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Blockchain Technology and Renewable Energy Access: A Case for sub-Saharan Africa

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***Abstract*—As the developed world continues to advance technologically and closes the gap in deficiencies of existing economic, financial and environmentally 'green' systems, while consequently improving the socio-economic indices of their respective countries and citizens; a measure of introspection is not amiss in considering the challenges that beset their third world counterpart- Africa. The continent still struggles with issues that relate to energy poverty and overall access, as there are indicators that a large majority still have no access to modern, affordable and reliable energy services. The major constraints are identified as inadequate or unavailable financing, invalid or non-existent policies and largely unstable political environments. The SE4ALL mandate in accordance with the Paris Agreement stipulates the need for effective climate change policy, the imperative for improved energy efficiency and the need for inclusion. A dynamic approach is therefore required to provide energy access to the most vulnerable, especially in the rural and urban slums of sub-Saharan Africa. This paper suggests that blockchain technology is potentially that medium and therefore assesses the current advancements, challenges and its potential application within the regional energy context using the diffusion of innovation theory. The results suggest alternative platforms such as Iota being deployed in the near term, due to a lack of requisite network infrastructure and the financial handicap of the region. However, the emphasis on innovative and disruptive business models for harnessing renewable energy sources towards improved energy efficiency and overall socio-economic development, remains. The key is in the adoption of technology that is tailored specifically, towards a sustainable energy future for sub-Saharan Africa.**

Keywords—energy, energy efficiency, Africa, blockchain, sustainable development

I. INTRODUCTION

The World Bank recently launched its blockchain (BC) operated new debt instrument- "bond-i", which is the world's first bond to be created, allocated, transferred and managed through its life cycle using distributed ledger technology. A$110 million was realised from the two-year bond in August 2018, with the Commonwealth Bank of Australia as lead arranger[1]. This feat marked the first time investors would support the World Bank's development drive in a transaction fully managed using blockchain technology. The excitement is understandable as this was a real market transaction that adopted the technology on this scale, thus providing considerable credibility to the platform.

Energy remains a major factor in the consideration for social and economic well-being of any society. Improvements in standards of living are evident in increased productivity in terms of food production, healthcare, housing and other desirable amenities. All these require increased energy consumption and statistics show that 80% of the global population living in developing countries consume only 30% of global energy, meaning that by 2030, 1.3 billion people out of the 2.7 billion today[1], would still have no access to modern, affordable and reliable energy services. Therefore, future economic development is largely hinged on a sustainable energy future. The focus consequently, should be to secure policies and programmes that insure our energy future towards sustainable development.

The advancements being made in the developed world towards climate change mitigation and steadying global temperatures invariably means that by 2030, the percentage of the 1.3 billion population without access to modern, affordable and reliable energy services will without a doubt be situated in sub-Saharan Africa[2]. The remedy in the face of inadequate national support systems to attract investment, inadequate financial capacity, dysfunctional judicial and regulatory environments, politically charged environments and inadequate incentives for business investments in deficient sectors such as energy[3], can only be addressed through a disruption in the business-as-usual approach.

The blockchain technology has key characteristics such as decentralisation, persistency, anonymity and auditability[4] and can significantly reduce costs and improve efficiency[5]. The beauty of this technology is that even though it has largely been applied within financial services, its reach is not confined to this space and thus makes it a viable option for solving Africa's energy access, poverty and financing challenges.

Energy Efficiency (EE) indices are largely improved through the financing and proliferation of smart systems and appliances within a given economic space. The paper addresses the inherent challenges and ultimately the modalities for the adoption of blockchain technology within this context. The overall objective is to ensure that the region is included in this wave of innovation and ultimately the fourth industrial revolution. The pertinence of this work is evident in the gap between the advancement of the blockchain technology and its application to the sub-Saharan African environment, with a focus to improve energy efficiency. To the best of our knowledge, the available literature does not address this issue.

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[1] https://www.worldbank.org

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II. BLOCKCHAIN TECHNOLOGY- OVERVIEW, APPLICATION AND LIMITATIONS

A. Technology Overview

BC technology possesses revolutionary potential equal to that of the Internet, and could be deployed and adopted much more quickly, given the network effects of current widespread global Internet and cellular connectivity [6].

Blockchains basically enable a given set of users to record transactions in a ledger that can be viewed by those specific users. The recorded transactions cannot be changed once they are published. Participants or users subsequently agree that a transaction is valid by "reaching consensus" [4], [5].

Distributed consensus facilitates agreement between individuals across a peer-to-peer network. Blockchains require this before a validated block is added to the chain. Miners are rewarded when this happens and they therefore compete against each other. This agreement is achieved through distributed consensus algorithms (DCA) [7]. They are as follows:

Proof of Work (PoW) [8,9], This consensus model is designed for cases of minimal trust amongst users of the system. [7], [8][9].

Proof of Stake (PoS) [12,13] operates on the premise that the higher a user's stake is in the system, the propensity to protect and advance the system instead of sabotaging it is higher.

Round Robin Consensus Model assumes a measure of trust exists between mining nodes and therefore eliminates any complicated consensus mechanism, which determines the participant who adds the next block to the chain.

Proof of Burn (PoB) prioritises the next block creating node based on a demonstrable burning of some of their coins by moving them to an unspendable address which is verified [4], [5].

The DCAs are structured to incur a considerable cost to the mining nodes. The completion of a block formation task is rewarded with a payment, comprising fees that each participant is obliged to pay, to secure transaction completion and an amount of the network's cryptocurrency [5].

B. Applications of Blockchain Technology

Blockchains are able to facilitate enterprise transformations. In the case of postal operators (POs) who act as intermediaries between vendors and customers, their roles can be extended in the provision of services such as, device management, identity services and supply chain management [4], [10]. This provides ample business opportunities for a traditional organisation, using blockchain technology.

Blockchain-based Multiparty Computation (MPC) markets enable the offloading of computational tasks onto a network of anonymous peer-processors[11].

Internet of Things (IoT) is expected to integrate smart objects to the internet and provide users with various services. Common applications of IoT include smart homes, e-health, smart grids, and logistics management with Radio-Frequency Identification (RFID) technology [4], amongst others. Transactions of smart property that are based on blockchain and smart contracts are a new IoT e-business model being proposed. The model adopts Distributed Autonomous Corporations (DAC) as decentralised transaction entities. This allows for exchange of sensor data and obtaining coins without a third party[5], [7].

Blockchains can be applied in public and social services. One typical application is for land registration. This allows land information such as those related to its status and rights, to be registered and publicised on blockchains. This would invariably encourage public service efficiency, as any alterations to the land details such as changes in ownership can be easily recorded and managed on blockchains [5].

Blockchains can also be applied in green energy. The proposed 'solarcoin' is expected to promote viable renewable energy (RE) sources. Solarcoin is a digital currency that rewards solar energy producers. The Solarcoin foundation permits mining and grants solarcoins for generating solar energy [10].

Blockchains were originally envisioned to enable currency transactions in minimal trust environments. However, considering learning and teaching processes as currency, BC technology can therefore be valuable to the online education market. Blockchain learning would allow teachers pack and place blocks into blockchains, where learning outcomes and achievements represent coins[5].

C. Limitations

As an emerging technology, blockchain faces certain limitations. They are enumerated accordingly.

The increasing amount of daily transactions ultimately makes blockchains heavy. The Bitcoin blockchain has surpassed 100 GB storage[5] due to all transactions being stored for validation purposes. Bitcoin can only process about seven transactions per second, which is insufficient for real-time transaction processing. The slow transaction speed is caused by original restrictions that were placed on block size and the time required to generate a new block. [5].

Blockchains offer anonymity for users. The transactions are done with addresses that are generated instead of real identity. However, privacy is not guaranteed, as the values of all transactions and balances for each public key are visible to the public. It has also been proven that a user's Bitcoin transactions can be traced to reveal user information, with an equal method to connect user pseudonyms to IP addresses even when using Network Address Translation (NAT) or firewalls [5].

The use of blockchain technology is not a panacea, and certain limitations must be considered. These include how to manage or penalise malicious users, how to apply controls and the inherent limitations of any blockchain implementation; before a sweeping embrace and adoption of the technology can happen. A blockchain system is effective in the enforcement of transaction rules and specifications, but limited in enforcing a code of conduct [7].

Blockchain technology has enabled a global network of value, that verifies transactions and allows the blockchain to be stored in a synchronised fashion amongst a range of varied users. However, users are tasked with the responsibility of managing their own private keys, as any loss of key would essentially translate into a loss information and mainly digital assets. No “forgot my password” or “recover my account” option currently exists for blockchain systems [7].

Another issue relates to taxation, as a potential shift from an income tax–based system to a consumption tax–based system could herald significant changes and system overhauls for societies, therefore how government regulation unfolds could be one of the most significant factors and risks to whether the blockchain industry flourishes [5], [7].

III. BLOCKCHAIN APPLICATION AND USE CASES IN THE ENERGY INDUSTRY

Blockchains can be used to create new business structures and ecosystems within the energy sector, that can compete favourably. BC ecosystems are fuelling new kinds of energy services- such as balancing grid supply and demand, scheduling consumer device operation for Electric Vehicle (EVs) charging remotely and running washing machines[5]. Microgrids enable residents within a given location, to effectively manage their use and even generate and sell power, using solar panels or other alternative renewable energy methods.

Blockchain infrastructure favours products that utilise renewable forms of energy. A portion of businesses in this space, encourage trade in the generated renewable energy, while others support adoption and better utilisation of household-level generation [10].

The emphasis on purchasing energy on a needs basis encourages the user to re-evaluate energy consumption and expenditure. This provides a solid foundation for Energy Efficiency(EE). BC technology is not without its limitations and challenges, in terms of seamless implementation in the energy industry; which is due in part to rigid industry regulation and established monopolies [12]. This is unfortunate considering the attendant benefits which have been outlined.

There remains considerable breadth and depth for the integration of blockchain technology within the energy sector and this is most certainly a welcome development, which should be explored with reasonable fervour.

IV. A CASE FOR AFRICA – ENERGY IMPERATIVES AND ENERGY EFFICIENCY GOALS

Developing countries remain most vulnerable due to their dependence on fossil energy, lack of functional regional electricity and gas markets and high technical and commercial grid losses [2]. It has been shown that the well-being of the poor remains largely disadvantaged, as they spend more income for low-quality energy services, as against the those who can easily afford these services and are rewarded with even higher quality in terms of service delivery [2]. By 2030, cities will absorb in excess of 73% globally generated energy and the expanding urban populations alongside increasing energy demands, signals the urgency for major investment in energy infrastructure and its related interventions.

Sub-Saharan Africa comprises all African countries that are located to varying extents, south of the Sahara. The Africa Millennium Development Gap Report 2015, tags the region as lagging behind, owing to a failure in reducing the proportion of people living in poverty by 50%, including those suffering from hunger. Success in this regard, would have signalled the eradication of extreme hunger and poverty[2]. In 1990, just over five out of every ten people- 56.5% were living in poverty, 48.4% is the estimated stand twenty years later. This equates to a 14% fall which should have been at least 28.3%, but still represents 50% of 1990 levels. However, of the thirty African countries assessed, five had increased poverty levels[3] [18].

Access to energy finance and investments have also been hampered by inadequate national support systems, inadequate financial capacity for energy investment, slow judicial processes for settling disputes, inadequate strategies for offshore financing, political and regulatory risks for investment in energy infrastructure and inadequate or non-existent incentives to businesses encouraging investment in new technologies[3].

Renewable energy is expected to play a pivotal role in satisfying increasing demand for electricity, transport, heating and cooling in urban areas, while equally enabling access to rural energy services[2]. Energy efficiency is a key consideration in this regard, as it potentially delivers faster and evident results in terms of energy savings which contribute in mitigating global GHG emissions and overall energy demand at relatively low costs. Innovative technology-based solutions and focused investment can help to reasonably manage energy consumption, curtail emissions and generate income; especially through conscious lifestyle patterns, improved manufacturing processes, electric vehicles and mass transit systems [2]. These proposals are already a reality for most developed nations, with significant renewable energy components recorded in the economic systems of The Netherlands, Norway, Sweden and Germany.

The Sustainable Energy for All (SE4ALL) Initiative was established to galvanise action in support of three interlinked objectives, with a 2030 timeline. They include, providing universal access to modern energy services, increasing the global rate of improvement in energy efficiency and increasing the share of renewable energy in the global energy mix[2]. SE4ALL affirms that business-as-usual solutions are ineffective in delivering these objectives, especially for those in the urban slums and rural parts of Africa. In order to achieve the interlinked objectives of the Sustainable Development Goal (SDG) 7-clean energy and the Paris Agreement, new and innovative mechanisms for energy service delivery that specifically impacts the people and communities currently being left behind, are both essential and imperative [20] [19].

A. *Countries in Focus: Nigeria, Ghana, Kenya, & Rwanda*

Nigeria is the largest economy in sub-Saharan Africa with a teeming population of approximately 200 million. However, limitations in the power sector constrain growth. Statistics capture installed capacity at 12,522 MW with thermal capacity at 10,142 MW and Hydro at 2,380 MW. A record 20 million households are currently without power and universal access target is currently set for 2030[4].

The country is an Economic Community of West African States (ECOWAS) member and is committed to

[2] https://www.un.org/africarenewal
[3] https://www.un.org/africarenewal
[4] https://www.usaid.gov/powerafrica

implementing the SE4ALL Country Action. The proactive development and formal adoption of the Action Agenda, with the Renewable Energy and Energy Efficiency Action Plans, facilitated the following targets[5] as summarised in Table I below:

TABLE I: NIGERIA'S TARGETS AND STATISTICS

NIGERIA	Targets and Timelines
Electricity Access	**Overall**: 75%; **Urban**:90% **Rural**: 60%(2020), 90% (2030)
Installed Generation Capacity	7500MW (2015); 115,000MW (2030)
Energy Efficiency	20%(2020); 50% (2030)
Renewable Energy Targets	**Hydro** (small and large): 9% & 13% contribution by 2015 and 2020 respectively; **Wind**: 1% contribution by 2020; **Solar**: 3% and 6% by 2020 and 2030 respectively

Ghana aims to industrialise, thereby providing enhanced economic opportunities for a rapidly expanding population of approximately 28.2 million. Electricity, remains a key constraint to the country's objectives, due to its unstable and yet expensive supply. Installed generation capacity stands at over 4,000 MW, however, actual availability remains around 2,400 MW due to changing environmental conditions, inadequate fuel sources and supplies and decrepit infrastructure[6]. Households without power is recorded at 1.2 million with a universal access target by 2020. The biggest challenges include inadequate financing of the energy sector, legacy debt, prohibitive generation costs, ambiguous or non-existent procurement framework and ineffective regulatory provisions that would normally encourage competition.

Ghana's SE4ALL targets for electricity access include, increasing effective electricity use in communities with existing on and off-grid solutions through specific programmes, providing universal access to electricity for its island and riverside communities and proliferating access to clean cooking solutions[7]. Additional energy statistics are summarised in Table II below.

TABLE II: GHANA'S TARGETS AND STATISTICS

GHANA	Targets and Timelines
Installed Capacity	Overall: 4,200MW; Hydro: 1,580MW Thermal (Renewable): 22.5MW
Current Access Rate	Overall: 83%; Rural: 50%, Urban: 91%
Renewable Energy Targets	Current contribution: 0.3%; target 10% by 2020

[5] https://www.se4all-africa.org
[6] https://www.usaid.gov/powerafrica
[7] https://www.se4all-africa.org

Kenya opened its energy market to Independent Power Producers (IPPs) in the mid-1990s and has leveraged on this to develop one of sub-Saharan Africa's most advanced power sectors. An established reputation as a creditworthy off-taker and abundant renewable energy resources such as solar, wind and geothermal, have enhanced the country's status in this regard. However, inadequate and run-down transmission and distribution infrastructure, scarce financial resources, questionable procurement practice and other innumerable challenges affect growth in the sector[8] .

Access to electricity was limited to 23% of the population in 2012, which is approximately 1.97 million households; while over 80% of the population relied on traditional biomass as the core energy source for cooking and heating. Kenya joined the SE4ALL initiative[9] and set the following targets, summarised in Table III below:

TABLE III: KENYA'S TARGETS AND STATISTICS

KENYA	Targets and Timelines
Electricity Access and Clean Cooking Solutions	100% access target by 2022
Energy Efficiency	2.78% reduction of total energy intensity annually
Renewable Energy Targets	Increase to 80% contribution

Rwanda is developing rapidly in all sectors and the government aims to take the country from the developing to middle-income category through its sustained effort. The national electrification rate reached 41%- made up of 11% off-grid and 30% on-grid, however, over 7 million people do not have access to electricity. Inherent challenges abound with grid conditions preventing efficient use of power, long-term imbalance of power supply and demand and inadequate or costly financing for off-grid companies. Rwanda**'s** SE4ALL initiative targets are to provide universal access to improved cook stoves and to extend energy efficiency improvements in the electricity sector by 2030[10]. Other statistics and targets are summarised Table IV below.

TABLE IV: RWANDA'S TARGETS AND STATISTICS

RWANDA	Targets and Timelines
Current Generation Capacity	Overall: 209MW; Hydro:110MW; Thermal:98MW
Current Access Rate	Overall: 41%; Urban:72% Rural: 9%
Universal Access Target	52% on-grid; 48% off-grid by 2024
RE Targets	60% of electricity contribution
SE4ALL Target	100% electricity access by 2030 50% of population access, on-grid and off-grid

[8] https://www.usaid.gov/powerafrica
[9] https://www.se4all-africa.org
[10] https://www.se4all-africa.org

B. Discussion

Energy generation has been shown to impact climate change and imbued due attention for energy efficiency and energy saving issues. Household energy use remains a pivotal consideration in this discourse, mostly for improved energy efficiency indices. A change in lifestyle patterns remain imperative, for any real intent to achieve low-carbon environments through energy savings. Subsequently, to realise conservation objectives and boost its metrics, a focus on managing household energy consumption is not misplaced [22], [23].

A change in the average consumers' investment decisions, reliably reduces domestic energy consumption and in turn reduces GHG emissions. These investment decisions relate to the purchase and general attitude towards energy-efficient home appliances, as a key determinant of proliferation within a given community or society. The "status quo bias" in consumer behaviour, was introduced to explain and emphasise the aversion to loss instead of focusing on future potential gains [22]. In this context, energy consumers are depicted as avoiding energy efficient investments, because of high initial costs and deeming future savings through energy conservation unreliable. This is due to potential price volatilities, which signal uncertainty for the consumers [22].

One of the strategic objectives of the ECOWAS policy is to ensure that all energy policies, programmes and initiatives, comprising large energy infrastructure and investments, remain unbiased and non-discriminatory in all aspects, including gender. The policy aims to target inequalities in the region, especially energy poverty, which has varying impacts on men and women [19].

The blockchain technology has been assessed and proven in the West. The key questions now are- in what form should the blockchain technology be employed within the region and what inherent characteristics of this context hamper or promote a blockchain-fuelled energy access objective?

V. DIFFUSION OF INNOVATION THEORY AND ANALYSIS

Rogers [24] defines five attributes for the Diffusion of Innovation (DoI), they are as follows:

Relative Advantage- this determines the degree to which an innovation is deemed superior to the its superseding idea.
Compatibility- determines the extent to which an innovation is seen as consistent with existing values, past experiences and the requirements of potential adopters.
Complexibility- assesses the degree to which an innovation is seen as somewhat difficult to understand and implement. A lower complexibility supports adoption, while a higher degree constrains the rate of adoption.
Trialability- represents the extent to which a given innovation may be experimented with on a limited basis; and
Observability- determines the extent to which the results of a given innovation are evident to others. The higher the degree of these attributes, the higher the propensity of adoption for that innovation.

A. Results

The results of analyses show that the following factors will affect the adoption of the blockchain technology to a large extent within the sub-Saharan Africa region.

Employment and Education: inadequate resources and capacity building opportunities to harness the latent human capital of the region.
Displacement and Resettlement of people due to tribal clashes and insurgent activities; leading to both political and economic instability.
Financing the technology remains prohibitive due to the lack of basic infrastructure, therefore raising the cost of investments exponentially.
Regulatory Provisions which are mostly riddled with inconsistencies and minimal enforceability.
Operational Modalities remains a challenge due to a lack of relevant infrastructure and capacity.
The Paranoia and Wariness associated with Bitcoin and blockchain technology is especially evident in the aftermath of significant financial losses experienced by most investors as in the case of Nigeria; where both the Swissgolden cryptocurrency and MMM Bitcoin scams collapsed, causing huge financial losses for at least 10 million people[11].

In spite of the above, the objective remains to create conditions that will accelerate socio-economic benefits in terms of improved energy access, reduce energy poverty and overall economic empowerment.[19], [20], [25]. The results are summarised in Table V below.

TABLE V. DOI ANALYSIS FOR SUB-SAHARAN AFRICA

INNOVATION ATTRIBUTES	BLOCKCHAIN TECHNOLOGY ADOPTION
Relative Advantage	The BC advantages have been extensively enumerated, but its adoption will be challenged due to a lack of network capacity and infrastructure, including considerable financing constraints. Cloud storage for local blockchains or the implementation of an Iota type platform which requires less computational power for devices, with minimal transaction times and fees may be more realistic in the near term.
Compatibility	Current market frictions with the technology still exist in the West, as regards scalability, costs, security and privacy. Peer-to-peer networks have been proffered to remedy these issues. There is an obvious need for BC adoption, however, due to the novelty of this concept for the region a basis for compatibility based on the defined terminology, is currently non-existent.
Complexibility	There is still a dearth of understanding as regards the technology, and the wariness of investors due to losses from previous BC based schemes, hampers the rate of adoption within the African context. This is attributed to the novelty of the concept in that region, owing largely to lack of skilled technical resources, poor education and awareness, exacerbated by deep financial constraints.
Trialability	The concentration of start-ups that have adopted the technology within the energy industry remains in the West. There is still a lot of room for experimenting with BC in Africa. However, a lot of courage and perseverance will be required to overcome the steep learning curve, in terms of its application to the high risk political and economic environments of the region.
Observability	The results of BC innovation are visible to its direct beneficiaries, i.e. those who have already adopted the technology and have harnessed its efficiencies and cost effectiveness. Inference for the various business models of adoption, can only be drawn from these cases for the African region and are not based off of actual experience. There is a need for experts and the creation of awareness within the target group to be willing to participate or co-operate with a given business model or start-up company/process.

B. Discussion

Cloud storage especially for local blockchains adopting a prosumer model between neighbours, may be more feasible in the near term, as would alternative platforms such as Iota[10] being adapted to context. This is simply due to a lack of requisite network infrastructure and the financial handicap of the region. A potential remedy is in the use of the blockchain technology to develop a fund, scheme or coin similar to the World Bank's bond-i, to finance the off-take of supply and dissemination of energy efficient heating, cooling and lighting systems to the region; or to generally encourage energy efficient schemes towards climate change mitigation and steady global temperatures.

The rewards could theoretically be based on the PoS DCA protocol, where the miner or node with the largest stake, is also the one able to push these appliances to the remote rural parts of the region or to a larger population of the urban poor. Rewards could equally be in the form of the higher adoption of EE appliances per household recorded on the blockchain, and through smart contracts the investor or supplier could also be the miner with the largest stake; duly rewarded with more of a particular cryptocurrency, similar to Solarcoin [10].

Evaluating the blockchain technology from the diffusion of innovation theoretical perspective, highlights the gap between the region in view and the developed nations who currently possess the advantage in terms of knowledge, skill, expertise and financial capacity to harness and reap the benefits that BC technology offers. However, the results of this analysis should not be considered a deterrent, rather a tool for further innovation in terms of not just adopting the BC technology, but equally developing innovative and customised business models to circumvent the challenges of the regional context and deliver similar, if not enhanced benefits for its people.

VI. CONCLUSION

The properties, applications and limitations of the blockchain technology have been reviewed extensively and the potential for its adoption within the sub-Saharan African energy context equally presented. Africa requires an innovative adaptation of existing blockchain business models and its proponents, to its unique environment. This paper is presented with the expectation to bridge the gap in this innovative and disruptive technology era, by including Africa's unique requirements and challenges in the blockchain discussion. It is the World Bank's expectation that developing economies will gradually embrace and adopt blockchain technology to improve their economies. As much as challenges and risks abound, sub-Saharan Africa's human, natural and economic resources, remain a pivotal consideration for the total inclusion and complete realisation of a truly interconnected global energy future.

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