The role of blockchain in the sustainable energy transition in the Arab region

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Review and consultation

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Key messages

Managing complexity | Blockchain, as part of a toolbox of emerging digital technologies, can help Arab countries manage an increasingly complex energy sector that is transitioning towards digitalization, decentralization and decarbonization, thereby contributing to key Sustainable Development Goals (SDGs) such as affordable and clean energy.

Digital roadmap for a holistic transition | Arab countries should develop a comprehensive digital roadmap to ensure that blockchain and other digital technologies are seamlessly integrated into energy, information technology (IT) and related sectors, providing a holistic transition that leaves no one behind.

Enhancing governance and regulation | Accelerating intellectual and technological capacity around blockchain requires strengthening energy governance and institutions. This is needed to define clear and adaptive regulatory guidelines for the use of blockchain, aligning it with national energy policies and standards.

Revamping infrastructure | A shift towards end-to-end digitalization requires reform in energy markets and infrastructure. Investments in digital infrastructure like high-speed internet and data analytics are pivotal, particularly in rural areas where access, digital literacy and use lag behind.

Skill development and education | Building digital skillsets in blockchain and other emerging digital technologies like artificial intelligence and IT through education and training is crucial for the workforce to support the sustainable energy transition and meet the SDGs.

Leveraging regional and global best practices | Decision makers should identify, adapt and adopt successful use cases, policies and regulations that resonate with local needs. Customization is key, ensuring fairness and equity across various contexts, from rural off-grid settings to urban grid-connected environments.

Regional and international collaboration | Fostering public-private and regional partnerships can accelerate the uptake of blockchain and other digital technologies via knowledge sharing, ultimately aiding in the achievement of both regional sustainability and global SDG targets.

Customization based on needs | Successful blockchain implementation requires a tailored approach, considering local requirements and technology-specific trade-offs like speed, security and cost. Hybrid models, blending traditional systems with blockchain, can offer immediate advantages in efficiency and security, which are critical for sustainable development.

Just, inclusive and sustainable transition | Paired with effective policy, emerging digital technologies like blockchain can be instrumental in accelerating the just, inclusive and sustainable energy transition, by enhancing transparency, accountability, efficiency and security.

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Abbreviations and acronyms

AI	artificial intelligence
BTC	Bitcoin, the cryptocurrency token native to the Bitcoin network
DAO	decentralized autonomous organization
DeFi	decentralized finance
DER	distributed energy resource
DEWA	Dubai Energy and Water Authority
EAC	energy attribute credit
ETH	Ether, the cryptocurrency token native to the Ethereum network
EV	electric vehicle
IT	information technology
IoT	Internet of things
kWh	kilowatt-hour
MWh	megawatt-hour
P2P	peer to peer
REC	renewable energy credit
RMI	Rocky Mountain Institute
SDG	Sustainable Development Goal
TWh	terawatt-hour
WFP	World Food Programme

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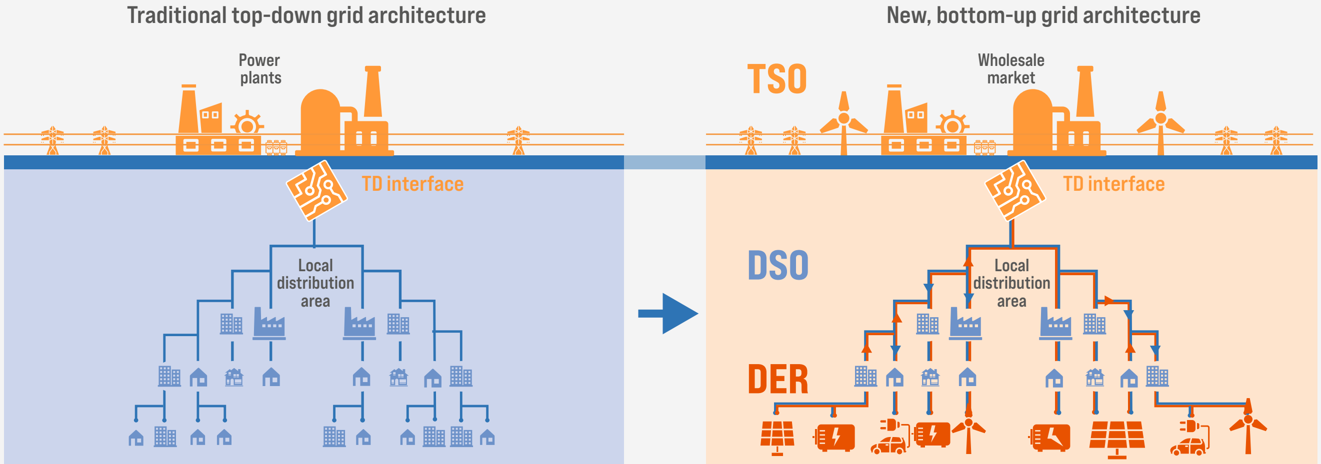
Introduction

The energy sector is becoming increasingly complex, due in part to the shift towards the decentralization, digitalization and decarbonization of energy. This requires more intelligent and transparent digital tools to manage this complexity, empowering stakeholders across energy systems, from suppliers and network operators to prosumers[1] alike. The proliferation of grid-edge assets, such as rooftop solar systems, smart buildings, smart appliances, electric vehicles and home batteries, generates a large amount of granular data. This data can be used to increase efficiencies in the power sector and match energy demand with production, reduce energy usage through better data exchange and communication, and further enhance these processes with advanced technologies and tools. Most consumers are technology agnostic. What matters to them is that new digital solutions solve problems and cater to what the user wants, making it simple to realize the benefits.

Emerging digital tools, including blockchain, machine learning and artificial intelligence (AI), and internet of things (IoT) devices can help bridge the energy access gap in the Arab region by increasing access to affordable, reliable and modern energy services for underserved populations. Emerging crowdfunding business models, particularly for those in rural areas, will be explored in this technical paper.

Historically, power sectors had a top-down grid architecture with a few large-scale power plants serving many consumers. This model has since shifted, with many small-scale distributed energy resources (DER) also sending power back to the grid, creating a multidirectional flow of power and data. Blockchain is an emerging tool that can help manage this increasingly complex energy system securely, efficiently and transparently, as part of a toolbox of innovations.

Figure 1. Increasingly complex power sector



Source: Adapted from Roberts (2018).

Note: TD, transmission-distribution interface; TSO, transmission system operator; DSO stands for distribution system operator; DER, distributed energy resources, such as solar, wind, batteries, EVs and others.

Overall, blockchain has the potential to accelerate the Arab sustainable energy transition by enabling more efficient, transparent and secure systems for effective resource management and service delivery. The present technical paper focuses specifically on the power sector and the emerging blockchain use cases being implemented within it. The technology enables the establishment of new business models, including innovative ways of financing renewable projects, energy attribute credit tracking and certification, distributed energy resource management, e-mobility solutions, local peer-to-peer (P2P) and wholesale power trading, among others.

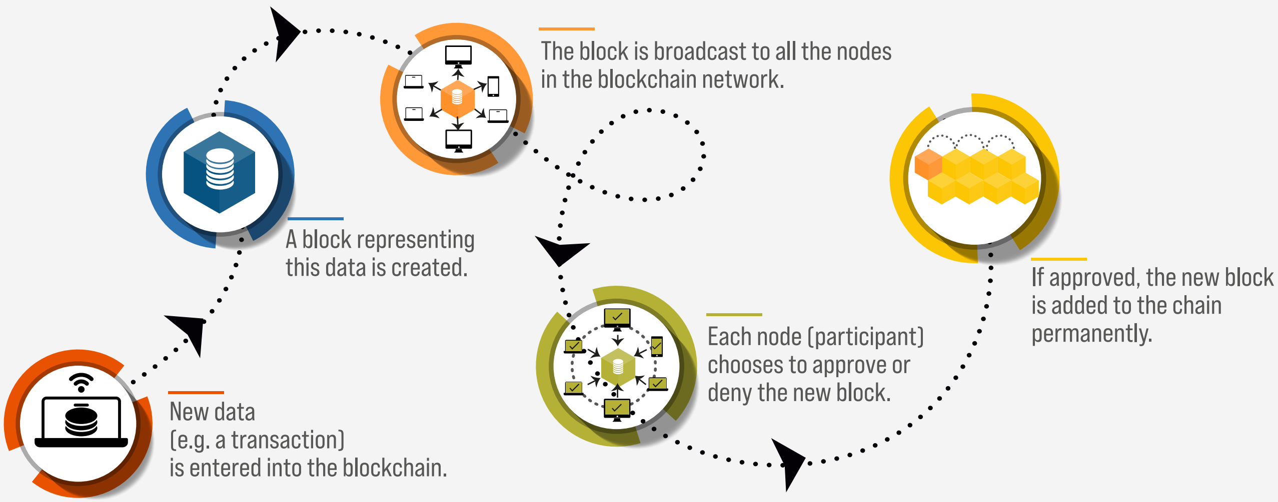
Challenges to blockchain adoption in the energy sector are also discussed, and certain use cases are elaborated, which can be adapted and applied in the Arab region. The successful implementation of blockchain solutions and the realization of their maximum potential will depend on a variety of factors, including technological awareness, regulatory frameworks, and financing and infrastructure availability. This will require collaborative efforts from Governments, private sector organizations and civil society.

A. What is a blockchain?

A blockchain is a decentralized, immutable database that securely records transactions. It enables fast, reliable and transparent information exchange among participants and can be used to virtually store almost anything of value in digital form. It also enables multiple parties to independently verify the state of a particular record, data point or event, and includes a built-in audit trail. Blockchain also offers the ability to create and enforce digital scarcity or "uniqueness", in contrast to conventional digital systems, where near infinite replication and duplication of data is the norm. This feature is what enabled the recent growth in non-fungible tokens, commonly known as NFTs.[2]

Importantly, blockchain refers to a category of distributed ledger technologies, not any one specific network, and while often conflated, blockchain and cryptocurrency[3] are two distinct concepts. Moreover, there are many different types of blockchains, ranging from general-purpose to specialized for a particular use case, and from fully public and permissionless to private and semi-centralized, each with different tradeoffs in terms of speed, security, privacy and cost. Both public and private blockchains have roles to play and should be selected and implemented on a case-by-case basis. For example, a P2P energy trading scheme may be better served on a private blockchain, purely for prosumers and consumers to access. Meanwhile, activities at a larger scale may be well served on a public blockchain due to the enhanced transparency and accessibility they offer. Different blockchains are also secured by diverse consensus mechanisms, which also come with their own set of tradeoffs in terms of energy intensity, cost, centralization and security.

Figure 2. How blockchain works



Source: Money, What is blockchain? 2022.

A consensus mechanism (proof of work mining in the case of Bitcoin[4], proof of stake in the case of Ethereum[5], or proof of authority in the case of Energy Web Chain[6]) is the system used by blockchains to validate the authenticity of transactions while maintaining the security of the chain. Miners, in the case of Bitcoin, or validators, in the case of Ethereum, are rewarded for this service to the network in the form of cryptocurrency tokens native to each blockchain, such as BTC for the Bitcoin blockchain or ETH for the Ethereum blockchain. While mining necessitates a high level of electricity use, proof of stake and proof of authority validation are substantially more energy efficient.

Technological progress in this space is rapid. For example, after years of development, Ethereum shifted its consensus mechanism from proof-of-work to proof-of-stake in September 2022 and reduced its energy usage by 99.99 per cent, from over 22 terawatt-hours (TWh) (annualized electricity consumption) to under 0.0017 TWh as at May 2023[7], thereby addressing one of the main concerns of high energy usage when it comes to blockchains. The chain also implemented several "improvement proposals" to simplify usage fees and make transactions more efficient. These are just some of the examples that demonstrate the technical ingenuity and drive to overcome challenges among blockchain communities, meaning roadblocks that exist today may not exist in the future, as various technologies continue to develop, enabling them to solve new challenges.

Importantly, applications that run on blockchain can be implemented by many industries to enable more efficient transactions, optimize workflows, streamline multiparty processes, boost accountability while minimizing disputes, and open up new markets through asset tokenization[8] (World Economic Forum, 2022). Multipurpose blockchains leverage the power of smart contracts[9] to enable the automation of business processes and can store a wide range of metadata about a product, such as renewable energy or carbon credits, and package it into tradable units across various types of relevant stakeholders in any market, such as the energy market. Cryptography enhances the security and integrity of the data, while maintaining privacy.[10]

Greater flexibility through decentralization

While still evolving, blockchain has the potential to revolutionize communication and coordination by providing a secure infrastructure for peers to connect and transact without the need for a central intermediary. This may change the way we transact, with the underlying transaction model shifting away from a centralized structure (banks, exchanges, trading platforms, energy supply companies) with higher transaction costs, towards a decentralized system (end customers and energy prosumers with lower transaction barriers). Third-party intermediaries, whose services are needed today in most industries, may no longer be required to the same degree in decentralized systems built on blockchain, given that transactions can be initiated and carried out directly "from peer-to-peer". This can cut costs and speed up processes. As a result, the entire system could become more flexible, requiring less transaction time and costs, as many previously manual tasks anchored around central entities are now carried out automatically through smart contracts in a decentralized manner. Hybrid approaches which blend the two models may be the most likely in the short term, whereby blockchain could improve the efficiency, security and accountability of more "conventional" centralized, institutional transaction models.

As the technology develops, blockchains continue to scale up and are able to process more and more transactions per second with lower and lower transaction costs, enabling new use cases. New "layer 2" blockchains which build on top of the base layer (such as Ethereum) inherit its security features while increasing throughput and reducing cost. Completely new blockchains that enable an increased degree of scale with reduced cost are regularly being developed. While not a panacea, blockchains can ultimately enable the exchange, validation and independent multilateral verification of data in an entirely new way and may bring a new definition of trust to a world where only a few gatekeepers currently control the flow of money, services and data (Rocky Mountain Institute (RMI), 2022).

B. Broader implementation of blockchain technology

Outside of the energy sector, blockchain has a potential role to play in various sectors, helping to achieve various targets as part of interlinked Sustainable Development Goals (SDGs). A non-exhaustive list is included in the table as an overview.

Overall, blockchain has the potential to support the achievement of the SDGs by enabling more efficient, transparent and secure systems for a more effective management of resources and the efficient delivery of services. In the following sections, specific applications for the energy sector will be explored, including successful ongoing case studies, challenges and ways forward.

The potential role of blockchain in select sectors (Beyond energy)

Sector	Description	Related SDGs
Agriculture	Blockchain can enhance traceability in the agricultural supply chain, helping to improve food safety and reduce waste. It can also provide a secure platform for transactions in agricultural marketplaces, helping small farmers access markets and get fair prices.	1, 2, 3, 5, 8, 12, 13
Aid and humanitarian efforts	Blockchain can help improve the efficiency and transparency of aid and humanitarian efforts by enabling the creation of decentralized platforms for distributing and tracking aid, reducing the potential for corruption and mismanagement.	1, 2, 3, 4, 6, 7, 10, 17
Digital identity	Blockchain can enable self-sovereign digital identity mechanisms that provide individuals with greater control over their identity, credentials and digital data.	1, 3, 4, 5, 8, 10, 16
Education	Blockchain can be used to create verifiable and permanent records of educational achievements, facilitating the recognition of qualifications across borders and sectors, and supporting lifelong learning.	4, 5, 8, 10
Environment and biodiversity	Blockchain can enable transparent and efficient carbon trading and other environmental marketplaces. It can also help track and verify efforts to protect biodiversity, such as sustainable fishing and wildlife conservation efforts.	3, 6, 7, 11, 13, 14, 15, 17
Financial inclusion	Blockchain can facilitate the provision of financial services to underserved and unbanked populations by enabling the creation of digital wallets and P2P transactions without the need for traditional financial intermediaries who control, record, monitor and become counterparty to the transaction.	1, 2, 5, 7, 8, 9, 10, 12, 13
Governance and public services	Blockchain can increase transparency, help reduce corruption and improve efficiency in government operations and public services, from tax collection to public procurement.	9, 10, 16, 17
Health care	Blockchain can enhance patient data management, enabling secure and efficient sharing of medical records among authorized health-care providers, and supporting research efforts. It can also improve drug traceability to combat counterfeit drugs.	3, 9, 16, 17
Land and property rights	Blockchain can help improve the security and transparency of land and property rights by enabling the creation of a decentralized land registry that is more difficult to tamper with than traditional centralized systems. This can help increase transparency by reducing information asymmetry, and improve access to land and property for disadvantaged groups.	1, 2, 5, 8, 10, 16
Supply chain transparency	Blockchain can help improve supply chain transparency by providing an immutable record of transactions, enabling the traceability and verification of products, such as food, medicine and fuel, from source to consumer. This can help reduce corruption and waste and improve sustainability. This is particularly relevant in complex, global supply chains involving many suppliers.	2, 3, 8, 9, 12, 13
Voting systems	Blockchain can improve the transparency and security of voting systems, ensuring that votes are counted accurately and reducing the potential for fraud.	10, 16, 17

Source: Economic and Social Commission for Western Asia (ESCWA), adapted from the United Nations Development Programme (UNDP) (2022).

1 The role of **blockchain** in the **sustainable energy** transition

Blockchain technology has the potential to radically change energy as we know it, starting with individual segments of the sector first and ultimately transforming the entire energy market. As part of this overall shift to digitalization, blockchain is enabling innovative financing mechanisms for rural, small-scale projects; more efficiently managing electricity grids from an administrative standpoint via automated smart contracts; enabling real-time matching of consumption with locally sourced clean energy (such as demand response, off-grid solar net metering and electric vehicle charging) while providing a trusted audit trail; and transparently processing payments and securing data, among others. All of this can contribute to the integration of higher shares of clean and sustainable resources and solutions in the energy and related sectors.

At the same time, blockchain is not a silver bullet and cannot solve all of the fundamental issues facing the energy sector itself. Blockchain and other emerging digital technologies are simply a set of emerging tools that are part of a toolbox of digital solutions to be used in conjunction with each other, often as part of existing established mechanisms (International Renewable Energy Agency (IRENA), 2019). In its current state, blockchain technology can also add cost and complexity to systems if not implemented thoughtfully, which is why, as with any technology tool, value added needs to be considered on a case-by-case basis. Identifying the niche areas where blockchain technology can have the most impact in the near-to-medium term is crucial, in order to prioritize efforts. This section attempts to identify these areas which could have the most impact in the Arab region's sustainable energy transition, particularly in the power sector, by looking at emerging use cases being implemented globally by private sector startups, government entities and others.

A. An evolving energy sector – Power sector complexity

Energy systems are transforming and becoming increasingly complex owing to the incorporation of multiple distributed energy resources, such as renewable energy generation from solar photovoltaics (PV) and battery storage systems. This transformation has triggered a need to shift power distribution from a low efficiency centralized model with high coordination costs to a decentralized distribution system comprising smart grids. Researchers and startups have discovered and experimented with several uses for blockchain technology in the energy sector because of its decentralized structure and the potential for more secure and transparent transactions (Khan and Masood, 2022).

The proliferation of grid-edge smart assets that are coming online, such as smart appliances, smart buildings, electric vehicles, rooftop solar systems and home batteries, is generating a large amount of granular data, which can be used to increase the efficiency of power systems and match energy demand with its production through better data exchange and communication, and with the help of emerging technologies and tools, such as AI.

Decentralization requires bridging the digital gap. The current digital infrastructure in energy markets presents significant challenges to the integration and efficient use of decentralized energy systems. Shifting a power generation unit from personal use to system services or energy trading often requires time-consuming, paper-based processes. As the energy sector moves towards balancing supply and demand dynamically, with millions of transactions made daily across many decentralized generation and consumption units, more efficient, speedier forms of interaction are required. Enhanced digital communication between distribution system operators and transmission system operators is vital, extending to complete digitalization of processes like congestion management and market communication. Crucially, real-time verification of market participants and their rights is needed to enable secure, cost-efficient and dynamic transactions. The development of digital identities for individuals and machines is becoming a central concern in this real-time energy economy. However, the absence of digital identification at the device or machine level is currently a significant hurdle to digitalization, and not just in the energy sector (Strüker and others, 2021).

B. Increasing energy access

Emerging digital tools, including machine learning and AI, IoT devices and blockchain technology, can help bridge the energy access gap in the Arab region. One of the most important use cases for blockchain technology in the energy sector involves increasing access to affordable, reliable and modern energy services for underserved populations. This section will explore the role of blockchain technology in increasing access to affordable, reliable and modern energy services within the Arab region via emerging crowdfunding business models, particularly for those in rural areas.

Box 1 | Sun Exchange – Increasing access to renewables via crowdfunding

Sun Exchange, a South African peer-to-peer solar leasing platform, enables global investors to own and lease solar cells to businesses in emerging markets, providing maintenance through local partners. The company harnesses blockchain and crowdfunding to increase access to renewable energy by identifying potential beneficiaries (schools, businesses), assessing project viability with local construction partners, and initiating crowd sales for the PV modules powering these projects. Installation follows, lasting 4-6 weeks. Beneficiaries pay investors for using the generated clean electricity, and investors start earning when the project generates electricity, receiving monthly returns in local currency or Bitcoin, net of fees. Investors can track project status, earnings, energy generated, carbon offset, balance, payments and withdrawals via a digital dashboard. To date, the platform has powered 68 organizations, prevented 19,000 tonnes of CO_2 and generated over 18,000 megawatt-hours of energy.[11]

Source: The Sun Exchange, 2023.

Decentralized finance

With blockchain technology, innovative means of increasing access to modern energy have been developed, trialed and implemented, particularly on the African continent. The role of blockchain in increasing access to financing has been particularly potent, with thousands of megawatt-hours (MWh) of renewable energy generated and tonnes of CO_2 avoided (The Sun Exchange, 2022).

Blockchain technology is increasingly used as a tool to leverage decentralized finance (DeFi) to accelerate sustainable energy access in developing countries. DeFi is an umbrella term for financial services on public blockchains, primarily Ethereum. With DeFi, you can do most of the things that banks support — earn interest, borrow, lend, buy insurance, trade derivatives, trade assets and more — but it is faster and does not require paperwork or a third party. As with crypto generally, DeFi is global, peer-to-peer (meaning directly between two people, not routed through a centralized system), pseudonymous and open to all.

Benefits of DeFi include:

- Openness: participants do not need to apply for anything or "open" an account. They receive access by creating a wallet.
- Pseudonymous: investors typically do not need to provide their name, email address or personal information.
- Flexibility: participants can move assets anywhere at any time, without asking for permission, waiting for long transfers to finish, and paying expensive fees.
- Speed: interest rates and rewards often update rapidly (in under a minute) and can be significantly higher than traditional investment avenues.
- Transparency: everyone involved can see the full set of transactions (rare in the case of private corporations) (Coinbase, 2023).

Through DeFi, funds can be distributed as micro-loans to residents of low-electrification communities, enabling them to gain more affordable access to solar energy. Access to direct, low-cost financing which unlocks capital from the global markets is enabling small-scale, off-grid consumers to install solar PV systems with no or minimal upfront costs. Consumers pay a fixed rate for their renewable power consumption to global investors, either in local currency or cryptocurrency, such as BTC or ETH. Investors are typically paid back their principal with interest for a fixed duration (for instance, up to 10 per cent interest in the case of Engie's Access programme in Africa). The decentralized and borderless nature of cryptocurrency, with minimal transaction fees,[12] makes it an ideal medium of exchange for this purpose. The transparency and immutability of blockchain transactions also mean that these payments can be audited and verified at any point by all parties, further minimizing risk.

Box 2 | Engie Access – Increasing access to renewables via crowdfunding

Engie Energy Access, an off-grid solar and mini-grid solutions provider, and the Energy Web Foundation are currently trialling financing methods through the usage of cryptocurrency and blockchain technology to accelerate sustainable electrification in Sub-Saharan Africa via microloans for solar infrastructure. Crowdfund for Solar (a decentralized staking platform that allows Energy Web Token holders to support the installation of solar energy infrastructure in Sub-Saharan Africa), built using Energy Web's open-source software stack, allowed participants to loan their cryptocurrency funds in exchange for a fixed return. The crowdfunding targeted $100,000, which was successfully achieved within seven hours after its launch.

Source: Engie, 2022a.

C. Accelerating the adoption of renewables

The previous examples on crowdfunding are not only a tool for increasing access but also for accelerating the adoption of renewable energy generation in rural and urban areas. Besides innovative financing mechanisms, blockchain is already playing an important role in distributed energy management and trade. Blockchain technology has a role to play in tracking and tracing renewable energy and sustainable fuels (including hydrogen and derivatives such as methanol and ammonia), providing transparent information to regional and global buyers looking for assurance of the origin and supply chain of their fuels. Blockchain-based solutions can offer transparency, security, efficiency and predictability with fewer fees and less time while providing real-time information on the movement and origin of goods, enabling better management of supply chains for fuels. They can help tackle challenges and issues related to trade facilitation, such as the need for innovation and digitalization of trade procedures. They can also boost Governments' ability to exchange trade data across borders and enhance transparency to consumers (ESCWA, 2023a; United Nations Conference on Trade and Development (UNCTAD), 2022).

1. Distributed energy resource management and trade

When it comes to DER management and energy trade, automated payments using smart contracts and transparent tracking of trade using digital identities and wallets while maintaining privacy are some of the key use cases enabled via blockchain. The technology can also be used to transparently verify the source of renewable energy, so that customers can be sure that what they are purchasing is sustainable.

Box 3 | Energy Web (Project EDGE) – DER management

Project EDGE (energy demand and generation exchange) is an Australian initiative that is testing the potential of DER to offer wholesale and local grid services within local ecosystems by leveraging blockchain. The project is aimed at transitioning from a one-way energy supply to a system that enhances the value of DER for all users through digital integration into Australia's power systems. Australia, which is a global leader in DER adoption, is witnessing the rise of new DER use-cases necessitating extensive data and control signal exchanges. Project EDGE enables stakeholders to utilize a distributed data exchange hub built on blockchain. This allows customers to contribute to wholesale markets and provide local network services, thereby encouraging electricity generation from batteries and solar PV systems and enhancing grid reliability. With these tools, Australians are better able to balance a rapidly decarbonizing grid. The project also offers a more efficient way for stakeholders to manage customer-owned energy assets.

Source: Energy Web, 2022c.

Box 4 | Grid Singularity – P2P renewables trading

Grid Singularity, a blockchain company based in Germany, has developed software to simulate and operate local energy exchanges, enabling P2P and community trading that accounts for related grid use costs. The role of blockchain is to ensure that the exchange is fully transparent and that all market actors, from households to large energy traders, have equal market access.

Source: Grid Singularity, 2023.

In addition to grid management, blockchain can also enable P2P energy trading, although use cases for this have been slower to take off, and regulatory hurdles often inhibit scaling due to jurisdictional differences.

2. Renewable energy tracking and certification

Blockchain is an efficient way of allocating generation assets to a specific point of consumption and can even be used to establish a hierarchy of priorities when it comes to sources of origin. This allows for the acceleration and automation of renewable energy certification processes, as there is a greater degree of traceability. This aspect is crucial in the case of long-term power purchase agreements (PPAs) based on renewable assets, as these agreements specify the need to certify that the energy supplied is from 100 per cent green sources. They also play a fundamental role today, because they promote renewable energy growth by encouraging large corporations to purchase sustainable energy.

Blockchain also guarantees the transparency and security of the transaction, which remains permanently recorded on the platform, allowing all parties to audit the results. This technology also makes it possible to work under smart contracts which are executed automatically when both parties fulfil the agreed terms, thereby cutting out intermediaries and simplifying the process. This reduces costs and increases privacy.

Similar to Iberdrola's pilot project, The Energy Origin (TEO) by Engie is engaging in sustainable energy certification via blockchain in order to replace traditional guarantees of origin which may not always be verifiable. This not only applies to power, but also to gases such as biomethane, hydrogen and liquified natural gas.

Going beyond electricity, blockchain is being used to certify clean fuels used to power industry, transport and other sectors (boxes 8 and 9).

Box 5 | Power Ledger – Tracking and tracing of renewables

Power Ledger, a blockchain solutions provider with projects in 10 countries, develops software that allows consumers and producers to track, trace and trade electricity. As the grid changes from a centralized to a distributed one, blockchain technology can help support the new configuration with a highly agile market. Power Ledger's platform, known as xGrid, permits the customers of an electricity retailer to trade solar power across the grid. The platform is designed to optimize pricing and enables households and businesses to sell solar-generated energy across the same or different electricity grids. Meanwhile, uGrid, another platform from the company, focuses on energy tracking and trading within embedded networks and microgrids like shopping centres and apartment complexes. It allows residents to trade solar energy with each other, keeping the investment, profit and benefits of renewables within the community. Both systems use blockchain technology for transactional transparency.

Source: Power Ledger, 2023a; Power Ledger, 2023b.

Box 6 | Iberdrola – Sustainable energy certification

Iberdrola group has begun a pilot project in Spain using blockchain to guarantee, in real time, that the energy supplied and consumed is 100 per cent renewable. The project connects the Oiz (Biscay province) and Maranchón (Guadalajara province) wind farms and the San Esteban hydroelectric plant (in Orense province) with the offices of Kutxabank and Euskaltel (both in the Basque Country), as well as with the Iberdrola Tower in Bilbao and the Iberdrola Campus in Madrid. Blockchain provides these customers with the guarantee that the electricity they receive and use in their buildings is 100 per cent renewable and allows them to trace its source by identifying which plants the consumed green energy comes from.

Source: Iberdrola, 2023.

Box 7 | The Energy Origin by Engie – Sustainable energy certification

The Energy Origin (TEO) uses blockchain to enable customers to select the energy-generating asset, trace it from the plant output to the consumption sites, and receive immediate access to tamper-proof certificates. Renewable electricity production and consumption is traced in near real time to let clients target 100 per cent renewable energy consumption. Blockchain enables time-stamped energy traceability and certification, tracking of generation and consumption attributes, and transparency and detail, including location, time and energy source type.

Source: The Energy Origin, 2023.

Box 8 | Clean Energy Certification from Siemens Energy

The Clean Energy Certification (CEC) from Siemens Energy is a digital service that uses blockchain to track the environmental impact of energy production by issuing automated, Government-approved certificates across the energy sector. The service connects physical assets with blockchain and covers accreditation schemes for green electricity, green hydrogen, e-fuels and other green energy carriers or energy-intensive goods.

Source: Siemens Energy, n.d.; IRENA and RMI, 2023.

Box 9 | GreenH2chain from Acciona Energía

Acciona Energía has developed GreenH2chain, a platform based on blockchain technology that guarantees the renewable origin of green hydrogen and provides data on the avoided CO_2 emissions. Customers have access to a digital platform to verify and visualize the entire green hydrogen value chain in real time and to quantify, record and monitor the decarbonization process of their own energy supply. The digital tool is fed with data from multiple sources along the green hydrogen value chain, making correlations and keeping balances among them and maintaining unique identification of every kilowatt hour of green hydrogen.

Source: Acciona, 2021; IRENA and RMI, 2023.

3. E-mobility

Increased electric vehicle (EV) use is driving demand for renewable energy and creating opportunities for vehicles to provide grid services through vehicle-to-grid technology. In fact, EVs are the fastest growing decentralized energy storage resources. They will not only constitute a large share of the future energy demand but will also provide a source of decentralized flexibility for ancillary services, i.e., to support the grid stability or prevent congestion.

As EVs become more common, the use of renewable energy for charging must be simplified for consumers. Blockchain technology can be used to give EV drivers and fleet operators the ability to choose their electricity supplier at public charging stations, through the integration of tools like self-sovereign identities and the Open Charging Network, to make charging easier and ensure the consumption of renewable energy.

In addition to Elia and BMW, Volkswagen (VW) and Elli are conducting tests with Energy Web and implementing blockchain technology to ensure consumers are afforded a choice in the type of electricity they consume whilst simultaneously ensuring its provenance.

Box 10 | Elia – Market integration of electric vehicles using blockchain technology

Elia Group, the Belgian and German Transmission Service Operator (TSO), in collaboration with Energy Web and BMW Group, has demonstrated a TSO-visible EV charging session, laying the groundwork for improved EV charging, including renewable energy-only charging and fast supplier switching. Using blockchain, Elia built a decentralized registry to test the authentication and authorization of EVs and charging stations for the grid balancing market. With the help of a decentralized identifier, Elia can now demonstrate a new way of asset identification for easier market access. BMW Group recently charged a BMW EV using this new solution, where the vehicle's digital identity was securely shared with Elia.

Source: Elia Group, 2023; Energy Web, 2022b.

Box 11 | VW, Energy Web, Elli – Market integration of electric vehicles using blockchain technology

VW, Energy Web and Elli cooperated in a proof of concept (PoC) to assess technical viability of using blockchain technology to decarbonize EV charging. The PoC lets EV owners choose their electricity source and scheduling, thereby ensuring the vehicle charges using locally produced renewable energy. Energy Web's blockchain platform offered a transparent record of each kWh used for charging, allowing users to verify the electricity's origin. The platform employs a 24/7 matching algorithm to enhance the use of sustainable, local electricity while also granting users significant control over their EV charging, including date, time, level of charge and energy source. Over three months, multiple VW ID.4s were successfully charged with local renewable energy through various session lengths. The tests, mostly conducted near Wolfsburg, Germany, maximized the use of nearby wind and solar energy.

Source: Energy Web, 2022d.

4. Energy attribute credit certification

Blockchain's transparency and immutability makes it an ideal platform for managing energy attribute credits (EAC), a certificate that represents proof that a certain amount of energy has been generated and fed into the grid. These credits can be bought and sold by individuals, companies or public entities as a way to offset their own carbon emissions, thereby supporting the development of renewable energy. EACs can be issued for a variety of energy generation technologies, including solar, wind and hydropower. They are often used as a compliance mechanism for renewable portfolio standards or carbon trading schemes. Each EAC typically represents the environmental attributes of the generation of a one-megawatt hour (1 MWh) of electricity produced by renewable sources.

Using EACs, end-users around the world can make reliable claims about their electricity usage such as *"my factory runs on 100 per cent sustainable energy", "our products are made with 100 per cent wind energy" and "our global electricity usage causes zero end-of-pipe emissions". Without the use of EACs, it would be difficult to make reliable claims because electricity is not a commodity that can be boxed and sent from the producer to the consumer. Instead, a producer injects an electrical charge into the grid in one place and a consumer (somewhere else) takes the same amount of charge off the grid. There is no way to track electrons through a grid. Therefore, the only reliable mechanism for making claims about the use of a specific charge that was taken off the grid is a system that registers/books all injected charges as unique units (MWh) (The International REC Standard (I-REC), 2022).*

It is not only electricity that can be tracked, but also hydrogen and other sustainable fuels, carbon capture utilization and sequestration, and any other products that rely on attribute tracking infrastructure. Such products will benefit from common rules provided by these standards and lead to increased understanding, use and growth of the underlying markets (I-REC, 2022).

Importantly, this requires third party verification at multiple stages. To register a new device, owners must submit detailed information about the production device to the EAC issuer, and these documents must be verified by a third party before the device can be registered. After this, production data from devices can be shared with EAC issuers. This production data must also be verified by a third party before it is accepted by the EAC issuer. Only then can EACs be issued per MWh of electricity production. These can be traded in a central registry, but can only be redeemed by a single consumer. Based on this EAC, consumers can make a claim about the electricity they purchased. Lastly, third parties must also verify certificate redemptions (correct number and type of certificates) by consumers in order to ensure their claim is credible. This complexity and the nature of EACs (uniqueness, transparency) makes them an ideal candidate for tokenization on a blockchain. Every certificate is as unique as the generator that produced it.

Besides the tokenization of these certificates (their digital representation on a blockchain), with blockchain technology, markets for these EACs can also be digitized and decentralized, thereby allowing certificates to be bought and sold at smaller scales and with reduced friction and fees. This helps to subsidize small-scale generators by providing access to global decentralized EAC marketplaces with reduced fees (enabling smaller transactions).

Reneum is another organization based in Singapore that is leveraging blockchain technology to enable customers to register their energy generation projects in order to earn RECs (or EACs) while also providing a decentralized solution for trading.

Box 12 | Singapore Power – Renewable energy certificate marketplace

Singapore Power's marketplace was one of the world's first blockchain-powered marketplaces for transacting renewable energy certificates (RECs). Singapore Power uses the I-REC standard, and the platform operates as a neutral engine that facilitates the transaction of RECs, where participating buyers and sellers around the globe are automatically matched based on respective requirements. Blockchain technology is used as an enabler to track the lifecycle of an REC - from issuance to transfer to redemption. What this means is that individuals and organizations alike can be fully assured of the integrity and security of their transactions. The company provides RECs from Singapore, Malaysia, Vietnam, Thailand, China, Indonesia and the Philippines from a variety of generation technologies.

Source: SP Group, 2023.

Box 13 | Reneum Institute – Energy attribute credits

Reneum, a non-profit organization based in Singapore, established a marketplace that directly connects capital to renewable project developers in emerging markets. It issues digital RECs (dRECs), or EACs, which producers can monetize as a secure subsidy, thereby supporting their operations and new developments. Built on the blockchain, Reneum's system provides a secure means to purchase renewable energy through stand-alone, unbundled dRECs. A blockchain-based token, RENW, is issued by Reneum for each 1MWh of renewable energy produced. Each token contains comprehensive project data, including the date of production, location, technology source, capacity, project owner, its Sustainable Development Goals (SDGs) alignment, and overall climate impact. Institutions can purchase these tokens from the Reneum e-commerce marketplace, and upon retiring them, they receive a green certificate called the Renew Record, a label that proves contribution to the energy transition.

Source: Reneum, 2023.

5. Carbon markets

When it comes to carbon credits, blockchain is an ideal technology to improve markets by preventing the “double spending” of these credits, while increasing access to these markets, as evidenced by recent investment trends. In just the last three months of 2021, some $3 billion worth of tokenized carbon credits were traded, accounting for hundreds of millions of metric tons of the greenhouse gas (Wall Street Journal, 2022). In the first six months of 2022, at least 23 million carbon credits were moved on-chain from centralized registries, representing about a quarter of credits listed at the time, according to data provider Trove Research. In terms of investment, $423 million from venture capitalists has been invested in crypto-based carbon tracking initiatives over the past 18 months (CoinDesk, 2022).

Other applications being explored relate to the documentation of ownership; metering, billing and clearing; asset management; guarantees of origin; and emission allowances. For instance, in November 2022, RMI announced they were building a digital registry on blockchain for sustainable aviation fuel certificates together with the Energy Web Foundation in order to bring more transparency to emission reduction claims about air travel and give travelers the confidence that they are flying sustainably (RMI, 2022).

Box 14 | KlimaDao – Digital carbon markets

KlimaDAO, a blockchain-based decentralized autonomous organization (DAO), is a project involved in the burgeoning digital carbon market. Governed by carbon market stakeholders through a token voting system, KlimaDAO facilitates and incentivizes the integration, trading and retirement of digital carbon assets. As at December 2022, the organization has facilitated the absorption of over 17 million tonnes of carbon. In early 2023, KlimaDAO, in collaboration with SCB Group and the Bangladeshi non-governmental organization BONDHU, funded a project for improved cookstoves for Rohingya refugees, exemplifying the use of emerging technologies in meeting SDGs.

Source: KlimaDAO, 2023.

2 | **Key** factors for a just and **sustainable energy** transition

A. Sustainable energy transition in the Arab region

By leveraging blockchain technology in ways that are already in use globally (decentralized project finance, large- and small-scale electricity trading, improved tracking and tracing, and certification, among others), policymakers and energy sector stakeholders within the Arab region can help close the access gap while also increasing the share of renewables and energy efficiency.

1. Energy access

Access to electricity in the Arab region was nearly 91 per cent in 2021, with about 42 million people having no electricity access.[13] Particularly large gaps remain in the Arab least developed countries (LDCs) of Mauritania, the Sudan and Yemen (ESCWA, 2023b; World Bank, 2023).

2. Renewable energy

Renewable energy penetration rates continue to lag behind in the Arab region compared with other regions, with only 5.1 per cent of the region's total final energy consumption generated by renewables in 2020, mainly from solid biofuels. Three countries (Egypt, Somalia and the Sudan) account for 72 per cent of the region's renewable energy consumption, mainly from traditional solid biofuels which account for 78 per cent of renewable energy in the region (ESCWA, 2023b; International Energy Agency (IEA), 2023).

3. Energy efficiency

The Arab region has historically had low levels of energy efficiency, with high levels of energy use per capita. The region's energy intensity has been relatively stable over the past 25 years, while other regions have reduced their energy intensity. Energy consumption, however, has more than doubled in the Arab region since 1990, with a direct increase in greenhouse gas emissions (ESCWA, 2023b; IEA, 2023).

B. Status of blockchain implementation in the Arab region

While still at an early stage, blockchain implementation in the energy sector in the Arab region is underway, led largely by countries in the Gulf Cooperation Council[14], and has so far been mainly focused on improved tracking and tracing and more efficient grid management.

Box 15 | Dubai Energy and Water Authority – Digital transaction strategy

The blockchain platform of the Dubai Energy and Water Authority (DEWA), which was established in 2017, automates processes such as tenancy contract renewals and the activation of electricity and water services (without having to physically visit a service centre), as well as EV transactions, with the aim of making them faster, safer and more efficient. These efforts align with the Emirates Blockchain Strategy 2021 and Dubai Blockchain Strategy, which aim to streamline and digitize government processes and reduce carbon emissions from the transportation sector. DEWA also collaborates with organizations like Smart Dubai and the Roads and Transport Authority to establish a unified national EV charging blockchain network that connects all public and private partners across the United Arab Emirates.

Source: DEWA, 2021.

Box 16 | Saudi Arabia – King Abdullah University of Science and Technology research initiatives

In Saudi Arabia, the King Abdullah University of Science and Technology (KAUST) has been researching the use of blockchain technology for managing distributed energy resources and demand response programmes to help maintain grid stability, particularly in regions with high penetration of renewable energy sources. The university was also the first in the region to issue digital diplomas on blockchain in 2018 in order to facilitate more secure and easier means of verification for graduates.

Source: Newswire, 2018.

Box 17 | Bahrain Sustainable Energy Authority – Renewable energy credit issuance

In July 2020, the Sustainable Energy Authority of Bahrain initiated a pilot phase for issuing the country's first renewable energy certificates through a blockchain-enabled electronic platform. This platform allows renewable energy producers to register and verify their energy output, with each registered megawatt-hour resulting in an issued electronic certificate. Leveraging blockchain technology ensures transparency and security in tracking each certificate, mitigating risks of electronic breaches. The platform also facilitates the sale of these certificates to interested investors, offering a solution for those unable to produce renewable energy themselves.

Source: Bahrain Ministry of Sustainable Development, 2020; Regional Center for Renewable Energy and Energy Efficiency (RCREEE, 2020).

Box 18 | United Arab Emirates – National system for carbon credits

In August 2023, the Ministry of Climate Change and Environment (MOCCAE) in the United Arab Emirates announced that it would establish a national system for carbon credits using blockchain to reduce emissions and enhance sustainable agriculture, environmental health and biodiversity in the United Arab Emirates. Blockchain will be used to increase transparency, reliability, efficiency and security in managing the issuance, transfer, calculation and tracking of carbon credits.

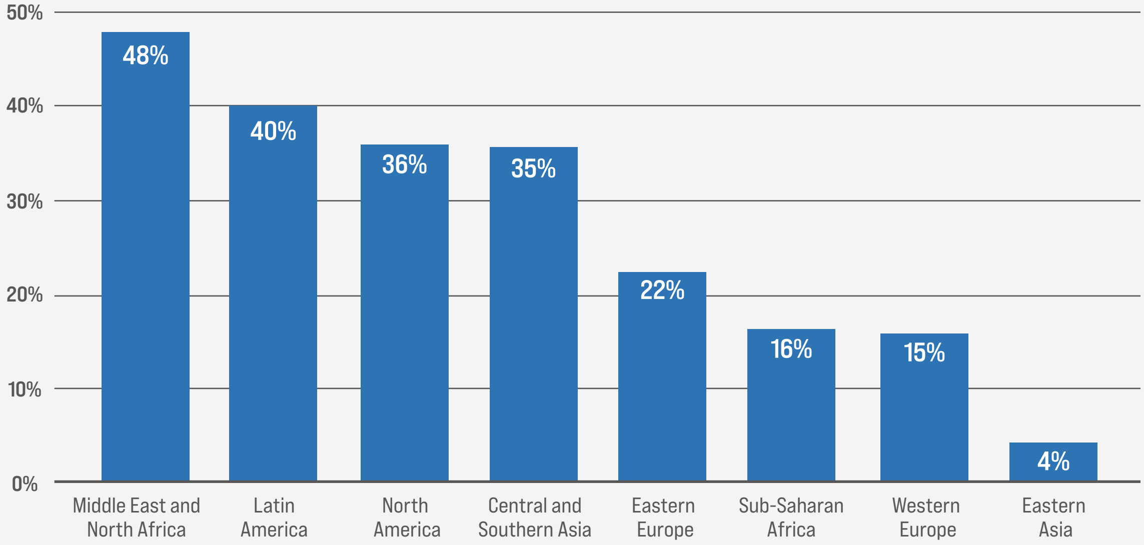
Source: Sustainability Middle East, 2023.

When it comes to financing and investing in clean energy projects using blockchain, implementation in the energy sector in the Arab region has been slower.

Outside the energy sector, however, one of the first examples of blockchain for humanitarian aid was launched in the Arab region. In 2017, the World Food Programme (WFP) tested a blockchain platform to enable Syrian refugees in Jordan to pay for food using an iris scan instead of cash or e-vouchers. The scan is authenticated and recorded on a blockchain, enabling beneficiaries to establish their identities without sharing unnecessary personal details. WFP is now running a full-scale pilot in Azraq refugee camp in Jordan. By the end of 2018, more than 500,000 Syrian refugees were able to redeem their cash transfers on the blockchain-based system (Massachusetts Institute of Technology, 2018; WFP, 2017).

Regarding cryptocurrency, the Arab region is one of the world's fastest-growing markets, with the volume of crypto received in the region jumping 48 per cent in the year to June 2022. While the region remains one of the smallest crypto markets, its growth to $566 billion received in cryptocurrency between July 2021 and June 2022 shows adoption is rising rapidly and familiarity and acceptance of blockchain technologies is growing (Chainalysis, 2022).

Figure 3. Year-over-year growth in crypto transaction volume by region, July 2020 - June 2021 vs. July 2021 - June 2022



Source: Chainalysis, 2022.

Dubai, in particular, has become a hub for crypto companies that serve customers all across Asia and Africa, not just in the Arab region. The Dubai Blockchain Center was established in 2018 with the goal of bringing together blockchain thought leaders, developers, investors and educators.

C. Challenges for blockchain implementation in the energy sector in the Arab region

1. Policy and regulatory frameworks

The adoption of blockchain in many jurisdictions is hindered by unclear or absent regulations. This obscurity extends not only to blockchain technology but also to decentralized renewable energy generation and storage, thus limiting opportunities for decentralized project finance and energy trading through blockchain. Additionally, existing policies often don't provide adequate support for the digitalization of the energy sector, leaving gaps in regulations across IT, cybersecurity and finance. There's also a lack of testing environments for new energy technologies, unclear rights for energy prosumers, and concerns about data privacy. While blockchain promises enhanced security, it isn't impervious to digital threats, thereby emphasizing the need for robust protective regulations.

2. Infrastructure and access to digital solutions

Globalization and the rapid digitalization of economies in the wake of COVID-19 has led to growing digital divides in the Arab region. Even if communities technically have physical access to digital technologies like computers and smartphones and an Internet connection, they may lack digital literacy and use. As at 2019, only 55 per cent of individuals in the Arab region had access to the Internet, with only 47 per cent of women and 34 per cent of individuals in rural areas having access (ESCWA, 2021). Parts of the region also experience energy vulnerability, mainly due to the countries' inability to provide universal access to reliable modern energy services, which has widespread socio-economic and environmental repercussions. All of these factors hamper the adoption of digital solutions like blockchain for efficient energy delivery, particularly in rural areas where the quality of energy and IT services is generally lower. The region also has limited instances of smart grids[15], which can fully harness the benefits of blockchain technologies by leveraging the latest IT and energy infrastructure.

3. Interoperability and compatibility with legacy systems

Different blockchains have unique features and advantages. This diversity can create challenges in ensuring effective communication between disparate blockchain systems. Different stakeholders may also prefer different networks, leading to a fragmented technological landscape that hampers seamless transactions and data flow. Energy trade across international borders introduces additional complexity due to varying regulations and blockchain standards. Furthermore, blockchain networks differ in transaction speeds and costs, posing integration challenges. Concerning legacy systems, utilities and energy providers often work with outdated software and physical systems, which are expensive and time-consuming to integrate with blockchain solutions. Transitioning to a new system can cause operational delays, especially if there is a lack of workforce training. Vendor dependencies further complicate the transition. For a comprehensive digital transformation, there is a need for more integrated use of technologies like IoT and AI along with blockchain.

4. Scalability, security and cost

Introducing blockchain-based solutions can bring scalability, security and cost challenges. If improperly implemented, these systems risk diminished performance and potential privacy breaches. Energy markets often require handling thousands of transactions per second, which may outstrip the capabilities of certain existing blockchain technologies. The financial aspect of digital transformation may be prohibitive, especially for rural communities and states with limited budgets. Furthermore, a strong economic rationale for blockchain is essential for creating the right regulatory environments. Like all digital systems, blockchain is not exempt from security threats, which necessitates robust cybersecurity measures and international standards.

5. Technical expertise

The blockchain field, being relatively new, faces both a quantity and quality shortage of professionals in the Arab region and globally. In Arab rural communities, there is a significant shortfall of technical expertise needed to design, install and maintain sustainable energy systems. This deficit presents a substantial challenge to implementing the latest digital technologies. Training and upskilling initiatives can help, but the industry must invest significantly to bridge this gap. From a gender lens, there has been progress globally, but more work is needed to ensure gender equity. A 2022 report, conducted by LinkedIn and cryptocurrency exchange OKX, found that the total number of people working in the blockchain industry among LinkedIn's worldwide members grew by 76 per cent year-on-year as at June 2022, with men accounting for 80 per cent of roles globally (LinkedIn, OKX, 2022).

6. Public awareness and acceptance

The general public in the Arab region and globally has limited understanding and acceptance of advanced digital technologies in the energy sector, thus hampering the effective implementation of blockchain. Common misconceptions about blockchain technology, especially its association with cryptocurrencies, obstruct broader acceptance. The notion of trust in a decentralized system is relatively new and introduces unique challenges, especially in regions where blockchain experience is limited. The substantial energy requirements of some blockchains further influence negative public perception of the technology. It is crucial to note, however, that for energy sector applications, energy-efficient blockchains, such as Energy Web, Ethereum, Hyperledger, Hashgraph[16] and others, are predominantly used, substantially alleviating concerns regarding energy intensity.

7. Cross-cutting challenges

The political and economic landscapes in some Arab countries present overarching challenges to the introduction and implementation of blockchain and other digital technologies in the energy sector. There's a need for localized training and equitable benefit distribution to ensure that the transition to digitalization is inclusive and leaves no one behind, particularly women and marginalized groups. Additionally, the unique challenges in the Arab region, such as instability and conflict, can inhibit progress in energy innovation and may compound the perceived risks associated with emerging digital technologies.

3 Conclusions and recommendations

Technology, data and blockchain, in specific, can play a pivotal role in achieving the SDGs by addressing various challenges across economic, social and environmental spheres. As Arab countries continue on the path towards a just, inclusive and sustainable energy transition, blockchain technology is emerging as a pivotal component in the digital toolbox to navigate the intricate energy landscape. As the energy sector evolves towards comprehensive digitalization, it is essential to glean insights from global best practices in policy, regulation and successful implementations. Customizing these to the region's unique needs can catalyse progress. The following recommendations outline a comprehensive approach to enable blockchain implementation as a key component of the sustainable energy transition in the Arab region:

- **Develop a comprehensive digital roadmap:** Arab countries should formulate a clear roadmap outlining the strategic integration of digital technologies, including blockchain, across the energy sector. This roadmap will not only facilitate private sector engagement and investment but also ensure a synchronized and holistic implementation.
- **Enhance energy governance and institutions:** Accelerating intellectual and technological capacity requires strengthening energy governance and institutions. Strong governance structures can define clear regulatory guidelines for the use of blockchain, aligning it with national energy policies and standards. This could facilitate a quicker and more organized rollout of blockchain projects. Institutions and regulatory agencies can monitor blockchain implementation for compliance with environmental, financial and operational standards, building trust among stakeholders. Enhanced governance also allows for better coordination between different governmental agencies, industry players and academic institutions, which is crucial for sharing knowledge and resources.
- **Establish robust regulatory frameworks:** Arab countries should formulate regulatory frameworks catering to critical aspects of the sustainable energy transition, such as renewables integration, net metering or billing for DER, energy storage guidelines, and the establishment of smart grids. These regulations should be adaptive, accommodating local nuances and necessities. Additional incentives, such as subsidies for low-income households, could encourage increased participation in DER adoption.
- **Accelerate progress on SDG7 targets:** With emerging digital technologies promising enhanced grid flexibility, it is imperative for Governments to set ambitious renewable energy benchmarks, aligning with the Paris Agreement and the 2030 Agenda for Sustainable Development. Such plans should be propelled by public ventures and fortified with resources by the global community.
- **Revamp energy markets and infrastructure:** A paradigm shift towards the end-to-end digitalization of the energy sector necessitates reform of energy markets and the requisite infrastructure. Policies should promote multidirectional power and data flows, restructure pricing mechanisms, and address any adverse impacts on vulnerable communities (such as rising energy costs in the near term). Recognizing the pivotal role of digital infrastructure, investments in high-speed internet, cloud computing, and data analytics are essential to underpin digitalization efforts within the energy sector.
- **Leverage regional and global best practices:** Decision makers should identify, adapt and adopt successful use cases, policies and regulations that resonate with local needs. Customization is key, ensuring fairness and equity across various contexts, from rural off-grid settings to urban grid-connected environments.
- **Cultivate digital skills and education:** By prioritizing reskilling initiatives, the region can foster innovation and expertise within the energy sector. To ensure the workforce possesses the skills necessary for blockchain and emerging technologies, robust investments in training and educational programmes are imperative to bolster expertise across the board and ensure seamless integration.
- **Promote regional and international partnerships and foster public-private partnerships:** Collaborations between the public and private sectors are instrumental in accessing expertise and capital required for digitalization endeavours. Initiatives should encompass pilot projects that pave the way for full-scale implementation. Realizing the full potential of energy integration and digitalization also necessitates forging strong regional and international partnerships in order to transfer technologies from leading countries in and outside the region to those just starting to implement blockchain in the energy sector. Operationalizing grid connections, joint infrastructure ventures, and fostering market ties across borders can yield substantial gains for the region and enable the use of emerging digital tools, like blockchain.

The digitalization of the energy sector presents countries in the Arab region with a transformative opportunity to pursue a just, inclusive and sustainable energy transition. By leveraging emerging digital tools like blockchain, as part of a toolbox, renewable energy integration can be increased while also increasing access to modern energy services and improving efficiencies, making progress more equitable and just. By adopting a holistic approach encompassing policy, regulation, technology and collaboration, the region can expedite its transition to a sustainable and digitally advanced energy landscape. Through these concerted efforts, the Arab region can lay the foundation for a prosperous and environmentally responsible energy future which leaves no one behind.

References

Acciona (2021). Acciona develops first platform to guarantee renewable origin of green hydrogen. Available at: https://www.acciona.com/updates/news/acciona-develops-first-platform-guarantee-renewable-origin-green-hydrogen/.

Al-Monitor (2022). Lebanese turn to cryptocurrency as economy tanks. Available at: https://www.al-monitor.com/originals/2022/02/lebanese-turn-cryptocurrency-economy-tanks.

Bahrain Ministry of Sustainable Development (2020). Sustainable Energy Authority issues first renewable energy certificate. Available at: https://sdgs.gov.bh/NewsDetails?nid=U/BbbNA6nsjaoAUZ4FXABw==.

Chainalysis (2022). The 2022 Geography of Cryptocurrency Report. Available at: https://go.chainalysis.com/geography-of-crypto-2022-report.html.

Chang, Kuo-Chi and others (2021). Barriers and challenges to smart grid technology deployment in the Kingdom of Saudi Arabia (KSA). 10.1007/978-3-030-76346-6_18.

CCN (2018). Abu Dhabi National Oil Company partners IBM to pilot blockchain across its value chain. Available at: https://www.ccn.com/abu-dhabi-national-oil-company-partners-ibm-to-pilot-blockchain-across-its-value-chain/.

CoinDesk (2022). Crypto carbon credits: slapping lipstick on a pig. Available at: https://www.coindesk.com/layer2/2022/07/18/crypto-carbon-credits-slapping-lipstick-on-a-pig/.

Coinbase (2023), "What is DeFi?." Available at: https://www.coinbase.com/learn/crypto-basics/what-is-defi.

DEWA (2021). DEWA's EV Green Charger initiative supports electric vehicle adoption in Dubai. Available at: https://www.dewa.gov.ae/en/about-us/media-publications/latest-news/2021/05/dewas-ev-green-charger-initiative.

Economic and Social Commission for Western Asia (ESCWA) (2019). Energy Vulnerability in the Arab Region. Available at: https://www.unescwa.org/sites/default/files/pubs/pdf/energy-vulnerability-arab-region-english_0.pdf.

ESCWA (2021). Digital divide and open Government in the Arab region. Available at: https://www.unescwa.org/sites/default/files/pubs/pdf/digital-divide-open-government-arab-region-english.pdf.

ESCWA (2023a). Blockchain for trade facilitation: a user implementation guide for Governments. Available at: https://www.unescwa.org/sites/default/files/pubs/pdf/blockchain-trade-facilitation-guide-english_0.pdf.

ESCWA (2023b). Review of progress in the Arab region under the Decade for Sustainable Energy. Available at: https://www.unescwa.org/sites/default/files/pubs/pdf/progress-arab-region-decade-sustainable-energy-english.pdf.

Elia Group (2023). Market integration of electric vehicles using blockchain technology. Available at: https://innovation.eliagroup.eu/projects/market-integration-of-electric-vehicles-using-blockchain-technology/.

Energy Web (2022a). Elia ReBeam- Frictionless EV charging using a supplier and charging point of your choice. Available at: https://www.energyweb.org/case-study-elia-rebeam/.

Energy Web (2022b). Elia successfully demonstrates TSO-visible EV charging in collaboration with Energy Web and BMW Group. Available at: https://medium.com/energy-web-insights/elia-successfully-demonstrates-tso-visible-ev-charging-in-collaboration-with-energy-web-and-bmw-35c80f4eab1d.

Energy Web (2022c). Energy demand and generation exchange. Available at: https://www.energyweb.org/case-study-project-edge/.

Energy Web (2022d). 24/7 green EV charging. Available at: https://www.energyweb.org/case-study-green-proofs/.

Engie (2022a). An innovative financing method for universal access to electricity. Available at: https://www.engie.com/en/news/crowdfunding-blockchain-cryptocurrency-energy-access.

Engie (2022b). Leveraging crypto to expand solar energy access. Available at: https://innovation.engie.com/en/news/news/new-energies/leveraging-crypto-to-expand-solar-energy-access-energy-web-foundation-viva-technology/27421.

Gramlich, Vincent and others (2022). Decentralized Finance (DeFi): foundations, applications, potentials, and challenges. Branch Business & Information Systems Engineering of Fraunhofer FIT. Available at: https://www.fit.fraunhofer.de/content/dam/fit/de/documents/Whitepaper__DeFi__English_Version_2022_07_15.pdf.

Grid Singularity (2023). Website. Available at: https://www.gridsingularity.com.

The International REC Standard (I-REC) (2022). An Introduction to REC schemes. Available at: https://www.irecstandard.org/what-are-recs/.

Iberdrola (2023), Blockchain in the energy market: How can blockchain be used to certify the source of green energy? Available at: https://www.iberdrola.com/innovation/blockchain-energy.

IBM (2023), What are smart contracts on blockchain? Available at: https://www.ibm.com/topics/smart-contracts.

International Energy Agency (IEA) (2023). Data provided by IEA.

International Renewable Energy Agency (IRENA) (2019). Innovation landscape brief: Blockchain, International Renewable Energy Agency, Abu Dhabi. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Landscape_Blockchain_2019.pdf

IRENA and Rocky Mountain Institute (RMI) (2023), Creating a global hydrogen market: Certification to enable trade. Available at: https://www.irena.org/Publications/2023/Jan/Creating-a-global-hydrogen-market-Certification-to-enable-trade.

Khan, Hamzah and Tariq Masood (2022). Impact of blockchain technology on smart grids. Available at: https://doi.org/10.3390/en15197189.

KlimaDAO (2022). Website. Available at: https://www.klimadao.finance/.

LinkedIn, OKX (2022). Global Blockchain Industry Talent Insights. Available at: https://theblockchaintest.com/uploads/resources/the%20Blockchain%20Academy%20-%20the%20Global%20Blockchain%20Employment%20Report%20-%202022%20March.pdf.

LO3 Energy (2023). Introducing Pando: optimizing clean energy outcomes for suppliers, developers, and their customers. Available at: https://lo3energy.com/.

Massachusetts Institute of Technology (2018). Inside the Jordan refugee camp that runs on blockchain. Available at: https://www.technologyreview.com/2018/04/12/143410/inside-the-jordan-refugee-camp-that-runs-on-blockchain/.

Newswire (2018). KAUST set to be first university in Middle East to issue blockchain credentials using blockcerts open standard. Available at: https://www.newswire.com/news/kaust-set-to-be-first-university-in-middle-east-to-issue-blockchain-20703496.

Power Ledger (2023a). xGrid. Available at: https://www.powerledger.io/platform-features/xgrid.

Power Ledger (2023b). uGrid. Available at: https://www.powerledger.io/platform-features/ugrid.

PwC (2016). Blockchain – an opportunity for energy producers and consumers? PwC Global Power and Utilities. Available at: https://www.pwc.com/gx/en/industries/assets/pwc-blockchain-opportunity-for-energy-producers-and-consumers.pdf.

PwC (2022). Making sense of bitcoin, cryptocurrency and blockchain. Available at: https://www.pwc.com/us/en/industries/financial-services/fintech/bitcoin-blockchain-cryptocurrency.html.

Regional Center for Renewable Energy and Energy Efficiency (RCREEE) (2020). Blockchain applications in the energy sector. Available at: https://rcreee.org/publications/blockchain-technology-energy-fields/.

Roberts, David (2018). Clean energy technologies threaten to overwhelm the grid. Here's how it can adapt. Vox Media. Available at: https://www.vox.com/energy-and-environment/2018/11/30/17868620/renewable-energy-power-grid-architecture.

Reneum (2023). Website available at: https://reneum.com/.

RMI (2022). RMI partners with Energy Web Foundation to build sustainable aviation fuel certificate registry, as part of ongoing decarbonization work with the sustainable aviation buyers alliance. Available at: https://rmi.org/press-release/rmi-partners-with-energy-web-foundation-to-build-sustainable-aviation-fuel-certificate-registry/.

Sedaoui, Radia (2022). Chapter 33 as part of M. Hafner, G. Luciani (eds.), The Palgrave Handbook of International Energy Economics, https://doi.org/10.1007/978-3-030-86884-0_33.

Siemens Energy (n.d.). Clean energy – growing from need to certification, webinar. Available at: https://www.siemens-energy.com/global/en/home/publications/webinar/webinar-clean-energy-certification.html.

SP Group (2023). Renewable Energy Certificate Marketplace. Available at: http://rec.spdigital.io/.

Sustainability Middle East (2023). National system for carbon credits using blockchain. Available at: https://www.sustainabilitymenews.com/technology/national-system-for-carbon-credits-using-blockchain.

Strüker, Jens and others (2021). Decarbonisation through digitalisation: proposals for transforming the energy sector, Bayreuther Arbeitspapiere zur Wirtschaftsinformatik, No. 69, Universität Bayreuth, Lehrstuhl für Wirtschaftsinformatik, Bayreuth. Available at: https://doi.org/10.15495/EPub_UBT_00005762.

The Energy Origin (2023). Website. Available at: https://theenergyorigin.com/; https://gems.engie.com/solutions-for-our-clients/green-energy-certification-transparency-blockchain/.

The Sun Exchange (2023). Website. Available at: https://thesunexchange.com/.

The Wall Street Journal (2022). Crypto crash stalls WeWork founder Adam Neumann's climate venture. Available at: https://www.wsj.com/articles/crypto-crash-stalls-wework-founder-adam-neumanns-climate-venture-11657963804?page=1.

United Nations (2022). Addressing Energy's Interlinkages with Other SDGs. Available at: https://sdgs.un.org/sites/default/files/2022-06/2022-UN_SDG7%20Brief-060122.pdf.

United Nations Conference on Trade and Development (UNCTAD) (2022). Project explores blockchain solutions for trade facilitation. Available at: https://unctad.org/news/project-explores-blockchain-solutions-trade-facilitation.

United Nations Development Programme (UNDP) (2022). UNDP RBAP: #Web3for2030: How can Web3 help achieve the Sustainable Development Goals. Available at: https://www.undp.org/publications/web3for2030-how-can-web3-help-achieve-sustainable-development-goals.

World Economic Forum (2022). How can blockchain open access to carbon markets?. Available at: https://www.weforum.org/agenda/2022/07/how-can-blockchain-open-access-to-carbon-markets/?utm_source=sfmc&utm_medium=email&utm_campaign=2781088_Agenda_weekly-5August2022&utm_term=&emailType=Agenda%20Weekly.

World Food Programme (2017). Blockchain against hunger: harnessing technology in support of Syrian refugees. Available at: https://www.wfp.org/news/blockchain-against-hunger-harnessing-technology-support-syrian-refugees.

World Bank (2023). Data provided to ESCWA by The World Bank.

Wu, Jiani and Nguyen Khoi Tran (2018). Application of blockchain technology in sustainable energy systems: an overview. Available at: https://doi.org/10.3390/su10093067.

Endnotes

1. A prosumer is someone who both consumes and produces power using distributed energy resources like solar, wind and/or battery storage.
2. An NFT is a unique digital token representing ownership or proof of authenticity of a specific item or piece of content on the blockchain. Unlike cryptocurrencies, such as Bitcoin or Ethereum, where each unit is identical (or fungible), each NFT has distinct information or attributes that make it unique. NFTs are commonly associated with digital art, collectibles, music, videos and other forms of creative content, allowing creators to monetize their work in new ways and giving buyers a verifiable digital certificate of ownership.
3. A cryptocurrency is a medium of exchange, such as the US dollar, but is digital and uses cryptographic techniques and its protocol to verify the transfer of funds and control the creation of monetary units (PWC, 2022).
4. The Bitcoin blockchain is currently being secured by over 415 terahashes per second from mining, which uses over 16GW of continuous power (as of May 2023 according to Cambridge Bitcoin Electricity Index and Y Charts).
5. The Ethereum blockchain is currently being secured by over 570,000 validators with over $32 billion in staked Ether (as of May 2023 according to Beaconcha.in).
6. Energy Web Foundation, Energy Web Chain Governance, 2023.
7. Crypto Carbon Ratings Institute, Ethereum's merge, 2023.
8. Asset tokenization involves representing the ownership rights of real-world assets as digital tokens on a blockchain.
9. Smart contracts are simply programs stored on a blockchain that run when predetermined conditions are met. They are typically used to automate the execution of an agreement so that all participants can be immediately certain of the outcome, without any intermediary's involvement or time loss. They can also automate a workflow, triggering the next action when conditions are met (International Business Machines Corporation, 2023).
10. Depending on the type of blockchain used.
11. These figures are correct as at August 2023.
12. Transaction fees depend on which blockchain is used and on when transactions are being made. "Gas prices", or the fees users pay to have a transaction processed, can substantially increase during periods of elevated chain use, making the chain inefficient for small-scale transactions.
13. Actual access rates could be lower than 91 per cent as access is measured mostly through the accessibility of grid networks, which does not guarantee the grids are energized, or the end users actually have sufficient electricity.
14. The Cooperation Council for the Arab States of the Gulf, also known as the Gulf Cooperation Council, is a regional, intergovernmental, political and economic union comprising Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates.
15. Smart grids are essentially modernized electrical grids that use advanced digital technology to improve the efficiency, reliability and sustainability of the electricity they deliver. They can enable the distribution of electrical energy automatically to consumers. These intelligent systems can balance supply and demand and are capable of detecting power quality gaps and voltage variation control.
16. Hashgraph is technically a distributed ledger technology and not a blockchain, but this distinction goes beyond the scope of this technical paper, as they accomplish a similar purpose and are often used interchangeably.

The present technical paper explores the transformative potential of blockchain technology in the Arab region to manage an increasingly complex energy sector, characterized by a shift towards digitalization, decentralization and decarbonization. It asserts the importance of intelligent digital tools in empowering stakeholders to adapt to evolving energy landscapes through increased transparency and efficiency. The report contends that successful blockchain implementation requires a thoughtfully designed, case-specific approach, weighing the need for transparency, speed, security and cost. As blockchain technology continues on its rapid development path, with new decentralized applications and use cases, Arab countries stand to benefit from integrating this tool within their overall digitalization strategies for a just, inclusive and sustainable energy transition.

The present technical paper also outlines the key challenges and opportunities for the technology in the Arab region. It highlights promising use cases from the region and around the world which leverage blockchain in the energy sector, and provides a set of strategic pillars and policy recommendations to ensure this emerging technology supports the sustainable energy transition in the Arab region.

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