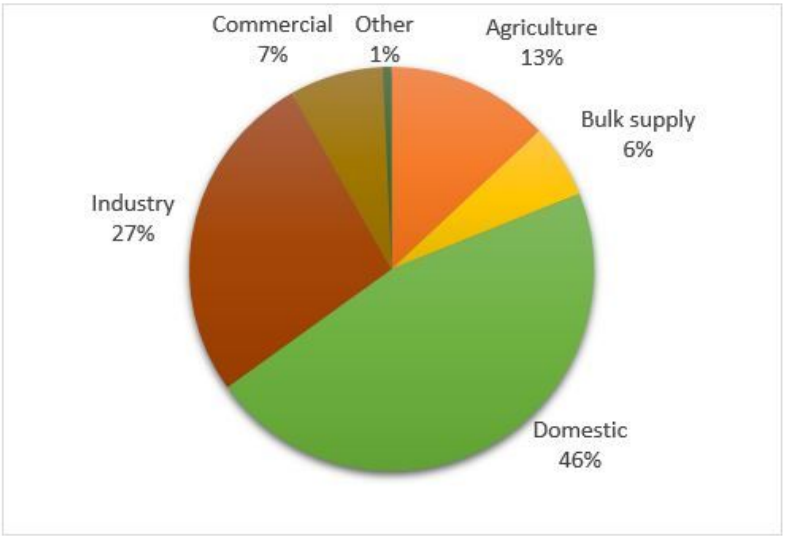

Figure 2

Energy consumption by different sectors

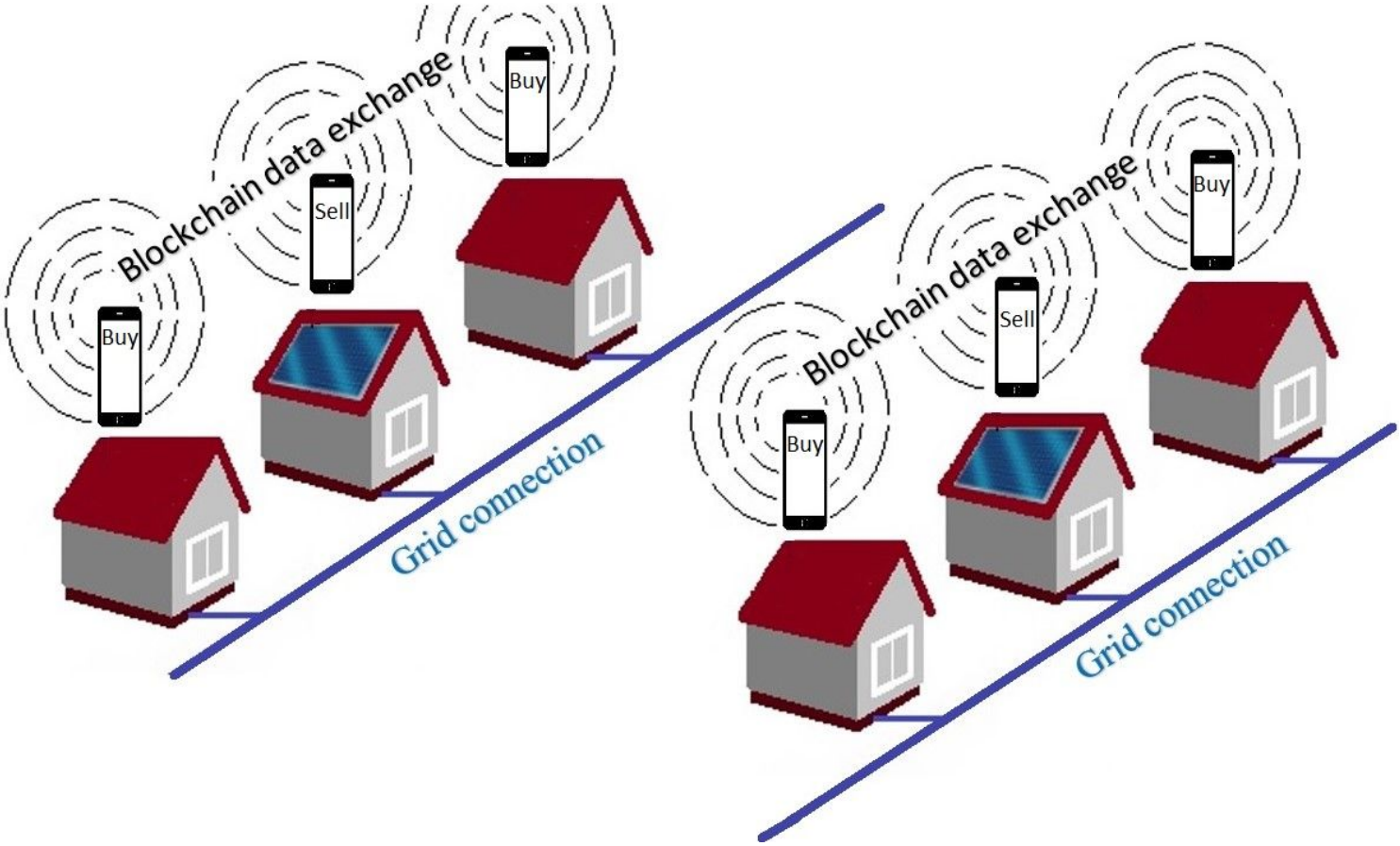

Figure 3

The formal structure for application of the blockchain technology.

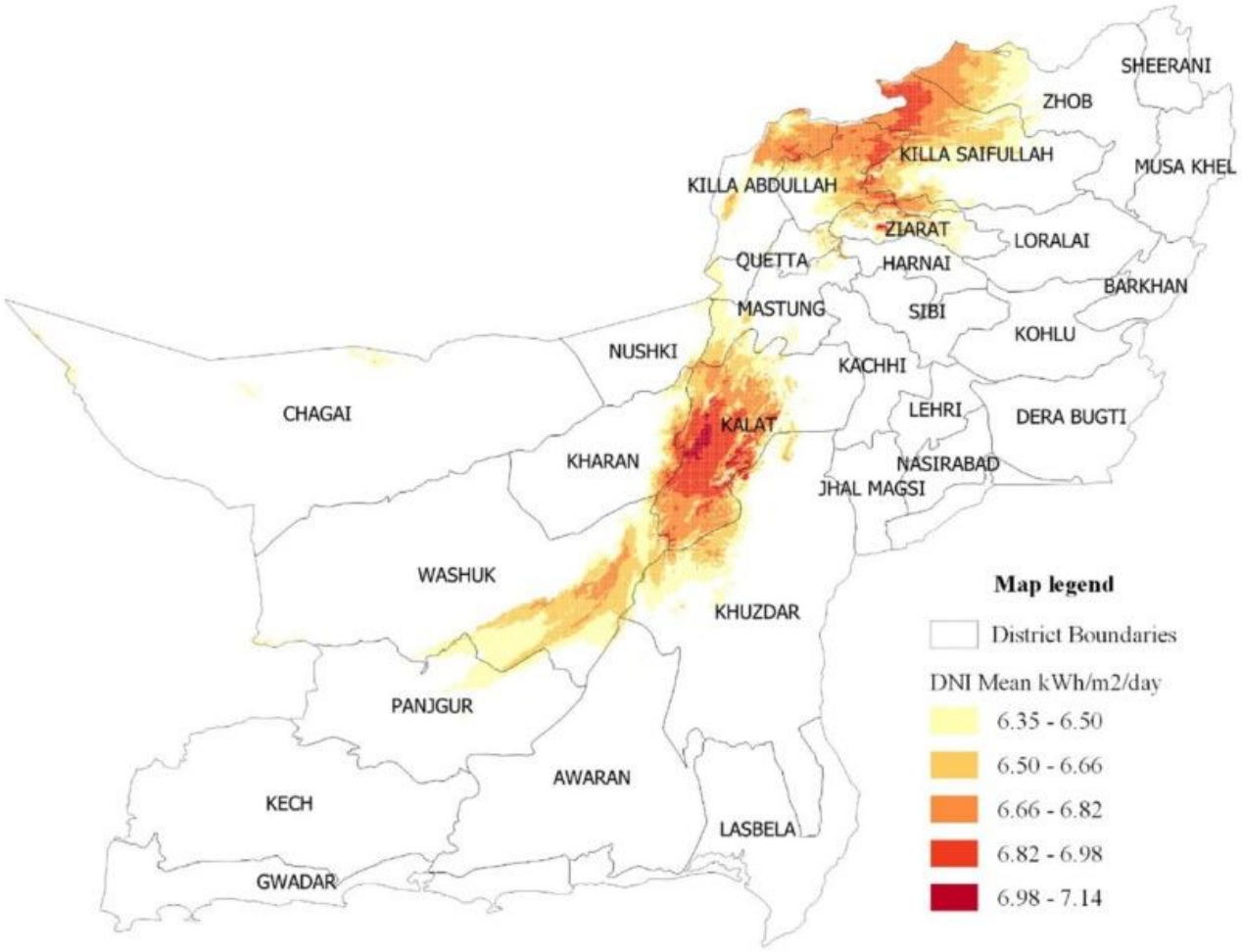

Figure 4

Solar energy potential in various district of Baluchistan. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

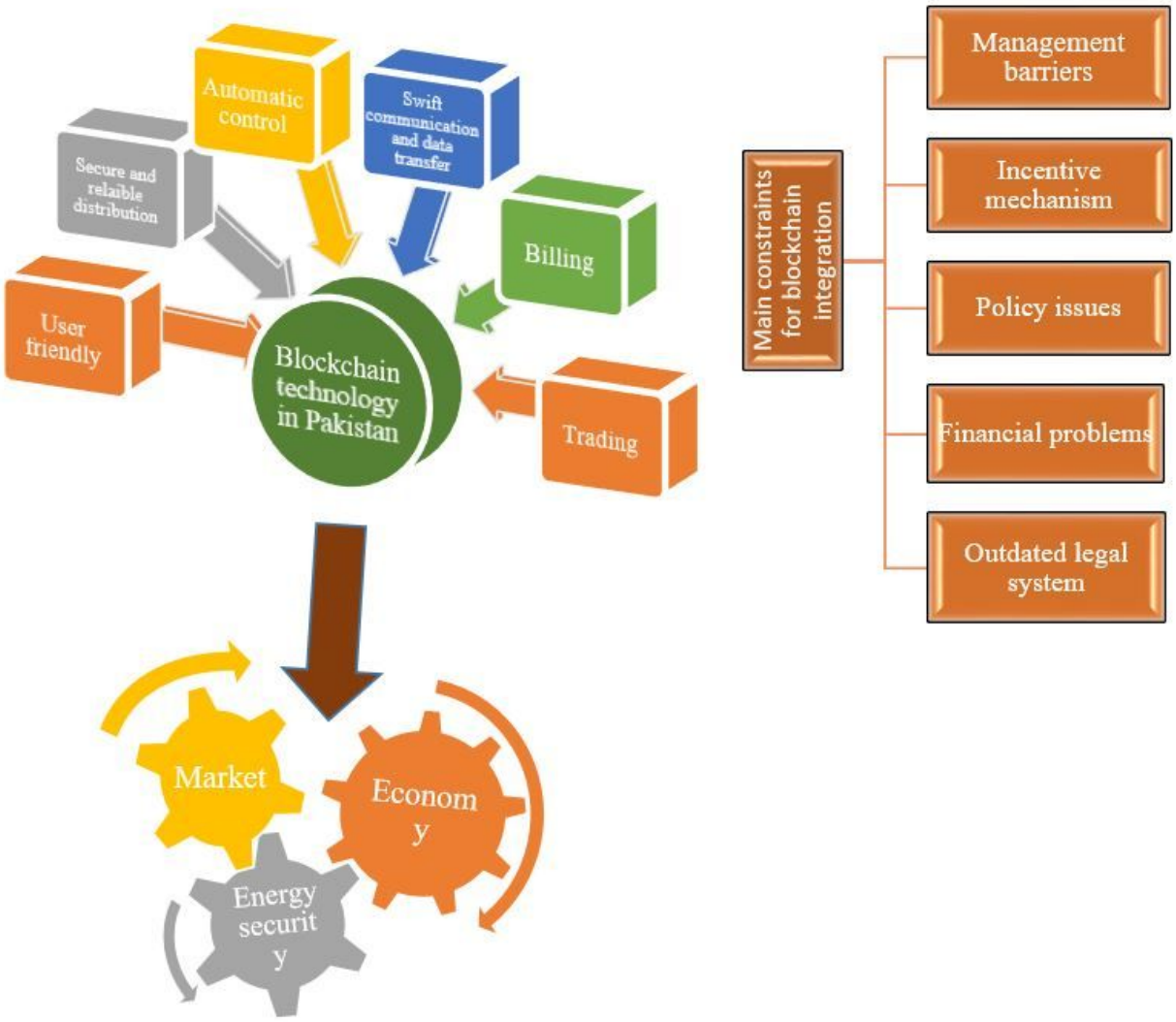

Figure 5

The practically driven aspects and constraints for blockchain technology execution in Pakistan.

Supplementary Files

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- GraphicalAbstract.jpg