Use cases for Blockchain in the Energy Industry

A critical review

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***Abstract*—This paper reviews major use cases for blockchain architectures relevant to the energy sector and continues with a critical review of issues to study in future research work including as related to energy consumption of blockchain architectures and ensuring a reliable distribution network and security of supply. It also reviews what is happening in the market with relation to smart contracts.**

***Keywords*—blockchain; smart contracts; business models; use cases; risks and opportunities; distribution network; energy consumption**

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1. INTRODUCTION

One of the most simple value propositions is that of the traditional energy supply business model. To remain profitable, national utilities rely on increasing kWh units sold [1] [2]. The basic model which is built on unit volume also drives the whole energy value chain to increase throughput and thus encourages sometimes unsustainable practices in the energy system [3], [4], [5]. Under the traditional business model, new entrants also have difficulty to compete in the market because of the market's national focus and because the business model relies on increasing unit sales [6].

However, it is also well known that business models can emerge and change in industries in response to emerging technological change, in particular technological opportunities, institutional change and pressures in the business environment. Management literature tells us that various dynamics can affect and create new markets, as well as change business models, such as disruptive and radical innovation [7], new technology paradigms [8] and others.

Meanwhile, blockchain technology[1] is often discussed as a promising avenue to support the energy transition, and could be especially transformative in developing countries where blockchain-based financing models could improve energy access to the poor. Some believe that blockchain technology aligns perfectly with the challenge of building an affordable, reliable and at the same time increasingly sustainable energy system, which is also just and equitable to people, and which supports business model innovation among start-ups and incumbents.

Many use cases have emerged for blockchain applications over the last few years, including many promising business models in the energy sector. As for other uses, today there are already 680 cryptocurrencies, there is a plethora of start-ups claiming to use blockchain technology and every major bank is in a blockchain consortium. Blockchain-related start-ups between 2014 and 2015 raised more than USD 800 million [10]. Venture capital investments in blockchain technology-related ventures have surged to USD 1.4 billion in 2016 [11]. As reported in a report by DENA, the German Energy Agency, and referring to Gartner's 2016 edition of the "Hype Cycle for Emerging Technologies" [12] the hype around blockchain is still sitting at its peak of inflated expectations, while bitcoin is already "sliding into the trough [of disillusionment]". Even the World Economic Forum (WEF) [13] a discursive platform for global leaders,

[1] Blockchain or "Distributed Ledger Technology" mainly records the ownership of assets of all participants in a network of blockchain participants. The main characteristic of the technology is that all participants have the same copy of the blockchain stored on their computer. This allows transactions without the need for a trusted third party, an exchange or a notary for the verification of a change in ownership. This is necessary in electronic systems because without verification, money or assets could be copied, which undermines the credibility of the system [9].

emphasizes the "explosive" potential of the technology. The current hot issue is how financial technology or fintech could revolutionize the world of money [14].

This paper reviews several new applications for blockchain in the energy sector. However, before we begin it is important to note early that blockchain architectures are not all the same. A rudimentary division that is often made between different kinds of blockchains is that of *permissioned* and *permissionless* blockchains [15]. In our paper we generally assume we are speaking about the characteristics of permissionless blockchains. Such blockchains are completely open access to everyone and no permission is required from any authority to become a participant in the network. Participants are unknown to each other and trust emerges from game-theoretical incentives.

Permissioned ledgers imply that the participants in the network are known and can be trusted to vote honestly, therefore there is no need to introduce artificial incentives to ensure that co-operation will occur. In some cases, permissioned ledgers could be used to make blockchain transactions more efficient and use less electricity, an issue that is increasingly discussed. Indeed permissioned ledgers do not require the incentive structures that often involve spending physical resources, such as computing power that translates into wasted electricity usage. In permissioned ledgers only trusted members are allowed to participate in the voting process, so the operation of the network can be made faster, more flexible and much more efficient — but at the cost of reduced security, immutability and censorship-resistance [16].

Having discussed briefly the potential too high energy intensity of some permissionless ledgers, we will now leave this concern aside and simply review the short history of promises for blockchain in the energy sector as per potential use cases, without considering the energy intensity of each architecture proposed for use in each business model. We do not have sufficient data to perform such an analysis at this time given the lack of real and long-tested applications in the energy sector so far, and the lack of transparently available information about each business model and its energy usage implications.

Our paper provides a general outlook on the potential opportunities as well as the potential risks associated with blockchain use cases and business models in the energy sector. We only can speculate at this time about how they may change the existing traditional energy supply business model, and what the potential for further disruption of the sector could be, or potentially how much of what is being proposed and promised is actually likely to be only hype. In this paper we also look at business model innovations for trading (using "smart contracts") and financing and facilitating peer-to-peer power generation. Indeed this type of business model innovation if supported by appropriate governance frameworks could lend itself towards more decentralized, democratized and sustainable energy systems around the world, but in order to do so blockchain technology or blockchain architectures chosen for the energy sector also need to become more efficient and less energy intensive, as we will discuss later. Having said that, society is today relying very heavily on technological solutions for human-centered problems and this approach to solving human problems is deficient as technology will never adequately substitute good human decision-making at least from the ethical perspective. Therefore too much reliance on solutions like blockchain will surely come with negative impacts to society. Companies will also exert market power to obtain blockchain technology and crowd-out competitors which could be otherwise offering higher social value. In the end we have to consider that by supporting blockchain for a theoretically more transparent and democratic energy sector, we may be losing more human-centered companies and approaches to offering energy services.

2. MATERIAL AND METHODS

Increasingly the value proposition of players in the energy sector involves previously ignored value propositions like environmental performance, affordability, reliability, perceived autonomy from the system, social responsibility or social inclusiveness, etc. Previously overlooked attributes, or less valued attributes, under a previous system can become more important under a new paradigm such as corporate social and environmental responsibility of the provider. Some consumers may also be willing to trade off some previous value received from a service in exchange for environmental value.

In addition, business models based on ownerless consumption can attract new customer segments, such as customers with lower financial capacity who may not be able to afford to purchase capital intensive technology. New energy business models of the future will deliver multiple benefits beyond the energy customer, towards the energy system itself, such as demand-side management reducing the need to reinforce networks [16] and fuel poverty alleviation having public health benefits [17]. Finally, carbon emission reduction is another value proposition or value capture element of many sustainable energy systems with wide benefits to society beyond customers.

When new entrants, start-ups or incumbents begin to innovate and propose new business models into the energy sector including value capture for less tangible and easily tradable value propositions, complexity is certain to occur in business model development. We will look at this specific business model paradigm in a future paper and also look at how new emerging and potentially breakthrough technologies like blockchain may be stimulants to complex business models that themselves create an innovative business environment simply because of the creation of connections between untraditional partners (e.g. between start-ups with blockchain technology and incumbents of the energy sector) and cross-industry strategic partnerships (such as between ICT players, the financial industry, traditional energy technology providers and energy utilities, or distribution and transmission operators).

Adding to the potential for further business model complexity in the energy sector, let's now add to the mix high levels of technological uncertainty. There is a high level of technological uncertainty involved in the onset of any potentially disruptive technology and this alone is difficult for companies to manage, especially when acting alone, and outside of a well functioning innovation ecosystem. One example is blockchain, and in general the digitalization trend in the energy sector. With this technological uncertainty we create business uncertainty, with investment opportunities but also significant risks to existing investments that is particularly important in the energy sector where distribution and transmission infrastructure is so critical to the security of supply of energy. A disturbance in the traditional patterns among the existing ecosystem of players, and the regulations they rely on to keep the system well under control, could also cause important disarray leading to industrial and economic impacts. Clearly low cost and reliable energy supply is sometimes key to the industrial competitiveness of a region.

Not only are there significant risks to manage in such a critical system to the economy, but there is high uncertainty as per the opportunities that could play out following the onset of new disruptive technologies. Such technologies do not only impact the system in a technological way, but the business practices of the players in this new innovation ecosystem impacts the way stakeholders interact and their expectations (including customer expectations). Therefore, such radical technological developments (even if hyped) can have a great impact on the existing system and the dynamics among stakeholders in that existing system. Technological change (or perceived technological change) can even impact regulatory reforms and they may not always be based on reasonable expectations, especially in the case of a hype around the technology.

In particular, Blockchain provides numerous opportunities and risks to existing business models, and even to existing sustainable business models that are already becoming mainstream around the world. To understand these opportunities and risks, we first aim to understand how blockchain technology is being used in the industry to date, and what are the various "use cases" where blockchain is (or can) impact the energy sector.

The methodology chosen for this first paper is qualitative and based primarily on an exploratory literature review. Our review is based on a wide source of literature (both peer-reviewed and grey literature such as articles and reports sourced primarily on the internet). The use of grey literature such as articles is necessary at this stage, as this is an early emerging area of research and many new and interesting use cases have been emerging only in the last 2-3 years.

3. RESULTS

In this section we look at what projects (or proposed use cases) exist among two categories of players in the energy sector: 1) incumbents and 2) start-ups or SMEs in the energy sector and we attempt to organize this collected information by key blockchain use cases for the energy sector and as relevant to each type of player, even though there are overlaps and relationships between the two.

Among more mainstream uses of the technology, today blockchain is being used primarily for payments in banking, financial and fintech markets. First, it can be used to streamline payment processing with so-called high efficiency, fast and secure transactions. Second, it is said that blockchain can empower global transactions, tearing down national currency borders. Third, it is said that blockchain can minimize auditing complexity for any financial ledger. Beyond that there are many applications ranging from land and property registry, asset ownership and security trading. Also international money transfer, as we know, and the recording of intellectual property rights and copyrights such as in the music industry, as well as for voting. As for payment systems, it could be sensible in uses where blockchain indeed results in cheaper, faster, less error-prone and safer payments than with current payment and settlement systems. However, too many applications today are not necessary given the use and needs of players in the market today (e.g. data management) and some projects to date have been overly ambitious. One example is the smart-contract enabled project DAO (Decentralized Autonomous Organisation) that made headlines in 2016 which was launched as a fully-fledged crowd funding platform and was implemented on the Ethereum blockchain. This case demonstrated the risks involved in such uses and in particular points to the legal issues that will be facing any developed smart contract implementation. It is clear from such early experiences that technological problems still need to be tackled before trust can be gained by users, but also before starting any project one must know more about one fundamental question: is a smart contract a contract at all?

Beyond that, for the energy sector, it must be said that Blockchain can be a very costly method of data management and is highly misunderstood in industries outside of the financial industry. Regulatory bodies understand it even less, or perhaps not at all, which means the energy sector (being a highly regulated sector for good reasons) is potentially not a good candidate for the propogation of uncontrolled blockchain technology. Despite this, beyond facilitating money transfer, it is also true that blockchain is able to facilitate many other systems such as registering dynamically the exchange of assets, and for making payments (including environmental or social goods) and this alone can be of interest to players in the energy sector under an increasingly competitive environment, at least in theory.

3.1 Examples of uses among Incumbents

Before looking at the few examples among incumbents it is worth noting that a recent German Energy Agency (DENA) survey shows that German energy industry executives have the perception that the basic idea of blockchain technology “seems to align perfectly with the challenge of building an affordable, reliable, and at the same increasingly sustainable energy system”. According to the DENA survey more than 80% of the decision-makers consider the further spread of blockchain in the sector very likely [18]. Of course this is just one source of information and industry participants’ current perceptions could be highly affected today by the hype on the internet, and throughout the consulting world, about potential opportunities. It is also so early that no major negative cases of blockchain use in the energy industry have taken up headlines yet to counter the positive banter and high expectations of industry consultants and the like. But this may also be due to the rather conservative nature of players in the energy sector. They are aware of the risks involved in tampering with the complex system they operate inside, and being predominantly engineers turned managers, they are probably well aware that smart contracts are not “intelligent” but rather smart as in “connected” which is not the same as intelligent. They know that essentially they are computer programs, and in fact they are not the same as legal contracts. In an industry where standards are essential to a well functioning system, energy players probably have a hard time adopting too early a technology with no standards. The relevant standard-setting bodies, the US National Institute of Standards and Technology, and the European Telecommunications Standards Institute, are said to be working on standards still for safe quantum encryption [19].

3.1.1 *For utilities that want to remain competitive with peer-to-peer power sales through blockchain*

While it is unclear if utilities are truly convinced about the power of blockchain to enable new ways of selling power, several consortiums have still formed recently to allow utilities to at least work together on the concept and learn more about it before moving forward. The Energy Web Foundation is supposedly working with electricity market participants from around the world to build a scalable, open source blockchain specifically tailored to energy market needs and designed to be energy efficient [20].

Singularity is also partnering with the Rocky Mountain Institute to establish an energy industry consortium with the goal of a more effective deployment of Blockchain to facilitate more effective operations in the energy sector [21]. The new consortium aims to conduct R&D in Blockchain and energy in order to help utilities, application developers, customers, and renewable energy companies understand how the technology could support, disrupt, or transform existing business models.

One example of a utility finding blockchain applications to attract new customers was reported by Bloomberg New Energy Finance. BNEF reported that Tokyo Electric Power Co. wants to win back consumers, reversing an almost 15 percent decline in its customer base since the Japanese government opened up the industry to retail competition. The country’s largest power provider formed a unit called Trende that will compete for customers with a solar and storage package and enable peer-to-peer power sales through blockchain [22].

Smaller firms or new entrants to the energy sector are slowly emerging with peer-to-peer trading of energy models so utilities may be starting to feel the pressure to learn more about blockchain in order not to lose what looks like a potential turn in technology allowing for potentially more competitive business models for certain types of customers. For example, LO3 Energy is credited with facilitating the first peer-to-peer energy trade of solar power on a microgrid in Brooklyn, New York, in 2016. It is reported that the same platform will also be used in Houston to help a group of businesses use their own resources to “micro-hedge” against swings in power prices instead of relying on a utility to do it for them [22].

Therefore, currently one business model that utilities may increasingly consider to remain competitive, also in the case of start-ups delivering competitive offers, is peer-to-peer power sales through blockchain. However, the way that such peer-to-peer selling would be organized on a larger scale, while continuing investments in the grid that supports such trading of power, is still to be understood. So far peer-to-peer trading with blockchain is only on a pilot scale in most countries.

3.1.2 For virtual transmission, and managing supply and demand in real-time

As solar and wind energy scale, power markets are increasingly challenged to balance supply and demand. In the past, and still today coal and gas generation provide “on call” power. These are in fact called “dispatchable” sources of energy. However, with wind and sunshine varying today’s actual output in many markets, there is now a demand for new “flexibility” services, to either adjust power demand to better match supply, or compensate backup sources of supply that can respond quickly in times of shortage. Blockchain (in theory) can enable more efficient monitoring and maintenance of power-industry infrastructure, based on secure, real-time data communicated by sensors. Maintenance can be facilitated on the network if an anomaly is detected, and if it is actually paid for by smart contracts. This could also lead (again in theory) to faster response times. Data is supposed to be secure because it is only available to nodes in the blockchain network. Blockchain is supposed to add a layer of security and coordination to current digital pilots, enabling quick, accurate data gathering and communication between hardware suppliers, utility maintenance, and emergency response teams.

Germany’s Tennet TSO GmbH is now working with batterymaker Sonnen GmbH and International Business Machines Corp. to form a virtual transmission line that uses blockchain to store excess power from wind farms in thousands of home batteries in the northern part of the country and unleash power pent up in the south. Such efforts could eliminate the need for new power lines that utilities depend on for returns [22]. The storage assets could also include electric cars.

Also, the municipal utility of Burlington, Vermont may be the first to use blockchain to get generation assets working together across its grid. The idea is that batteries could charge when there's excess wind power, and businesses automatically could draw down power demand when electricity prices are high [22].

Another innovation in terms of business model is proposed by the UK-based company Electron. The company is also using blockchain to develop a platform for the balancing of power demand and supply, via a flexibility marketplace. They call it an "energy eBay," as it opens up participation in power markets. Energy customers that adjust their energy consumption would obtain compensation from the trading platform and this should in theory result in higher consumption in periods of high renewable power supply. It should also lead to lower consumption in periods of relatively low supply. Real-time price signals drive the transactions of power generators and storage providers. The company has been developing a blockchain-based asset register for the marketplace that includes the ability to transact between all included assets, such as smart-home technologies [10].

3.1.3 Connecting electric vehicle charging stations

For electric-vehicle (EV) charging, blockchain also holds great new potential for energy payments at charging stations. A blockchain wallet could be used to allow drivers to pay for access. They could also view maps of the charging network that highlight choices based on each user's preference and real-time pricing data. Power prices at each station can be established by the grid operators and the residential power suppliers if blockchain microgrids have been set up in the area [23]. German utility innogy[2] is using the Ethereum Blockchain, assisted by a startup called Slock.it. They specialize in providing Blockchain expertise to large corporations. BlockCharge, the proposed venture, promises seamless and affordable charging of electric vehicles. BlockCharge also has a physical artifact, the "Smart Plug," which can be used like a normal plug but has an identification code linked to it. Users authorize the charging process with an app that they install on their smartphones and which connects to Blockchain, and allows the blockchain to manage and record all of the charging data. Any electric plug could be used to charge the vehicles of electric car owners under this business model. BlockCharge in fact aims for a worldwide authentication, charging, and billing system with

[2] RWE's (Innogy) holds a leading position as a provider of charging stations in Europe. The utility successfully exported its technology to cities outside Germany, including Amsterdam, cooperating with companies such as Daimler, and Renault/Nissan. As of August 2016, more than 1,400 RWE (Innogy) charging stations had been installed across Europe and the United States [24].

no intermediary. The business model includes a one-time purchase of the proposed Smart Plug and a micro-transaction fee for the charging process [21].

3.2 *Examples of use cases among SMEs, New Entrants and Start-ups*

Today, there are 140 start-ups operating in the energy blockchain space alone, according to Crunchbase (a global start-up database) [9]. Start-ups seem to be pioneering business model innovation in blockchain applications in the energy sector. Meanwhile incumbents may try to develop strategic alliances with such start-ups but as technology evolves more quickly than companies can adapt, the traditional model of acquiring innovations from start-ups and continuing with business as usual, with overall the same business models, may finally be disturbed.

Start-ups or new entrants may finally have a real potential to transform the energy sector via innovations such as blockchain-based business models. However, to be successful in actually becoming such transformative actors for the energy transition, serious players are needed, not those who take advantage of the hype around the technology and quickly sell out to main players in the market for quick financial returns.

3.2.1 Trading energy, RECs or Carbon Emissions

Business models with “smart contracts” for the buying or selling of services or attributes (outside of distribution networks) is an area requiring further attention from researchers – both engineers and economists. Risks and opportunities for meeting goals like climate change and energy transition targets, while interacting with necessary grid infrastructure, must be assessed carefully.

US-based start-up TransActive Grid enables members to trade their energy with blockchain. Its first transaction was successfully launched in 2016 but it was only among 5 homes producing energy through solar power on their roofs with another 5 homes on the other side of the street [25]. Power Ledger from Perth, Australia is a start-up with a similar initiative [26].

Grid Singularity, an Austrian start-up, aims to move beyond an energy exchange platform and host other applications such as energy data analysis, benchmarking, smart grid management, trade of green certificates, a decentralized mechanism for investment decisions, and energy trade validation [27]. Other envisioned use cases for such an exchange include assessments of generation capacity and availability, pricing and origin, forecasting, energy trading, virtual power plants, and microgrid management [18].

Meanwhile blockchain technology can also be used for the trading of renewable energy certificates (RECs) that are given to solar producers based on generation estimates and forecasts rather than actual generation. Some companies that are experimenting with services to allow power generators and others to sell certificates from energy generation are: Volt Markets (an energy origination, tracking, and trading platform powered by smart contracts on the Ethereum blockchain), solar-panel designer Ideo CoLab, sensor maker Filament, and the exchange operator Nasdaq.

RECs can also be issued to producers for each kWh produced by their solar panels with Ideo CoLab which has integrated its capabilities with Nasdaq's Linq platform as well as Filament's hardware – using digital sensors with blockchain capabilities. Small solar power producers can then normally track, prove, and trade power [23].

3.2.2 Enabling peer-to-peer power generation and distribution and models to increase energy access in developing countries

A more obvious use case in the energy sector or blockchain is the use of cryptocurrencies for monetary transactions. Some companies starting this movement are: Bankymoon, SolarCoin, and BlockCharge. Mostly start-ups are active in this use case for blockchain but utilities are also catching up. Some are launching joint ventures and cooperations. The value proposition is that via blockchain, the intermediary between two parties is removed. Full decentralization of the energy market could be achieved in theory with such applications of blockchain as you detach financial transactions from a central control unit. Such developments might also allow for innovations that improve energy access in developing countries over time.

One application is smart prepaid meters that only release power to residential customers once they have topped up their accounts and transferred money to their electricity provider. This system could have benefits in countries with high inflation rates. South African startup Bankymoon developed the idea and uses Bitcoin as a cryptocurrency to perform remote payment transactions using the company's Bitcoin-compatible Smart Meters. This works well in cash deprived public schools, for example. Donors who want to support the schools can send crypto-money to the smart meter of the school of their choice directly, allowing the schools to be supplied the electricity automatically and without the need to trust any middlemen for the transaction [28].

SolarCoin is another example. Two members of the SolarCoin Foundation have come up with the idea of an energy-backed currency, similar to the gold reserves that are supposed to stabilize "real" currencies. SolarCoin is already present in 17 countries and is intended to be circulated worldwide: any owner of a solar photovoltaic installation may apply and claim his SolarCoins for free. To do so, the solar owner simply registers his solar installation online with data proving the existence and operation of his solar installation [29].

Other start-ups also include M-PAYG which is actively working in Tanzania and plans to move into Uganda and Malawi. They make transactions using crypto-currencies and allow for real-time monitoring of solar panels. The models are leased and 5 USD per month gives the customer a flat rate of solar energy.

MPAYG is starting its business model with providing energy. Other partners are delivering the towers to roll out wireless internet connectivity to rural areas. The business model is to allow for more value added services such as data calls, e-health, e-farming, insurance, e-banking, payments, education and content [33].

Another business model is offered by Coinfy, which allows for cross-border payments using blockchain payments, and allows for payments between off-grid solar companies and people lacking access to energy sources. Finally, KWHCoin is a blockchain-backed community where the cryptocurrency is backed up by unites of clean renewable energy. The KWHCoin, unlike other cryptocurrency projects, has value at the generation of a Kwh of renewable energy, and creates value based on a network of active renewable energy generation and distribution. The main value added of the business model compared to others is that it focuses on the “grid’s edges”[3].

3.2.3 Using blockchain for microgrids

As for how blockchain could enable microgrid investments, several examples are available especially in the United States. The State of New York is working to rebuild its power grid as a distributed platform. It will leverage a framework that allows power companies and new entrants to collaborate. This platform, Start-up LO3, is using the Ethereum blockchain to allow consumers to buy power either from a microgrid or from local producers. Brooklyn Microgrid is also a project supported by LO3 and Siemens, to create a microgrid for Brooklyn based on this concept [31]. Members of the microgrid would be able to use blockchain-enabled metering to exchange power without having to use a centralized authority or expensive infrastructure to manage flows. Members control their energy-use preferences with a mobile app or a smart home system in this concept, and their blockchain meters will purchase energy from the solar owners based on preset cost preferences.

Other examples are Enerchain from PONTON that has been used for regional mini-grids and for wholesale trading in Germany. Also, an example of a local grid is the NEW 4.0 (Norddeutsche Energiewende). NEW brings together the producers and the consumers of this energy to manage demand and supply side via a marketplace (price, dynamic grid usage fee) using blockchain [32].

[3] “Edges” of the grid are defined as smaller distributed energy resources, such as solar panels in the residential market, electric vehicles, microgrids, wind farms and demand response technologies.

3.2.4 *Using blockchain for financing social action*

It has been proposed to use blockchain to finance social action or to obtain some sustainability goal like filling the solar finance gap in Africa. In one pioneering social initiative, the crowd-funding platform Usizo connected to blockchain-enabled smart meters in underfunded South African schools so that donors can pay the school's electricity bills. Blockchain-based payments allow donors to ensure that 100 percent of each donation is used for its intended purpose. M-PAYG, a Danish company, provides prepaid solar-energy systems to people living below the poverty line in developing markets and is leading a major project to electrify Uganda's largest refugee camp. The idea is also that owners of small solar-generation systems gain access to new income streams [33].

ImpactPPA aims to disrupt renewable energy to finance and accelerate global clean energy production by decentralizing and tokenizing energy generation through power purchase agreements (PPAs). EcoKraft GmbH is developing a next-generation social impact investment platform (although so far it is only a pilot program) for community energy projects in developing countries. Smart meters are to collect consumption data from households in Malawi and send it through SIM cards (GMS data system) to Germany [32].

Sun Exchange has built a blockchain based solar energy finance platform that is supposed to fill part of the funding gap for commercial and industrial solar energy projects in Africa. It should enable anyone in the world to buy and then earn revenue from solar panels powering Africa. The Sun Exchange is supposed to be a marketplace where you can purchase solar cells and have them power other entities in the sunniest locations on earth. You lease your solar cells purchased through The Sun Exchange to end users, hospitals, schools, factories, and large commercial users, allowing the owners to obtain solar powered rental income no matter where they are in the world. It works similar to crowd-funding. The project will only go ahead once all the solar cells have been sold [29, 33].

4. DISCUSSION

In general, we show that many use cases are indeed emerging but with unproven impacts on the sector for the time being, however they point indeed to the potential development of an energy cloud system in the future if enough important players adopt the movement across both the energy, ICT and financial industries. If governments and companies can indeed deal with the risks in a serious way, including via the development of new regulatory frameworks and standards, a stable playing field could be created to set the pathway well for a safe and affordable energy cloud system, of course relying still on a minimum level of basic infrastructure and reliable middlemen players for the secure and affordable distribution of electricity in the grid.

The attractiveness of blockchain to all incumbents in the energy sector is yet to be seen and understood but so far from this quick analysis we can see that today more start-ups and new entrants are announcing blockchain-based business models than incumbents are announcing reconfiguration of business models or new complementary business models, using blockchain opportunities.

Of course, this makes sense given that incumbents are potentially afraid of disrupting an already well-functioning business model, and increasing risks or losing their reputation among clients in a more and more liberalized market, by investing too heavily in this unknown technology. Not to mention, the regulatory risk associated with such investments will also be a major concern for corporate players. Meanwhile, some utilities may be smart enough to acquire blockchain start-ups in the energy sector and make themselves leaders in especially increasingly competitive energy markets or markets undergoing liberalization towards different levels of customers, while also remaining smart enough to take things slowly in a complex innovation ecosystem such as that which exists in the energy sector.

In the following section we review a few key concerns with the application of blockchain technologies in the energy sector – distribution power grids and the reality of combining blockchain technologies in such a complex and important system as the energy system.

4.1 Blockchain technologies and distribution power grids

Blockchain technologies are considered as a promising route in order to facilitate the penetration of renewable intermittent energy sources (RIES), in particular but not exclusively in urban zones, where the decentralized setting of RIES is indeed intrinsically structural. Indeed, the construction of blockchain-based communication undoubtedly presents appealing characteristics. Blockchain can answer adequately to many challenges posed by the appearance of prosumers, along with the corresponding need to locally trade power production and consumption, also in the perspective of providing the necessary imbalance to the power grid.

All these considerations nonetheless share a common assumption point in that the physical infrastructure of the power grid, i.e. the copper wires, the transformers and the related components, are given and available. On top of this assumption, the behaviour of the distribution grid in terms of power flow, voltage and frequency levels – not to mention harmonics - as a result of an increased exchange of power following a successful implementation of blockchain technologies, is completely eluded in the recent literature.

Indeed, neither a method to quantify the possible effects on power distribution grids in terms of increased RIES penetration – notably in terms of relevant indicators useful for decision-support - nor a precise evaluation of possible reinforcement needs – including reactive power and harmonics reduction strategies - have been proposed so far.

This field, sitting at the crossroads between (i) distribution grid simulations able to capture real-time behaviour and deviations, and (ii) planning demand/supply matching at the local level remains essentially unexplored, whereas it should accompany all the other considerations related to blockchain technology implementation. The analogy could be given with planning an attractive internet offer, implying a massive exchange of physical bits, without considering the physical limitations of optic fiber infrastructure. Appropriate consideration of grid behaviour and related remediation strategies will increase the feasibility of blockchain implementation sustaining large RIES projects but will unavoidably increase both CAPEX and OPEX figures.

Finally, the same considerations exposed above regarding distribution grid reliability and resilience, also apply to security concerns. Indeed, this represents a particularly important aspect for any power grid, which is heavily regulated by national and international norms. Massive penetration of RIES on any power distribution grid can potentially lead to transient overvoltages and crossing of current limits. Hence, any massive implementation of RIES must be accompanied by appropriate implementation of security components such as breakers, current limitators, grounding structures and, in the future, flexible SOP devices (possibly coupled with local storage capacities). The present security infrastructure of distribution grids cannot be considered as *de facto* sufficient: additional – potentially very relevant - costs must be accordingly evaluated and provisioned therefore in any blockchain-based RIES development project.

In view of the above arguments, any future implementation of blockchain infrastructures sustaining the deployment of RIES in any given territory should imperatively take these technical elements into account:

a) Implementation of a wide-ranging power distribution grid simulation taking RIES penetration into account and determination of weaknesses on the basis of quantifiable indicators;
b) Inclusion of real-time monitoring of the distribution grid, e.g. by using technologies such as GridEye by the grid owner/operator with possibilities to switch off generating capacities.
c) Inclusion of grid management related obligations and constraints in future smart contracts;
d) Precise evaluation of additional CAPEX and OPEX costs related to distribution grid adaptations and potential reinforcements, including security;
e) Distribution of above-mentioned costs among stakeholders, including utilities owning and/or managing the power distribution grid;
f) Development of a sensible tariff system for grid usage that does not prevent the penetration of RIES, all the while covering all grid-related costs (maintenance, security, amortization).

In addition, implementation of blockchain technologies in the power distribution system, even in dispersed and partial configurations (i.e. not covering the whole extension of a given distribution grid on a given territory) should probably be accompanied by a liberalization of the power metering market [34].

In most countries, the latter is either completely under monopoly regime or only partially open to competitive bids. However, such a constrained configuration can potentially act as a further brake to the development of blockchain approaches, since the availability of metering data is mandatory for a successful implementation. Liberalization of the metering services would therefore facilitate deployment of and value creation within blockchain technology deployment, while it must take place under strict observation of recognized standards as to ensure transactional trust. Of course, existing electric utilities can participate in this new market and intrinsically possess a competitive edge since they already own expertise in this field. Here again, the importance of potentially involving existing power distribution companies in future business configurations is highlighted. Meanwhile, presently there is clearly a lack of test-cases and literature studies which may help to robustly and quantitatively assess the link between the penetration of blockchain technologies in the energy sector and the liberalization of the metering market. Hence, this issue undoubtedly will need further scientific investigation in the near future.

In summary, whereas blockchain technologies are able to provide a peer-to-peer energy trading framework favoring the implementation of RIES, while avoiding non-physical intermediaries such as banking agencies, promoters cannot avoid dealing with the physical intermediary constituted by the distribution grid itself. Hence, utilities must be embedded very much upfront in the any blockchain-based RIES project and be considered as central stakeholders, to be involved in the overall value proposition.

4.2 Energy Consumption

Energy consumption of many blockchain architectures is also still an important issue that needs to be further studied and resolved[4]. Today energy consumption is on the order of 100 MW for bitcoin alone, which is a concern of course, but currently research shows that the energy consumption of bitcoin will not be the primary reason to put bitcoin at risk [36]. Also different studies still estimate different energy consumption figures and little is known about how the technology (or different architectures of the technology) will improve in the future, or what architectures will be adopted for the energy sector on a larger scale.

Nevertheless, we must consider the energy consumption of blockchain technologies very seriously. The possible reduction of energy consumption of blockchain technologies primarily rests in the evolution of mining algorithms and is thus counter-intuitively disconnected from the energy domain itself. The amount of

[4] According to https://digiconomist.net/bitcoin-energy-consumption bitcoin already consumes the same amount of electricity (62.92 tWh/year) as the country of Switzerland (as of April 26, 2018).

self consumption per kWh exchanged on the grid should probably decrease before blockchain technologies can bring a significant added value in terms of increased sustainability.

As little information is available on the energy consumption of different architectures for the energy use cases that are being proposed since basically the last 2-3 years, much more empirical evidence and research work will be needed in the coming years to understand better how much energy blockchain applications will consume if the world moves actually towards a much more AI-facilitated and virtual management of energy services and value propositions. Until then we can only highlight that the energy consumption issue is one to be resolved and discussed openly. Many datacenters are already being criticized for their lack of heat recovery or optimal placement with regard to heat recovery, and while this is one issue with regard to the increasing energy consumption of AI, another one is the question of how to limit the energy consumption of a distributed ledger technology which consumes energy all over the world in different computer infrastructures and can not be managed in any other way besides limiting computing complexity in the architectures chosen for blockchain-based business models.

4.3 Policy Issues and Challenges

Blockchain is open source, under development and open to interpretation by anyone. Dark markets make use of blockchain via the use of privacy-centric cryptocurrencies. Today Europe is exploring the appropriate level and methods to regulate blockchain markets. China announced the closing of a number of trading houses. The Central Banks of Germany and France have expressed their wish to reign in cryptocurrencies. The European Commission has pled for “increased vigilance” towards such currencies. An important hub for Bitcoins, South Korea, aims now to regulate the trade in Bitcoins. But what can we imagine in the regulatory environment for the energy sector with regard to blockchain? It is clear that regulation could play a major role in opening up market opportunities, or closing them completely.

The challenge to regulators is to quickly develop proactive regulation that creates the environment necessary to ensure consumer protection and ensure a system with critical elements for a well functioning society, such as the reliable and secure supply of energy. It must also allow for this systemic stability without disturbing too much blockchain’s disruptive potential. Furthermore, lack of regulation in the blockchain technology sector might make companies wait before investing. Energy companies already tend to wait a long time for technology to develop (and policies to emerge) before investing in new technologies.

The other challenge with regard to blockchain technologies as applied to the energy sector is that differences in regulations are expected worldwide not only as related to the financial sector, but also as related to blockchain uses in other sectors and of course the energy sector. This means that companies will face high levels of regulatory risk, and regulatory complexity which may be too costly for them to manage, as it will require expensive consulting services, which could be in itself one reason that many consulting companies are writing about blockchain opportunities with great fervor.

Adding to regulatory uncertainty and regulatory risk (also due to regulators not understanding what they are regulating) we must also not minimize technical risks related to blockchain and relying too heavily on smart contracts. According to Gartner, a well known international consulting company, enterprises should "weigh up" if a contract cannot be undertaken using the old, legally binding traditional contract. If possible it should opt for the tried and tested method. Essentially smart contracts are a piece of software and there are bugs in software. It is very hard to be sure you haven't got a bug in any piece of software [19].

5. Conclusion

In conclusion, we believe that blockchain technology may not (itself) radically transform the energy sector and this is related to various limitations highlighted in this paper (grid reliability and security issues, energy consumption issues, regulatory risk, as well as its inherent levels of technological uncertainty for firms). The key reason however is related to the complexity of managing properly the grid (e.g. grid reliability and stability in heavily decentralized power exchange configurations), and this aspect linked to the complexity and risks involved in the application of complicated smart contracts to an already complex sector This is at least our viewpoint with regard to the short term, while in the long-term we may indeed see a more cloud-supported energy system itself financed in a completely different way than today.. This itself (the financing element stimulated by blockchain-based fintech innovations) could lead at least towards a significant increase in the democratization of the ownership (and even the democratization of value creation) for future energy systems. However, again the issues involved in dealing with smart contracts still apply to this level of use cases.

Today what we think is more likely to occur is that new business models and new ways of thinking about energy services (and new value propositions) will be inspired or stimulated by the hype around blockchain (whether it is indeed just hype, or not). In that way, one can see how blockchain technology innovation could have indeed an impact on the energy transition even under a scenario where blockchain applications do not undertake mainstream acceptance by energy sector stakeholders in the end.

The thinking around digital finance or new ways of financing renewable distributed energy systems, as inspired by blockchain technology, may start to significantly change the way companies in the sector think about doing business and open their minds to new options with regard to financing models that support distributed generation and the systems needed to distribute energy in a heavily decentralized power exchange configuration.

Other than this, this paper has made the case that we still need the grid and that more work is needed to understand other implications of blockchain in the energy industry, including how much energy blockchain applications will consume if the world moves actually towards a much more connected and even AI-facilitated and virtual management of energy services and value propositions.

For the short term, we also see that the application of blockchain technologies to electric power exchange at the local or regional level will have to physically rely on the grid itself. On the other hand, we may soon witness the creation of links between industries and non-traditional players with traditional players in the industry and pseudo innovation ecosystems that did not exist before because of blockchain.

Other innovations or business model innovations, currently unknown to us today, could be stimulated by this industry convergence with regard to business model innovation in the energy sector and lead to truly breakthrough solutions. Completely different solutions or architectures might be developed by new players while the original technology that gathered the stakeholders to think together could have been blockchain-based. More research is needed to understand the value network impacts [38] of blockchain technologies on various interconnected energy innovation ecosystems, including their impacts on new thinking with regard to business model innovation in the energy sector.

Having said that, everything said about blockchain with regard to the future of the energy system is pure speculation at this point. In the short-run we can be more certain about the potential risks involved in applying the technology in its existing state of development (e.g. regarding energy consumption, risks to the grid, etc.) In particular HEIG-VD will continue to tackle the issue of distribution grid reliability/stability in heavily decentralized power exchange configurations and projects are already underway today in this field [35].

Finally, it is also important for us to point out that more socioeconomic research will be needed to understand the impacts of blockchain on the market, including on customers and the value of services offered to them, and at what cost to users. A related but very important political science question also to researchers and policy-makers is about how will more traditional subsidies in the energy sector relate to developments in blockchain, as well as subsidies for renewable energy. Moreover, which new institutions may be needed to govern better the integrated systems it may evolve towards, will the public accept new technologies like blockchain, or digital finance innovations in general, and what will be the impacts of these developments on society in general, including on employment? Researchers on institutional change could also contribute to better understanding about what other institutional adjustments might be required [39] (e.g. educational systems) and how governments and regulations can evolve quick enough with technologies like blockchain, and artificial intelligence in general, in order to allow for a cost-effective, safe and intelligent transition towards a digital society.

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