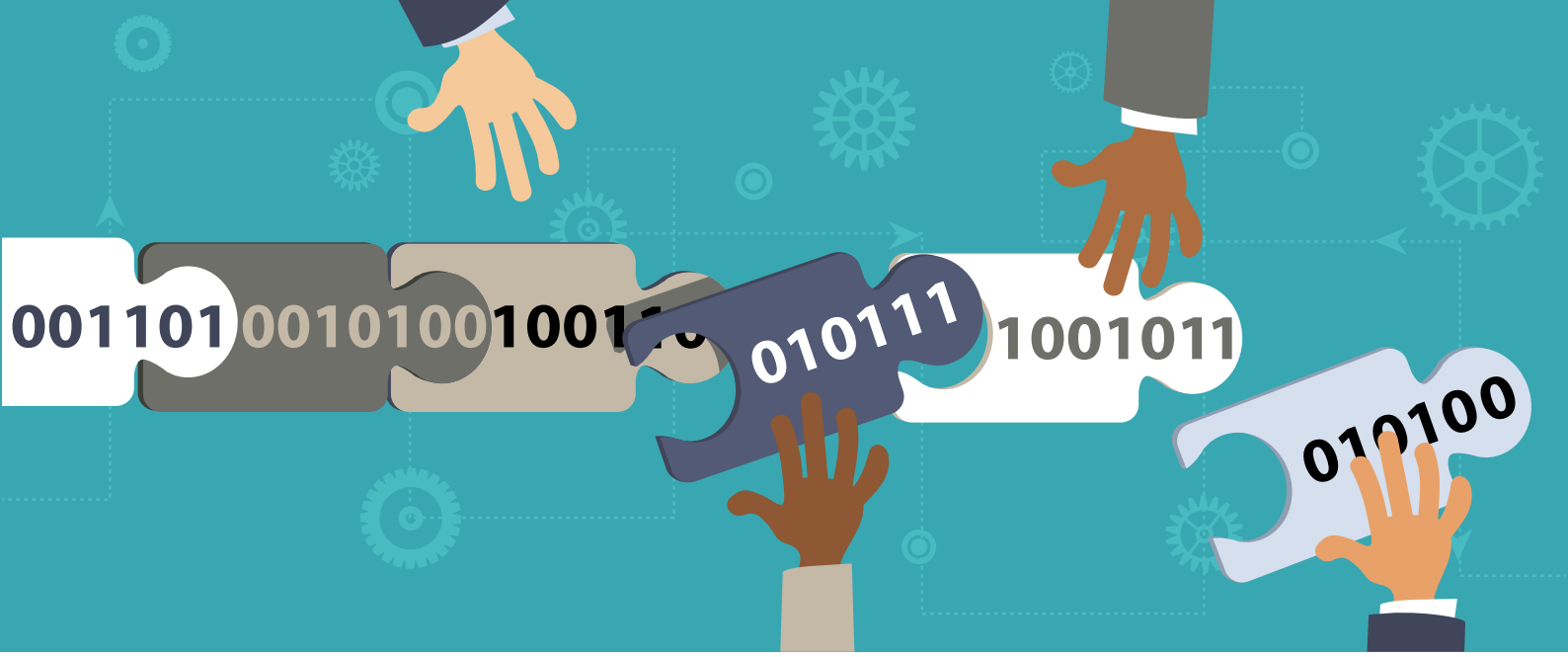

Overview Report

Distributed Ledger Technologies/Blockchain: Challenges, opportunities and the prospects for standards

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RAND EUROPE

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Preface

RAND Europe was commissioned by the British Standards Institution (BSI) in January 2017 to carry out a rapid scoping study to examine the potential role of standards in supporting Distributed Ledger Technologies (DLT)/Blockchain. The current document, intended for dissemination to interested parties, aims to serve as an overview of the study, which was conducted over a 6-week period. A more comprehensive report, with more detailed results of the analysis and findings and complete descriptions of the methods, was also submitted to the BSI.

DLT/Blockchain refers to a type of database which is spread over multiple locations (i.e. a distributed database) and which can be used like a digital ledger to record and manage transactions. Although the technology is at a relatively early stage of adoption and significant challenges remain, it is becoming apparent that DLT/Blockchain holds the potential for major opportunities across several sectors. Furthermore, standardization efforts related to DLT/Blockchain have recently gathered momentum with the setting up of the International Organization for Standardization (shortened to ISO) technical committee on Blockchain and electronic DLT.

In this report, we present an overview of the current landscape of DLT/Blockchain developments and closely examine the issues that are central to the development of DLT/Blockchain. We articulate a set of areas for further consideration by DLT/Blockchain stakeholders regarding the potential role of standardization. Rather than providing a definitive list of topics, the aim of the study is to provoke further discussion across the DLT/Blockchain community about the potential role of standards in supporting the development and adoption of the technology. We carried out the research using a mixed methods approach involving a focused review of the literature, in-depth interviews with stakeholders from public and private organizations, and an internal workshop. Although the study is primarily intended to inform the BSI's approach towards developing a standards strategy in relation to DLT/Blockchain, it is also likely to be of relevance to stakeholders in the DLT/Blockchain community, including policymakers, industry, other standards organizations (national and international), and academia.

RAND Europe is a not-for-profit policy research organization that helps to improve policy and decision making in the public interest, through research and analysis.[1] RAND Europe's clients include European governments, institutions, NGOs and firms with a need for rigorous, independent, multidisciplinary analysis.

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1 For more information on RAND Europe, please see http://www.rand.org/randeurope.html (as of 13 March 2017).

Acknowledgments from RAND Europe

We were able to carry out this exciting study because of the support of a number of people. First, we would like to thank the British Standards Institution (BSI), who commissioned the study, and in particular Tim McGarr and Emelie Bratt, for their helpful advice and feedback throughout the project. We would also like to thank Tom Price at the Department for Business, Energy & Industrial Strategy, for his useful insights on the subject. We are grateful to the guidance and advice provided by members of our senior advisory group: Prof Tomaso Aste (University College London), Dr Catherine Mulligan (Imperial College London), and Prof Raghavendra Rau (University of Cambridge). We would also like to thank the many individuals who kindly agreed to be interviewed as part of this study. We would like to acknowledge the guidance and support provided throughout the project by Jon Freeman (RAND Europe) and Catriona Manville (RAND Europe). In addition, we thank Rebecca Ioppolo (RAND Europe) for her research support. Finally, we very much appreciate the helpful and timely comments of our RAND Europe quality assurance reviewers, Molly Morgan Jones and Elta Smith.

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Background and context

Distributed Ledger Technologies (DLT) have received growing attention in recent years as an innovative method of storing and updating data within and between organizations. A distributed ledger is a digital ledger[2] that is different from centralized networks and ledger systems in two ways. First, information is stored on a network of machines, with changes to the ledger reflected simultaneously for all holders of the ledger. Second, the information is authenticated by a cryptographic signature. Together, these systems provide a transparent and verifiable record of transactions. Blockchain technology is one of the most well-known uses of DLT, in which the ledger comprises 'blocks' of transactions, and it is the technology that underlies the cryptocurrency Bitcoin. However, the possible uses of DLT go well beyond the financial sector; its use has also been explored in education, the creative industries, and the agriculture and food industries (to name a few).

A note on the terminology used in the literature and this report in relation to Distributed Ledger Technologies and Blockchain

Because the technology is under active development, the terminology is evolving and formal definitions have not been fully established. Indeed, as discussed later, one of the challenges encountered in the Distributed Ledger Technologies/Blockchain community is insufficient clarity about and inconsistent understanding of the terminology being used by stakeholders. Recognizing that the terms DLT and Blockchain are often used interchangeably in the literature, from this point forward, unless specified, we use the more all-encompassing term 'DLT/Blockchain' throughout this report.

The key features of DLT/Blockchain, as distinct from other relational databases, are associated with its distributed nature. In DLT/Blockchain, multiple copies of the ledger are held by different parties, with data added by consensus and without the need for a third party. As a result, DLT/Blockchain can provide gains in efficiency, trust and data reconciliation across all ledger participants. This means that DLT/Blockchain is able to offer:

- An *immutable record*: Data added to the ledger is in theory unchangeable, secure and preserved for the life of the ledger, with the agreement of all participants as to the contents.
- *Disintermediation*: Nodes are able to interact directly, without the need for an intermediary. This includes the ability to initiate direct transactions of data or digitized assets (which may be a dedicated cryptocurrency, such as Bitcoin,[3] or a digital representation of real-world assets, such as land titles or fiat currency[4]).
- A *lack of central control by one party*. Additions to the ledger or changes to the governing structure are decided on a consensus basis by multiple participants.
- *New opportunities for management and sharing of data*. These opportunities are achieved by facilitating the storage and access of various forms of data for participants.

2 As used in this document, the term digital ledger refers to a computer file used for recording and tracking transactions. These transactions need not be monetary in nature and may refer to interchange, addition, and modification of data in the computer file.

3 Bitcoin is an open source, decentralized, peer-to-peer payment network maintained by users, with no central authority. Bitcoin provides completely digital money for transactions on the Internet/web (i.e. it has no offline equivalent). For more details, see Bitcoin (2017) and Glance (2015).

4 The term 'fiat currency' refers to 'currency that a government has declared to be legal tender but it is not backed by a physical commodity.... Most modern paper currencies are fiat currencies; they have no intrinsic value and are used solely as a means of payment' (Investopedia, 2017).

The potential applications of DLT/Blockchain are wide ranging, and the potential benefits to the UK are considerable (Government Office for Science, 2016). A recent report noted three main opportunities presented by the particular functionalities of DLT/Blockchain: enabling cryptocurrency[5] exchange, managing contracts and creating new forms of contracts (e.g. smart contracts[6]), and prompting new applications by third parties to create new efficiencies (Government Office for Science, 2016). The distributed nature of the ledger, in which past transactions can be independently verified and protected from tampering, has potential utility for a broad range of transactional and verification services, such as financial transactions, smart contracts, identity management, and the verification of records.[7] While the financial sector has shown widespread early interest in DLT/Blockchain, other public and private organizations that rely on recordkeeping and management of secure transactions may also benefit – for example, agencies involved in collecting taxes, issuing passports, conducting asset transfers, and recording asset claims, such as land registries.

Permissioned and permissionless ledgers

Permissionless, or *public*, *ledgers* are seen by some as the 'purest' form of Blockchains (Brennan & Lunn, 2016). A typical example of a permissionless, or public, Blockchain is the one that underlies the Bitcoin network. In this type of configuration, the participation is 'permissionless' and anyone can take part in the ledger and validate transactions, with fully devolved authority (Bogart & Rice, 2016). Participants are identified through pseudonyms or are kept anonymous, and transactions are validated by 'miners' through an incentivization system (Biondi et al., 2016). This form of distributed ledger enables high security but also incurs high transaction costs due to the resource-intensive consensus mechanism[8] (Brennan & Lunn, 2016).

Permissioned, or *private ledgers* have attracted attention from businesses (Bogart & Rice, 2016). This type of ledger restricts transparency by disclosing the identity of participants in the network; access is restricted to a certain number of participants, which are known to each other, and is subjected to approval from other members of the network.[9] No 'proof-of-work' is needed to validate transactions, unlike in the case of permissionless ledger, and therefore there is no incentivization system (Biondi et al., 2016). Permissioned ledgers can be distributed for closed communities that share similar but competing interests, or they can be private for one or more organizations that share common interests (Biondi et al., 2016).[10]

As the opportunities for the use of DLT/Blockchain in the market grow, issues related to the governance of the market, interoperability of these emerging platforms and an understanding of 'good practice' in the development and use of DLT/Blockchain will become more pressing. As discussed later, many challenges to the full adoption and use of DLT/Blockchain remain. DLT/Blockchain itself, once adopted, may present new concerns regarding topical issues, such as data protection, legal status of contracts and individual privacy.

5 Cryptocurrency refers to a digital or virtual currency which uses cryptographic measures for security purposes. See http://www.investopedia.com/terms/c/cryptocurrency.asp [accessed 13 March 2017].

6 A smart contract is 'a set of promises, specified in digital form, including protocols within which the parties perform on these promises' Szabo (1996), as quoted in Murphy & Cooper (2016).

7 See, for example, the Blockcerts project, which encourages the recording of academic certificates on a Blockchain for efficient verification by employers (Blockcerts, 2017).

8 Consensus mechanism is a method of authenticating and validating a value or transaction on DLT/Blockchain without the need to trust a central authority. See Seibold and Samman (2016).

9 The transaction validation process is also restricted and relies on whitelists to permit participants and some elements of distributed consensus.

10 Permissioned ledgers are currently being looked at, especially in the financial services, because they introduce trust in the ledger system. This in contrast to permissionless ledgers, which rely on 'trustless' transactions; they can also be cheaper due to their simplified consensus mechanism, but they may increase risks for the ledger integrity (Brennan & Lunn, 2016).

However, identifying appropriate policy responses to address these concerns while avoiding derailing a nascent technology will be a critical step in the development of DLT/Blockchain, and success will depend on the outcome that is intended to be achieved. For questions bound up with existing regulatory frameworks, such as those relating to consumer protection, competition and the enforceability of contracts, this may involve regulation or legislation at a national or European level. At the other end of the spectrum, addressing some issues may instead involve voluntary codes within or between businesses. Similarly, standards[11] are likely to play a role at International Organization for Standardization (shortened to ISO) or national level.

Smart contracts

Smart contracts are a form of automated digital contract in which the terms of the transaction are embedded in computer code, to be automatically fulfilled by the software upon acknowledgement of a particular input. At their most basic, smart contracts are 'a set of promises, specified in digital form, including protocols within which the parties perform on these promises' (Szabo, 1996, cited in Murphy & Cooper, 2016). Whilst the concept was first articulated in 1996, the immutability and distributed nature of DLT/Blockchain has brought renewed attention to the concept. Although they are commonly cited in the literature as a potential application of DLT/Blockchain, questions remain over the legal status, enforceability and technological feasibility of such contracts.

Source: Murphy and Cooper (2016)

Research objectives

A range of standardization-related initiatives have commenced across the globe, examining different aspects of DLT/Blockchain (e.g. Blockcerts, 2017; Chain Protocol, 2017; Hyperledger, 2017; Interledger, 2017; ITU, 2017; W3C, 2016). Notably, an ISO technical committee[12] set up in 2016 was tasked with examining standardization issues related to DLT/Blockchain (ISO, 2017a). The aim of the committee is to 'support interoperability and data interchange among users, applications and systems (ISO 2017a).' The committee is being led by Standards Australia and includes, at the time of writing , 17 participating countries (including the UK, represented by the British Standards Institution (BSI)) and 17 observing countries (ISO, 2017b).[13] As a constituent member of the ISO, the BSI will be a key voice in the international discussion regarding the development of the DLT/Blockchain market and utilization of DLT/Blockchain by public and private bodies. Understanding the current landscape of the DLT/Blockchain market and the priority areas for the UK regarding the development of standards will be an important step in developing a strategy to maximize the benefits of this technology for UK and global stakeholders.

Against the backdrop of this changing landscape, the BSI commissioned RAND Europe to carry out a rapid scoping study to understand some of the areas related to DLT/Blockchain that would potentially require standardization based on stakeholder needs in the UK. The study is intended to inform the BSI's approach towards developing a standards strategy in relation to DLT/Blockchain. In addition, the research will be used

11 A standard is an agreed way of doing something. It could be about making a product, managing a process, delivering a service or supplying materials – standards can cover a huge range of activities undertaken by organizations and used by their customers.... Standards are the distilled wisdom of people with expertise in their subject matter and who know the needs of the organizations they represent – people such as manufacturers, sellers, buyers, customers, trade associations, users or regulators.... Standards cover a wide range of subjects from construction to nanotechnology, from energy management to health and safety, from cricket balls to goalposts. They can be very specific, such as to a particular type of product, or general such as management practices.' (BSI, 2017)

12 The ISO technical committee is called ISO/TC 307 Blockchain and electronic distributed ledger technologies (ISO, 2017a).

13 The first international meeting of ISO/TC 307 took place in Sydney, Australia, in April 2017.

by the BSI as input to hold discussions in the context of the ISO technical committee on DLT/Blockchain. More specifically, the purpose of this study is three-fold:

1) to explore the potential role of standards in supporting DLT/Blockchain based on the needs of stakeholders;
2) to identify what sectors could benefit most from the advent of DLT/Blockchain standards to accelerate implementation of the technology; and
3) to identify key stakeholders that would need to work together on developing standards related to DLT/Blockchain.

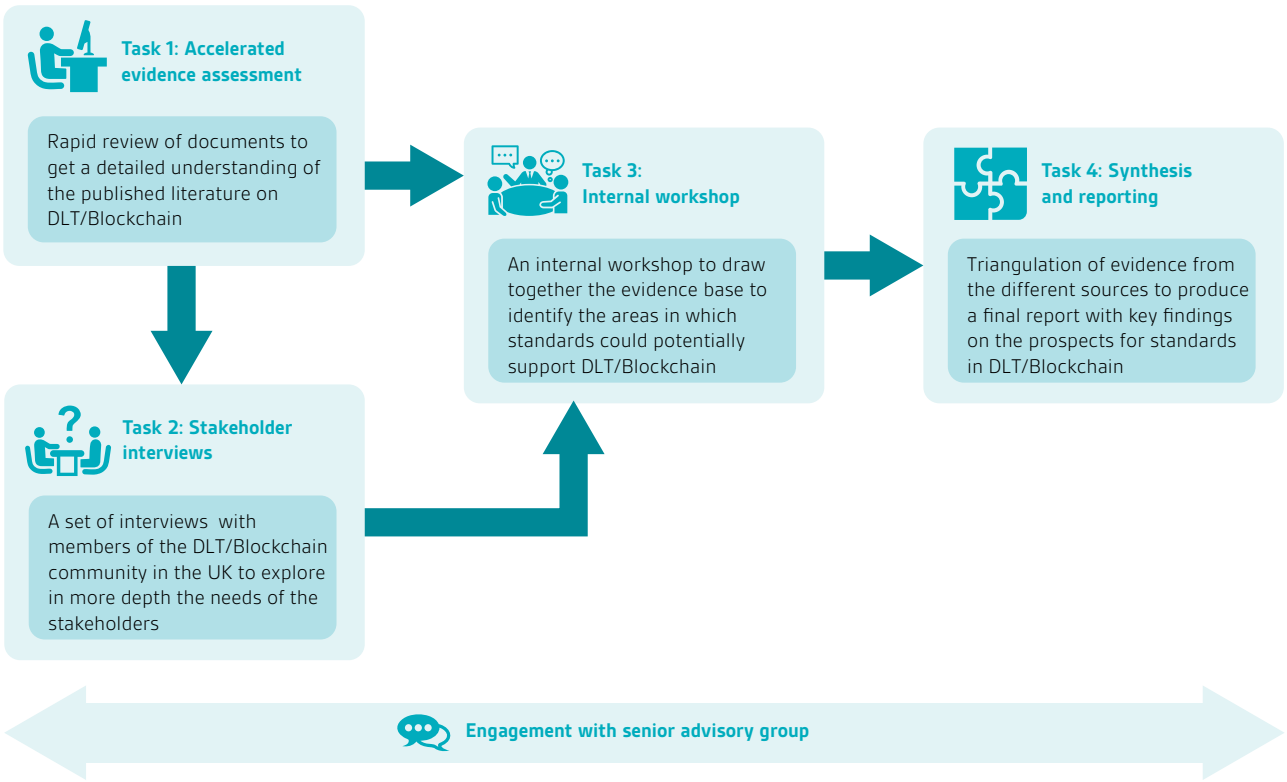
Study design and methods

The objectives of this rapid scoping study, conducted over a 6-week period, were addressed through four primary tasks, as illustrated in Figure 1. Given the cross-sectoral implications of DLT/Blockchain, RAND adopted a broad, sector-neutral approach to understanding the needs of stakeholders. RAND's approach combined research methods to leverage, synthesize and develop existing knowledge and understanding on the current landscape, key areas and sectors, and stakeholders for DLT/Blockchain. RAND assembled a senior advisory group for the study to provide additional knowledge and insight directly relevant to the UK DLT/Blockchain sector. RAND consulted members of the senior advisory group at various points in the study to obtain their feedback. The overall aim of RAND's approach was to determine the main challenges and opportunities related to DLT/Blockchain and, from these, to extrapolate a set of priority issues for stakeholders which could potentially be addressed through the development of standards. The main components of the work were:

- an accelerated evidence assessment of existing literature on DLT/Blockchain tailored to the requirements of the study (Task 1);
- a series of interviews with stakeholders in the DLT/Blockchain community in the UK (Task 2);
- an internal workshop to identify the prospects for using standards based on the evidence collated in Tasks 1 and 2 (Task 3); and
- a synthesis of the evidence from the different sources to produce the final report (Task 4).

Each of these components is discussed in more detail in Appendix A.

Figure 1 – Methodological schema of the research approach



Source: RAND Europe

Limitations of the analysis

There are some caveats to consider for those interpreting the analyses presented in this report. First, because of the tight timelines within which the research had to be completed (6 weeks), we undertook an accelerated assessment of the evidence. By design this was not a systematic review of the literature. Nevertheless, we ensured that the analysis was as comprehensive as possible within the time constraints.[14] We reviewed a diverse range of academic and grey literature to obtain a rounded picture of the current state of play as regards DLT/Blockchain.

There is an increasing body of information on DLT/Blockchain available in the public domain and the literature frequently tends to discuss future or potential opportunities and challenges. We believe that this is an inherent characteristic of the topic, which is in a nascent stage of development and has recently been receiving a growing amount of attention in the media.

Additionally, the study was not intended to cover detailed issues related to the technical and implementation aspects of DLT/Blockchain. The analysis therefore does not discuss these points in detail but, rather, focuses on the market issues related to DLT/Blockchain.

We conducted a series of in-depth interviews to validate the findings from and complement the accelerated evidence assessment. As the analysis was based on a small sample of stakeholder interviews, the findings from this component of the study should be treated with some caution and should be considered to be more along the lines of a perceptions audit. Within this small sample, we attempted to seek expert opinions and views on DLT/Blockchain and the potential role of standards across a range of stakeholders in the UK covering experts from industry, academia, government, and the third sector (e.g. industry trade organizations, industry-led consortia). The discussions in this report present the majority opinions conveyed across the sample of interviewees. Where appropriate, we have also attempted to articulate a divergence of views.

Finally, the set of priority areas for potential standardization that we identified is neither an exhaustive nor a definitive list; rather, it is intended to serve as a set of topics for further examination and debate by the BSI and by the DLT/Blockchain community more generally.

Notwithstanding the caveats discussed above, we hope that the analyses presented in this report will be useful to inform future thinking related to the role that standards could play in supporting the growth of DLT/Blockchain.

14 For example, in relation to keywords; furthermore, as noted previously, we adopted a 'snowballing' approach to identify additional articles from the bibliographies of selected articles.

Assessing the challenges and opportunities in relation to DLT/ Blockchain

Summary box: Challenges and opportunities related to DLT/Blockchain

What are the challenges facing DLT/Blockchain?

- Lack of clarity on the terminology and perceived immaturity of the technology
- Perceived risks in early adoption and likely disruption to existing industry practices
- Insufficient evidence on business gains and wider economic impact
- Lack of clarity on how the technology is/would be governed
- Uncertainty around regulation
- Multiple non-interoperable implementations and resulting fragmentation
- Maintaining security and privacy of data
- Ensuring integrity of data and strong encryption
- Energy-intensive nature of the technology
- Lack of clarity regarding smart contracts and how to implement them through DLT/Blockchain

What are the opportunities for DLT/Blockchain?

- Providing efficiency gains (including cost savings) for businesses and end-users
- Enabling new revenue sources
- Enabling new economic and business models
- Improving resilience and security in transactional systems
- Empowering end-users and improving trust in transactions
- Offering benefits for recording and reporting of data and activities through immutability capabilities
- Enabling management of digital identity through public key cryptography
- Providing the underlying mechanism for smart contracts and enabling smart auditing capabilities

Despite the potential of DLT/Blockchain technology and its perceived capability to transform existing systems, processes and businesses, challenges remain for the realization of benefits to the prospective sectors and use cases[15] identified by stakeholders. In order to understand the broader landscape of DLT/Blockchain technologies and the role that standards could play in its development and adoption, it is essential to understand the challenges faced by DLT/Blockchain as well as the opportunities that the technology offers. This section of the report begins by discussing some of the important challenges to the wider development and implementation of DLT/Blockchain. This is followed by analysis of the opportunities presented by DLT/ Blockchain.

15 'Use case' is a term that originates in software engineering, where it refers to a list of actions or sequence of steps which usually define the interaction between the actors and the (software) system. As used in common parlance and also in this document, use case refers to a scenario, set of scenarios, or examples of scenarios in which various stakeholders interact, mostly in relation to a technology or technological ecosystem for specific outcomes; e.g. a commonly cited Internet of Things use case is the Internet-enabled smart meter, which, by keeping record of when and how much the utility in question (e.g. energy, gas, or water) is consumed, can give end-users better control over their consumption (Tracy, 2016).

Challenges faced by DLT/Blockchain

Lack of clarity on the terminology and perceived immaturity of the technology

The difficulty in understanding what DLT and Blockchain stand for, and what the technology can actually do, is reiterated by multiple sources (see, for example, Andreasyan, 2016; Barclays, 2016; SWIFT Institute, 2016; Parliamentary Office of Science and Technology, 2016). The use of the terms 'Distributed Ledger Technology' and 'Blockchain' is often conflated (Mainelli & Mills, 2016). Contributing to the lack of clarity regarding terminology is the variety of approaches to and differences in the technical implementation of DLT/Blockchain. There appears to be a lack of understanding among businesses, consumers and authorities about how the technology operates, the potential use cases for DLT/Blockchain and the likely short- and medium-term market development potential (Brandman & Thampapillai, 2016; Deloitte, 2016; Euro Banking Association Working Group on Electronic Alternative Payments (EBAWGEAP), 2016; McKinsey & Company, 2015). The perceived immaturity of the technology also creates challenges for businesses that potentially want to use DLT/Blockchain.

> *The description of Blockchain tends to pre-determine peoples' understanding and to very quickly go into Bitcoin, and suddenly we are not talking about Blockchain implementations of particular solutions. We are now looking at something that is very similar to Bitcoin.* [INT01]

Perceived risks in early adoption and likely disruption to existing industry practices

Even if economic benefits are expected, the costs of adoption and implementation of DLT/Blockchain for existing businesses in the short term may be considerable. This is particularly the case for incumbents with large existing back-office processes, complex legacy IT systems, or processes created to comply with existing standards which could require costly redesign (INT05; INT06; Crosby et al., 2015; Deloitte, 2016; McKinsey & Company, 2015). In addition, the running costs associated with the adoption of DLT/Blockchain are as yet unclear (Kakavand et al., 2017; Krawiec et al., 2016; Maye, 2016). Some back-office processes may not be easily removed or replaced by DLT/Blockchain solutions in the near term. DLT/Blockchain solutions may have to implement established, sector-specific business practices (both technical and operational) and standards and overcome cultural resistance by market incumbents to achieve wider market acceptance (INT10; Crosby et al., 2015; McKinsey & Company, 2015; Shackelford & Myers, 2016).

Insufficient evidence on business gains and wider economic impact

Given the challenges of adoption, it is unclear in some cases whether a DLT/Blockchain solution is an improvement over a more traditional, centralized ledger (e.g. in terms of performance or other transactional parameters, such as security or throughput) (INT11; Deloitte, 2016; Maye, 2016; McKinsey & Company, 2017; Morrison 2016a, 2016b, 2016c, 2016d, 2016e; Tierion, 2016). Until further proofs of concept are piloted and tested, uncertainty regarding which use cases are viable and realistic may remain. In the absence of wider adoption among businesses, it is not easy to make a sufficiently clear assessment of DLT/Blockchain's broader economic impact in the medium to long term.

> *The big obstacle … in adopting Blockchain is 'What are you going to use it for, and if you do, are you going to save money with it or make more money that you currently do?' Existing systems may be old, but if they do the job, why would we pay to decommission them and do something new? Technology doubt is a massive obstacle for new technology, and especially Blockchain.* [INT12]

Lack of clarity on how the technology is/would be governed

Given the distributed nature of ledgers and their function as an immutable record, setting out clear rules for the governance of the ledger will be a key challenge for both permissioned and permissionless ledgers (European Securities and Markets Authority (ESMA), 2016a, 2016b; Mills et al., 2016; Kakavand et al., 2017;

Mainelli & Mills, 2016). DLT/Blockchain is likely to require individual users to interact with the ledger and transact using their individual private keys. Therefore, the management of keys – and protocols for key loss or theft – will be important (Mills et al., 2016; Oates & Samudrala, 2016; Peters & Panayi, 2015; SWIFT, 2016), and they must be designed to avoid introducing additional vulnerabilities through a 'back door' (Tierion, 2016). For ledgers that are shared between multiple legal entities – whether permissioned or permissionless – a key challenge will be establishing liability among partners for the activities taking place on the ledger. Examples are liability for losses experienced by businesses in the event of an operational failure or compromised keys, or legal responsibility in the event of data loss or theft (ESMA, 2016a, 2016b; Mainelli & Mills, 2016; World Economic Forum, 2016b).

Uncertainty around regulation

Understanding how operations on DLT/Blockchain relate to the wider regulatory environment – or to the development of specific regulation in light of DLT/Blockchain – will be a key element in the development and adoption of DLT solutions (Accenture Digital, 2016; Deloitte, 2016; McKinsey & Company, 2017). Smart Contracts Alliance and Deloitte (2016) highlight that, from a regulatory perspective, the functions and impact of DLT/Blockchain will be more important than the technology itself.[16] Furthermore, regulatory bodies will need to develop the skills required to understand and interpret the activity taking place on the ledger, to identify potential risks, and to ensure user compliance with existing regulation (Deloitte, 2016).

Multiple non-interoperable implementations and resulting fragmentation

To realize the full benefits of DLT/Blockchain, it will be critical for ledgers to be able to exchange information with other ledgers and with legacy IT systems (INT04; INT05; EBAWGEAP, 2016; ESMA, 2016a; Mills et al., 2016; Mainelli & Mills, 2016; Shah, 2016; SWIFT, 2016). In the short and medium term, it is unclear whether large businesses would be prepared to overhaul their existing operating procedures; DLT/Blockchain solutions will, in most cases, be required to co-exist with legacy IT structures and business processes (Morrison, 2016a, 2016b, 2016c, 2016d, Mills et al., 2016; INT12).[17] De Meijer (2016) highlights how there are at least dozens of fragmented DLT/Blockchain systems competing, each with their proprietary, non-interoperable standards and protocols, which raises challenges for interoperability and competition (e.g. in the form of barriers to entry for new entrants).

> *There will not be one big Blockchain (like the mobile network). Banks will have tens of thousands of ledgers. Millions of Blockchains will exist. These will need to speak with each other and interconnect.* [INT03]

Maintaining security and privacy of data

Organizations will need to think carefully about maintaining the integrity and security of data stored on a ledger – and of the data relating to the transaction and ledger activity itself (Deloitte, 2016; EBAWGEAP, 2016; ESMA, 2016a, 2016b; Mills et al. 2016; Mainelli & Milne, 2015; SWIFT, 2016). Similarly, for many ledgers, a transparent record may be preferred or purposeful – although one with the functionality to restrict users' ability to access sensitive or commercial data. Organizations will need to ensure that data can be accessed only by those with appropriate permissions – and that any access is in line with prevailing data protection legislation (EBAWGEAP, 2016; Mainelli & Milne, 2016). Although distributed ledgers are perceived to be more secure than centralized systems, this does not always translate into security for every single account (Kakavand et al., 2017; Parliamentary Office for Science and Technology, 2016).

16 This was also suggested by interviewee INT10.

17 Oral evidence provided by Simon Taylor in the House of Lords select committee on Economic Affairs inquiry on Distributed Ledger technologies on Tuesday, 19 July 2016. See The Select Committee on Economic Affairs (2016) for more details.

Ensuring integrity of data and strong encryption

Whereas DLT/Blockchain may present opportunities in this regard, such as multiple copies of a ledger in the event of a cyberattack or computer failure, the distribution of access and management rights across multiple nodes may in itself present a security risk, in that malevolent entities have multiple 'back doors' through which to attack the system (INT02; ESMA, 2016a). The issue of trust in the system, ascertaining integrity of other users in the distributed ledger, and carrying out transactions in a consistently secure manner are thus key challenges to wider DLT/Blockchain adoption (Brennan & Lunn, 2016; Christidis & Devetsikiotis, 2016).

> *Currently identity is being viewed as being a human factor, but if we want to attest the composition of a network, for instance, then we need to start identifying the devices that participated in that network. This is going to be worth [a lot of value] in the IoT space – 'How do I believe that what this device is telling me is correct?'* [INT01]

Energy-intensive nature of the technology

The distributed nature of DLT/Blockchain (in which changes are made to multiple ledgers simultaneously) means that certain ledger designs may be significantly more energy intensive than centralized alternatives (INT06; ESMA, 2016a; McKinsey & Company, 2015, 2016). This is likely to be a more significant problem for permissionless ledgers than for permissioned ones, in which scaling can be planned and managed (ESMA, 2016b). With large numbers of stakeholders and technologies (with different approaches to DLT/Blockchain implementation), the energy costs of running such a system and ensuring that effective cost-estimation mechanisms are in place (particularly on the server side to manage demand) may pose a significant challenge.

Lack of clarity regarding smart contracts and how to implement them through DLT/Blockchain

At the current stage of development, this lack of clarity may restrict smart contracts to simple agreements in which there is minimal subjectivity as to whether terms have been fulfilled and in which those terms can be represented in a simpler, binary fashion (i.e. the contract is either fulfilled or not fulfilled) (INT10; Mainelli & Milne, 2016). A number of these challenges stem from the perceived lack of clarity and varying definitions of smart contracts themselves rather than from DLT/Blockchain as a technology.

> *There is a lot of confusion in the smart contract space. Too many people think a smart contract is an e-contract, a digital version of a contract that used to be on paper. It is a set of rules of engagement; it is not an electronic version of a legal document.* [INT01]

Opportunities offered by DLT/Blockchain

Providing efficiency gains (including cost savings) for businesses and end-users

DLT/Blockchain can help automate a number of processes which are currently done through human action or that require third-party involvement, thus presenting opportunities for efficiency gains (Brandman & Thampapillai, 2016; Tandulwadikar, 2016; Deloitte, 2016; ESMA, 2016a, 2016b; EBAWGEAP, 2016; McKinsey & Company, 2015; Government Office for Science, 2016). DLT/Blockchain can remove the need for actively intermediated data synchronization and concurrency control by a trusted third party in a supply chain, and this could also translate into efficiency gains (Mattila et al., 2016). Similar observations are made by Brennan & Lunn (2016), who argue that the opportunity for sectors which currently rely on trusted third-party intermediation could be in the form of cost removal, improved transactional efficiency and novel revenue streams.

The driving forces, I'd say, are the efficiency gains, which are removing the need for reconciliation in the transfer of valued information assets. If companies can derive significant competitive advantage from doing that, naturally that would drive adoption. And also taking the valid products that are attractive to end-users – that would definitely drive adoption. [INT06]

Cloud-based Blockchain technology and support for national and local public bodies

Crown Commercial Services, the central procurement and commercial services agency for the UK government, has signed agreements with DLT/Blockchain service providers to provide national and local public bodies with access to cloud-based Blockchain technology and support. Current agreements include a Specialist Cloud Service agreement with Capgemini to provide DLT/Blockchain-related consultancy services (Gov.uk, n.d.a), and a Platform-as-a-Service agreement with Credits to provide a cloud-based Blockchain platform and related development (Gov.uk, n.d.b; Credits, n.d.).

Enabling new revenue sources

The adoption of DLT/Blockchain could lead to new revenue streams, products and services for businesses (Brennan & Lunn, 2016; EBAWGEAP, 2016; Government Office for Science, 2016). More efficient transaction processes may also create additional revenue opportunities by facilitating an improved cash flow and reducing the amount of collateral required for transactions, thus facilitating the use of this capital elsewhere in the economy (Brandman & Thampapillai, 2016; McKinsey & Company, 2015; EBAWGEAP, 2016; Deloitte, 2016; ESMA, 2016a); however, the extent of this predicted impact on liquidity is debated.

E-money: Licences for Blockchain-based providers to issue digital currency

The UK Financial Conduct Authority (FCA) has recently begun granting licences for Blockchain-based providers to directly issue e-money. The Small Electronic Money Institution (EMI) license permits businesses to issue digital currency and receive payments under certain conditions and reporting requirements. Current EMI licenses have been awarded to Tramonex, a cross-border payments provider whose model was developed in part with a £248,000 grant from Innovate UK (Research Councils UK, 2015) and utilizing the FCA regulatory 'sandbox' (Financial Conduct Authority, 2016); and Circle, a payments provider (Popper, 2016).

Enabling new economic and business models

The adoption of DLT/Blockchain could also enable new business and economic models. The ability to transfer assets without a third-party intermediary could create opportunities for peer-to-peer transactions and thus facilitate the growth of the 'sharing economy' (Tapscott & Tapscott, 2016a). There may also be opportunities for the wider financial and economic system, such as bringing greater numbers of people into the mainstream financial system (Mills et al, 2016; Tapscott & Tapscott, 2016a; Government Office for Science, 2016) and the creation of new forms of financial institutions (INT10).

Royal Mint Gold: A Blockchain-based platform for trading of 'digital gold'

In 2017, The Royal Mint will launch Royal Mint Gold (RMG), a Blockchain-based platform for the trading of 'digital gold', a digitized representation of physical gold bullion stored off-ledger (Royal Mint, n.d.; Reuters, 2016). Investors will be able to directly purchase and trade digitized gold bullion at a rate of 1 'RMG' for 1 gramme of gold held in The Royal Mint's vault, with the stated intended benefit being to increase transparency and reduce counterparty risk by facilitating direct ownership. (Royal Mint, n.d.).

Improving resilience and security in transactional systems

DLT/Blockchain has the potential to increase the resilience of systems and data storage due to its distributed nature and its lack of a central point of failure (Deloitte, 2016; ESMA, 2016a; Mills et al., 2016). The opportunities provided by the distributed nature of the technology are also highlighted by Mainelli (2017), who suggests that DLT/Blockchain[18] provides a technology that is not owned by a single entity and that therefore in the event of failure everyone can keep their own copy of data and transactions. This form of resilience and security provides the opportunity to create new identity systems where users own the data, which remains universally consistent and cannot be destroyed (INT02; Mainelli & Gupta, 2016).

Empowering end-users and improving trust in transactions

DLT/Blockchain can improve trust in transactions without the need for third-party intermediation (INT05; INT10; INT11; Bogart & Rice, 2016; Brandman & Thampapillai, 2016; Deloitte, 2016; Oates & Samudrala, 2016). It can put end-users in control of their own data and transactions, as their personal information is not stored on a centralized database that is more vulnerable to being hacked (Nesta, 2017; Shackelford & Myers, 2016). As highlighted recently (Government Office for Science, 2016), key areas of opportunity for DLT/Blockchain are in relation to cybersecurity, authentication of trust, identification and verification of user identities, and doing so through a transparent mechanism (also INT02). Mattila et al. (2016) suggest that this opportunity could be in the form of disintermediated, censorship-resistant and tamper-proof digital platforms of distributed trust.

> *Blockchain really allows a trusted and proven mechanism to exchange data safely with external and internal bodies whilst validating integrity of data. It gives the human-to-human trust we need as a society.* [INT05]

Offering benefits for recording and reporting of data and activities through immutability capabilities

As mentioned previously, DLT/Blockchain is able to offer an immutable record of transactions: that is, transactions cannot be deleted or altered. This immutability of DLT/Blockchain records may have additional benefits for recording and reporting of data and activities (ESMA, 2016a; McKinsey & Company, 2015; O'Dair, 2016; Oates & Samudrala, 2016; Government Office for Science, 2016; Mainelli & Manson, 2016). These include, for example, (a) providing a clear financial trail for auditors (Deloitte, 2016; ESMA, 2016a; Mills et al., 2016; McKinsey & Company, 2015; World Economic Forum, 2016b); (b) enabling regulatory compliance through 'smart code' rather than just legal code (Government Office for Science, 2016); (c) improving transparency by providing a trail of transactions in permissionless ledgers; and (d) reducing error and fraud in data by enabling tamper-proof distributed platforms (Brandman & Thampapillai, 2016; Deloitte, 2016; Government Office for Science, 2016).

Govcoin systems: Blockchain-based system to issue benefits payments

The UK Department for Work and Pensions in conjunction with GovCoin Systems has begun piloting a Blockchain-based system to issue benefit payments through an app (Plimmer, 2016). The trial, which began in 2016, is currently in the second phase with 1000 volunteers, with plans for a more extensive roll-out later in 2017 (Green, 2016).

18 In the article, DLT/Blockchain is referred to as Mutual Distributed Ledgers (MDLs).

Enabling management of digital identity through public key cryptography

DLT/Blockchain can enable efficient and cost-effective management of digital identity by relying on the use of public key cryptography,[19] leading to significant security improvements (INT08; Nesta, 2016). DLT/Blockchain can allow users to retain control over their personal information. This could lead to lowered cost of identity verification and more efficient ways of doing business-to-consumer (B2C) transactions (Bogart & Rice, 2016). More efficient identity management can result in improved transparency with respect to audit processes (INT01), compliance with privacy laws and regulations (Crawford et al., 2016), and compliance with know your customer (KYC)[20] and anti-money laundering (AML) processes (ESMA, 2016b; Mainelli & Manson, 2016).

Providing the underlying mechanism for smart contracts and enabling smart auditing capabilities

Smart contracts implemented through DLT/Blockchain can allow self-enforcement and self-execution of mutual agreements among businesses, individuals or machines. This can help businesses and end-users reduce administrative costs and lower risks in transactions (particularly in online transactions) (Bogart & Rice, 2016; Deloitte, 2016; EBAWGEAP, 2016; ESMA, 2016a; Guo & Liang, 2016; McKinsey & Company, 2015; Peters & Panayi, 2015; Schatsky & Muraskin, 2016). Smart contracts could be crucial for connected devices that may power the future machine-to-machine (M2M)[21] economy (Huckle et al., 2016). As DLT/Blockchain-based systems become more widespread, this could enable the use of 'smart audits',[22] thereby reducing the need for third-party verification to a great extent (INT01; Schatsky & Muraskin, 2016). This could facilitate improved analysis of complex value chains and reduce the possibility of fraud, including in the food sector (INT07) and in the pharmaceutical (INT02; INT03; INT04), luxury items, diamond (INT01; INT02), fashion and electronics industries (Crosby et al., 2015).

In Table 1 we summarize the key observations with regard to these challenges and opportunities. Clearly, the opportunities for DLT/Blockchain are vast; however, the challenges remain significant. Furthermore, the DLT/Blockchain landscape is complex and varied; therefore not all challenges and opportunities will be applicable to all DLT/Blockchain designs.

19 Public key cryptography is intended to enable an individual to send messages in such a way that only the person who receives them can understand them even if the method of encryption is discovered by 'an enemy' who intercepts the messages. See Beardon (2011).

20 Know your customer (KYC) is the process of a business identifying and verifying the identity of its clients. See PwC (2015).

21 M2M communications refers to 'technology that allows for the automatic exchange of data or information from one device to another through wired and wireless communications links… [and] could be considered to be an integral part of the IoT' (Gunashekar et al., 2016).

22 Smart auditing refers to automated auditing of goods and services using computing methods and additional technology, such as smart sensors and intelligent data analysis. See Rezaee et al. (2002) and Bukhsh and Weigand (2011, 2013) for further details.

Table 1 – Summary of key challenges and opportunities in relation to DLT/Blockchain

Challenges	Insufficient clarity regarding and inconsistent understanding of the terminology, combined with the perception that DLT/Blockchain is an immature technology, poses challenges to wider adoption of DLT/Blockchain.
	The potential high costs of initial implementation, perceived risks associated with early adoption of DLT/Blockchain, and possibility of disrupting existing practices may pose significant challenges to businesses.
	The lack of clarity about the improvements the technology offers over existing solutions may delay its adoption by businesses. In the absence of widespread DLT/Blockchain adoption, the broader economic impact of the technology in the medium and long term is difficult to determine.
	Because of the nascent nature of the technology, there is a lack of clarity with regard to the governance of DLT/Blockchain systems.
	There is uncertainty related to the way current regulatory frameworks would apply to DLT/Blockchain and the changes that might be needed in the event of wider DLT/Blockchain adoption across sectors.
	The emergence of multiple non-interoperable DLT/Blockchain implementations could lead to a fragmented ecosystem and limit widespread adoption.
	Potential security vulnerabilities and concerns about data privacy are seen to be significant challenges, particularly if users are entrusting DLT/Blockchain solutions with personal data.
	Safeguarding data integrity and ensuring strong encryption mechanisms are perceived as key challenges to the wider adoption of DLT/Blockchain.
	The distributed nature of DLT/Blockchain systems and the need for increased computing power can potentially result in high energy consumption and associated costs.
	Key obstacles remain with respect to the legal enforceability of smart contracts, primarily related to the lack of clarity regarding the definition of smart contracts and how to implement them through DLT/Blockchain.
Opportunities	By automating processes and reducing the need for third-party intermediaries, DLT/Blockchain solutions have the potential to provide significant efficiency gains and cost savings for businesses and end-users.
	The adoption of DLT/Blockchain technologies could potentially enable new revenue sources for businesses.
	The growth of the DLT/Blockchain ecosystem could result in the creation of novel business and economic models, such as new forms of business collaboration and cryptocurrencies.
	The decentralised nature of DLT/Blockchain and the lack of a central point of failure could facilitate transactional systems to become more resilient and secure.
	DLT/Blockchain has the capability to empower users by putting them in control of their own information, and it has the potential to improve users' trust in carrying out transactions.
	The immutability of DLT/Blockchain transactions can offer a number of benefits, including providing a clear audit trail and reducing the propensity for fraud.
	DLT/Blockchain can enable efficient and cost-effective management of digital identity through the use of public key cryptography.
	DLT/Blockchain technology could be used to implement the underlying mechanism for smart contracts and enable the use of smart auditing capabilities across different sectors.

Sector-specific observations on the challenges and opportunities of DLT/Blockchain

The available evidence on the sector-specific potential and uses of DLT/Blockchain varies. It indicates that some areas, such as financial services and supply chain management, have invested more resources in proof-of-concept studies than have others areas. Several interviewees noted that highly regulated sectors, such

as financial services, healthcare and pharmaceutical industries, may find the adoption of DLT/Blockchain more beneficial owing to its ability to provide an audit trail (INT01; INT02; INT04; INT06; INT10). For sectors that rely heavily on international supply chain and logistic coordination, the case for international norms and discussion between global stakeholders was seen as more important than engagement with national or regional stakeholders (INT07; INT12; INT13). Security, interoperability and identity management were seen as a priority for the healthcare sector (INT02; INT05; Krawiec et al., 2016). In addition, Krawiec et al. (2016) suggest that the following two aspects would be important for DLT/Blockchain adoption in the healthcare sector: (a) common architecture for sharing healthcare records; and (b) rules related to storing data (e.g. whether data should be on-chain or off-chain).

For the financial industry, to build a network effect that would benefit consumers and various industry stakeholders in equal measures, interoperability was deemed to be a priority (INT06; INT10; Accenture Digital, 2016). Tapscott and Tapscott (2016a) discuss specific uses and suggest that reconciliation and asset safekeeping within the financial industry would be important. Tapscott and Tapscott (2016a) also argue a role for DLT/Blockchain in the Internet of Things (IoT) to address privacy and payments-related concerns in a machine-to-machine (M2M) economy. The potential role of DLT/Blockchain in addressing security issues in IoT is also mentioned by some interviewees (INT01; INT05; INT06).

The prospective role of standards to support DLT/BLockchain

Summary box: Key points related to the prospective role of standards to support DLT/Blockchain

- Standards could play an important role in ensuring interoperability between multiple DLT/Blockchain implementations and, in doing so, could help reduce the risk of a fragmented ecosystem.
- Using standards to establish a stronger consensus on consistent terminology and vocabulary could improve understanding of the technology and help progress the market.
- Establishing standards to address the security and resilience of, and the privacy and data governance concerns related to DLT/Blockchain could help create trust in the technology.
- Standards could play a role in digital identity management and foster end-user trust in the technology.
- There are potential opportunities for standards to play a role in sectors where provenance tracking is important.
- It may be too early to think about standards related to the technical aspects of DLT/Blockchain.

This section synthesises the challenges, opportunities and issues in order to assess the role that standards could play in supporting DLT/Blockchain. In doing so, RAND identify several areas for action where RAND believe it would be valuable to carry out further constructive dialogue related to the potential role of standards to support the growth of the DLT/Blockchain ecosystem in the UK. The list of topics RAND has highlighted is not definitive, and RAND's intention is not to be prescriptive; rather, the list is a spectrum of wide-ranging topics that would benefit from further exploration and consideration by stakeholders within the DLT/Blockchain community. While the focus of the study has been on the UK perspective, RAND notes that some of the insights RAND has presented in the discussion below are likely to also have relevance for the global DLT/Blockchain community. Before these topics are examined in detail, in the box below RAND highlight a selection of quotes from the stakeholder interviews conducted to contextualize the discussions related to the prospective role of standardization activities in the context of DLT/Blockchain.

The potential role of standards to support DLT/Blockchain: Views from the ground

I think all the bodies will start looking into standards because it just makes sense for wider adoption. Having some kind of standards would make people a little less scared. Then it would also be useful for everyone knowing that it's compliant with that standard, so provides these features, etc. There's a lot of confusion, so anything that helps with that is useful. [INT08]

I think the current challenge is the lack of standards; people are not ready to commit millions of pounds in changing their system or using DLT/Blockchain. [INT05]

Based on what I've seen, I would say, yes, this is the right time [for developing standards] and … where I see the risk is across the whole of the system. I would say that risks are where there is a hand-off from one organization to another or one geography to another or an area to another; this is where the risks are and this is where standards would be needed the most. [INT07]

For the moment, there is too much 'hype' around Blockchain, and actors are looking at the context rather than at what the technology can actually do. It would be easier to come back to the main function of Blockchain before starting to think about standardization … [INT11]

I think standards are going to be really important to some issues related to portability and interoperability. These are going to be really important to give some kind of confidence as to how this would work and ensure that by starting there is some resilience in the systems. [INT02]

Standards could play an important role in ensuring interoperability between multiple DLT/Blockchain implementations and, in doing so, could help reduce the risk of a fragmented ecosystem

The main prospect for standardization mentioned by the majority of interviewees (INT01; INT04; INT05; INT06; INT07; INT09; INT10; INT13) is to ensure interoperability between the multiple implementations of DLT/Blockchain that currently exist or that will exist in the future. As the technology finds broader use cases, it is crucial that the various systems be able to 'talk' to each other using a 'language' that is universally understood (INT01; INT04; INT05; INT06; INT08; INT09) and to ensure the integrity of data exchanged (INT05).[23] Standards addressing interoperability could help reduce the risk of fragmentation in the DLT/Blockchain landscape, where numerous use cases, applications and systems would not be able to interact with each other. Standards could also help to establish interoperability within and across sectors as use cases develop to find cross-sector applications, thus helping to create a competitive market (INT04; INT05; INT07; INT09; Mills et al., 2016; Lamarque, 2016; Oates & Samudrala, 2016).

Despite the consensus that emerged from the participants we interviewed, the actual role of interoperability and the extent to which interoperability would need to be achieved is not yet clear. Standards for interoperability would need to be coherent and proportional to the objectives of the stakeholders to ensure that innovation can flourish (INT01).

> *One key thing that has to work for [DLT/Blockchain] to take off is that the technology has to be interoperable. Otherwise, it won't work. That's where standards should be concentrated.* [INT10]

Using standards to establish a stronger consensus on consistent terminology and vocabulary could improve understanding of the technology and help progress the market

The perceived immaturity of the technology and the resulting lack of clarity over the various terms used in the DLT/Blockchain community in relation to DLT/Blockchain (including the use of 'DLT' versus 'Blockchain') were seen as potential challenges to the wider adoption of the technology. The lack of understanding of what DLT/Blockchain is and what it can do are perceived as obstacles to growing the market (INT02; INT14). In this regard, several interviewees suggested developing a broader consensus on the definition and terminology for DLT/Blockchain (INT02; INT04; INT06; INT09; INT13). Similar observations are made in the literature (Mainelli & Mills, 2016), stating the need to adopt taxonomies and performance standards that contain outcome-focused sets of definitions and categorizations in relation to DLT/Blockchain.

> *I think that is one of the big things where standards would be needed is that they could help make a stronger taxonomy about what the different terms actually mean. This would ensure people are speaking the same language.* [INT12]

23 For example, so that data are not corrupted when transferred from one ledger to another.

However, standardizing the terminology could prove to be a difficult process, as a number of companies developing systems, protocols and services based on DLT/Blockchain already have their own definitions and implementations.[24]

Establishing standards to address the security and resilience of, and the privacy and data governance concerns related to DLT/Blockchain could help create trust in the technology

As noted above, organizations relying on DLT/Blockchain would need to carefully consider the security and integrity of end-users' data stored on the ledger. For example, the decentralized nature of DLT/Blockchain and the distributed access and management rights across multiple nodes in the network could present a serious security risk, with malicious entities potentially having multiple 'back doors' through which to attack the system. In this regard, several interviewees suggested that standardization would be needed to ensure security and resilience of the networks and to facilitate trust, and that this would be important in determining the wider adoption of the technology in the medium to long term (INT02; INT05; INT08; INT10). Furthermore, standards on data governance were identified as being key to ensuring that the data held on DLT/Blockchain systems cannot be easily manipulated and that their integrity is protected, and that in doing so, standards would mitigate data privacy concerns (INT02; INT05; INT08; Mainelli & Mills, 2016).

> *I think anywhere where data is being used, consumed, shared and distributed, standards are important from a basic control point of view and security standpoint. [INT12]*

However, given that the technology is still at a nascent stage, when thinking about developing standards, it may be necessary to exercise due diligence (including the possibility of building on existing standards) on the role that standards could play and to conduct further research in order to understand the spectrum of activities that security standards could focus on.

Standards could play a role in digital identity management and foster end-user trust in the technology

In order to foster end-user trust in the technology, allowing end-users and businesses to manage and verify whom they are transacting with was cited as an important area for standards (INT05; INT10). However, a number of existing processes (including several proprietary processes) for authentication and digital identity management exist.[25] This suggests that, in order for standards related to digital identity to be useful, the nature of identities (i.e. sovereign, national or worldwide identities) being targeted and the objectives of the authentication process would need to be carefully defined.

Standards could help manage risks associated with identity, liability, responsibility and compliance from a cross-sector perspective (Mainelli & Mills, 2016). In particular, authentication of digital identities for financial transactions implemented through DLT/Blockchain-based solutions (Shrier et al., 2016) to ensure KYC/AML compliance may differ from the existing processes. This highlights the importance of being able to assess and verify transactor/transactee identities in a DLT/Blockchain implementation (INT01) and of the possible need for changes to existing standards to reflect evolving business practices.

24 A useful example would be three cryptocurrency-related platforms – Bitcoin, Ethereum and Ripple. Although Bitcoin and Ethereum platforms are both based on DLT/Blockchain, their purposes are different. Bitcoin is a payment network. Ethereum allows any kind of data to be stored on DLT/Blockchain and provides an agreement (i.e. smart contract) on how that data will be updated. Both are intended to be trustless systems. Although often seen as competing systems, Bitcoin and Ethereum are intended for different purposes. In contrast, Ripple provides a marketplace for trust – giving the end-user control over whom they trust. In addition, Ripple uses a somewhat different mechanism for ledger security, called trust graph. For more details, see https://bitcoin.org/en/faq; https://ethereum.org/ether; and https://ripple.com/technology/ [accessed of 13 March 2017].

25 For example, 3SKey for Banks by SWIFT, Authentication schemes provided by CA Technologies, or open standard, decentralized authentication protocols such as OpenID.

There are potential opportunities for standards to play a role in sectors where provenance tracking is important

Several interviewees mentioned provenance and DLT/Blockchain's capability to deliver provenance tracking (i.e. the ability to provide a complete trail of transactions) as essential to unlocking its innovation potential (INT02; INT05; INT06; INT10; INT11; INT12). Particularly in sectors which trade in physical goods, DLT/Blockchain's provenance capabilities would be crucial to effectively linking the digital identity (and history) of the product with its physical attributes to provide tracking of goods (Greenspan & Zehavi, 2016). Such sectors as pharmaceuticals (INT02; INT10),[26] supply chains for single-source products (INT07),[27] and diamond trading and transfer (INT01; INT02; INT11) could potentially benefit from standards (including sector-specific standards where applicable) which provide a way for different regional and national stakeholders to verify, transfer and transact products and services across the entire lifecycle of those products and services.

The use cases of DLT/Blockchain for provenance tracking have been limited to small pilots, and the extent to which DLT/Blockchain-based solutions would scale up is not fully established. This suggests that further research on the use cases and on ontologies that could contribute to a robust DLT/Blockchain design[28] for provenance tracking may be required before the role of standards is discussed.

It may be too early to think about standards related to the technical aspects of DLT/Blockchain

Currently, there is limited consensus on the potential for standards on technical aspects (e.g. format in which data is stored, size of blocks, communications protocols) and their impact on DLT/Blockchain adoption. Some interviewees (INT01; INT04; INT09) questioned the need for a standardized approach to DLT/Blockchain technology itself. They suggested that such an approach would be suitable only for particular applications within DLT/Blockchain and would not necessarily be adopted by others.

> *I don't think we should be setting standards about the technical aspects. High-level standards on what those standards should look like – for example, interoperability and interaction with other providers – but don't set standards about how many characters should be in this field.* [INT10]

Considering the relative immaturity of the technology, aiming for standards on technical aspects could prove counter-productive at this stage. Interviewees (INT03; INT04; INT10) emphasized that markets and industry-based stakeholders could play a stronger role in relation to standards that focus on technical aspects.

Discussion

The evidence from the literature review and interviews on the role for standards suggests the need for a measured approach to developing standards in the near term and medium term. Although a majority of interviewees agree that standards have a role to play in shaping the development and adoption of DLT/Blockchain in the long term, most of them were also of the opinion that additional time may be needed to enable a more informed approach to deciding which aspects and uses of the technology should be prioritized (INT02; INT03; INT04; INT05; INT06; INT10; INT12; INT13). Similar analysis is presented in the literature, with De Meijer (2016) and SWIFT Institute (2016) suggesting that further clarity is needed on the overall technological landscape needed before a stronger case for standards emerges.

26 Possible benefits suggested but yet to be fully demonstrated in relation to the pharmaceuticals industry are anticounterfeiting measures, limiting distribution of fake drugs, and more efficient and effective drug testing and piloting (INT02; INT07).

27 A useful example is the pilot of the Provenance system for tuna fisheries in Indonesia and across the wider stakeholder supply chain. See Provenance (2016).

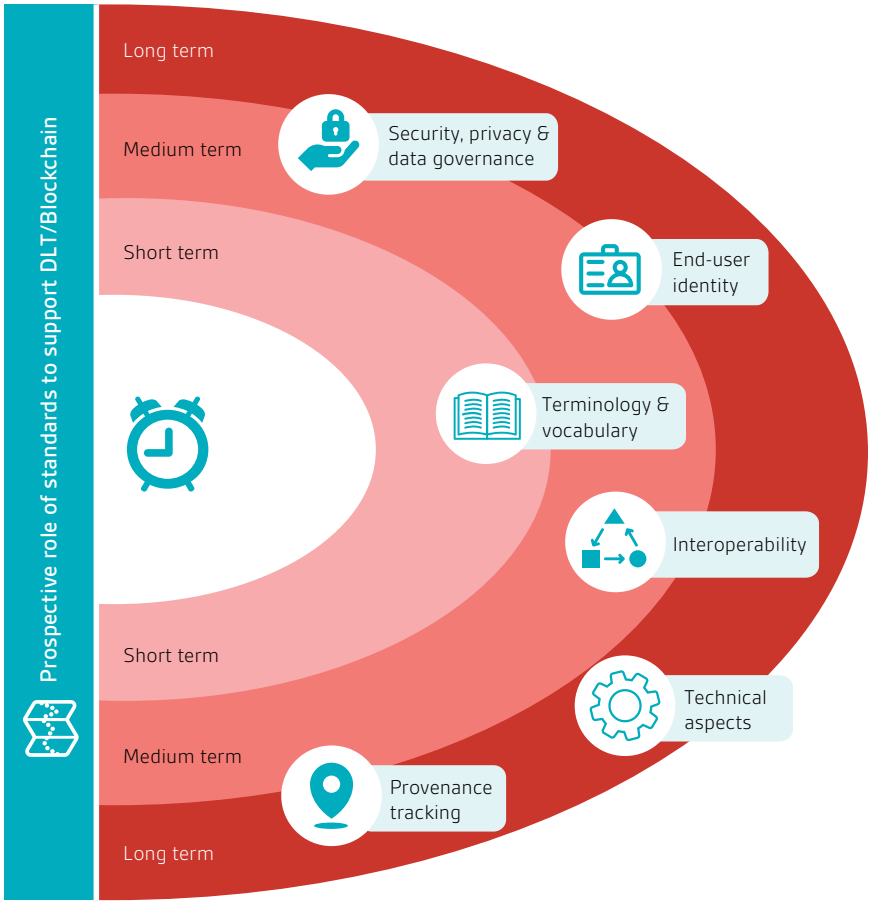
28 See Kim and Laskowski (2016) for a more detailed discussion on ontologies that could enable provenance tracking using Ethereum. See also Kim (2016).

In arguing a better prospect for standards in the medium and long term, one interviewee (INT11) suggested that once the technology is more mainstream and a better understanding of its strengths and weaknesses emerges, the priorities for standards will become clearer. While discussing medium-term possibilities, another interviewee (INT10) emphasized interoperability as a key outcome to be targeted. It was also suggested that given the likely disruptive influence of the technology, some aspects (e.g. technical aspects of DLT/Blockchain) of standardization may develop in a longer timeframe than others (INT10). The same interviewee suggested that in the near term, initiating and fostering a discussion with various stakeholder groups on standards could be crucial to developing a shared understanding of their needs.

Our analysis suggests that standards could prove to be important to the wider development and adoption of DLT/Blockchain. We have identified several areas where standards could – to varying degrees – potentially overcome the challenges and support innovation, growth and competitiveness in the DLT/Blockchain ecosystem. Some of these areas, such as standards in the context of provenance tracking and management of digital identities, are more specific than others, such as standards to ensure interoperability and consensus on terminology. Generally, standards were seen as being important to facilitate trust and support innovation, and thus to the development of new applications. In addition, standards were also seen to have a role in coordinating and 'defragmenting' a market constituted of 'piecemeal initiatives' and to 'unlock network effects' (INT01; INT09; Digital Catapult & Open Data Institute, 2016; Mainelli & Milne, 2016). This would help to build market confidence and allow for the coordination of various actors within and across sectors to foster convergence (INT09). The process of standardization enables stakeholders to 'stop and think' about the use of technology to solve social problems and to enable 'legibility'(Narayanan as quoted in Schepers 2016).

As mentioned previously, the priority areas we have proposed in our analysis are not intended to be definitive or prescriptive. The aim is to provoke further exploration of these topics in a collaborative manner by stakeholders within the wider DLT/Blockchain community about the potential role of standards in supporting the development and adoption of the technology. In Figure 2, we illustrate these priority areas and provide an approximate indication of the relative timelines for potentially developing standards in relation to these areas. To reiterate, our analysis suggests that despite the consensus on the overall importance of standards to support the growth of DLT/Blockchain, views differ with regard to the areas for potential standardization and the timelines for developing and implementing standards. The timelines shown in Figure 2 are merely indicative at this stage and are based on our examination of the DLT/Blockchain ecosystem established through the rapid scoping study we have undertaken. Further research and continued engagement with the stakeholder communities that would input to them is needed to establish a better understanding of the timelines for developing standards.

Figure 2 – Areas where standards could potentially play a role in supporting DLT/Blockchain, and an indication of the prospective timelines[29]



Source: RAND Europe

UK-specific observations on the development of DLT/Blockchain standards

In this section we cover some initial observations in the context of the role the UK could play as the prospects for DLT/Blockchain standards develop further and the interests of stakeholders become clearer. This discussion is primarily informed by the insights provided by the experts we interviewed, and we acknowledge that further research is needed to validate and build on these observations. Where relevant, evidence from the desk research has been cited. Highlighting the extent of consensus building that would be essential to any future standards-based activity, this discussion indicates that further stakeholder engagement will be critical in order to inform the UK's approach to standards to support DLT/Blockchain.

29 Note that the 'vertical axis' in the figure does not carry any meaning; that is, provenance could just as easily go at the top of the visualization as at the bottom. What the figure attempts to present is the relative position of the different topics in relation to the 'time axis'. For example, to help progress the market, the DLT/Blockchain community could, in the short term, focus on developing standards related to establishing a consensus on consistent terminology. In the medium to long term, after having addressed issues related to inconsistent definitions and terminology, standards development could be focussed on other areas, such as security, privacy and data governance, and interoperability.

The influence of the UK's position as an important financial hub

London's position as a financial capital and hub for financial technology (FinTech) start-ups was mentioned by several interviewees as being potentially relevant when thinking about the future development and adoption of DLT/Blockchain-based platforms and solutions (INT03; INT04; INT05; INT06; INT10; INT12; INT13; see also Yeandle et al., 2005; World Economic Forum, 2016a). The willingness of UK businesses to experiment with emerging technologies and potentially disruptive innovations was also cited as a strength by more than one interviewee (INT05; INT10; INT14).

> *London is a pre-eminent global hub for finance. DLT/Blockchain can have a global application. The UK has an opportunity for export.* [INT04]

The advantages of a market-led regulatory regime in the UK

The UK regulatory regime was cited as an advantage by several interviewees (INT05; INT06; INT10; INT12; INT13). In particularly, the ability to balance market-led activities against enabling competition to thrive has been mentioned as a strength for the UK (INT05; INT10). For example, the 'forward-looking' approach taken by Bank of England and Financial Conduct Authority (FCA) on not only cryptocurrency but also DLT/Blockchain as the underlying technology was noted as being a factor that would strengthen the wider DLT/Blockchain ecosystem in the UK beyond financial services (INT05; INT06).

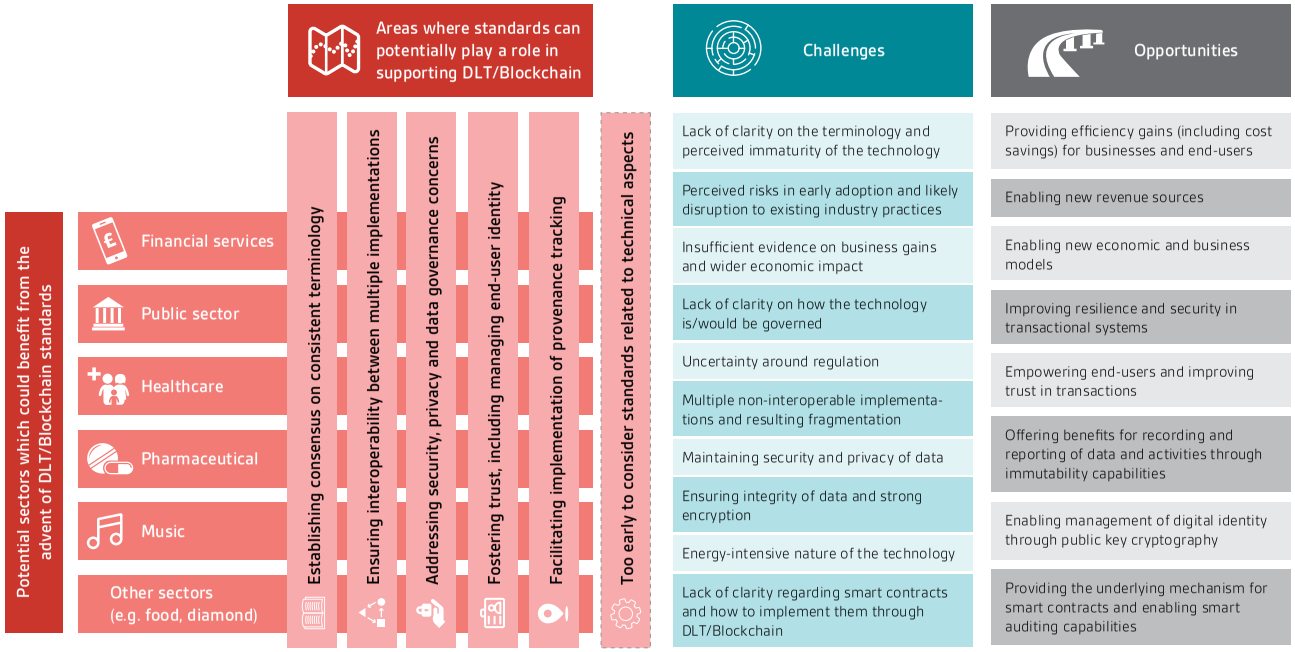
> *The UK has a fairly strong position, largely driven by organic growth of the industry, [for] solving private sector needs. Many FinTech firms are trialling the use of DLT, for example, through the regulatory sandbox. Local councils are also beginning to drive the way forward in the use of DLT for government services.* [INT15]

Concluding remarks

This analysis suggests that the opportunities arising from DLT/Blockchain are vast; however, there are many challenges to contend with although it is a field characterized by rapid change and uncertainty, steps can be taken to better understand the current realities, drivers of change and impacted sectors. In this regard, the analysis in this report notes that there is scope for standards to play a role in supporting the technology, for example, to act as an enabler to create the necessary space for the development and adoption of Blockchain/DLT and its market. However, as is generally the case with emerging technologies, the timing for developing and introducing standards (which may build on existing standards) is critical. A standards strategy that occurs too late with regard to a technology potentially risks missing opportunities to maximize the benefits the technology could deliver. The analysis we have undertaken aims to provide a rounded perspective on the evidence base that could be used for future discussion and decision making related to the role for standards to support DLT/Blockchain.

In Figure 3, we show a visualization that depicts: (a) the areas we have identified where standards could play a role in supporting DLT/Blockchain; (b) the potential sectors which could benefit from the advent of DLT/Blockchain standards; and (c) the overarching challenges and opportunities identified in relation to DLT/Blockchain.

Figure 3 – Visualization depicting (a) the areas where standards could play a role in supporting DLT/Blockchain; (b) the potential sectors which could benefit from the advent of DLT/Blockchain standards; and (c) the challenges and opportunities identified in relation to DLT/Blockchain.[30]



Source: RAND Europe

30 This visualization provides a very high-level 'summary' of the analyses presented in the report. The DLT/Blockchain landscape is complex and varied; therefore, not all the areas for standards and not all the challenges and opportunities identified in this study will be applicable to all DLT/Blockchain designs and sectors

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Appendix A: Methodological approach

Below we present further details about the methodological approach.

Accelerated evidence assessment (Task 1)

To build a rounded picture of the current state of play with regard to DLT/Blockchain within the study timelines, we conducted a rapid review of the academic and grey literature available online. One of the primary aims of this task was to establish a deeper understanding of the challenges and opportunities that are central to the development of DLT/Blockchain and of their implications for the potential development of standards within the area. To align with the overall objective of the study, the emphasis of the task was on the market issues related to DLT/Blockchain rather than the technical or implementation-specific aspects. We also used this task to identify (a) key sectors that could potentially benefit from the emergence of DLT/Blockchain standards and (b) the main stakeholders whose prospective inclusion in the standardization of DLT/Blockchain would be relevant and important to advance the area.

The search was conducted using Google Scholar and Google searches to ensure a sufficiently broad coverage of the academic, policy and consultancy literature. We also searched a limited number of technology blogs and news sites. A number of search strings were developed to retrieve the articles. An initial long list of articles was generated; these were then screened for relevance on the basis of their title and abstracts. To ensure that we obtained as much relevant evidence as possible, we also used a 'snowballing' approach to identify additional articles from the bibliographies of selected articles. For pragmatic reasons, the search was limited to articles from 2006 onwards. Our searches revealed that the majority of relevant literature was published in the past seven years. Finally, before we started to conduct searches, we consulted our senior advisory group to identify existing literature sources and to validate the search terms used in the analysis.

Stakeholder interviews (Task 2)

As mentioned previously, the overarching objective of the research is to understand, on the basis of the needs of the stakeholders in the UK DLT/Blockchain community, some of the important areas related to DLT/Blockchain that potentially require standardization. To allow us to explore this in more depth as well as to validate and enrich the findings from the accelerated evidence assessment, we conducted a series of interviews with a selection of stakeholders in the UK DLT/Blockchain community. We were particularly interested in (a) examining each of our experts' general understanding of DLT/Blockchain and the evolving landscape within the UK and internationally (where appropriate); (b) their perceptions and awareness of the notable challenges and opportunities; (c) their insights into the key areas where standards could potentially support DLT/Blockchain; and (d) any sector- or topic-specific observations they had with respect to the development and adoption of DLT/Blockchain.

In total, we conducted 14 interviews in February and March 2017 across a range of stakeholder groups in the UK – including different industry sectors, academia, government, and the third sector (e.g. industry trade organizations, industry-led consortia). The interviews were semi-structured and lasted between 45 minutes and 1 hour. Thirteen of these interviews were conducted by telephone. One interviewee responded to the questions via email. The semi-structured format ensured that a similar set of questions was asked of all interviewees, but it also allowed for emergent issues to be explored. All interviewees were sent an interview information sheet and topic guide a few days in advance. This included information about the aims of the project, the purpose of the interview, a note on confidentiality, and a list indicating the topics to be covered during the interview. To safeguard the anonymity of the experts we interviewed, the analysis presented in the report does not make any specific references to either individuals or stakeholder groups (we use the identifiers INT01, INT02, etc. to make reference to insights from the interviewees).

Internal workshop (Task 3)

After collecting and analysing the data in Tasks 1 and 2, the study team organized an internal workshop to draw together the evidence base, with the aim of: (a) undertaking a thematic examination to corroborate the primary challenges and opportunities identified from the literature and interviews in relation to DLT/Blockchain; (b) validating the different sectors and stakeholders which could be impacted; and (c) identifying the main areas and topics in which standards – either national or international – could potentially support DLT/Blockchain.

Synthesis and reporting (Task 4)

In the final phase of the project, we triangulated the evidence from the different sources to produce a final report with observations and key findings that addressed the core objectives of the study. This included: (a) demonstrating the prospects for developing standards in relation to DLT/Blockchain, with a focus on the UK perspective; (b) identifying sectors that might benefit from the advent of DLT/Blockchain standards; and (c) identifying stakeholders that would need to work together on developing standards related to DLT/Blockchain. The analysis identifies a series of areas or topics for further consideration related to the potential role of standards to support the growth of the DLT/Blockchain ecosystem in the UK.