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Conference Paper

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29th European Regional Conference of the International Telecommunications Society (ITS): "Towards a Digital Future: Turning Technology into Markets?", Trento, Italy, 1st - 4th August, 2018

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Serrano-Calle, Silvia; Delarue, Erik (2018) : Smart Technologies Applied to the Energy Sector. Renewable Energy Expansion Strengthened by Digital Communications and Distributed Ledger Technologies?, 29th European Regional Conference of the International Telecommunications Society (ITS): "Towards a Digital Future: Turning Technology into Markets?", Trento, Italy, 1st - 4th August, 2018, International Telecommunications Society (ITS), Calgary

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Smart Technologies Applied to the Energy Sector. Renewable Energy Expansion Strengthened by Digital Communications and Distributed Ledger Technologies?

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Abstract

The development of variable renewable energy (VRE) and their massive installation are some of the challenges that the economies of a large part of the world will have to face in the coming years to help ensure a reasonable sustainability of the planet. On the other hand, the advances that have been happening in recent decades in the telecommunications sector and the expansion of the Internet have helped to create a new scenario, giving way to growth opportunities in different economic sectors and new business models. One of the most disruptive tools that has emerged in this new digital ecosystem is what is known as Distributed Ledger Technology (DLT). The opportunity and applicability to strengthen VRE expansion is discussed in this article. To this end, selected case studies and main findings of interviews with experts are discussed. The introduction of blockchain technology, in particular in its use as a platform for smart contracts, offers a great potential, highly valued by experts, in addition to adding other relevant characteristics such as efficiency generated in operational terms and traceability, but also new opportunities for consumers and prosumers to build strong energy communities committed with a sustainable energy transaction. However, among the elements to be improved, we highlight the regulatory uncertainty regarding smart contracts' security in terms of automatic mechanisms and its legal endorsement for use within the EU; adopting standards to facilitate scalability; and other issues of a more technological nature that should also be improved for a massive implementation in terms of optimizing energy efficiency of the model.

Key words: Blockchain, Digital Policy, Energy Policy, Smart Energy, Sustainable Development Goals

JEL codes: L86, O33, Q28

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1. Introduction

The Energy sector faces important challenges this century such as climate change, inequality, security of supply, access to affordable and clean energy, or sustainable energy consumption, to mention a few key topics. However, to take on board the challenges that come is undoubtedly a very complex task, that requires diverse sort of coordinated actions from different sectors and stakeholders, public policies, information dissemination, social mobilization and changes in social behavior among some others.

Fortunately, new scientific and technological progress can help to ensure a smooth transition towards a better future. These advances should go hand in hand with the necessary actions from different sectors and stakeholders to address the challenges.

Over the last few years, digital transformation and telecommunications innovations with potential disruptive effects on operations and activities for the economic system and users have received close attention from researchers, industry and more recently regulatory authorities and governments.

This paper explores how new digital smart technologies can contribute to solve some of the challenges faced by the energy sector. The digital transformation of the energy business and particularly, the adoption of distributed ledger technology (DLT), combined with smart contract applications can become a very powerful tool to increase the introduction of variable renewable energy (VRE) and its massive installation in the smart cities.

The social perception towards sustainability is changing. There is a strong connection between sustainability and energy. One of the most remarkable events happened recently regarding the challenges of this century towards the sustainability of the World has been the commitment with the Paris Climate Agreement (United Nations, 2015a) signed at the UNFCCC 21st Conference of the Parties (COP21) in Paris in 2015, and its entry into force on 4 November 2016 (United Nations, 2016).

Another relevant fact was the adoption in September 2015 by more than 150 country members, under the auspices of the United Nations of the new 2030 Agenda for Sustainable Development. The Agenda is a plan of action including all countries and stakeholders, acting in collaborative partnership to implement the plan (United Nations, 2015b). The Agenda introduces a new relevant approach defining 17 Sustainable Development Goals (SDGs) and 169 targets that are focused, ambitious and achievable. These SDGs define challenges over the following 15 years in critical areas for humanity and the planet. Among those actions there are specific goals related mainly with energy, e.g. Affordable and Clean Energy (SDG nº 7); Climate Action (SDG nº 13); Industry, Innovation and Infrastructure (SDG nº 9); Sustainable Cities and Communities (SDG nº 11); or Responsible Consumption and Production (SDG nº 12).

The European Union (EU) has been a front runner in terms of climate change action. As such, it has also become one of the main supporters of the Paris Agreement (EC, 2016a) and the need of changes towards achieving the SDGs and generate growth (EU, 2017b). In November 2016, the EU published its “Clean energy for all Europeans” package, better known as the so-called “Winter Package” (EC, 2016b), adopted by Members States, setting a new European energy framework to contribute to the 2030 Agenda for Sustainable Development and the SDGs adopted by the United Nations in 2015. The package pursues three main goals, related to energy efficiency, renewable energy, and putting consumers first. The implementation of the ambitious

targets committed in the Paris Climate Agreement have accelerated the necessary transition towards a clean energy system in the EU. The share of renewable energy in gross final energy consumption has been continuously increasing in the EU in previous years, from 8.5% in 2004 to 16.7% in 2015, to reach the target of 20% by 2020 (EU, 2017a). The aim is to avoid dangerous levels of global warming. Citizens and energy communities are in the center of many of these policies and are essential for the success of the designed actions. Urbanization is growing and the trend will continue during the XXI century, with more people living in smart cities (Yigitcanlar, 2017).

The energy sector is of great importance for the competition of the economy and the quality of life of citizens. Opportunities from an improved energy system are significant (WEF, 2018). The EU started working on the 2020 strategy with the aims to turn the EU in a more competitive position in the global market, emphasizing smart, sustainable and inclusive growth. The 2020 strategy on climate change was focused on three main goals that were interrelated: the renewable energy target; the reduction of GHG emissions; and the improvements in energy efficiency. In June 2018 the EU co-legislators -the Commission, the European Parliament and the Council- reached an ambitious political agreement on the governance of the Energy Union to get a simplified, robust and transparent governance; calling Member States to prepare a national energy and climate plan for the period 2021 to 2030, and to ensure that EU and Member States work together towards further enhancing the set up in the Paris Climate agreement (EC, 2018a). The last legislative proposals on Energy Efficiency were also approved in June 2018 and joined the already approved 2016 legislative proposals on Clean Energy for All Europeans package, the revised Renewable Energy Directive (EC, 2018c), and the Energy Performance in Buildings Directive. The remaining main legislation: the revision of the Emissions Trading System, the Effort Sharing Regulation and the Land Use Change and Forestry Regulation, were also adopted earlier in 2018. All these regulations are aligned with the objectives of the Energy Union and the commitments of EU's 2030 energy and climate targets. The new regulatory framework includes an energy efficiency target for the EU for 2030 of 32.5% with an upwards revision clause by 2023. And a target of 32% renewable energy for the EU for 2030 (EC, 2018b).

In a few decades, telecommunications development and internet expansion have transformed the way people interact. Thanks to high capacity networks and mobile access everywhere at any time new disruptive business models and opportunities have emerged across sectors around the world. ICT markets and new roles adopted by agents and users have contributed to create a digital ecosystem full of potentially transformative possibilities. The EU has established a Digital Strategy to boost growth and strengthen Europe's position as a world leader in the digital economy, improving connectivity and access, but also investing in network technologies and digital infrastructures (EC, 2015). Advances in telecommunications and digital innovations can ensure better access to modern and smart energy for all. In particular, the use of DLT or blockchain technology can provide many advantages to existing energy markets as the paper explores, but also contribute to create new energy communities committed to environmental sustainability, significantly improving achievements towards the SDGs, particularly those related to energy. From a security and privacy perspective blockchain technology could be in many aspects better to the current IoT technologies (Kshetri, 2017), but the use of IoT combined with DLT could provide good opportunities in energy markets.

The potential of blockchain technology (Boucher, 2017), that could be briefly described as a transparent and decentralized digital tool to record transactions, a DLT, based on a chain of

cryptographically linked blocks where transactions are introduced, broadcast to all the nodes of the network, verified following a consensus mechanism and kept, has found many interesting applications across sectors, from financial systems, e.g., use of cryptocurrencies, to supply-chain management, or other different applications such as voting, medical records, or patent and property rights protection. There are many opportunities of DLT and the application of smart contracts to be used in the energy markets, simplifying processes and transactions, reducing costs and time, and increasing efficiency. Blockchain can be an enabler of commodity trade finance for autonomous organizations in the energy sector (IBM, 2017), or facilitate the creation of energy communities to promote higher shares of VREs (Mengelkamp et al., 2018) or contribute to strengthen sustainable smart city networks (Sharma & Park, 2018).

The main contribution of this paper can be summarized as:

1. A review of case studies of DLT and smart contracts application, suitable to be applied to the energy sector with solid benefits in terms of efficiency, and consumers and prosumers engagement.
2. Identification of the main challenges and opportunities, attitudes and motivations towards the early adoption of blockchain technology and its capacity to strength VREs development, gathered from interviews conducted with energy experts, and digital technology specialists.

The remainder of the paper is structured as follows: Section 2 sets the scene by providing a review of digital smart technologies and distributed platform ledgers; a discussion of the rationale for its application to foster the expansion of VRE and main challenges for renewable energy are included in section 3. Section 4 describes the methodology to analyze the opportunity of smart technologies and DLT to increase VRE expansion. Results and main findings are described in Section 5. Finally, conclusions and future research are given in Section 6.

2. Digital Smart Technologies and Blockchain

Advances in new digital smart technologies in recent years are becoming strong drivers to change and improve the way society perceives the energy sector and uses energy, adopting actions towards a higher sustainable and efficient use. There are many digital smart technologies that can contribute to improve energy efficiency. Sometimes the difficulties for policy makers lie in identifying which ones to support in order to provide the right regulatory incentives (Goldbach et al., 2018). Blockchain has captured European Commission attention recently and several initiatives have been launched in the last months, e.g., the EU Blockchain Observatory and Forum in February 2018 (EC, 2018d).

The more popular and perhaps first main application known of blockchain technology emerged with the creation of the cryptocurrency bitcoin in 2008 (Nakamoto, 2012), since then blockchain has received a lot of public attention across different sectors, from finance (The World Bank, 2017; Benos et al., 2017), insurance (Gatteschi et al., 2018) to real estate (Lantmäteriet, 2017), utilities, agriculture, industry (Mendling et al., 2018), healthcare (Gammon, 2018), education (Grech & Camilleri, 2017), smart cities (Sharma & Park, 2018) or public sector (UK, 2016). Nowadays, blockchain continues being one of the most trending technologies (Gartner, 2018). Below we reflect on what is making this technology potentially attractive.

Blockchain is essentially a shared, public or private, ledger technology (Narayanan et al, 2016). Transactions over the nodes in the network occur over peer-to-peer connections, but there is not a central or unique administrator on the other side, and actions can succeed without the need of a third party attesting to the facts. It is basically decentralized by design. Another interesting characteristic of the technology is that the nodes of the network share the information of the blocks (DL) and cannot be modified once the new transactions have been verified and accepted as parts of the chain following a defined mechanism, that essentially differentiates the different sort of blockchains available, e.g., Bitcoin, Ethereum, Kadena, Ripple. The number of communities in the blockchain space and online repositories is continuously growing with some large clusters exploring hundreds of projects and applications, e.g., communities on GitHub (Deloitte, 2017).

The major success of the technology in economic terms is that the model by design reduces uncertainty. This is achieved using distributed shared ledgers based on the decentralized consensus mechanism ensuring consistency and integrity of the database and by cryptographic encryption. The lists of blocks of transactions are distributed to all nodes of the network and contain the list of all the transactions history that have taken place from the creation of the block. This is a much more efficient and improved mechanism compared with traditional distributed databases. New transactions are inserted at the end of the chain and linked to the previous blocks. The process of adding and verifying the new transaction records is done by the miners. Depending on the blockchain platform the mechanism of action for the miners varies. Two critical elements in the design of the blockchain are the cryptographic security, i.e., essential for access and security of records; and the mechanism of creation of new blocks (Narayanan et al., 2016).

As mentioned before, the distributed ledger can be public, private or partially private, depending on the openness to participate in the network and the validation rights. New nodes (agents) can have access to the data, i.e., write or read transactions, or to add new transactions, e.g., validate new entries or modify (Bashir, 2017). There are some advantages and disadvantages for every option. If the blockchain is public then, proof-of-identity authentication mechanisms are required to guarantee security of transactions, or proof-of-work (PoW), e.g. bitcoin's consensus mechanism. Proof-of-stake is another consensus mechanism, e.g. casper protocol in Ethereum. In private networks permissioned systems do not have to solve validation functions to trust transactions, this makes them faster and more affordable in computational terms, but security risks increase. The computational cost in terms of energy consumption varies with the difficulty of the PoW puzzle required for reaching consensus. This computational effort, however, can become significant, and as such can be a major constraint in terms of sustainability of the model.

2.1 Smart contracts

There is no agreement on a unique definition of smart contract. The cryptographer Szabo (1997) was the first one introducing the idea of a smart contract in a mechanical device. In the context of DLT smart contracts could be defined as programs written on the underlying DL that are executed automatically by the nodes on the network under certain conditions, i.e., executable code.

This application opens many opportunities for blockchain technology. In terms of operation, smart contracts require more information regarding the network and previous transactions, e.g. to execute a payment after energy has been dispatched. Following Bashir (2017) smart contracts should fulfill the following properties: automatically executable; enforceable; semantically

sound; secure and unstoppable. The first two should be mandatory whereas the last two could be relaxed. The actions taken as a result of the execution of the smart contract are also recorded in the ledger. Despite the potential of smart contracts many issues need to be solved, records keeping or data sharing could be a potential problem. General Data Protection Regulation (GDPR) could be one of the major threats for smart contracts and blockchain (Olly, 2018). For example, with the recent entry into force in the EU, 25 May 2018, of the Regulation (EU) 2016/679 (EU, 2016).

Figure 1 shows the functional architecture of a possible implementation of blockchain smart contracts application.

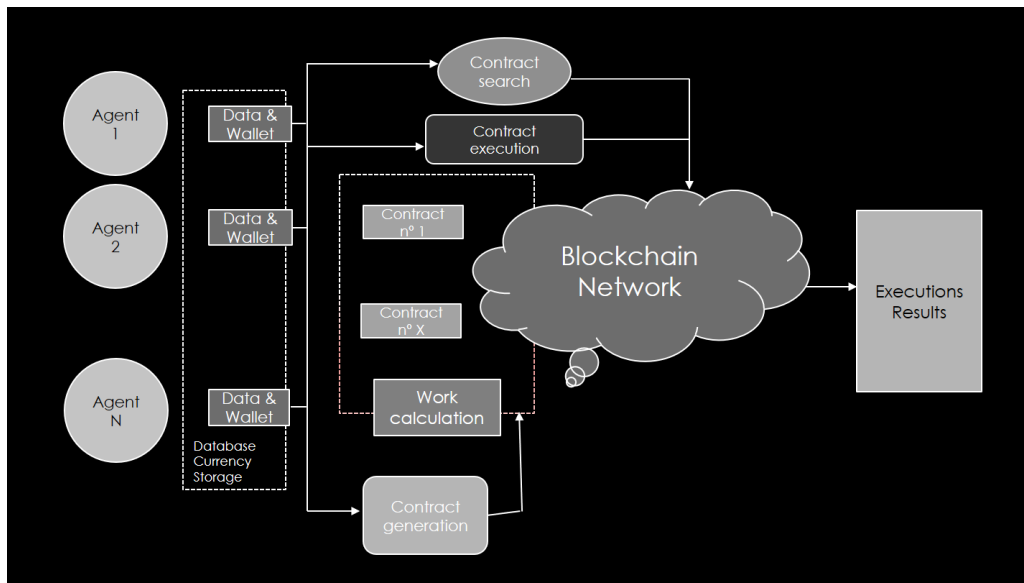


Figure 1. Smart contracts. Blockchain functional architecture. Source: Authors

The use of smart contracts has many potential uses and advantages. However, the degree of automated executable processes and the legal value of those processes could be object of a much deeper discussion. Other major concerns regarding the use of smart contracts are security and confidence. The platform Ethereum is one of the main largest public blockchains that has been designed with the functionality of smart contracts application, leading to the creation of many decentralized autonomous organizations, already participating in the Ethereum network using the smart contract application with different sort of requirements in terms of security and access (Yuan et al., 2018).

3. VRE expansion

Interoperable smart grids, connected homes and electrification of the transportation in smart cities and industries will be based in the near future on an increased use of renewable energy. Actions to improve energy efficiency have increased during previous years in all sectors in private and public sector worldwide with growing renewable power (REN21, 2017). Nowadays, generation from distributed variable renewable energy sources is still a challenge at a high scale. Due to the volatility of VRE, their massive integration in the general system is difficult to accomplish from a technical perspective without a suitable generation backup during the

periods when renewable resources are low to satisfy the demand (Denholm, 2012). Climate change concerns and medium and long-term sustainability of the planet have broadened the focus of energy sector contribution from the power sector to a sustainable development and a significant reduction of CO₂ emissions (WEF, 2018). The consumption of energy resources and the percentage of GHGs is higher in cities today, around 80% of GHGs are generated in urban areas (C40, 2018). Future sustainable challenges are related with the development of smart cities; but to achieve it, technology by itself is not the solution (Ahvenniemi et al., 2017), it will be necessary to change citizens' behavior. Energy communities (Ioannis et al., 2017) could become a key driver to achieve it with renewable energy projects (Hou et al., 2017), and digital technologies, e.g., blockchain can be an enabler towards sustainability (Schneidewindt, 2017). Policy makers can foster the introduction of new technologies, e.g., DLT, providing funding or regulatory support for renewable energy projects and innovation (Lam & Law, 2018).

Microgrid energy markets offer an opportunity to include small-scale participants (Gangale et al., 2013; Geelen et al., 2013), particularly consumers that also produce energy, better known as prosumers. Energy efficiency policies place customers at the center of the new actions. With an increasing number of small VRE installations, and prosumers -home, SME or communities' systems-, becoming relevant stakeholders, there will be great incentives for all agents as a result of digital innovation and blockchain introduction; but also for traditional players, Distributions System Operators (DSOs) and Transmission System Operators (TSOs) (Hadush & Meeus, 2018), what could be defined as win-win solutions. Potential benefits of blockchain in the energy sector goes from lower transaction costs to increase market competition. There are many new opportunities to explore for utilities and traditional players, but also micro-generators. Online decentralized platforms introduce transparency that can lead to a better understanding for consumers in terms of origin of energy-generation and possible changes in their behavior as consumers. This can open new paths towards a more conscious society and move customers' choices towards more sustainable pattern lead by local energy communities.

4. Methodology

To date, there is a lack of structured assessments of the potential advantages and opportunities of DL technologies that take into account a multi-disciplinary perspective for the energy sector, though blockchain is receiving a lot of public attention and several studies have been published recently regarding blockchain (e.g., Hileman & Rauchs, 2017; Shrier et al., 2016).

In this study we explore energy contracts and elements of new energy communities, focusing mainly on technical enablers and regulatory aspects that can act as drivers of renewable energy expansion with the support of early technology adoption that have not been explored. Two case studies in the energy sector have been identified following this approach. The second part of the research consists of semi-structured interviews and a structured survey with multi-choice questions and open remarks.

4.1 Sample and procedure

Selected participants have been interviewed to shed light on relevant issues regarding change, attitude and technology acceptance from different perspectives; main relevant stakeholders in the energy sector, i.e., TSOs, DSOs, energy companies, e.g. oil, gas and electric utilities; digital start-ups; industrial consumers and associations; end consumers; consultants, policy-makers; media; academic and civil society organizations. Semi-structured interviews have been

conducted, and an anonymous web-based questionnaire was elaborated and sent directly via email to 124 experts working in the energy sector, telecommunications, industry and public organizations. A total of 64 surveys have been completed at the end of the period. The sample is small but the level of confidence is 95% ($Z=1.96$), and is compensated with the size of the sample population as by the definition of the research objectives, it was limited to only experts. All participants can be considered experts in the field. The initiative has enjoyed broad stakeholder support. Main findings are detailed in Section 5. The fieldwork took place from April till June 2018.

4.2. Case Studies

Case Study Helios Project. Joint Research Center European Commission

The first Case study is Helios Project (Ioannis et al., 2017). This was a proof of concept of blockchain focused in energy communities with the support of the European Commission. Micro-generation and renewable energy production, in particular solar energy, was studied under the paradigm of distributed ledgers. A platform named Helios, running on Ethereum, was introduced for generators to facilitate the exchange of energy in a bounded area. The idea was to develop a complete model, including smart contracts to support visibility, transparency, and financial transactions - auditability and accountability were also introduced - and the proposal of a payment medium or token payment, the Helios coin. The whole infrastructure of the system was tested at the physical layer and smart contracts were implemented. Main findings of this case study are that Blockchain technology could be a disruptive enabler of micro-generation, e.g. in-house or other sort of prosumers; the creation of energy communities can be fostered with the use of DLT that introduce transparency on transactions, visibility on green energy generation and sustainability; and accountability while preserving privacy. The aim of digital transformation in this micro-generation scenario is to foster higher shares of renewable energy sources in densely populated metropolitan areas in Europe.

Case Study Brooklyn Microgrid. Brooklyn (New York)

The second Case Study considered is The Brooklyn Microgrid (BMG Project). This is a pilot project that has been studied by Mengelkamp et al. (2018). In their work they demonstrated that blockchain was a suitable technology to operate decentralized microgrid energy markets. The BMG project is one of the most relevant projects of the company LO3 Energy (vid. www.lo3.energy.com). "LO3 is developing blockchain based innovations to revolutionize how energy can be generated, stored, bought, sold and used, all at the local level". This project has captured international interest and has been recently covered by international press (The Guardian, The New York Times, Fortune, Politico, Inverse, Reuters Japan, MIT Tech. Rev., Scientific American...). The BMG could be defined as an energy community as the term "energy community" was characterized by (Ioannis et al., 2017). The community and the microgrid energy market is located in Brooklyn, New York. The microgrid can operate autonomously from the main power lines (transmission grid) during power outages without compromising security of supply to the neighbors (consumers and prosumers) of the energy community. This project has been selected among others, e.g., smart meters connected to blockchains to enable payments and energy flows in distributed networks for its energy community spirit.

5. Results

The exploration through interviews with experts have shed some light to identify the more relevant issues and concerns of blockchain technology adoption taking into account opportunities and attitude towards the application of DLT and smart contracts.

Regarding the degree of development of blockchain technology today, see Fig.2, more than 50% of the respondents consider that the technology is in a mid-position, not too matured yet.

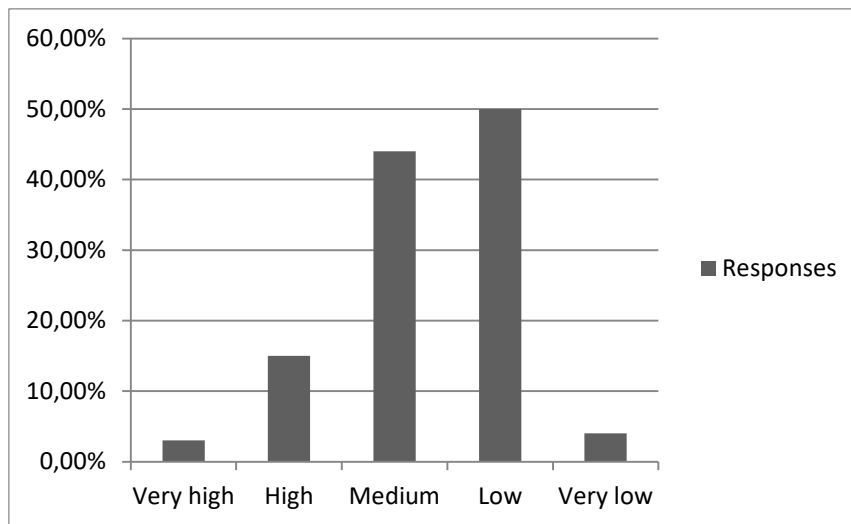


Figure 2. Degree of development of blockchain technology today

When taking into account the degree of technology maturity blockchain in comparison with other new digital technologies, e.g., Artificial Intelligence (AI), big data and Internet of Things (IoT), big data and IoT are perceived as more mature than blockchain, see Fig.3.

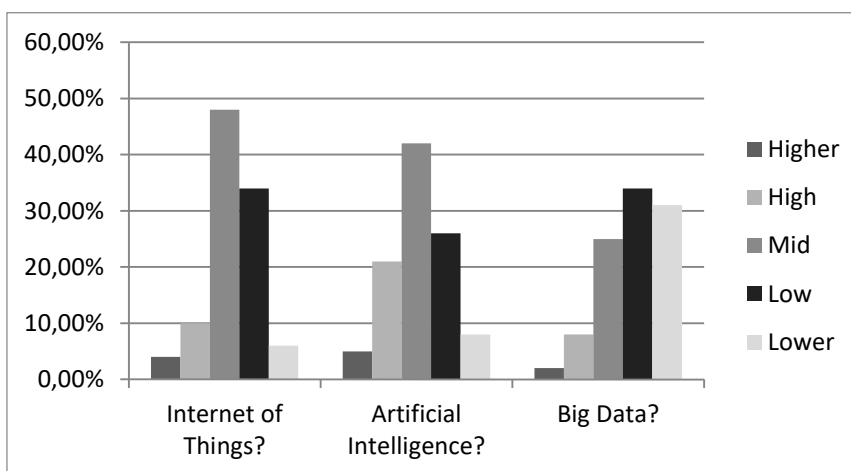


Figure 3. Degree of development of Blockchain in relation to different smart technologies

Mobility and localization of the agents are considered by respondents non-restrictive factors towards the adoption of smart technologies, e.g. blockchain, 52%. This question was asked to find relationships among well-established communities and the degree of difficulty of adoption of new technologies related with new social patterns of mobility.

In terms of possible disadvantages of (later) blockchain introduction in the energy sector in comparison with other sectors, e.g., industrial, retail, finance..., 68% of survey respondents don't see major disadvantages.

More investment in the development of blockchain is regarded for more than 67% of the respondents to be necessary to speed the introduction of DL in smart grids.

Renewables installation, in terms of investment costs, could be reduced if blockchain were adopted, the reason for respondents is in terms of efficiency, that would increase. Lower transaction costs would be achieved according to more than 62% of the respondents.

Regarding applications, smart contracts are highlighted as one of the new findings, with higher opportunities of efficiency and effectiveness. However, regulatory concerns, on one side and security concerns, on the other arise. For technology experts automatization in smart contracts could be understood in different levels, as one of the interviewee highlighted.

Among the main applications of blockchain in the case of the energy sector that could foster smart grid development (see Figure 4) respondents outline flexibility, fast transaction time, scalability, empowering and greater control of the energy market or energy storage, regarding the technology itself as an enabler to develop a major sustainability consciousness

Energy consumption and sustainability of digital distributed ledger model has been highlighted by several interviewees as a constraint factor for a suitable development.

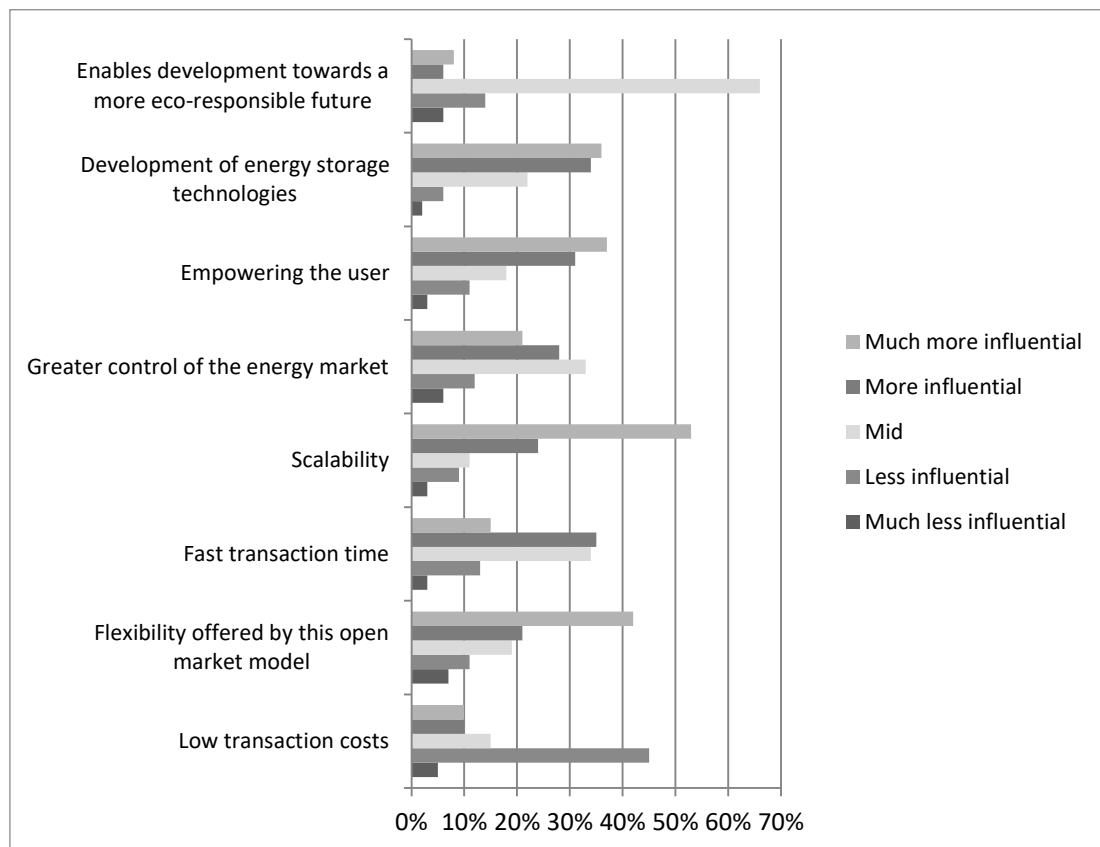


Figure 4. Blockchain's enable factors to foster smart grids development

Main findings on digital and blockchain technology evolution

There are some concerns among the experts regarding the threat of other technologies that could emerge replacing the current models, more than 71% of responses.

Regarding the evolution of blockchain technology there are major concerns among respondents, 83% of them consider in the future of DL will evolve from the current concept. With the use of international standards, many interviewees believe they will open other markets for the European digital players.

Companies that are working on, or have developed a private blockchain, are considered by respondents, 77%, to be in a better position in the energy market of the future (next 5 years) than those that didn't yet.

Regarding the influence of success experiences regarding the introduction of blockchain in different sectors, respondents highlighted that this will have a positive impact on the energy sector, 81%.

The election among public vs. private blockchain is not clear for the respondents and interviewees are divided in their responses, 45% said public blockchains are more viable, on the other side 44% believe mixed models public-private blockchains are more viable, and the remaining 11% consider private blockchains as a suitable solution.

Key findings on regulatory challenges

Regarding the legal framework, the current situation is a factor that restricts blockchain introduction in the smart grids for 40% of the respondents.

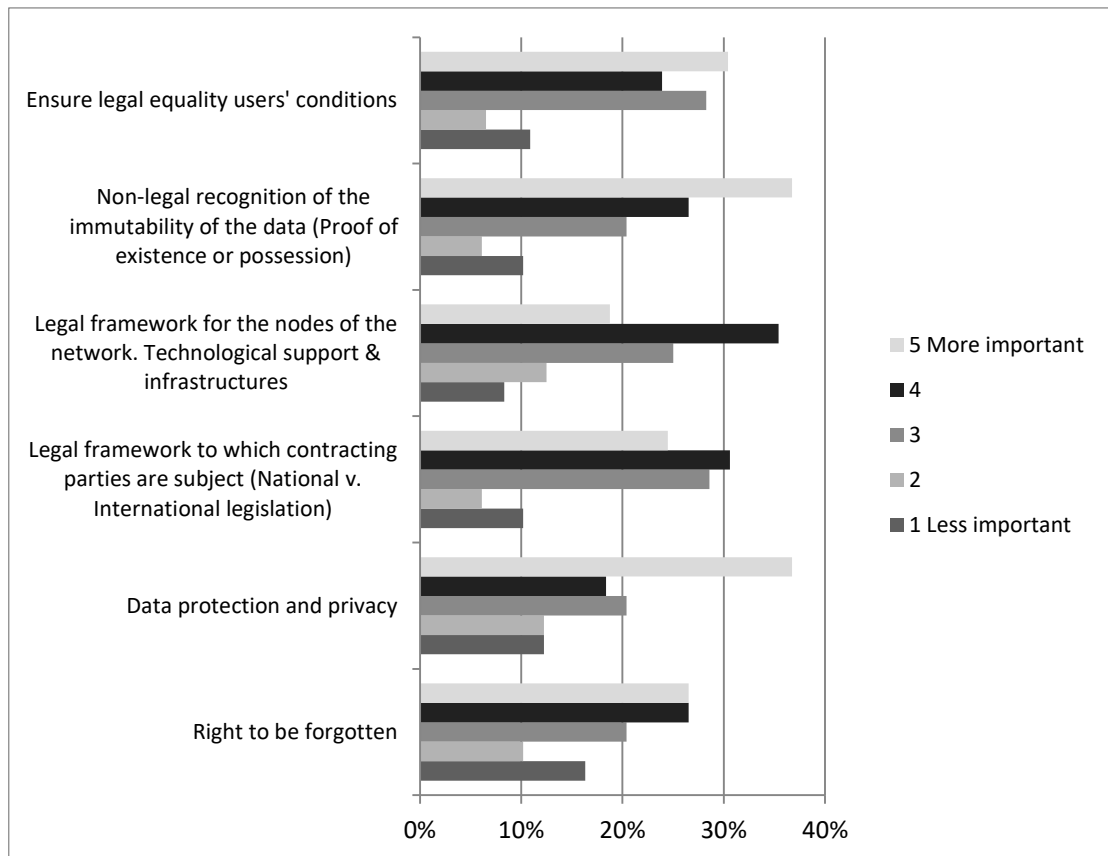


Figure 5. Importance of aspects in the Legal framework for blockchain development

Respondents don't reach an agreement in terms of the best way to regulate blockchain smart contract applications in energy markets, while 31% answered that it is highly achievable, 23% think on the contrary that it will be hardly achievable.

Within the legal framework, the most important aspects to develop for respondents are data protection and privacy, a legal framework for the nodes of the network and the contracting parts are subject to, the right to be forgotten, and ensuring equality for users, see Figure 5.

Regarding the flexibility of energy companies well positioned in the market nowadays, the risk of not willing to change or adopt blockchain is valued by the experts as low, and a relieved factor in any case, report 64% of the answers.

To configure the new future regulatory framework for blockchain technology most of respondents believe this is not a factor that compromises the future of the technology in the long term, but could be better if governments will support it.

Main findings on social perception and willing to adopt digital technologies

The change in customers' behavior is seen as one of the major challenges for the respondents. With nearly 72% identifying the transition from consumer to prosumer as a difficult or very difficult challenge.

Well informed customers in opinion of the majority of the experts interviewed and those that answered the survey consider that civil society could assume the effort to adapt to DLT.

However, in terms of time frame, most of the experts suggest that the period till the society will be ready to implement smart grids with peer to peer as the main option will go from 10 to 20 years.

Distributed ledger platforms can be understood as enablers for the creation of new forms of interaction among citizens and the way they consume, produce, or release energy, through communities evolving towards what could be defined as "open energy communities", highlighted one of the interviewees.

Regarding attitudes towards the value proposition of blockchain's implementation. Opinions differ from experts to customers interviewed. There are behavioral challenges to be solved that go far beyond technology adoption.

The last question of the survey summarizes the general perception. The question was: Based on your experience and knowledge of blockchain technology, do you consider that the advantages of blockchain outweigh the disadvantages? Figure 6 shows results. The overwhelming majority of experts believe there are more advantages.

To summarize, the main risks highlighted by interviewees are: Lack of necessary investment; the adoption of a suitable regulatory framework for Blockchain and digital technologies in the energy sector. Concerns on setting standards for security, have been also highlighted during the interviews, following other initiatives for other disruptive technologies, i.e., IoT standards, e.g. SAREF in the EU.

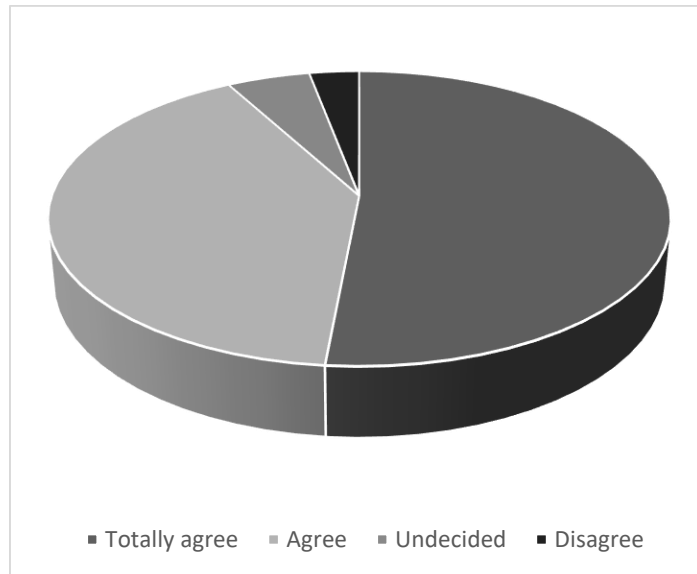


Figure 6. Blockchain advantages outweigh disadvantages?

Interoperability is a major concern for some of the industry experts. Implementation of effective identification and authentication protocols, as highlighted by technology experts, too. Integrity of data and privacy, mainly related with GDPR application emerged during the interviews.

Another relevant issue highlighted by several of the respondents was the energy consumption required to use the technology, this is related with the cryptographic requirements to work in public blockchains. In terms of security of the cryptographic technics used today, additional questions arised regarding security protection with advances in quantum computing. On the other hand, respondents find many advantages on the numerous benefits blockchain introduction and in particular smart contracts can provide to the energy sector. Those span from efficiency and costs reduction to transparency, security, enhancement of traceability, reliability, visibility of “green” energy generation, auditability and sustainability.

6. Conclusions

Fully interoperable smart grids in smart cities will increase the use of renewable energy and its share in the energy mix, ensuring a more sustainable environment thanks to the reduction of GHGs. Digital technologies inclusion, in particular, blockchains will introduce traceability, speed, efficiency and network instruments that will increase efficiency, but not only that. DLT incorporates much wider changes, i.e., deeper customers’ awareness towards the environment and consciousness. The creation of energy communities will improve the resilience of the grid and automatic and better demand response management. Digital communications and new smart technologies for one side, and renewable energy and sustainability on others, have attracted a lot of attention by the recent literature. However, there is a lack of academic research on those subjects ensuring a multidisciplinary approach. This research aims at filling that gap. The analysis of recent case studies in the energy sector regarding blockchain technology and smart contracts’ application have shown that the technology by itself is not a solution to achieve SDGs but can help, increase the transition towards sustainability. The

creation of energy communities towards VRE expansion and smart technologies can positively change agents' behavior with blockchain, i.e., transparency and security.

The case studies have shown that access to internet connection and use of distributed ledger technologies can provide positive benefits to the deployment of variable renewable energy and trade in energy markets, facilitating the incorporation of prosumers at large scale. The creation of energy communities, as mentioned, can improve a coordinated demand response and change patterns of consumer behavior contributing to the necessary energy transformation to achieve sustainability and SDGs. However, as the participants in the survey have considered, there are some key elements to be solved before a full expansion of VRE and DLT takes place. Focusing in the EU, it is necessary to establish a suitable regulatory framework to broaden blockchain and some of the relevant applications like smart contracts, essential in the energy market when the operation exceeds a privacy network or community.

Additional findings contribute to the debate about the EU strategy for a resilient Energy Union and the pursue of SDGs, requiring to foster higher shares of renewable energy sources in Europe. Unintended side-effects of digital technology e.g., privacy and security concerns should be considered, and standards and interoperability that can be active drivers to boost projects and achieve a faster energy transition towards sustainability.

The next aim of the current research is to continue with new case studies and to extend the interviews with an international panel of multidisciplinary experts, to have a better framework to address global potential problems and challenges regarding the global introduction of DLT in the energy sector.

Acknowledgements

We want to thank all the people who have participated in the survey and the interviews.

The author S. Serrano-Calle thanks Universidad Politécnica de Madrid for the support received to conduct this research during a research stay at KU Leuven. This paper is a result of a research collaboration with the Energy and Environment Group at KU Leuven.

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