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Research article

Blockchain applicability in the management of urban water supply and sanitation systems in Spain

Antonio Rodríguez Furones *, Juan Ignacio Tejero Monzón

Water and Environmental Sciences and Technology Department, University of Cantabria, Av. de los Castros, S/N, 39005 Santander, Spain

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ABSTRACT

Blockchain constitutes a disruptive technology that is currently changing business models and the way organizations operate. This paper explores the applicability of blockchain technology, and of distributed ledger technologies in general, to urban water supply and sanitation services in Spain. The potential of this technology for improving processes in this sector is assessed through a specific methodology of strategic analysis developed for this purpose. First, the technical, legal and managerial factors that condition the potential use of this technology to address the global, operational and governance challenges faced by urban water management are explored. Second, strategic analysis tools (e.g. value chain, factors of competition, and benchmarking) are used to model a water utility organization as a set of processes and characterize blockchain as an enabling technology with both benefits (traceability, immutability, and disintermediation) and limitations. Based on cost-benefit analysis, use cases in which the implementation of a blockchain could improve the organization's performance can be discerned. The results identify the processes and sub-processes of urban water utility management for which the use of a blockchain could improve performance: comprehensive maintenance, the management of serious incidents, and supplier management. Essentially, the methodology developed identifies management processes whose requirements are efficiently met through automation derived from blockchain solutions. Regardless of the management models currently in place in Spain, the traceability and disintermediation benefits of blockchain solutions can help to overcome governance and efficiency challenges associated with the management of urban water supply and sanitation services.

1. Introduction

This paper proposes to assess the potential of blockchain – understood as a technological tool – for improving efficiency in the management of urban water supply and sanitation systems. To this end, a methodology was developed and applied to support decision making when seeking blockchain use cases that address the challenges found within the urban water sector in Spain.

To begin with, existing management models are reviewed, together with the key strategic challenges they face in the short, medium, and long term. Available scientific literature analyses the current challenges of the urban water sector and its business models. Simultaneously, a growing body of literature looks into the possibilities of blockchain for transforming current business models. This includes literature reviews (Asgari and Nemati, 2022).

1.1. Urban water cycle management models in Spain

Within the integrated urban water cycle, supply and sanitation services involve a set of resources (infrastructure, technology, human resources, intangibles, etc.), processes, and management systems that aim to meet user requirements for the supply of potable water and the treatment of wastewater, in a manner that is both satisfactory in terms of quantity and quality and sustainable over time (Fernández Pérez, 1995).

At present, three basic models of integrated management of urban utilities coexist. These differ in terms of the relationship between the service provider and the public owner, which in most cases is a local administration (Government of Spain, 1985):

- Direct management. The public service is provided by the owner through an organizational structure that can adopt different legal forms based on the legal framework in place at any given time. It can function in the form of either a municipal service or a public

* Corresponding author.
E-mail address: antonio-miguel.rodriguez@alumnos.unican.es (A. Rodríguez Furones).

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Table 1
Urban water management models in Spain (2020).

	Management Model (% of population supplied)
Joint Venture	22%
Private Company	33%
Public Company	35%
Municipal water service	10%

Prepared by the authors. Source: XVI National Survey of Potable Water Supply and Sanitation (AEAS and AGA, 2022).

Table 2
Urban water management models in Spain, basic characteristics.

Direct Management	Delegated Management		
	Public company	Joint venture	Private company
Small municipalities that directly manage water services.	Public company that manages water at the local or regional level.	Management at the regional level with a tendency to expand.	More dispersed presence at the municipal level, depending on the concessions.
	Large volume of customers.	Large volume of clients and large grid.	Private companies, specialized in water infrastructure management.
No independent company is involved.	Public administrations are the only shareholders.	Company owned by public administrations and private entities.	

Prepared by the authors. Source: activity reports of Spanish water operators (Aqualia, CYII, CABB, Agbar Group, etc.).

company that administers the service itself – which constitutes a form of delegated management.

- Indirect management. The service provider is a private operator who, generally through a public service concession contract, is responsible for the operation of the system in exchange for financial compensation. In supply services, this cost is usually covered by a tariff applied to end users.
- Mixed management. Through a public-private partnership (PPP) (Tsitsifli and Kanakoudis, 2008), the service is provided by a company in which both the administration owning the service and a private operator in charge of its operation are shareholders. Compared to a conventional concession, this system aims to have greater control over the actions of the service operator, with the aim of aligning the objectives of the service provider and the service owner.

Table 1 shows the relative weight of these different urban water management models in Spain in 2020. This distribution has remained similar in recent years, although recent political-legal developments and economic trends in Spain and Europe may alter it in the short or medium term (Tornos Mas et al., 2019).

As detailed in Table 1, different forms of public-private collaboration are the most common mechanisms found in Spain. Several models coexist: public companies, such as Canal de Isabel II (CYII), EMASESA, and the Consorcio de Aguas Bilbao Bizkaia (CABB); mixed companies with the long-standing participation of private operators, such as occurs in large municipalities like Valencia or Barcelona; as well as the pure concession model found in cities such as Santander, Salamanca or Castellón.

Table 2 summarizes the characteristics of service operators, pointing out the most relevant issues facing each management model (PwC, 2018).

The coexistence of the different management models described in Table 2 makes it easier for a service holder to choose the one that best suits its specific characteristics and the specific circumstances of the supply or sanitation services it provides.

1.2. *Challenges of water utility management*

Given the current situation of integrated urban water management in Spain, and based on the objectives established by the Water Framework Directive (European Union, 2000) and the global policies – especially Agenda 2030 – agreed by the Public Administration at its different levels (central, regional, and local), key strategic challenges have been defined. These should be taken into consideration when seeking to develop a model for the optimal management of urban water service (Zarghami et al., 2008).

These strategic challenges have been classified into three broad categories, according to the nature of the issues to be addressed (Cosgrove and Loucks, 2015):

- "Global" challenges: current aspects of the global situation that decisively condition the strategic planning of urban water services, and that also affect other sectors. According to the terminology of "strategic analysis" methodology, these challenges are derived from a PEST study (Political-Legal, Economic, Socio-Cultural, and Technological factors), and from an analysis of the current context to determine the threats to a given economic activity (CNMC, 2020).
- "Operational" challenges: issues that are unique to the sector, such as those involving investment and changes in the processes and in the management of urban water services. In this area, the management processes of service operators must be aligned with operational objectives (environmental, economic, social, etc.).
- "Governance" challenges: consequences of changes and improvements in the relationship with users and in the financing of services, as called for by the Water Framework Directive and other public policies sponsored by the European Union with the aim to evolve towards a more open governance model (Akhmouch and Correia, 2016). The management processes employed by service operators are essential for improving organizational governance (transparency, regulatory compliance, etc.).

The pressure to improve and redefine management processes has its origin in endogenous causes (e.g. continuous improvement, customer experience, etc.) and exogenous causes (e.g. the regulatory framework) (Cosgrove and Loucks, 2015).

Table 3
Blockchain typology.

			Read	Write	Commit	Example
Blockchain type	Open	Public permissionless	Open to anyone	Anyone	Anyone	Bitcoin, Ethereum
		Public permissioned	Open to anyone	Authorized participants	All or subset of authorized participants	Sovrin
	Closed	Consortium	Restricted to an authorized set of participants	Authorized participants	All or subset of authorized participants	Multiple banks operating a shared ledger
		Private permissioned ("enterprise")	Fully private or restricted to a limited set of authorized nodes	Network operator only	Network operator only	Internal bank ledger shared between parent company and subsidiaries

Source: Hileman and Rauchs (2017).

1.3. Blockchain as an enabling technology

1.3.1. The distributed ledger technology approach

The recent development of distributed ledger technology (DLT) has its origins in the paper "Bitcoin: A peer-to-peer electronic cash system", published by Satoshi Nakamoto (2008), although earlier work was conducted by Nick Szabo (2005). Nakamoto intended to implement a new financial model without intermediaries based on a virtual cryptocurrency, utilizing a distributed P2P network with a large number of nodes, peer-to-peer consensus mechanisms among users, and advanced cryptographic techniques that would guarantee a high level of security, as well as traceability and transparency in transactions.

Although bitcoin continues to operate, this initial idea has evolved, generating new blockchain networks of various types (public, private and permissioned) that support new cryptocurrencies (in the case of public blockchains) and new applications that take advantage of the possibilities derived from traceability, immutability, and trust associated with DLT (Morkunas et al., 2019).

To ensure that records have these attributes, the architecture and design of a DLT must comply with five basic components: a P2P network, consensus protocols followed by all nodes, cryptographic developments, common validation rules, and a shared logbook (Hileman and Rauchs, 2017). Following a strategic analysis approach, the most useful classification of the different DLT variations available is based on the profiles of potential users, as detailed in Table 3 (Hileman and Rauchs, 2017).

In turn, the definition of the different components presented in Table 3 conditions the benefits associated with the use of each of these types of blockchains. Thus, public networks (the only proper blockchains, according to some authors) generate cryptocurrencies during mining (the process of creating blocks) as a mechanism of remuneration for their activity (Du et al., 2019), while the use of permissioned networks can be satisfied with fiat currencies, since proprietary nodes make up the network.

1.3.2. Characterization of blockchain technology

In any process of digital transformation, in operational terms, it is necessary to characterize the available technologies to assess whether they can help improve an organization's performance (Vial, 2021). As an enabling technology, the fundamental competitive advantage of blockchain technology – and that which makes it a disruptive technology – is that the security it provides over the transactions and records collected allows it to dispense with intermediaries whose role it is to authenticate or guarantee the integrity and traceability of data throughout the process. The automation of this task is known as 'disintermediation'.

As for the technology's current trajectory, according to Gartner (n.d.):

> "While Bitcoin and Ethereum are constantly in the news, blockchain may seem to be just around the corner. However, most initiatives are still in alpha or beta stages. Companies are still deciding how to use this technology, but the lack of use cases and the volatility of Bitcoin has led to concern over the viability of this technology. In the long term, Gartner believes this technology will lead to a complete overhaul of all industries."

Therefore, in terms of the advantages associated with its use, DLT in general enables for processes running on it to be endowed with the following attributes (PWCNetwork, 2020):

- Confidence in the data recorded and managed.
- Security during data transactions.
- Cost and time reduction (if disintermediation is in place).

With regard to the costs and risks associated with implementing a blockchain, the following aspects should be taken into consideration in a cost-benefit analysis to facilitate decision making:

- Processing limitations (transactions per second).
- Energy cost. Distributed networks require the continuous operation of a high percentage of their nodes (dependent on the specific consensus protocols of each network), which implies a high energy consumption for both running and cooling machines.
- The risk of bifurcation (only for public blockchains) (Tu and Xue, 2019). The bifurcation of a public blockchains into forks occurs when some of the nodes that make it up split off to define a new blockchain with different operating protocols.
- Legal and regulatory limits. Implementing a blockchain involves redefining the processes and the roles of the various 'information brokers' involved. Where the functions of these actors are defined and supported by a legal framework, they cannot be automated unless the regulatory environment is changed.
- Investment in necessary hardware and software.
- Change management (Tabrizi et al., 2019). The implementation of a blockchain-based solution entails, for all the above reasons, a substantial modification in the organization's operations. In practical terms, it is necessary to consider the risks and threats inherent to the management of an organizational change that is decisive in determining the success of the technology's implementation.

1.3.3. Applications designed to improve management processes

A number of applications based on blockchain technology are being developed with the aim of optimizing specific processes within organizations. Among existing applications, the following two are the most relevant for improving management processes – because they facilitate disintermediation and/or the traceability of transactions:

- The Self Sovereign Identity (Ferdous et al., 2019) is a digital identity model in which the user is the owner of the data. Thanks to the immutability of blockchain records, it becomes unnecessary to involve a validating agent to confirm that the user's information is unaltered.
- The Smart Contract (Zheng et al., 2020) is an algorithm designed to enforce agreements made between several parties. The program runs on blockchain, which, being a decentralized system, is not controlled by any of the parties involved, guaranteeing the integrity of transactions. Blockchains on which this algorithm can be programmed (e.g. Ethereum, with the Solidity programming language), allow to automate the execution of clauses or instructions between different agents involved in a process, within an environment that is equally or more secure than the traditional one based on authentication intermediaries. Thus, this results in a reduction of costs, incidents, and the time taken to execute an agreement between parties.

In addition to these applications, other blockchain uses exist, taking advantage of its capacity for disintermediation and traceability of records in other sectors. For example, cryptocurrencies; tokenization, or the virtualization of assets to manage asset transactions in a digital blockchain environment; STO; etc. The possibilities these applications offer to improve the competitiveness of the productive fabric and the governance of the public sector have drawn the attention of the European Commission, which has urged member countries to encourage their use, modifying the regulatory framework and opening specific lines of investment. In this vein, the European Blockchain Partnership (EBP) (European Commission, 2022a), which resulted from a Declaration of Cooperation signed in April 2018 by 22 member countries, including Spain, launched the European Blockchain Services Infrastructure (EBSI), a permissioned public blockchain. The objective is to develop specific use cases that foster the common European space on issues such as decentralized finances, digital identity, and certification of academic training and work experience. Example use cases include the notarization of documents, sovereign or self-managed digital identity, academic diplomas, secure data exchange, etc.

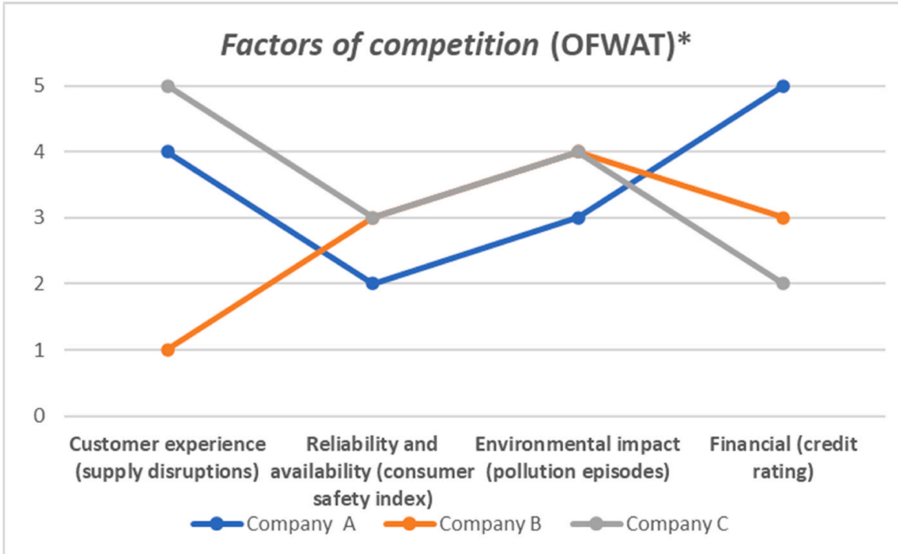

Fig. 1. Example of applying OFWAT indicators (assessment by categories) as FoC (OFWAT, n.d.). Figure by the authors.
*OFWAT: The Water Services Regulation Authority for England and Wales.

2. Methodology

To assess the suitability of applying blockchain technology to address the challenges of the integrated urban water cycle sector, a specific methodology was designed to comprehensively analyse each activity of a service operator from a management perspective. To specifically determine if and to what extent distributed ledger technology (DLT) can improve the efficiency of each process, the methodological design comprised two essential components:

1. Analysis and modelling, in terms of value generation, of the different processes that make up the activity of an integrated urban water cycle operator.
2. An assessment of whether DLT can in fact act as an enabling technology serving to optimize the organization's management of each process.

The following subsections present the main tools that were incorporated into this approach. The correct application of these tools facilitates generating a process map on which to assign (or evaluate) an organization's resources and check that they are distributed in line with the required critical success factors and, where appropriate, identify potential improvements to optimize the management of the most relevant processes.

2.1. Value chain

According to the methodology for value chain analysis developed by Michael Porter (1985a), an organization's resources are structured into processes in order to meet its objectives and remain true to its mission. These processes are classified into two broad categories:

- Primary activities: Processes that, when executed in succession as links in a chain, produce a good or provide a service.
- Support activities: Activities that help perform primary activities more effectively. These are common and necessary functions, such as human resource management, finance, and information technology, among others.

This tool, in combination with the tools discussed below, allows an organization to identify the processes that contribute the most value and those of lower priority for accomplishing its mission (Porter, 1985b).

2.2. Generating value

At a methodological level, the generation of value in an organization's processes can be studied by using tools such as factors of competition (FoC) or critical success factors (CSF) (Freund, 1988).

Factors of competition (Kim, 2005) are the attributes of an organization's product or service that are most valued by users. In terms of value generation, this tool is essential for assessing and guiding the organization's management towards user satisfaction or customer centricity via monitoring mechanisms and benchmark management systems.

Application of this technique not only makes it possible to assess how well the product or service offered by a company matches its customers or users, but also to compare the organization's performance with that of similar organizations. Fig. 1 presents an example of applying FoC to compare different companies.

Monitoring dashboards like those shown in Fig. 1 make it easier for an organization to make decisions and achieve its intended objectives as efficiently as possible, developing a competitive advantage. It has traditionally been considered that there are two mutually exclusive ways to build this competitive advantage, according to Michael Porter's generic strategies (Yamin et al., 1999): cost leadership, so as to offer the cheapest prices, and product differentiation based on attributes valued by customers.

2.3. Benchmarks between operators

Operators of urban water supply and sanitation systems use indicators to measure their degree of compliance with their own and industry standards. Through benchmarking mechanisms, factors of competition and critical success factors are compared with similar experiences and organizations, thus giving an indication of their relative positions with respect to other operators (Cabrera Rochera et al., 2014).

In fact, in the last decade, the dashboard for this type of organization has evolved from a set of indicators focused on monitoring and improving the technical and operational efficiency of the systems, which is undoubtedly essential, to the progressive inclusion of indicators that measure user or customer satisfaction derived from contact with the organization (the customer journey, according to Rosenbaum et al.,

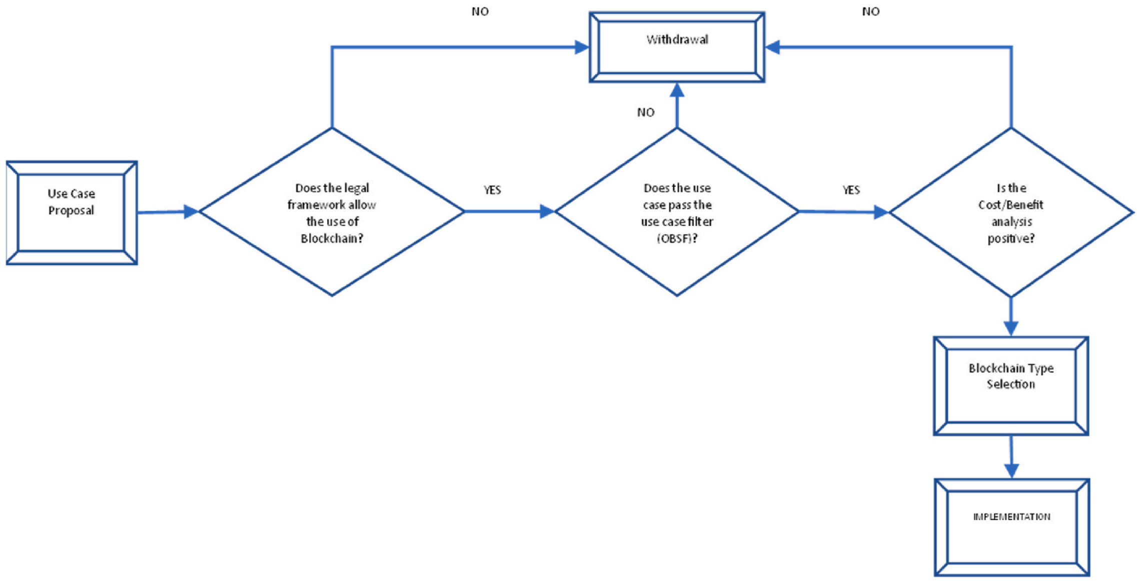

Fig. 2. Value generation of distributed ledger technologies. Prepared by the authors.

2017). An example worth highlighting is OFWAT's approach to the comprehensive assessment of service provision by the organizations operating the integrated urban water cycle in England and Wales since 1989 (OFWAT, n.d.).

2.4. Cost-benefit analysis

Cost-benefit analysis (Parviainen et al., 2017) focuses on calculating, in financial terms and in detail, whether the benefits of an investment will outweigh the costs involved. The use of this methodology usually involves analysing different context scenarios to identify conditions under which the project would be profitable.

Organizations consider several indicators when carrying out the cost-benefit analysis of a specific project, including some *ad hoc* indicators developed for each specific organization. The most common indicators are: Net Present Value (NPV), Internal Rate of Return (IRR), Return on Investment (ROI), and Payback Period (Canto and Mejía, 2007).

Although in mathematical terms the NPV method is the most reliable, sometimes the difficulty of accurately internalizing all the costs (which may sometimes be intangible or difficult to evaluate) and the benefit of the project leads organizations to use several of the above indicators in the decision-making process.

In the case of blockchain, the benefits associated with its potential implementation could be classified under two broad headings (Mekić et al., 2018):

- Calculated directly: Cost reduction and savings associated with streamlining (time reduction).
- Calculated indirectly: The attributes of immutability, traceability, trustworthiness, and reputation, when applied to a particular process (as appropriate), can have a positive impact on profits from the final product or service.

In turn, the costs associated with the implementation of a blockchain solution can be classified according to the same criteria (Tabrizi et al., 2019):

- Calculated directly: Investment, maintenance and operational costs, and the costs of implementing the application.
- Calculated indirectly: The costs of change or other environmental and reputation costs may be incurred. The costs of change are high when implementing a blockchain solution because disintermediation involves significant process changes that are met with cultural resistance, which should be addressed using appropriate change management methods.

3. Results

The first result of the work conducted was a concrete methodology to evaluate potential blockchain use cases in the integrated urban water management sector in Spain. The defined methodology, which applies and integrates the tools detailed under Section 2 in a specific manner, can determine in which processes and to what extent distributed ledger technologies can improve the efficiency of each activity within urban water supply and sanitation systems. This approach was then applied in practice to use cases of urban water cycle management in Spain, as explained in Section 4.

3.1. Approach

Digital transformation processes in any organization require performing a cost-benefit analysis to study their profitability and potential feasibility (Parviainen et al., 2017).

In the case of blockchain, if it is modelled as an enabling technology that makes it possible for an organization to improve the efficiency of its processes, there are analytical tools that allow finding out which processes will benefit from improved efficiency and performance by using this technology. The use of these analytical techniques makes it easier to rule out those situations in which the use of blockchain will not be appropriate according to current conditions and limitations.

In terms of constraints, before considering the cost-benefit analysis of a specific project or idea it is necessary to assess whether the legal framework makes it difficult or impossible to apply distributed ledger technologies (eliminatory boundary condition) and, if there is no such restriction, filter the use case through the Oxford Blockchain Strategy Framework (OBSF) to assess whether blockchain can improve the management of the process under analysis (University of Oxford, n.d.).

Once both milestones have been overcome and assuming that the cost-benefit analysis is positive, it becomes necessary to define which blockchain network of those in existence may be the most suitable for the specific case under study.

Fig. 2 details and integrates the methodology developed and implemented during this study for analysing the value generation of distributed ledger technologies.

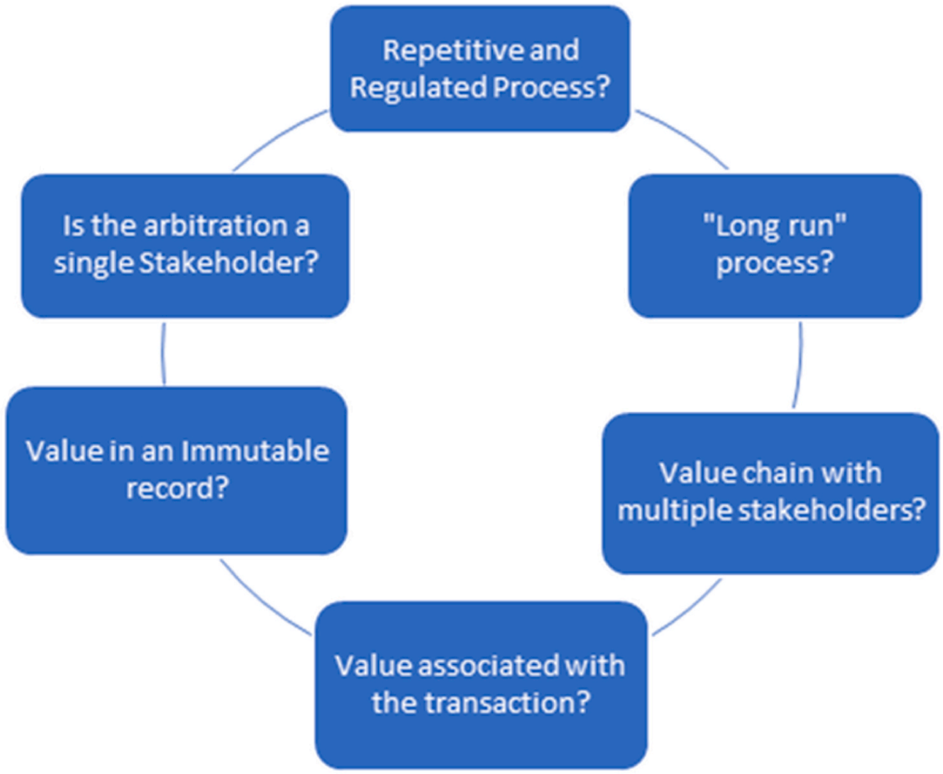

Fig. 3. Oxford blockchain strategy framework. Source: University of Oxford (n.d.).

The different tools incorporated into the methodology summarized in Fig. 2 are detailed in the following subsections, which also explain how these tools were applied in each case.

3.2. Compatibility with the current legal framework

The benefits provided by solutions based on distributed ledger technologies are based on redefining the processes, the mode of operation of the organizations. Therefore, the implementation of blockchain solutions depends on the absence of boundary conditions that limit or prevent the rethinking of the activity.

Therefore, for any use case under study, the current legal framework (Millard, 2018) should be analysed in detail to verify whether, for example, disintermediation based on a blockchain solution can be effective, or whether the functions of the potentially dispensable intermediary are legally regulated and must be maintained.

The Oxford Blockchain Regulation Framework (University of Oxford, n.d.) is a questionnaire developed by the University of Oxford that helps to identify the degree of “friendliness” of legislation towards creating an enabling environment for developing a business ecosystem based on blockchain solutions. This analysis focuses on the degree to which existing regulations meet the following five criteria:

- Based on results: If legislation were to be based on regulating the way in which the activity or service should be performed, this would significantly complicate the re-engineering of processes, making the benefits associated with distributed ledger technologies very difficult to realize.
- Protecting all stakeholders: If legislation is geared towards safeguarding the interests of all stakeholders beyond the direct participants alone, potential blockchain-based solutions have a greater scope due to their traceability and immutability and their P2P (peer-to-peer) architecture.
- Promoting transparency: If legislation is concerned with transparency in service provision and in public governance and accountability, the traceability and immutability of blockchain solutions allow the efficient development of solutions and processes in line with these increasingly demanding requirements (European Union, 2006).
- Respect for competition: The less interventionist legislation is, in the sense of taking sides for a given technology or sector, and the more the principle of “technological neutrality” is applied and competition between the actors involved is facilitated, the more useful distributed ledger technologies will be as clear drivers of efficiency in corporate processes.
- Promoting innovation: If the legal framework includes mechanisms that not only facilitate innovation but also strongly encourage it, such as a sandbox (Financial Conduct Authority, 2015), the potential of blockchain applications can be harnessed to generate “coopetition” ecosystems (Chou and Zolkiewski, 2018) that help the current production model evolve.

Therefore, in general terms, the legislation inspired by Anglo-Saxon common law tends to generate a more suitable legal framework for DLT than that developed based on continental European law. Nonetheless, in October 2017 the Council of Europe asked the European Commission to develop specific initiatives to generate a blockchain ecosystem in the European Union that would improve the competitiveness of its productive fabric. Furthermore, the European Union is committed to promoting digital transformation, taking advantage of the possibilities offered by DLT, as mentioned in the Next Generation funds (European Commission, 2022b: Heading 1: Single market, innovation, and digital economy) and the constitution of the European Blockchain Services Infrastructure mentioned in Section 1.3.3 (European Commission, 2022c).

3.3. Use case filtering

The Oxford Blockchain Strategy Framework (University of Oxford, n. d.), summarized in Fig. 3, proposes a preliminary study of use cases

Table 4
Primary processes associated with the main areas of activity in integrated urban water management.

			Oxford blockchain strategy framework						
Main areas of activity (primary processes)	Critical success factors	Conditional legal framework	Repetitive and regulated process?	"Long run" process?	Value chain with multiple stakeholders?	Value associated with the transaction?	Value in an immutable record?	Single stakeholder arbitration?	Evaluation (o/6)
Drinking water catchment	Water availability guarantee, Costs.	*YES (sector-specific legislation*	✓	✗	✗	✗	✓	N/A	2/6
Water potabilization	Reliability, Costs	*YES (sector-specific legislation*	✓	✗	Case-dependent	✗	✓	N/A	2/6–3/6
Wastewater purification (primary, secondary and tertiary stages)	Reliability, Costs	*YES (sector-specific legislation)*	✓	✗	Case-dependent	✓	✓	N/A	2/6–3/6
Sewage sludge treatment	Reliability, Costs	*YES (sector-specific legislation)*	✓	✗	✗	✗	✓	N/A	2/6

Prepared by the authors.

based on a six-item questionnaire. A particular case could be discarded at this initial stage based on the outcome of this questionnaire.

The criteria summarized in Fig. 3 are explained below:

I. Is it a repetitive and regulated process?

In principle, the more often a process is executed and the more structured it is, the more it makes sense to automate it, because of the implicit time savings and because the investment required for its automation usually pays off in terms of savings in associated operational costs.

II. Is it a long-running process?

The longer the time required to execute a process, the greater the benefit achievable from its systematization on blockchain.

III. Are there multiple stakeholders in this process or value chain?

The potential cost reduction obtained from blockchain are associated with disintermediation (Rejeb and Rejeb, 2020).

IV. What and how much value (not only monetary) is generated in the transaction?

The necessary investment in hardware and software for a process to run on blockchain will be justified from an efficiency perspective if the recorded transactions and their associated information have a specific value for the parties involved.

V. Is there value in an immutable record? Is an immutable record a requirement?

One of the main attributes of DLT is to guarantee the immutability of the information recorded (Hofmann et al., 2017), so if the records associated with a certain process need integrity, traceability, etc., a blockchain solution could meet these requirements.

VI. Is arbitration currently performed by a single stakeholder?

When the capacity to arbitrate possible conflicts in the execution of a process is held by a single agent, its automation to dispense with that intermediary is more feasible than when the arbitration is more complex, involving two or more agents. In the latter case, systematization is more complex, more costly and potentially less beneficial.

If at least five of the items in this questionnaire receive affirmative answers, the application of blockchain to the proposed use case may be feasible, so long as the legal framework allows for it to be accommodated. Ultimately, feasability depends on the corresponding cost-benefit analysis.

3.4. *Selection of the type of blockchain*

If the result of the cost-benefit analysis is positive for the specific use case, the most efficient blockchain should be chosen from among those available and in accordance with the types described above. To this end, the Oxford Blockchain Strategy Framework (University of Oxford, n.d.) sets out the three dimensions that need to be addressed to facilitate the decision-making process:

- Application Layer: requirements that, from the point of view of interaction with the user/customer, are necessary for the application to be useful for its initial purpose and that condition the choice of the most suitable blockchain (e.g., programming requirements, interface, etc.).
- Networking Layer: hardware constraints, internet exchange platforms (Huang et al., 2017), etc. that influence the choice of the blockchain to be used.
- Protocol Layer: takes into consideration aspects relating to type (open/closed) (Helliar et al., 2020), transaction processing speed, etc., that are crucial to the choice of a blockchain technology.

The blockchain that would provide the most value for the digital transformation process proposed would be chosen according to the final conclusions of this analysis.

4. Discussion

The above methodology was applied to different processes comprising the integrated urban water cycle. The purpose was to assess the suitability of blockchain-based solutions for different use cases. The results practically rule out or do not give priority to the use of this technology in 'productive' processes involving the physical, chemical, or biological treatment of water. This is because the automation of reliable, immutable, and traceable records and transactions does not provide a comparative advantage in the use and management of operational data,

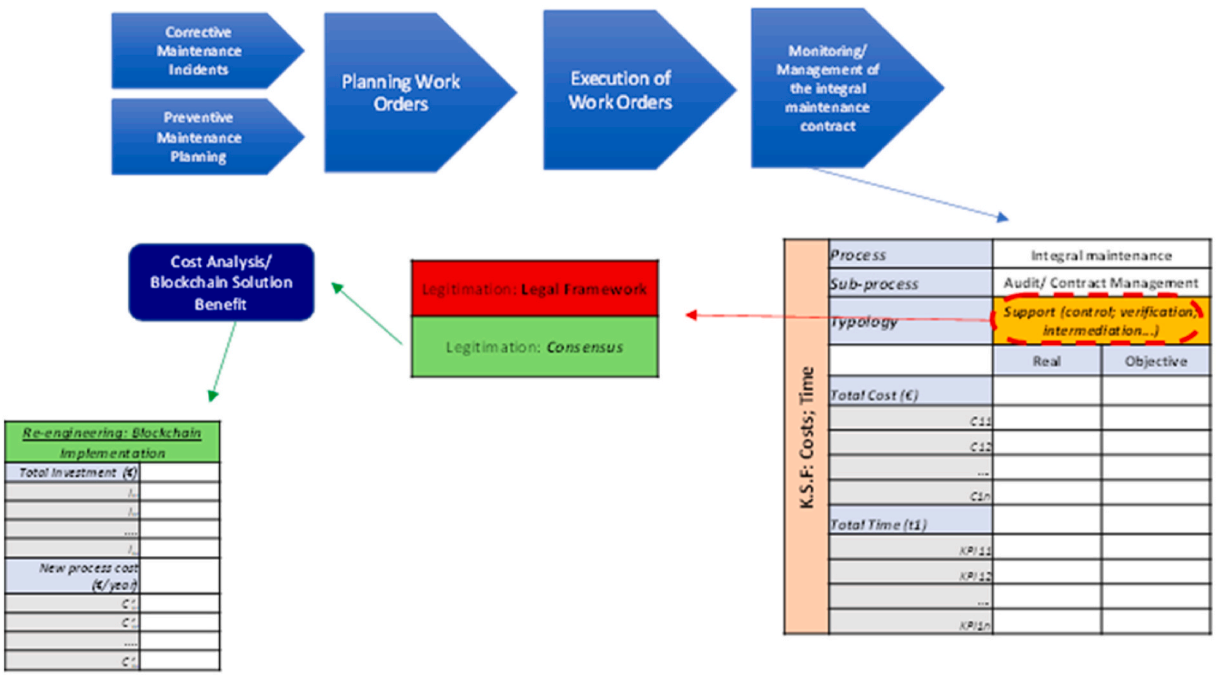

Fig. 4. Blockchain use case - urban water supply and sewerage treatment services: Supervision of the comprehensive maintenance contract. Source: prepared by the authors.

or the added value of acquiring these attributes does not compensate for the cost of implementing and maintaining blockchain technology.

As detailed in Table 4, the productive processes that comprise the primary activities of integrated urban water management were discarded. This resulted from applying the methodology of value generation analysis described in Section 3. Two fundamental reasons led to this exclusion: the constraints of the legal framework, and non-compliance with the requirements established in the Oxford Blockchain Strategy Framework.

Conversely, support processes that verify the fulfilment of quantitative results based on recorded data are likely to benefit the most from running on blockchain. The implementation of this technology should be given priority where the impact is greatest in terms of value (not exclusively monetary value).

The following use cases illustrate positive effects obtained from implementing blockchain solutions. These cases show good potential for improving the efficiency of support processes that are key from the point of view of the main challenges faced by urban water cycle management in Spain, as detailed in Section 1.2. It is nevertheless important to keep in mind that, due to its disruptive nature, the implementation of blockchain in these use cases entails changes in how processes are executed and, therefore, in the functions of employees, which implies managing organizational change to overcome likely resistance.

4.1. Use case: comprehensive facility maintenance contract

Value chain analysis has identified system operation as a core activity to be provided by service operators (Xiong et al., 2018) – service owners in direct management and concession holders in indirect management. The concept of 'operation' here encompasses the processes and sub-processes that are essential to ensuring the collection, treatment, and distribution of drinking water, and the collection, conveyance, treatment and return of sewerage and wastewater from treatment plants.

Meanwhile, more and more operators are outsourcing the preventive and corrective maintenance of system infrastructure to specialized companies, following the economic logic of generating economies of scale and transforming fixed costs into variable costs (Zarghami et al., 2008). These contracts have evolved towards a "comprehensive maintenance" model (López-Campos and Crespo Márquez, 2018), where the evaluation of the service to which the successful bidder commits is measured through specific indicators (control points meeting quality and timing standards), which determine both remuneration and potential penalties. The management of these contracts presents difficulties due to several factors (Márquez et al., 2009):

- Knowledge asymmetry: the maintenance contractor usually has more information than the service owner.
- The reliability of reference data for the execution of contractual clauses is often deficient.
- Service operators on occasions have limited resources to monitor this type of contract.

In this context, management of the process of monitoring (both preventive and corrective) maintenance activities carried out by outsourced companies could be improved by running a blockchain that allowed programming Smart Contracts (Hewa et al., 2021). Thus, the clauses stipulated in the contract could be executed in a manner that were:

- Automated: according to established indicators (e.g. the frequency of control point monitoring, schedule, and attendance records, etc.).
- Reliable: so long as the data recorded for calculating the indicators are reliable (e.g. by incorporating Internet of Things sensors or near-field communication (NFC) tags).
- Fast: reducing delays in invoicing, paying, or applying penalties by eliminating bureaucratic tasks or third-party arbitration of disputes.

Taking the sub-process "Management and supervision of the comprehensive maintenance contract" as a use case, Fig. 4 summarizes the application of the methodology detailed in Section 2.

In this case, the methodology followed indicated that this process would see its requirements satisfied if run on a properly implemented blockchain solution. As represented in Fig. 4, this would have an impact on the service provided to users, since better infrastructure maintenance would better guarantee a properly functioning water service.

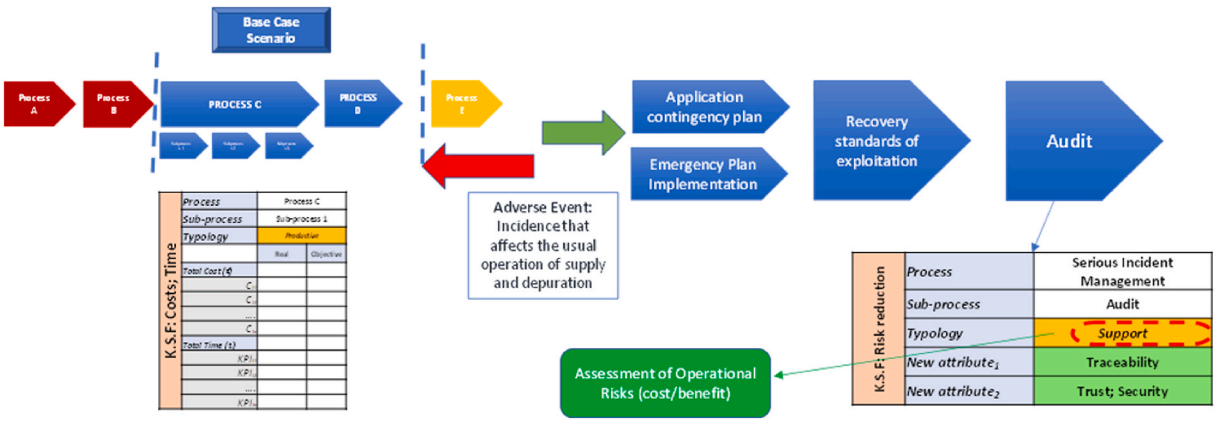

Fig. 5. Blockchain use case - urban water supply and sewage treatment services: Management of a Serious Incident Audit. Source: prepared by the authors.

4.2. *Use case: pre-established evidence about incidents*

Serious incidents in the operation of urban water supply and sanitation services in Spain entail potential economic, labour, and even criminal liabilities (Government of Spain, 2007). Their implications can be severe in environmental or health terms (e.g. industrial or work accidents). The causes of these incidents are diverse in nature and can be exogenous or endogenous (e.g. poor operation of critical system infrastructure, unforeseen external events, etc.).

Whichever the case, these events imply undergoing audits and, if necessary, even legal proceedings to establish responsibilities among the actors involved. These processes are based on collecting, organizing, and interpreting reliable data (e.g. maintenance logbook or historical records of critical operating parameters) in order to correctly assess what occurred.

In this respect, the management of the process of assessment and auditing of severe incidents can be improved by recording on a blockchain the parameters that are critical for the operation of water supply and sanitation services. The immutability and traceability of these records would ensure they were sufficiently reliable to adequately assess any potential incident, thus constituting pre-established evidence (Ibáñez Jiménez, 2018).

Taking the sub-process "Audit in the event of a serious operational incident so as to establish responsibilities" as a use case, Fig. 5 summarizes the application of the methodology detailed in Section 2.

Consequently, the development of such solutions facilitates better governance, in terms of transparency and accountability, enabling urban water cycle management to evolve in line with today's governance challenges, driven by an increasingly demanding civil society.

4.3. *Use case: traceability of reagents and supplies*

In the current context of delocalized production, "hyper-optimization", and globalization of supply chains, it becomes increasingly important to have reliable data that guarantee the traceability of the reagents necessary for the correct operation of systems, in accordance with the criteria of the Business Continuity Management methodology (Gibb and Buchanan, 2006).

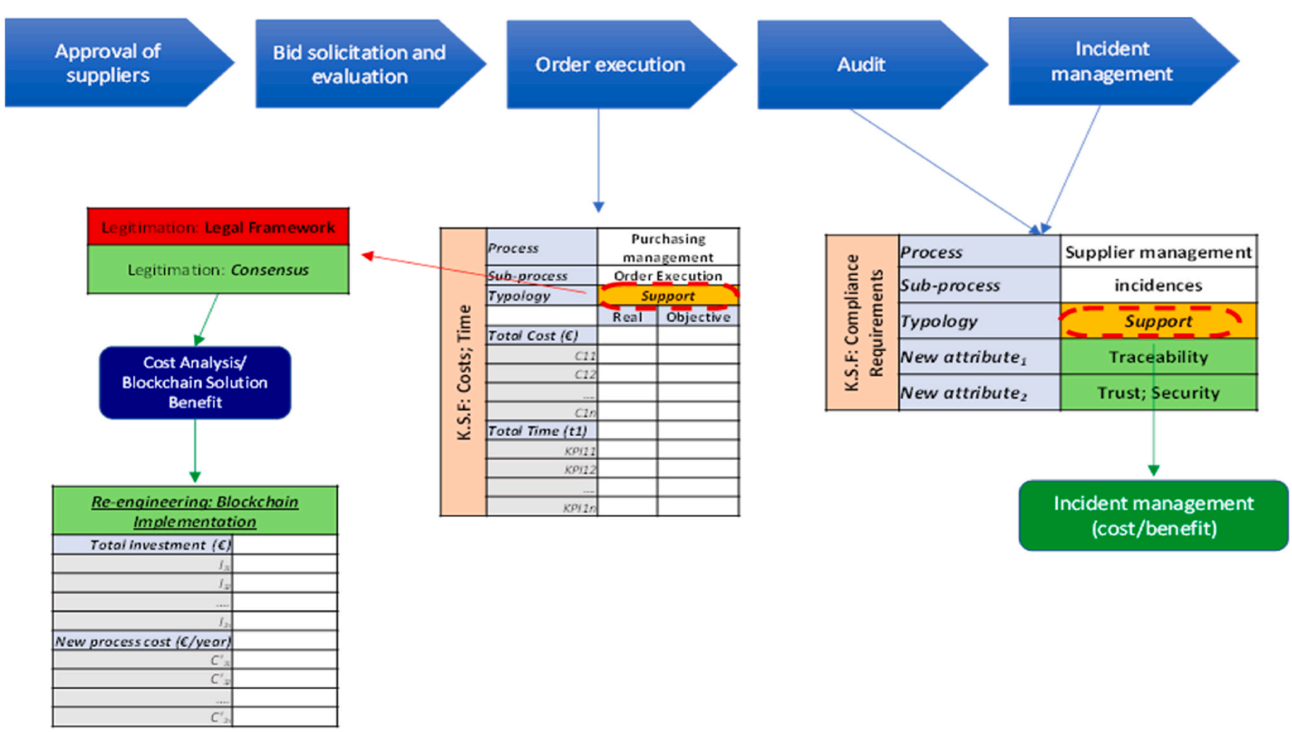

Fig. 6. Blockchain use case – urban water supply and sewage treatment services: Monitoring of procurement contracts. Source: prepared by the authors.

Table 5
Summary of the use cases studied: support processes.

Use case (process)	Sub-process	Critical success factors	Conditional legal framework	Oxford blockchain strategy framework: Repetitive and regulated process?	"Long run" process?	Value chain with multiple stakeholders?	Value associated with the transaction?	Value in an immutable record?	Single stakeholder arbitration?	Evaluation (0/6)	Blockchain type
Comprehensive Maintenance	Contract management	Costs, time	NO	✓	✗	✓	✓	✓	✓	5/6	Programmable (Smart contract) (Ethereum, etc.)
Serious Incident Management	Audit/ Determine legal liabilities	Risk reduction (traceability, immutability)	YES (concept of pre-constituted evidence)	✓	Case-dependent	✓	✓	✓	✓	5/6 - 6/6	Programmable (Smart contract) (Ethereum, etc.)
Supplier Management (2)	Order execution	Costs, time	Partial (customs procedure)	✓	✓	✓	Case-dependent	✓	✓	5/6 - 6/6	Programmable (Smart contract) (Ethereum, etc.)
Supplier Management (1)	Monitoring and incident management	Compliance with requirements (traceability)	Partial (customs procedure)	✓	✓	✓	✓	✓	✓	6/6	Programmable (Smart contract) (Ethereum, etc.)

Prepared by the authors.

In situations where the origin and characteristics of supplies are essential for the fulfilment of the supplier's contractual requirements, recording these data on a blockchain makes it possible to dispense with the intermediaries who, in traditional supply chains, ensure compliance with the established conditions (Sunny et al., 2020). In other words, the task of reviewing these data can be automated in a virtual environment.

In a manner similar to the use case of the comprehensive maintenance contract presented in Section 3.2, the execution of the supply contract can be improved by programming a Smart Contract (Hewa et al., 2021) that would automate conditional remuneration to the supplier in accordance with established performance indicators. Thus, a blockchain solution would reduce the time and costs associated with supplier management.

Taking the sub-process "Supplier management and traceability of reagents and supplies" as a use case, Fig. 6 summarizes the application of the methodology detailed in Section 2.

In this case, the traceability offered by blockchain for following the supply of raw materials would help to ensure correct potabilization and purification, increasing user satisfaction by improving the guarantee of urban water services and controlling environmental effects.

4.4. Summary of the use cases studied

This study identified processes within the integrated urban water management system in Spain that have the greatest potential to benefit from blockchain technology. Table 5 summarizes the results of the analysis of the three chosen use cases.

As summarized in Table 5, the use cases described in Section 4 have been studied from the point of view of key success factors and the current legal framework, as detailed in the previous sections, and have positively exceeded the requirements of the Oxford Blockchain Strategy Framework. Consequently, blockchain technology can help to efficiently address some of the challenges of the urban water sector in Spain – namely, the support processes that are essential for the proper management of water supply and sanitation systems.

5. Conclusions

Blockchain, like any distributed ledger technology (DLT), aims at improving process management. The evolution of computing capabilities will lead this enabling technology to become a disruptor of business models in years to come, and, in particular, of urban water utilities currently facing management challenges.

This study developed a specific methodology of strategic analysis for evaluating the suitability of blockchain for improving processes within integrated urban water management in Spain. The application of this methodology found that, in this chosen context, primary activities would not substantially benefit from blockchain technology. However, the results indicate that it is likely to act as an enabling technology for support activities, where disintermediation and traceability can optimize processes. Namely, the processes that were found to have the greatest potential to benefit were the management of maintenance contracts, incidents, and supplies.

Smart contracts, which can be developed in a programmable blockchain, facilitate supervision by a service owner over service providers. This applies both in outsourcing arrangements, under a model of direct management, and in operational arrangements, under a model of indirect management. Smart contracts stand out as one of the major blockchain applications for improving management processes within the integrated urban water cycle.

Thanks to the immutability of the data collected, it is possible to generate pre-constituted evidence that facilitates correct auditing of serious incidents that may occur during the operation of water supply and sanitation infrastructure. In addition, it improves transparency vis-à-vis civil society and service owners, facilitating active monitoring of service management, in line with current governance challenges arising from an evolving regulatory framework (European Union, 2000).

Regardless of the management model, DLT can be useful for improving management processes, both from the points of view of operational efficiency and governance. That is, the potential of this technology is independent of the urban water cycle management model in place.

The application of blockchain technology entails the redefinition of processes in the broadest sense, including multi-organizational processes, in a quest to optimize the supply chain from a global perspective. This automation can lead to cost reduction and faster processing.

The great benefits associated with DLT, namely traceability and disintermediation, carry with them cultural changes. Therefore, for its implementation among operators within the integrated urban water cycle, it is advisable to employ change management methods.

5.1. Potential future lines of research

While the implementation of a blockchain in itself can improve management processes, future research should look into how digital convergence could lead to synergetic solutions (Sandner et al., 2020). That is, the combination of DLT with other disruptive technologies (i.e. Artificial Intelligence and the Internet of Things) could potentially optimize productive processes, comprehensively affecting urban water cycle management. Other lines of research could include adapting the proposed methodology to extend it to other countries; proposing legal adjustments that would better accommodate the possibilities offered by DLT; and looking into new possibilities that may be derived from new blockchain networks currently under development.

CRediT author statement

Antonio Rodríguez Furones: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft, Writing - Review & Editing, **Juan Ignacio Tejero Monzón:** Conceptualization, Supervision, Writing - Review & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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