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Facilitating the energy transition in Pakistan's power sector through blockchain-based applications

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Abstract

With the global clean energy transition in focus, one of the most crucial sectors within the energy industry that needs to transform is the power sector. In this paper, we focus on the role Pakistan's power sector can play in the country's clean energy transition. The scope of this paper is limited to the role of the residential power sector in Pakistan. First, we understand the current status of the power sector. Second, we understand the policies relevant to the power sector in Pakistan. Third, we focus on the residents of Pakistan and the challenges they face with respect to the structure of centralized top-to-bottom power sector, residential access to electricity, reliance on the centralized authority and unfair billing of consumed electricity. Consequently, it is established that while Pakistan needs to decarbonize its power sector, decentralization can accelerate the process. Since decentralized systems do not have a central authority to manage the system, and there is a lack of trust in the current centralized authorities, a mechanism is required for trusted, secure and tamper-proof transactions in the power sector. Blockchain, which is a digital ledger technology, can facilitate the establishment of trust in the power sector. Therefore, the role of blockchain in the power sector is studied and applications that are relevant to Pakistan are suggested. Finally, requirements to implement blockchain based applications are discussed, which includes facilitating blockchain-based startups in the power sector, empowering prosumers to take an active participatory role in the power sector, developing regulations and building capacity for innovative blockchain implementations.

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Chapter 1: Introduction

Pakistan, as part of the Paris Agreement, has committed to reduce twenty percent of its carbon emissions by 2030 (Butt et al., 2021). In addition, Pakistan's Alternative and Renewable Energy Policy of 2019 has set a goal to produce thirty percent of power through renewable energy means (GoP, 2019). On the directional policy level, the goals are in place for a steady clean energy transition. However on the ground level, the residential power sector, which has the largest consumption of electricity in Pakistan, faces several challenges. From the author's personal experiences and observations as a Pakistani, it was noted that there is a severe lack of trust in the centralized electric utility system. Along with that, since the author has an electrical engineering background, it was observed that blockchain technologies are at the forefront of developing trust through secure and tamper-proof ledgers which can complement or replace the centralized authorities. While blockchain is rapidly gaining popularity in the financial sector through the trade of crypto-currencies such as Bitcoin and Ethereum, there is a wide array of blockchain-based applications in the power sector (PwC, 2019a). The aim of this dissertation was to establish a link between the clean energy transition in the power sector of Pakistan, and the role that blockchain-based applications can play to facilitate the transition. Based on this aim, the research questions are as follows:

1. What are the opportunities within the power sector to accelerate energy transition in Pakistan?
2. What blockchain-based initiatives can bring innovation to Pakistan's power sector?
3. What is required to implement blockchain-based applications in the power sector in Pakistan?

To answer the questions, the background and context of Pakistan's power sector as well as blockchain and its applications in the global power sector required to be understood. For that purpose, the following questions were answered through the literature review:

4. What is the status of the power sector in Pakistan?
5. What are the key policies relevant to the power sector that Pakistan has produced in the past?
6. What is the role of blockchain in the power sector?

The second chapter covers the literature review and answers the fourth, fifth and sixth questions listed above. The third chapter elaborates on the research methodology for this dissertation. The fifth, sixth and seventh chapters analyse and discuss the first, second and third research questions listed above. The last chapter concludes the dissertation and offers recommendations for future research.

Chapter 2: Literature Review

What is the status of the power sector in Pakistan?

Currently, more than 40 million people in Pakistan do not have access to electricity which is around 20% of the total population as seen in Figure 1 (IEA, 2019). In addition to providing access to electricity, the demand for electricity has steadily increased because of continuing development and urbanisation across residential, commercial and industrial sectors. However, Pakistan's electricity sector has transitioned from a situation of power deficit to power surplus in 2019 because of increased electricity generation. In 2020, Pakistan generated around 38.5 GW of electricity from thermal, hydro, renewable and nuclear sources as shown in Figure 2 (Butt et al., 2021). Around 70% of the electricity is generated from thermal sources, which is the highest contributor of CO_2 emissions (IEA, 2019). In 2018, approximately 58M tonnes of CO_2 emissions were produced which can be seen in Figure 3 (Butt et al., 2021). Since the highest percentage of generated electricity is consumed by the residential sector (see Figure 4), it factors to the majority of the CO_2 emitted during power generation. (IEA, 2019)

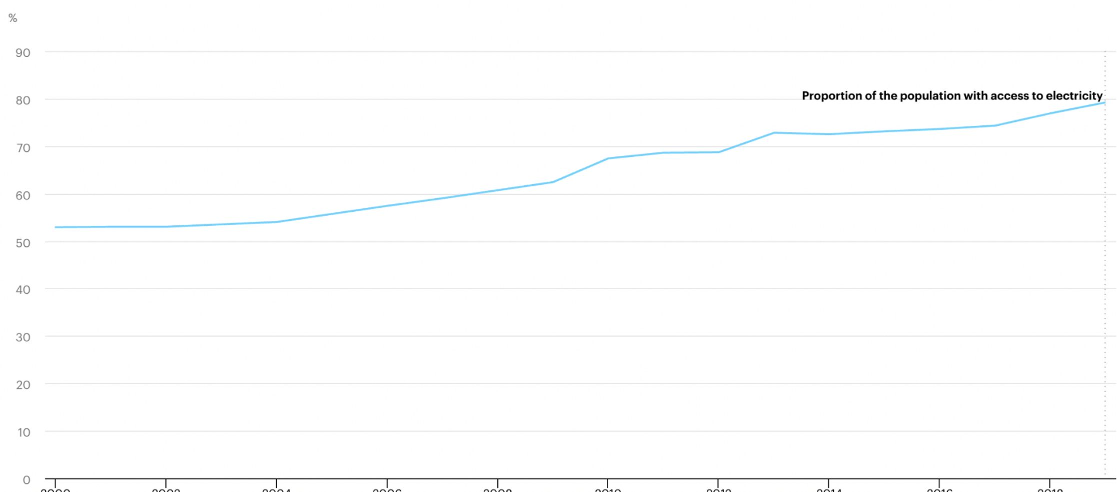

Figure 1: Proportion of population with access to electricity (SDG 7.1), Pakistan 2000-2019. (IEA, 2019)

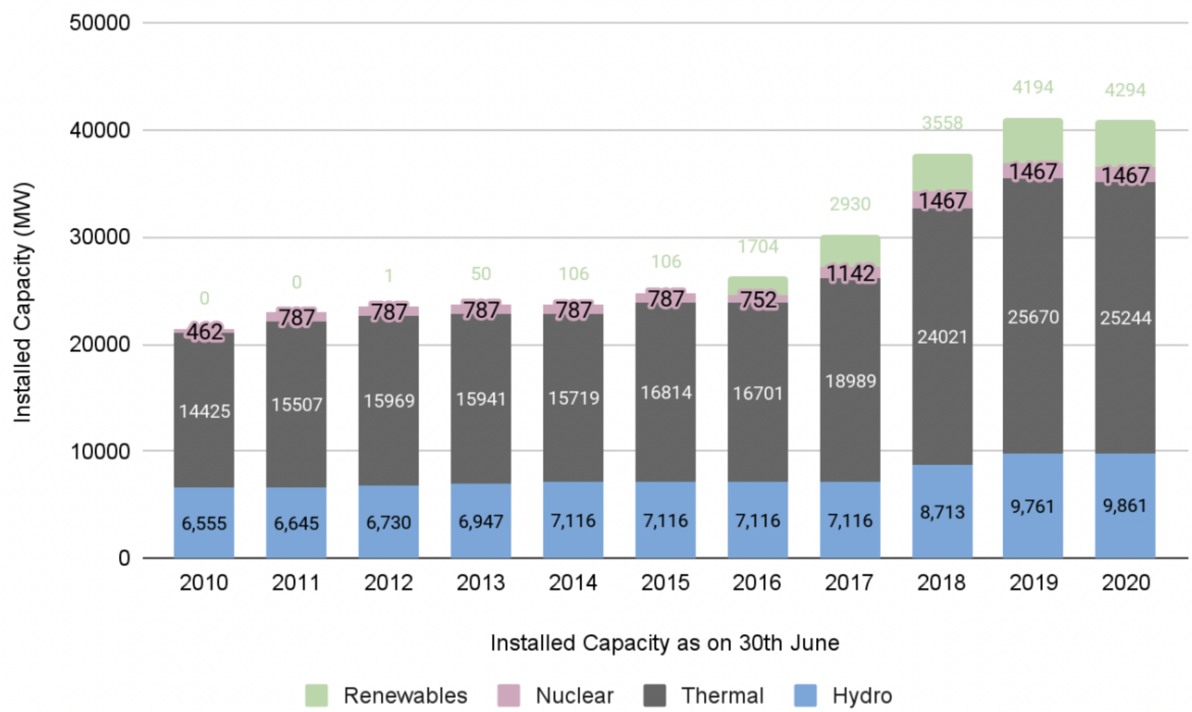

Figure 2: Installed capacity with breakdown by generation source, Pakistan 2010-2020. (Butt et al., 2021)

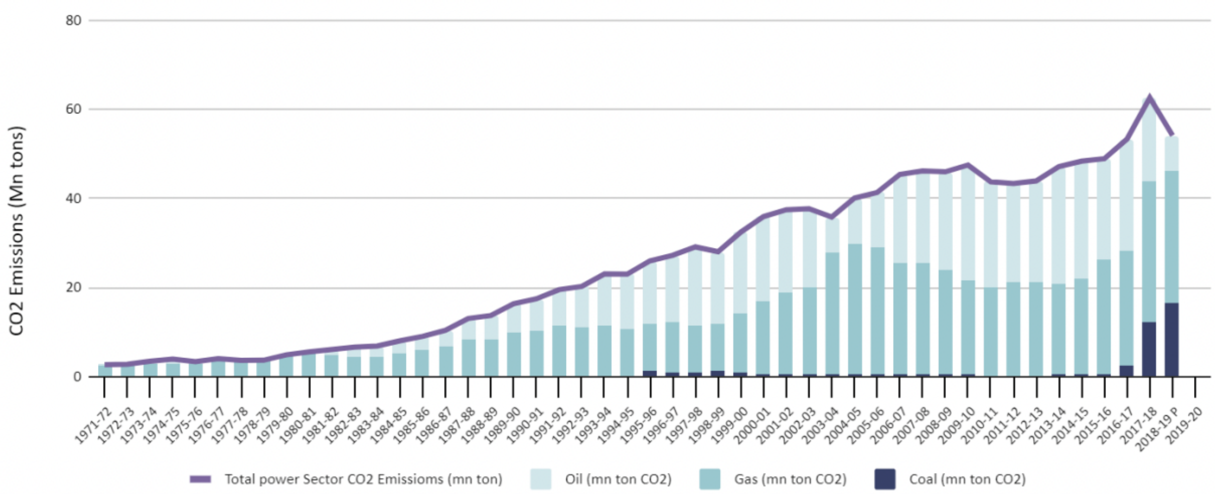

Figure 3: CO2 emissions of the power sector by source, Pakistan 1971-2019. (Butt et al., 2021)

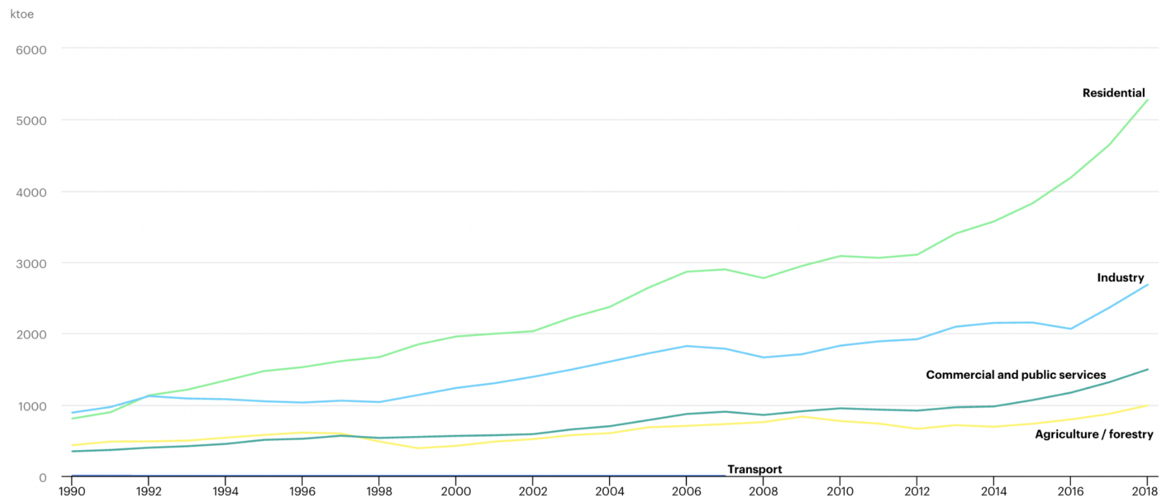

Figure 4: Electricity final consumption by sector, Pakistan 1990-2018. (IEA, 2019)

Even though Pakistan's contribution to the global greenhouse gas emissions is 0.8%, resulting in the country ranking 135th in the world for its emissions per capita. However, according to the Global Climate Risk Index 2014, Pakistan is ranked 3rd in the world. Therefore, it is exposed to severe risks induced as a result of climate change, including but not limited to floods, droughts, heat-waves, landsliding, and desertification (Butt et al., 2021). Between 1994 and 2013, Pakistan had an estimated economic loss of USD 3.99 billion each year due to catastrophes induced because of climate change. In addition to economic loss, millions of people were dislocated with their cities' infrastructure destroyed and agricultural produce damaged (GoP, 2016).

As a part of the Paris Agreement, Pakistan has developed the Nationally Determined Contribution (PAK-NDC) in 2016, which identifies the possible interventions required to embark upon pathways aiming to minimize the carbon footprint. The PAK-NDC has been submitted to the United Nations Framework Convention on Climate Change (UNFCCC) as a vision for 2025 (GoP, 2016).

For the scope of this dissertation, the focus will be limited to the interventions aimed at reducing the emissions in the power sector. Before understanding the interventions presented in the PAK-NDC that are planned to be implemented by 2025, the past policies that are relevant to the power sector are reviewed in the next section.

What are the key policies relevant to the power sector that Pakistan has produced in the past?

Power Policy 1994

The Power Policy of 1994 was Pakistan's first power policy focused on conserving power and increasing power generation capacity by 13,000MW. For this purpose, they introduced support for Independent Power Producers (IPP) to facilitate and incentivize the private sector in contributing towards the country's electric power capacity. It gave immunity to IPPs from income tax, custom duties and sales tax for imported power infrastructure and equipment. Along with that, it also fixed tariffs and provided foreign exchange insurance to protect the IPPs from monetary risks. However, most of the IPPs invested in thermal and nuclear power generation, which increased the ratio of thermal and nuclear power generation in the total power generation from 40% to 70% after the 1994 policy was implemented (GoP, 1994).

Hydropower Policy 1995

After the Power Policy of 1994, the ratio of hydropower generation decreased from 60% to 30% of the total power generation in Pakistan. Therefore, to incentivize indigenous hydropower resources towards power generation, the Hydropower Policy was launched in 1995. The policy extended exemption from taxes and custom duties, along with setting a fixed tariff for sale of electricity to the national grid (GoP, 1995).

Policy for New Private Independent Power Projects 1998

In 1998, a revised version of the Power Policy of 1994 was introduced. Independent Power Producers were allowes to bid on projects based on their offer of Energy Purchase Price or Capacity Purchase Price. Along with that, the National Electric Power Regulatory Authority (NEPRA) was launched to facilitate the regulatory requirements and their implementation in the power sector. Similar to the 1994 policy, the 1998 policy continued the same exemption from taxes and custom duties to promote the increase in generation capacity through local and foriegn financing (GoP, 1998).

Policy for Power Generation 2002

In 2002, Pakistan introduced the Policy for Power Generation which promoted public-private partnerships, along with private sector and public sector projects. The aim was to further increase the power generation capacity and incentivize foreign investment in the sector. The two options introduced were unsolicited proposal option for innovative projects, or bidding for conventional projects. The high level goal was to have an additional capacity of 20,000MW in the national grid by 2015 (GoP, 2002).

Policy for Development of Renewable Energy for Power Generation 2006

In 2006, Pakistan introduced the Policy for Development of Renewable Energy for Power Generation with the goal to introduce 10% renewable power projects (excluding large hydropower projects) in the power supply mix by 2015. Prior to this, the policies were focused on hydropower, thermal or nuclear power with no reference to other sources of renewable power. The Policy for Development of Renewable Energy for Power Generation encouraged renewable energy technologies, which included small hydropower plants as well as wind, solar and biofuel power plants. To incentivize the implementation of new technologies and attract investment, taxes and custom duties were exempted for participating Independent Power Producers (IPP). Multiple financing mechanisms based on dividends and equity were also allowed to encourage local and foreign investment. In addition, the policy also facilitatied the manufacturing of renewable energy technologies locally in order to reduce costs and generate jobs. Along with increasing the generation capacity, the policy aimed to increase energy access and security to off-grid communities in remote and rural areas. Therefore, this was the first policy to address decentralization of power, especially through renewable power technologies (GoP, 2006).

National Energy Policy 2010–2012

The interim energy policy was introduced on an ad-hoc basis as a reaction to the extreme loadshedding in the country. Focused on power conservation and increasing electricty generation, the policy included the use of Rental Power Plants (RPPs) and rehabilitated the existing public power plants with the contribution of Independent Power Producers (IPP) (BBC, 2010).

National Power Policy 2013

The National Power Policy of 2013 introduced several goals which included the increase in electricity generation capacity, promotion of conservation of power, emphasis on low-cost electricity generation from coal and renewables, minimization of loss during electricity generation, transmission and distribution and reduction of theft of electricity (GoP, 2013).

Power generation policy 2015

Pakistan announced the Power Generation Policy 2015 to offer incentives for foreign and local investors to address the increasing demand of electricity, along with utilizing local thermal and renewable energy resources for affordable electricity generation (GoP, 2015).

Nationally Determined Contributions (PAK-INDC) 2016

As part of the Paris Agreement 2015, Pakistan has committed to reduce the projected greenhouse gas emissions and contribute towards limiting the ride in global average temperature. For this purpose, the Nationally Determined Contributions (PAK-NDC) was submitted in 2016 to highlight the challenges faced by Pakistan, along with possible interventions to address climate change. The goal is to reduce twenty percent of the overall projected carbon emissions by 2030. However, the policy provides a high level strategy till the year 2025 (GoP, 2016).

Focusing on the power sector, the PAK-NDC has identified multiple mitigation strategies within the energy supply and demand sectors. On the supply side, the first option is to improve the efficiency of the national grid. The national grid facilitates the centralized, uni-directional flow of electricity. Transmission and distribution of electricity from the source of generation to the consumer contributes to significant losses, which can result in upto eighteen percent of the generated power going to waste. In addition to saving cost by reducing the electric power losses, this is also a good opportunity to mitigate greenhouse gas emissions (GoP, 2016).

The second option presented on the energy supply side is to invest in large scale, distributed grid connected solar, wind and hydroelectricity. As renewable power sources, the options are included after analysing their viability as low-carbon options and cost-effectiveness (GoP, 2016).

A few other options on the supply side include improvement in coal efficiency and carbon capturing. On the demand side, the mitigation options listed in the PAK-NDC include provision of efficient electric water pumps, lighting, stoves, water heaters, refrigerators and air conditioners (GoP, 2016).

Alternative and Renewable Energy Policy 2019

The Alternative and Renewable Energy (ARE) Policy provides a directional framework to integrate ARE into Pakistan's power projects in the energy industry. The policy envisions to accelerate the country's sustained transition to indigenous, clean energy consumption. In order to achieve that, the policy allows for the displacement of fossil fuels with ARE sources, as long as the average cost of the ARE is lower (GoP, 2019).

In addition to the high level directional strategy, the policy is scoped out for implementation of public, private and public-private partnership (PPP) projects. From the technological perspective, the policy considers renewable energy sources, which includes solar, wind, geothermal and biomass, and alternative energy sources, which includes biogas, tidal, and other hybrid systems. The policy also covers technologies which may be required for the implementation of ARE, such as energy storage systems (GoP, 2019). Since the policy states that any new technology which will be integrated in the energy system of Pakistan in the duration when the ARE Policy 2019 is applicable, implementation of innovative technologies, such as blockchain in the energy sector, will also adhere to the ARE Policy 2019. The term *'new technology'* according to the ARE Policy 2019 is defined as: *'technology using which not project is not in construction or operation in the country'* (GoP, 2019).

With the goal to enhance and accelerate the development of ARE power projects, the policy is structured to encourage private sector investment in the power sector. Within project development options, the policy provides the option of competitive bidding through tenders, government-to-government projects, and unsolicited projects. Unsolicited projects are specifically for technologies which have not been implemented in the energy sector previously. Unsolicited projects are only approved on a 'cost plus' method, and the Alternative Energy Development Board (AEDB) has to approve it after a feasibility study. In addition to the time required for the feasibility study, the AEDB estimates around 6 month for the approval of the unsolicited project (GoP, 2019).

One flexibility the policy offers is that each of the five provinces in Pakistan has the right to scope and develop their own generation, transmission and distribution projects. While it allows provinces to pilot projects on their own accord, it also raises the question of disparity between power systems between provinces. From the perspective of blockchain, the scope of the blockchain would be geographically limited to transactions within a province. This is beneficial for startups since the logistics will be dealt with on a smaller scale at the provincial level, rather than at the larger scale on the federal level. However, for projects expanding to multiple provinces, approval would have to be granted by the AEDB (GoP, 2019).

For private retail off-grid or distributed generation systems, approvals for tariffs have to be granted along with the license to operate by the National Electric Power Regulatory Authority (NEPRA). The policy demands anyone generating electricity to file for a generation license, A financial incentive provided by the ARE Policy is that projects are exempt from Corporate Income Tax and Customs Duty. In addition, local and foreign investment both are allowed to be raised to provide financing to the project (GoP, 2019). To apply for the license, the following is stated by the policy:

'If a Project is (a) producing electricity at one location but selling it to multiple non-domestic customers, or if (b) selling to domestic customers regardless of how many locations it is producing the electricity at, then such a Project shall be required to obtain a Generation License. In this case, the sale shall be more in the nature of a Distribution company (DISCO) operating a mini/micro grid. In this case, a No Objection Certificate shall be required from the DISCO in whose territory the sale is occurring, but the DISCO shall be bound to issue such NOC within 30 days of application by the Project if its grid is not being used by the proposed project. If such a project requires building private transmission/distribution line, the same shall be approved by NEPRA, and after completion of such line, the relevant DISCO shall be obligated to take over the Operations & Maintenance of the same upon payment of costs for the same by the sponsor, which consent shall be obtained from the DISCO prior to final approval.' (GoP, 2019).

This paragraph clearly ignores the possibility of a domestic customer generating electricity, and selling it to other domestic customers, i.e., prosumers. For households to go through the same process as small to medium enterprises to get the No Objection Certificate from the local Distribution Company (DISCO), which comes under Pakistan Electric Power Company (PEPCO), would cause hurdles for the adoption of a decentralized, peer-to-peer grid which is the ideal application to be supported by blockchain. However, a great regulatory requirement captured by the ARE policy is the environmental impact assessment report for any generation above 5MW (GoP, 2019). Although, the exact procedure to conduct the assessment is still unclear in the policy. Another regulatory requirement which would ensure fair pricing is that the tariff is controlled by the local DISCO (GoP, 2019).

Even though prosumers as a stakeholder have not been acknowledged by the ARE policy, instruments such as wheeling and net metering are a part of scope. Wheeling refers to the private power generation project utilizing the public transmission and distribution system. Net metering refers to the spill over of power produced through clean energy sources by the household back to the public power grid. Eventually, the consumption utility bill is adjusted by the power produced by the household (GoP, 2019).

An essential consideration by the policy is the recognition that carbon credits are a source of accessing carbon credit markets and climate change mitigation funds. However, the policy is limited to encouraging public and private organizations to access the international carbon market such that revenue from carbon credits flows into Pakistan (GoP, 2019). It does not consider carbon credit trading within the country, or other mechanisms to encourage carbon emissions reduction.

What is the role of blockchain in the power sector?

The traditional analog, centralized and fossil-fuel dominated energy sector is rapidly transitioning. Focusing on the power sector within the energy sector, there are three potential ways to accelerate the transition: digitalization, decentralization and decarbonization of the power sector (Peter, 2019; Rivial, 2019). While solutions such as smart meters on the consumer end produce large amounts of data which helps in digitizing operations and maintenance (Rivial, 2019), minimizes losses and modifies consumption patterns, acceleration of the energy transition within the power sector requires the sector to be managed through a modified, decentralized architecture (Peter, 2019) in countries like Pakistan, where the centralized infrastructure is inefficient. The decentralized nature of energy systems is mainly geared by exponential price reduction of distributed renewable power generation systems, such as off-grid solar PV systems (Rivial, 2019). To empower decentralized stakeholders to have a direct contribution to the production, trade and consumption of their power; the modified architecture needs to facilitate transparency between these stakeholders and security of transactions. Therefore, the stakeholders need to be assured that the decentralized system can be trusted (Paredes, 2019).

Blockchain, which is a distributed ledger technology (DLT), is currently emerging as a digital tool to facilitate the digital decentralization of the power sector through its transparent and secure data management system (Paredes, 2019). While blockchain is not a stand-alone solution, it can optimize several processes in the value chain of the power sector (Peter, 2019). These can range from trading of off-grid power, maintaining transparency in tariffs and transacting financial payments. The blockchain technology has the potential to enable trust in the decentralized structure of the power sector (Peter, 2019). In order to understand the role of blockchain in the power sector, it is important to understand blockchain and how it works.

What is blockchain?

Blockchain is a digital data management system which allows peer-to-peer transactions in an encrypted, transparent manner. In simple words, it is a tamper-proof file which stores data of all the transactions that have been conducted between a group of entities, and all the transactions can be viewed by each entity in the group. From a technical perspective, it is a combination of several technologies including digital databases, peer-to-peer networks and cryptography (Paredes, 2019; PwC, 2019a; Rivial, 2019).

How does it work?

When two entities agree to a transaction, the details about the transaction are stored on a 'block' of data. When multiple transactions take place, a block is created for each transaction. These blocks of data are encrypted for security, and distributed to each device in its respective blockchain system (PwC, 2019a).

Where is the data stored?

Once each device in the system receives the block of data, it stores the file locally after verifying the data's credibility. The verification is done using a unique algorithm for each blockchain system, after which a unique alpha-numeric code is attached to the block of data. The local verification and storage on each system makes the data decentralized and more secure than a centralized database. In traditional data management systems, the data is stored on a central server. Therefore, in case the data on the central server is manipulated, its security is breached. However, in a blockchain system, data on all of the devices will have to be tampered for the security of the system to be breached. Thus, this decentralized data management system of multiple blocks of data connected together makes the blockchain technology more secure in comparison to traditional data management systems (Peter, 2019).

What attributes of blockchain make it suitable for the power sector?

Blockchain has the potential to complement centralized bodies such as energy companies through grid transactions, and create trust between parties that wish to trade energy with each other through the grid (PwC, 2019a). Another potential application is peer-to-peer trading, which can potentially eliminate the central body and enable households to trade with each other. Blockchain makes the process of energy trading transparent and tamper-proof through communication, verification and storage of transaction records. Within the power sector, this is crucial for the data streams from smart meters, off-grid power generation systems, grid-based networks, electric billing utilities, etc. Understanding the structure of blockchain systems leads us to highlight its two novelties: transparency and security, through which trust can be developed among trading entities in the power sector (Peter, 2019; PwC, 2019a).

First, blockchain enables the data stored within it to be stored locally on each participating device, which makes it transparent to every stakeholder in the system (Peter, 2019). Therefore, if any transaction has to be tracked, verified or reviewed, it will be available to everyone in a transparent manner. It is important to note that this does not mean that stakeholder's privacy is not protected. Information can be encrypted to ensure privacy of data, such as personal information (Peter, 2019; PwC, 2019a).

Secondly, it provides security since the data can not be tampered in the decentralized system (Peter, 2019; PwC, 2019a). Transparency and security of the data allows individual entities to conduct peer-to-peer transactions in a blockchain network with other entities that they might not directly know. At the same time, it replaces central institutions such as power companies to provide more control to the decentralized entities over their own transactions. Therefore, the entities conducting transactions develop a trust in the system because of the benefits provided by the blockchain technology (Peter, 2019; Rivial, 2019).

Intermediary marketplaces and centralized systems tend to be cost intensive because of being infrastructure, labor and operation intensive. There is a need to research, develop and implement a decentralized system based on blockchain (Paredes, 2019). A decentralized system is a more effective approach to reduce electricity transmission costs, as well as associated power losses since it brings the production and consumption closer to the user, i.e. the prosumer. As the adoption of decentralized systems increases, their architecture in the power sector will require blockchain systems to be implemented (Burger et al., 2016; Rivial, 2019).

Chapter 3: Research Methodology

The dissertation is based on inductive, qualitative research methods. The scope of the work is intertwined in transdisciplinary themes which makes it complex and multi-faceted. The themes include: 1. challenges and opportunities in Pakistan's power sector; 2. applications of the blockchain technology; and 3. policies relevant to Pakistan and blockchain-based applications in the power sector. The goal is to examine these themes and how they link with each other, along with suggesting innovative blockchain-based applications for Pakistan's power sector and recommending policies and other requirements to implement the afore-mentioned applications. Qualitative research methods are best suited for robustly researching intertwined transdisciplinary challenges with a system, and developing recommendations which are suitable to the specified context (Eisenhardt et al., 2016; Patel and Mehta, 2017). Another reason for choosing qualitative research methods is due to the lack of quantitative data available about Pakistan's power sector and about global blockchain-based applications in the power sector.

Within qualitative research methods, thematic analysis was done to understand the nature of challenges faced by the residential power sector in Pakistan. For this purpose, news articles were analysed since they capture the voice of the larger population. This included digital archives of local newspapers: Dawn, Express Tribune, ARY News and Samaa TV. First, the archives were searched with keywords including:

1. Standard relevant terms such as electricity, power outage, load shedding and theft of electricity.
2. Localized terms such as 'kunda', which is the Urdu word for the tool used for theft of electricity
3. Utility companies: Karachi Electric/KE, Water and Power Development Authority/WAPDA, Pakistan Electric Power Company/PEPCO

Then, news shown as 'relevant news' in the suggestions was also analysed. A total of 50 news articles between the dates of 2017 to 2020 were vetted, coded and analysed to capture the recent challenges faced by residents that are associated with the power sector in Pakistan. The emerging themes are discussed in Chapter 4.

Based on the literature review for blockchain and its applications in Pakistan's power sector, the next step included thematic analysis to understand the blockchain based applications in the global startup industry. For this purpose, IRENA's Blockchain Innovation - Landscape Brief (2019) was used to compile a list of the blockchain-based startups in the power sector operating globally. While some of these startups were no longer operational, the startups that were operational were: CarbonX, Electrify.Asia, Enerchain, Energy Blockchain Labs, Greeneum, LO3 Energy, Power Ledger, SOLshare, Sunchain, Veridium. The content on their websites was coded and analysed to establish themes around their model, operations, requirements and impact. The themes are discussed in Chapter 5 and Chapter 6.

Finally, review of policies of blockchain strategies of Bangladesh, India and Nigeria, along with review of policy recommendation documents published by PricewaterhouseCoopers LLP (PwC) and Information Technology and Innovation Foundation was conducted. The choice of Bangladesh and India's strategic policies was based on their regional similarity with Pakistan. In addition, Pakistan's context is similar to Bangladesh and Nigeria's context because all three countries are in their nascent stages of implementation of blockchain-based applications. In Chapter 6, these policies shaped the recommendations provided for implementation of blockchain-based applications in Pakistan's power sector.

There were several limitations with the research methodology. First, certain data with respect to Pakistan's power sector was not available. For example, the data around off-grid decentralized power systems does not exist. In addition, there is limited literature on Pakistan's power sector policy. Second, blockchain technology is still paving its way through research and commercialization. The most popular use cases are in the financial sector. The applications in the power sector are mostly in their prototype stages. Therefore, there was a lack of data regarding successful or unsuccessful implementations of blockchain-based applications. Therefore, startups and their websites were considered to understand the implemented applications. While government based initiatives of blockchain technology exist in the power sector, these have not been reported or analysed widely.

Chapter 4: What are the opportunities within the power sector to accelerate energy transition in Pakistan?

Undoubtedly, there have been several advancements to produce electric power through renewable energy, however, decentralization of the electricity grid is a key enabler of the energy transition. The energy transition requires changes in the end-to-end value chain including but not limited to the generation, consumption and trade of power. Traditionally, consumers have had a passive role in the energy value chain, despite being the key stakeholder of the utility. The current power system is centrally managed, where power is generated in massive quantities at power plants. From there, it is centrally distributed to regions, and the households and commercial units with those regions. To accelerate the energy transition in the power sector, the available renewable energy sources have to be tapped into. With the advent of mini and micro solar and wind generation systems, it is possible to increase the pace of switching to renewables through a distributed generation system. Therefore, a shift is required to facilitate the centralized system with decentralized systems, where people have a direct contribution to producing, trading and then consuming power (Paredes, 2019).

Contribution of decentralized power systems towards the energy transition?

While Pakistan has a high potential of renewable energy sources, especially solar and wind power, de-carbonization of the power sector is only one route towards energy transition. In Pakistan, around twenty percent of the population is not connected to the national grid. To understand the potential of decentralized power systems, it is important to understand the impact on communities that are not connected to the grid as well as communities that are connected to the grid. The bifurcation of population based on energy access is necessary, since the communities have different challenges they face as a result of the extent of access they have to electricity.

Communities that are not connected to the grid

Remote, rural communities that are not connected to the grid still rely on burning kerosine, wood and other thermal fuels to produce electricity for daily use. As seen in Figure 5, most areas that are not connected to the national grid are in geographically ideal locations for micro-solar power systems.

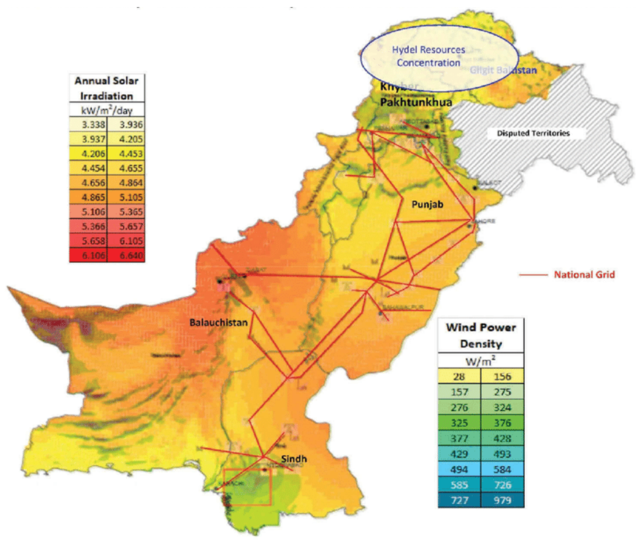

Figure 5: Map of the Pakistan national grid, along with hydel, solar and wind power generation resources. (Sheikh et al., 2019)

While Pakistan has a projection of producing thirty percent of the electricity from renewables by 2030, it is crucial to ensure that the off-grid communities are equitably a part of the country's transition to clean energy. Currently, even though Pakistan has surplus generation capacity on the national grid, twenty percent of the population does not have access to electricity. This is primarily because of the lack of transmission infrastructure, because of which communities that are not connected to the grid can not get access to the surplus power that is generated. While one solution is to extend the power transmission lines, it would not be economically feasible due to the scattered nature of remote settlements. Even if implemented, the transmission losses to the remote areas would be huge, eventually reducing the generated power as well as increasing the net carbon emissions. Therefore, a more appropriate solution will be to place decentralized off-grid solar power systems in remote locations.

With the Alternative and Renewable Energy Policy of 2019, Independent Power Producers (IPPs) should invest in mini and micro off-grid solar power systems for local communities, especially in Balochistan, which is the south-west region of Pakistan. The national grid is absent in more than ninety percent of the region, which mostly has scattered rural settlements. Investing in off-grid would also reduce the investment expenses towards large grid and transmission infrastructures, therefore allowing the national renewable energy targets to be achieved in an optimal manner. Therefore, renewable energy targets highlighted in the Alternative and Renewable Energy Policy of 2019 of Pakistan can be met more economically and more sustainably through decentralized systems.

With decentralized systems installed in rural, remote locations, local businesses would flourish as they procure, deploy and maintain the systems. While access to electricity directly leads to a better quality of life, increased employment opportunities in the decentralized power sector would also contribute towards prosperity. For solar power systems, average employment opportunities created per unit of power are the highest as compared to other power generation sources. Localised control of deployment of decentralized power systems would empower the communities and reduce the dependency on the national grid.

Communities that are connected to the grid

While decentralized systems have the potential to improve the energy access for around twenty percent of the population, it also has benefits on a national level. If Pakistan is able to achieve the renewable energy generation share of at least thirty percent by 2030, the average generation cost of the country would be significantly lowered since the cost of off-grid systems is cheaper for each unit of power produced, as compared to a large-scale power system. Additionally, the cost for off-grid battery storage systems is predicted to reduce by sixty seven percent in the next decade, and around eighty percent in the next three decades. As a result, it would cumulatively save approximately PKR 5 billion in the next twenty years because of the reduced need for large-scale generation and transmission infrastructure and decrease in transmission losses.

Another advantage of implementing decentralized systems in areas that are connected to the grid is the trading of decentralized power with the grid. The Alternative and Renewable Energy Policy of 2019 introduced the concept of net metering, which brings forward a number of significant opportunities to trade electric power. Net metering is a result of wheeling, which is when a decentralized grid can sell excess power to the grid and balance it off their electric utility bill. By trading generated power to the grid, the concept of prosumers is established. Prosumers are people who can produce as well as consume electric power. Prosumers are a central stakeholder of the decentralized system where grids are connected.

While these are opportunities for the future, at present, there are significant challenges being faced by consumers that are connected to the grid. The first challenge is that consumers have to face severe electricity outages, especially during high-demand hours. Often these outages are planned, however unplanned outages are also common due to failures in transmission infrastructure. This leads to an unreliable supply of electricity, which breaks the trust the consumer has towards the utility company.

The second challenge is around theft of electric power. Consumers who do not pay utility bills, or are disconnected from the local grid because of unstable housing, steal electricity from the distribution lines. As a result, either the neighbours have to pay for the stolen electricity, or else the utility company bears the loss. If the consumers have to pay for stolen electricity, the excessive bill is beyond their expected utility bill budget and often, they would refuse to pay for the stolen electricity that they have not consumed. Unfair billing hampers the trust that consumers have in the centralized utility company, since they are being asked to pay more than the electricity consumed.

The third challenge, driven by excessive, unfair billing is that consumers refuse to pay. Unpaid bills pile up with minimal accountability since there is no hassle-proof way to cut off the access to electricity unless the consumer does not pay the electric bill.

The fourth challenge is unfair increase in tariffs. When the utility companies face major losses because of theft and unpaid bills, it leads to exorbitantly increasing the prices to recover the losses. This enrages the consumers who are already struggling to pay the bills, and therefore further reduces the trust in the centralized utility companies.

Each of the challenges associated with the centralized power system hampers the trust that the consumer has on the reliability of electric supply and the payment structure, eventually seeking complete or partial relief from the centralized power system. Decentralized power systems, either as a replacement or as a complementary asset to the consumer’s household is an optimal solution.

However, some consumers might need additional power supply, while others might be generating excess power on their decentralized systems. This induces the need for energy trading. However, the need is to provide energy trading in a way such that:

1. People can trust the other person or entity they are trading with;
2. People can trust that they are make financial payments with the determined price;
3. People can trust that they will have a reliable supply of electricity.

As discussed in the literature review, blockchain-based initiatives in the power sector can induce trust because of their transparent, tamper-proof ledger technology.

Chapter 5: What blockchain-based initiatives can bring innovation to Pakistan's power sector?

Trading of electricity: peer-to-peer (P2P) trading and grid-based trading

One of the applications of blockchain in the power sector is direct trading of electricity between stakeholders that produce and/or consume electricity (Lei et al., 2021). There are two scenarios within trading of electricity. The first scenario is when residents can transact electricity directly, which is called peer-to-peer (P2P) trading. This can be implemented for communities that are connected to the central grid, as well as those that are not connected to the central grid. The second scenario is when residents can sell the excess electricity that they have produced to the grid, which is grid trading. This can only be implemented for communities that are connected to the central grid. In both the scenarios, there is an active role of prosumers, i.e. people who consume electricity as well as generate it. It is important to note that the trade is of electricity, i.e. units of power. This trend of direct selling of excess supply is called the 'sharing economy' (Diestelmeier, 2019). However, doing peer-to-peer transactions in return for financial remuneration has the establishment of trust as a prerequisite. The financial payment made in lieu of the electricity sold can be done by integrating it with digital payment systems, which can be in fiat currency or crypto-currency or both. People usually buy and sell with their trusted, known networks. To enable them to transact with unknown people, a secure, tamperproof blockchain system is required as a platform to make these transactions (Diestelmeier, 2019).

Peer-to-peer (P2P) trading allows prosumers to avoid the need of a central utility company. The current power sector in Pakistan is predominantly centralized in the areas which are connected to the grid. For example, Karachi Electric (KE) is the central utility company for Karachi, a metropolitan city with a population of approximately 15 million people. Peer-to-peer networks have several advantages whether they are implemented as complementary systems to the central grid, or as stand-alone systems. In cities such as Karachi where there is a dominating reliance on the central grid, peer-to-peer networks can complement it to make the power systems more efficient and trust-worthy. In remote areas, such as villages within the Balochistan province, peer-to-peer networks can have benefits as stand-alone systems.

For communities that are connected to the grid, the role of residents in the centralized power sector in Pakistan is limited to buying electricity from the central utility. If peer-to-peer trading is practiced, consumers can diversify their participation in the power sector by becoming a prosumer. As a prosumer, residents can generate electricity, and then either consume it themselves or supply it to other residents in the peer-to-peer network (Diestelmeier, 2019). One of the ways that prosumers can produce electricity is through distributed renewable technologies, such as roof-top solar panels. A simple example of a peer-to-peer trading transaction is selling of solar electricity between neighbors who have a rooftop solar power system installed. On a more advanced level, peer-to-peer power trading can be among multiple residents within a local community as well.

In a peer-to-peer network, it is necessary that the people can trust the network they are trading with. Ideally, in a peer-to-peer network, the central authority does not moderate the transactions or hold the participating residents accountable. As a result, central authority will not have control over provision of electricity, issuance of utility bills, or collection of payments. The independence from a central authority will result in avoiding manipulations that can lead to unfair billing or excessive increase in tariffs. However, it places the responsibility on the peer-to-peer network to establish trust within the network. Blockchain-based systems address this requirement. With blockchain-based peer-to-peer networks, prosumers can trade electricity while ensuring that the transactions are secure, tamper-proof and transparent (Atlam and Wills, 2019).

There are three ways Pakistan's power sector will benefit from peer-to-peer networks. First, trading of electricity through peer-to-peer networks can address the concern of lack of trust, such as unfair billing. In Pakistan, as discussed above, there is a lack of trust in the central utility companies. If a resident has used 250 units of electricity, they should be charged for 250 units at the tariff that was set. However, since the utility bills are sent at the end of the month and resident's do not have visibility of their electricity usage throughout the month, the utility company manipulates the bill to either increase the number of units of electricity used, or the tariff at which it is charged. Blockchain-based peer-to-peer networks prevent manipulation from the central utility company because once a transaction is done, the quantity of electricity and the tariff is recorded in the ledger in real-time. Once it is recorded, it is not possible to tamper the record (Atlam and Wills, 2019). The advantage that a blockchain system provides is that direct trading of power units can take place without an intermediary body. While trading is between anonymous entities, the system can be trusted because of blockchain's secure, tamper-proof structure (Peter, 2019).

Second, in Pakistan, there is a lack of reliability in the supply of electricity from the grid. There are two reasons for this: fluctuation in electricity demand and transmission line failures. With decentralized peer-to-peer networks set up for electricity trading, the electricity generated by the prosumers can contribute to the electricity supply. Therefore, if there is a high demand of electricity, the prosumers with excess electricity generated can trade with other prosumers who need it. In addition, if there is a failure in the transmission lines from the main grid to the area of the local community, the prosumers in the peer-to-peer network can generate and trade excess electricity with the local community. As a result, the residents will have alternate solutions in scenarios where access to electricity is interrupted from the grid.

Third, areas that are not connected to the main grid do not have quality access to electricity. Peer-to-peer networks for trading of electricity can set up decentralized grids within the local communities. For example, in a remote village, residents can set up roof-top solar panels. If households are generating electricity in excess, they can sell it to other households who need it. If the grid is connected to local shops and businesses, they can also buy or sell electricity from households. In addition, it can also generate income for the prosumers selling electricity. An advantage of setting up decentralized peer-to-peer networks in remote communities is that it saves the transmission cost. With a local grid, residents have reliable access to electricity as well as the cost per unit will be cheaper since there will be no transmission costs.

For communities completely off the grid, peer-to-peer transactions can allow prosumers to set up a closed grid for their community. This could be done on a private blockchain-based ledger, which can be permissioned only for the participants of the community. The Bangladeshi startup SOLshare enables off-grid prosumers to trade solar power through this technology. So far, SOLshare has transacted 48,000PV of solar power, across 34 grids in India and Bangladesh and therefore impact 2570 lives. They managed to save 1756L of diesel and 4970kg $CO2$ every year. As a startup, they have also raised an investment of $1.46 million to enable them to scale further (SOLshare, 2021).

For trading electricity through blockchain-based networks, there are several software and hardware instruments required, along with regulatory policies. Data sources, such as smart meters, have to be installed to implement the hardware structure for trading power. Along with hardware integrity, the blockchain algorithms ensure that the data of transactions is validated and securely stored. In addition to hardware requirements, smart contracts have to be monitored for delivery of the power that is sold (Peter, 2019).

Logistically, a transaction of power units in a blockchain-based peer-to-peer network is done through smart contracts. Smart contracts are electronic contracts that are automatically executed if the set conditions are fulfilled (Swan, 2015). Conditions are set according to the agreements between the existing stakeholders in the network. The conditions cover legal or regulatory requirements, as well the tariff rate. There are three significant benefits of smart contracts. First, they remove the need for a central authority to enforce a contract and as a result, the self-enforceable contracts reduce the operational costs associated with transactions. Second, they are tamper-proof and therefore, can be trusted by the transacting participants (Walport, 2016). Third, the smart contracts are dynamically programmable. This means that conditions can be programmed based on real-time data. For example, if excess power units are available or if the price of power per unit falls below a certain threshold, a household can automatically request power (Peter, 2019). Smart contracts can integrate with other hardware systems and prosumers can conduct certain actions at certain times (Diestelmeier, 2019; Peter, 2019). For example, when the demand is low, and hence the electricity tariff is low, the smart contract can be programmed to automatically run the water pump.

Currently, the policies in the power sector are structured around the centralized, vertically managed infrastructure. However, with the integration of prosumers in the power sector, the policies will have to be revised to regulate the involvement of prosumers (Diestelmeier, 2019).

Similar to every technology that has not been matured, there are technological challenges with respect to the implementation of peer-to-peer transactions. The first challenge is related to the hardware implementation. If the user does not have a smart meter, the generated and consumed units can not be tracked and as a result, excess power can not be calculated (Livingston et al., 2018). The second challenge is that even though the blockchain network is tamperproof, theft through local transmission wires is still a possibility. Thirdly, the physical flow of electricity remains in a single direction. Therefore, even if a single prosumer is trading electricity with another prosumer, there is a mini-grid set up between them to enable the trade. Nonetheless, this can still prove to be beneficial since prosumers can buy and sell electricity from other prosumers who are connected to the mini-grid (Livingston et al., 2018).

Acknowledging the challenges associated with trading of electricity in a peer-to-peer network, let's understand the second scenario. This is based on trading of electricity with the grid, i.e., grid-based trading. Grid-based trading allows the prosumers to sell decentralized electric power that they have generated to the centralized grid. As a result, through net-metering, the utility bill from the centralized power system is adjusted to reflect the net units of power consumed. The benefit of grid-based trading is that it would increase the share of power generated from renewables. At the same time, since prosumers would be generating electricity in a distributed manner, such as roof-top solar panels, it would reduce the dependency on the centralized grid. In case of power outages from the centralized grid, the residents would have access to the electricity generated in their households.

Grid-based trading of electricity requires integration of households with the centralized grid, which means the central electric utility company will be involved. In Pakistan, as discussed before, there is a lack of trust on the central utility company because they have the ability to manipulate the quantity of power units used, or the tariff according to which the residents are billed. To ensure a tamper-proof, trusted platform that can support grid-based trading between prosumers and the centralized grid, a blockchain-based platform is recommended for secure transactions. This would mean that transactions are carried out through smart contracts where the quantity of the electricity traded and the tariff is recorded, which can not be amended once the transaction is done.

There are several requirements for implementation of grid-based transactions with a blockchain system. The first requirement is that there should be a policy which allows prosumers to make transactions with the centralized grid. The second requirement is that there should be dynamic, attractive tariffs to encourage households to generate excess renewable energy that can be fed into the grid. If there is excess electricity but the demand is low, the tariff should be lower as compared to the tariff when the generated electricity is limited but the demand is higher. The local Distribution Operators are responsible for setting the tariffs according to the Alternative and Renewable Energy Policy 2019, therefore they would be responsible for setting dynamic tariffs that can incentivize grid-based trading of electricity. The third requirement is that the regulations around settlement or complaints should be devised to ensure that there is a fallback mechanism in case of error. The fourth requirement is to devise data protection policies to protect the identity of the prosumers. This is because data related to electricity generation and usage trends of the prosumers might be collected to understand the availability of electricity in the centralized grid.

Trading of carbon credits and renewable energy certificates

With Pakistan’s commitment in the Nationally Determined Contribution (NDC) to reduce carbon emissions by twenty percent by 2030, it is important that the carbon emissions are tracked. Similarly, Pakistan has a goal to have thirty percent of the generated power from renewable sources. As recommended above, decentralization is a huge opportunity in the power sector to accelerate the energy transition. As decentralization of power generation increases, the load is reduced on the centralized grid and energy access to is increased in remote communities, tracking of carbon emissions and renewable power generation becomes difficult. The centralized authorities can no longer track the decentralized power generation sources or the carbon emissions released (Livingston et al., 2018).

In this scenario, blockchain technology connected with smart meters can be applied towards tracking of power generation, electricity usage and carbon emissions. As a result, the blockchain network of traders can trade carbon credits and renewable energy certificates, both of which are market mechanisms to promote the reduction of carbon emissions (Bao et al., 2020; Bürer et al., 2019). Companies that are unable to meet their required regulatory standards for carbon emissions or renewable energy production can buy carbon credits or renewable energy certificates from other participants that have generated power from renewable energy sources beyond their required regulatory standards for carbon emissions (Bao et al., 2020).

Powerledger, a blockchain-based startup in the power sector in Australia allows for the tracking of electricity units used, along with the carbon emissions based on the source of electricity. When a participant of the Powerledger network, which can be a community or an organization or a resident, generates renewable electricity, they are issued a renewable energy certificate. If another participant of the same network wants to buy the renewable energy certificate, they can use the blockchain network for the transaction. The transaction is made according to the agreement in the smart contract, and is tamper-proof once it is recorded in Poweledger's blockchain system. Similarly, carbon credits are units of carbon emission that a participant is allowed to release in a particular time period. If a participant has excessive carbon credits, they can sell their unused carbon credits on Powerledger's blockchain network to another participant who requires it. This transaction is also done through smart contracts (Powerledger, 2021).

If a company has emitted carbon emissions beyond their approved threshold, they will have to compensate by buying carbon emission credits from other participants. In parallel, participants who generate renewable power, for e.g. prosumers can generate electricity from roof-top solar panels, can issue renewable energy certificates based on forecasted estimates of generated power (Albrecht et al., 2018; Bürer et al., 2019). In some cases, the renewable energy certificates are also awarded on the basis of actual power generation rather than the forecasted estimates (IRENA, 2019). These credits and certificates can be traded for financial compensation. Since these transactions are decentralized and can not be individually tracked by a central authority, participants can be ensured of the security and transparency of the trading process through blockchain. This would include the authorization of authentic carbon credits and renewable energy certificates, as well as the reliability of receiving the financial payment in return (Albrecht et al., 2018; Bao et al., 2020). The digital record of renewable power generation in decentralized systems can be useful for national or regional governments to monitor renewable power generation and track carbon production (Paredes, 2019).

The advantage that Renewable Energy Certificates provide towards the energy transition is that they can incentivize production of renewable energy. This is because the certificates are unique, and can be traded and priced in a dynamic manner to reflect the demand in the market. Once the demand is higher, incentivizing renewable energy would lead to a reduction in the carbon emissions produced in the power generation sector (Albrecht et al., 2018; Paredes, 2019). A direct benefit to the prosumers who are able to produce renewable energy in excess is the income from selling carbon credits or renewable energy certificates.

While Pakistan’s Alternative and Renewable Energy Policy of 2019 has recognized that carbon credits are a source for accessing carbon credit markets internationally, there has been no policy regarding trade of carbon credit or renewable energy certificates within the country’s residents, communities or organizations. Additionally, there is no mechanism in place for transactions for carbon credits or renewable energy certificates. Therefore, the first requirement is to have a directional policy to encourage trading of carbon credit or renewable energy certificates to incentivize reduction of carbon emissions. The second requirement is to facilitate the implementation of required hardware and software instruments to track, record and transact carbon credits and renewable energy certificates. This will include smart meters, blockchain-based platforms for transactions and national registries to track carbon credits and renewable energy certificates.

Chapter 6: What is required to implement blockchain-based applications in the power sector in Pakistan?

Facilitating startups to lead the implementation of blockchain-based applications in the power sector

Blockchain can be applied through several organizational models, including government based initiatives, startups, private corporations, etc. However, startups have an appetite for the implementation of innovative technologies (Livingston et al., 2018). According to Livingston (2018), startups based on blockchain in the power sector have raised over $300 million between 2017 and 2018. Within Pakistan, the startup industry is booming. In just the first half of 2021, startups in Pakistan have raised $101 million as compared to a total of $66 million in 2020. Most of these are technology based startups which are bringing innovations such as artificial intelligence based applications and digital banking applications to Pakistan (Mangi and Kay, 2021).

With a risk-appetite for innovative technologies and various examples of blockchain based startups in the power sector around the world, startups are a viable model to implement blockchain-based applications in the power sector of Pakistan. However, to encourage and facilitate the prospective entrepreneurs to form blockchain-based startups in the power sector, it is important that policies are developed to incentivize these startups.

The first recommendation is to provide startup incubation programs or innovation bootcamps specifically targeted towards blockchain based innovations in the power sector. This will provide a network to aspiring entrepreneurs to connect with subject matter experts, entrepreneurs in the same domain, and other startups in the power industry. For example, to implement peer-to-peer trading of electricity, entrepreneurs can pair with existing startups or enterprises that provide off-grid renewable energy technologies, such as roof-top solar panels.

The second recommendation is to provide seed funding to entrepreneurs who have blockchain based ideas, which reflect the potential to proceed to the pilot phase. Once the startup is in the pilot phase, regulatory bodies should work with the startup in a controlled environment, also called a 'sandbox', to ensure that the regulatory frameworks are devised to facilitate blockchain-based applications. Sandboxes are a part of several blockchain policy frameworks, including Nigeria, India and Bangladesh (GoB, 2020; GoI, 2021; GoN, 2021).

The third recommendation is to incentivize startups to bid for government power-related projects. For example, this could include setting up a national renewable energy certificates registry to track the power generation from renewable energy sources in Pakistan. At present, the Alternative and Renewable Energy Policy of 2019 has set up a process for unsolicited projects for innovative technologies which have not been implemented in Pakistan. However, according to the process elaborated in the policy, the approval can take up to six months (GoP, 2019). The policy should revise the process to make it simplified, as well as incentivize startups with tax-breaks and seed funding to increase adoption of blockchain as a technology in the power sector.

In addition to initiating the implementation of innovative technologies in the power sector, another advantage of incentivizing startups is that it leads to creation of jobs. Along with incentivizing startups, it is also important to ensure that the residents of Pakistan are ready to adopt technology-based applications such as trading of electricity, carbon credits and/or renewable energy certificates.

Empowering prosumers to take an active participatory role in the power sector

If prosumers take an active participatory role in the blockchain-based decentralized power sector, the policies in the power sector also need to be revised to define the role of participants in the decentralized power sector, incentivize and regulate the integration of the prosumers to protect their transactions and identity, and tackle market competition to avoid unfair electricity tariffs. The aim is to liberalize the centralized power sector to give prosumers a greater role to allow generation and distribution of electricity in a distributed manner (Diestelmeier, 2019).

As consumers are incentivized to produce and supply power, they will have to be given financial incentives to encourage them to be active participants of the market. Currently, there is an influx of off-grid decentralized solar panels being used by consumers in their households in Pakistan (Butt et al., 2021). The actual data of the number of off-grid electricity sources in Pakistan is not recorded at present. However, to engage the consumers in installing additional solar panels to produce renewable power in excess, and then sell to other participants requires a seamless infrastructure that can allow efficient metering, integration of smart distribution grids, and instant financial transactions after sale (Diestelmeier, L., 2019; PwC, 2019a).

Smart meters installed on the prosumer's end are a crucial hardware requirement for blockchain systems to be successful. Smart meters are electricity meters that empower prosumers by providing transparency of electricity use, as well as analyse trends of electricity generation and demand requirements. Coupled with smart contracts based on blockchain, peer-to-peer or grid transactions can be carried out automatically based on optimum tariffs and electricity demand (Diestelmeier, L., 2019; PwC, 2019a).

Currently, the power tariffs have a flat-rate in Pakistan based on the location and area of the resident's house. However, smart grids are systems which allow real-time reflection of electricity generation, excess power capacity on the grid, and demand in the community. This could provide financial incentives to prosumers for expanding their decentralized power generation units, and encourage them to do peer-to-peer transactions to trade power in the blockchain network (Diestelmeier, L., 2019). Currently. Pakistan's regulations allow the consumers to feed back to the central grid if they are producing excess power through off-grid solar panels in return for reduction in utility bills or monetary compensation (Mustafa, 2017), however the rate is not dynamic and the flow is not bi-directional directly between consumers. Along with that, since the network is not tamper-proof, the quantity and rate of electricity sold to the grid is often manipulated because of the central authorities.

Addressing direct power consumption of blockchain-based systems

Blockchain, as a technologically intensive system, uses multiple devices which consume electricity. This includes computing systems such as central processing units (CPUs) and graphics processing units (GPUs), storage systems such as hard disk drives or solid-state drives, cooling systems, power supplies and connectivity networks such as internet modems and routers. While its applications in the power sector can significantly reduce costs and optimize electricity usage, blockchain has a significant potential to use excessive electricity (Lei et al., 2021). However, there are three ways to address this challenge by implementing blockchain solutions such that their direct power usage is kept to a minimum level.

First, it is important to accurately analyse the direct electricity use by blockchain systems. This includes integrating the system with power measurement devices, which can adapt to the locational variances of the system. For example, cooling systems in a warmer climate will use more electricity than cooling systems in a colder climate. Integration of power measurement devices in each component of the system will allow accurate measurement of the electricity consumed (Lei et al., 2021).

Second, private blockchain systems have comparable power use to existing centralized systems. Therefore, it is more energy efficient to deploy a private blockchain rather than a public blockchain. In public blockchains, anyone on the internet can become a participating body as well as authorize transactions. In private blockchains, the participating and validating bodies are restricted (Froystad and Holm, 2016; Lei et al., 2021). In the context of Pakistan, private blockchains can be implemented within communities such that the participants are selected if they are a part of that community. However, to avoid the dependency on certain selected bodies for authorization, it is better if all the selected participants of a private blockchain have the ability to authorize transactions as validating bodies. Therefore, since this is a combination of public and private architecture of blockchains, it is called a consortium blockchain network architecture (Froystad and Holm, 2016; Lei et al., 2021).

Third, the power consumed by the blockchain depends primarily on the algorithms it uses (Ferdous et al., 2020; Wang et al., 2019). As blockchain technology advances, there are several variations of authorization of transactions in a blockchain system. To authorize a transaction, blockchain systems require consensus from the participants of the network. This consensus is achieved through an algorithm. If unanimous consensus is not achieved, the transaction is rejected. If the consensus is achieved, the transaction is stored in the record (Miglani et al., 2020). There are several ways of authorization which differ on the basis of their scalability, reliability and power consumption (Hartnett, 2018).

Three of the popular mechanisms are proof-of-work, proof-of-stake and proof-of-authority.
The proof-of-work algorithm requires the validating bodies to solve a computationally intensive exercise. In return, it gives the first validating body a monetary or in-kind reward. In the power sector applications, this could be a financial reward, units of electricity, or carbon credits. This algorithm is ranked as the highest in terms of its use of power, which is why it is the most in-efficient (Tar, 2018). Consequently, it is recommended to not use proof-of-work in the power sector (Lei et al., 2021).

The proof-of-stake algorithm uses significantly less power than the proof-of-work algorithm. The cryptocurrency ethereum, which is a financial application of the blockchain system claims a 99% reduction in its power consumption as it plans to switch from the proof-of-work mechanism to the proof-of-stake mechanism. (Fairley, 2019). Proof-of-stake relies on the validating body depositing a certain monetary or in-kind stake. Similar to the reward in the proof-of-work algorithm, this could be a financial reward, units of electricity, or carbon credits in a power sector application. If an incorrect transaction is authorized, the validating body will lose the stake. Since this is not computationally intensive, it uses less power. As a result, it is highly recommended to use the proof-of-stake algorithm in power sector applications (Lei et al., 2021).

The third popular mechanism is called proof-of-authority. This algorithm is similar to proof-of-stake, however the validating bodies stake their own reputation. Proof-of-authority gives the validating bodies the right to vote and reach a consensus. While it also consumes less power, the control given to a limited number of authorities has the potential to induce centralization in the authorization process. Since the applications discussed above are gearing towards decentralization in Pakistan, proof-of-authority is not the best option for power sector applications in the country (Lei et al., 2021).

Developing regulations for implementation of blockchain-based applications in the power sector

As a rapidly evolving technology, blockchain needs to be integrated into the regulatory frameworks for a seamless adoption. A lack of regulatory framework for a novel technology in the country will hinder the trust from adopters: prosumers, communities and organizations. Therefore, regulatory requirements should address frameworks to allow new entities to participate in trading of power units, recognize smart contracts, determine conditions for decentralized trading of power and regulate financial payment mechanisms (Peter, 2019; PwC, 2019b).

First, frameworks to address legal issues need to be included in regulations. For public blockchains, it is difficult to set regulations since the network can span over multiple locations, each with their own jurisdictions. However, with private or consortium blockchains which are restricted networks, legal issues can be addressed internally (GoB, 2020). Despite internal resolutions, it is important to address the stakeholders and their roles in the blockchain. For example, if there is a fault in the technical implementation of the blockchain network, the person or organization taking responsibility should be identified in the legal framework (PwC, 2019b).

Second, smart contracts need to be accepted as legal forms of contracts. At present, there is no regulatory framework around acceptance of smart contracts in the legal court. To implement blockchain-based solutions, smart contracts are an essential part of the system. Therefore, they should be used as the source of truth in case of a legal dispute. In addition to that, smart contracts should be allowed to be used as a replacement for energy bills, if required. Smart contracts should also have their own terms and conditions to allow the prosumers to understand the validity and termination guidelines (McQuinn, 2019; PwC, 2019b).

Third, to implement smart contracts in blockchain-based systems, prosumers need to prove their identity. The process of proving identity is redundant and heavily reliant on in-person ID check in Pakistan. However, the financial regulator in Pakistan has been recently testing a biometric verification system through a smartphone application. Similar digital identity verification should be accepted towards finalizing smart contracts. Along with digital identity verification, digital signatures should also be accepted while doing transactions in blockchain networks. Here, it is important to note that proving identity is important to avoid the inclusion of sanctioned people in the blockchain network. Public blockchains allow pseudonyms, which can be difficult to verify and track in case the person is on a nationally determined sanctions list. Therefore, private blockchains are safer to implement from a regulatory perspective (GoB, 2020; GoI, 2021; GoN; 2021; McQuinn, 2019; PwC, 2019b).

Fourth, prosumer privacy and data protection regulations need to be developed. With smart meters, all the generation and consumption patterns will be recorded. This data can prove to be extremely beneficial to all stakeholders in the network, especially retailers and network operators. They can have an increased visibility on the power usage trends and make commercial decisions accordingly. However, prosumers should have the right to refuse access to their data, or have the right to sell the data about their generation and consumption trends. Even when data is shared, it should be encrypted to avoid sharing of personal information. Finally, prosumers should have the right to withdraw their consent at any point to share data related to their power generation and usage patterns (GoB, 2020; GoI, 2021; GoN; 2021; McQuinn, 2019; PwC, 2019b).

Fifth, blockchain-based systems should follow the standards for interoperability to encourage easier entry by the new players to the market and enhance commercialization of the technology. Since it is a technological system, there are several ways the interoperability can be maintained in the infrastructure. For example, coding structures and devices should not be proprietary. Instead, they should be widely accessible so local and international players can integrate with the existing systems. Moreover, blockchain based solutions should also be interoperable among different industries. For example, the framework of a blockchain network for power transactions could also be utilized for financial transactions in the country. One way to ensure interoperability is to make the standards open-source, so they are easier to access and follow by other parties. Another way to ensure interoperability is to follow the International Standard Operators (ISO) code ISO/307 which is being developed for blockchain solutions specifically (GoB, 2020; GoI, 2021; GoN; 2021; McQuinn and Castro, 2019; PwC; 2019b).

Capacity building for implementation of blockchain technologies in the power sector

Given blockchain is not a technology that is applied in Pakistan on a commercial level, there is a lack of technology knowledge related to blockchain in the employment sector. Therefore, to address the gap, training and courses should be offered to relevant stakeholders to become equipped with appropriate blockchain technologies. In addition to that, it is important to educate policy makers and strategists in the power sector with blockchain-based technology, its advantages, applications and requirements (McQuinn and Castro, 2019; PwC; 2019b).

The first recommendation to achieve this is through partnerships with academia to arrange trainings for the professional network, as well as integrate it within university-level curriculum to equip the prospective graduates with innovative technology skills. The second recommendation is to allocate research funding as well as technology support to academic institutions to encourage research and development for blockchain-based applications in the power sector. The third recommendation is to allow university level projects to work with the government to address challenges, such as energy access in a remote community, through blockchain based applications. This would kick-start the process of implementing blockchain-based applications in pilot phases (GoB, 2020; GoI, 2021; GoN; 2021; McQuinn and Castro, 2019; PwC; 2019b).

Chapter 7: Conclusion

This paper considers the potential of blockchain-based applications in the power sector to address the challenges faced by the residential power sector in Pakistan. The aim is to alleviate the challenges faced by the residents, along with facilitating the energy transition. Based on the commitment towards the Paris Agreement, as well as Pakistan's power policies, it was established that decentralization can be a tool towards accelerating the decarbonization of the power sector, as well as addressing the Pakistani population's lack of trust on the centralized power sector authorities. Decentralized off-grid solutions such as rooftop solar panels can be beneficial for remote communities, by saving their transmission costs, reducing the cost of generated power per unit and ensuring reliability of power supply. In addition, decentralized solutions can complement the centralized grid by reducing the power demand from the grid, as well as contribute towards a renewable energy generation mix.

Blockchain-based solutions can be applied to the power sector in Pakistan to establish trust towards the centralized authorities, ensure secure trading of power and associated transactions in decentralized peer-to-peer networks and allow tracking and trading of carbon credits and renewable energy certificates. To implement these solutions, blockchain-based startups need to be facilitated to contribute towards innovative initiatives. In addition, the government needs to work on regulations to ensure protection of data and privacy of prosumer, establish legal frameworks for blockchain-based transactions, facilitate deployment of pre-requisite hardware such as smart meters and develop policy to ensure standards are maintained for interoperability of solutions. Furthermore, capacity building for technology intensive applications is also required.

For future work, it is recommended that the aspect of just transition is explored if blockchain based solutions are implemented. Will the applications be accessible to the entire population, or will only a segment of the population who have access to monetary capital, education and technological capacity? Secondly, despite implementation of blockchain based solutions, certain challenges will not be addressed. For example, if theft of electricity is done through the distribution network's hardware, it will be out of the jurisdiction of a blockchain ledger. Therefore, challenges which exist in parallel will have to be acknowledged and addressed for an optimum implementation of the recommended technological applications. Third, mechanisms to measure and analyse the success of pilots will have to be designed so that the effectiveness of the technology can be understood, especially with respect to the cost associated with it.

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