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Smart water chain: Immutable, distributed and decentralized water transaction ledgers

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Abstract. Blockchain is a transactional data storage system where data can be stored reliably without the need for a central database or trusted authority. The data can be anything like financial transactions, supply chain processes or medical records. It is similar to a classical database but uses a decentralized ledger and allowing each participant in the network to have their own copy of the ledger and be able to see all transactions. Data stored in the distributed ledger can only be read or written, not deleted or updated unlike traditional central database. Reliable data is essential for the water industry for information about the current status of any water system, to build trust between stakeholders at all scales, and for effective forecasting and future scenarios by reducing uncertainty. The aim of this study is to examine the potential of using blockchain-based algorithms (smart contracts, chain codes, decentralised identifiers etc.) for the water industry on the edge of digital transformation, and to propose water-related data processing system architectures for different water quantity-quality based scenarios.

1. Introduction

In the first quarter of the 21st century, while many sectors such as energy, economy, health services, transportation, banking, water management, etc., took a step towards digitalization, blockchain technology has become a cornerstone because of its main features; immutability, decentralisation, enhanced security, distributed ledgers, consensus, and faster settlement. The basic results of these features are data reliability and trust built between stakeholders [1]. Smart contracts or chain codes are programs stored on a blockchain that run when prespecified conditions are met. They are used to automatize the execution of an agreement so that all stakeholders can be simultaneously certain of the result without the mediation process [2].

The qualitative and quantitative sustainability of water depends on the resilience and efficiency of water systems from source to user. In that case, reliable data is essential for system efficiency, real-time monitoring and forecasting in terms of sustainable water management. This essentialness requires reliable storage and processing of water-related data at all scales [3]. Although an autonomous water system works entirely on blockchain and smart contracts has not been implemented yet, there are theoretical or experimental studies such as pollution monitoring systems, intelligent water management systems [4-5].

The aim of this study is to propose four blockchain-based decentralised autonomous system architecture for measuring, monitoring and storing water-related data for different cases. Firstly, a blockchain enabled water market is introduced by focusing the water market and water economics concepts. Later on, three cases are introduced to underline how blockchain-based system architectures have huge potential to create trustless systems, that the stakeholders do not need to know or trust each other or any third party for the system operations, between water users at all scales. The purposed system architectures aim to ensure: i) enable the usual benefits of blockchain technology to be utilized in the digitalization of the water markets such as; trust, security, immutability, transparency, coordination. ii) reliability of urban water systems for consumers. iii) reliability between riparian countries discharge treated wastewater into the same inland sea or located in the same transboundary river basin. iv) reliability between stakeholders of circular water economy.

2. Material and Methods

2.1. Water Markets

Basically, a market is a platform for transactions in which something of value may be exchanged. Free market economy is defined as where products are exchanged by a willing buyer or seller. The water market concept extends this idea to water [6].

Although the free market economy leaves only the producers that innovate and creates products consumers want and at the same time, driven by profit, incentivise producers to increase the efficiency of production, in that case the main beneficial points are to avoid monopolies in water access and distribution, defining property rights clearly and well-defining the economic value of water to maximize welfare. By revealing the true value of water, water markets can provide effective and urgent solutions to water scarcity. It can also achieve ecosystem restoration and sustainable water management by pricing unit change in water quality or valuing unit discharge to water resources. Water markets are based on rights to the quantity or quality of tradable unit water that allows water to be transferred from one user to another, temporarily or permanently. A well-managed water market, together with the determination of property rights, seriously encourages water savings and brings all stakeholders to the table to find the water supply demand balance. Strategy to solve water-related problems by creating a free market economy is a common method by irrigators to assist agricultural water management [7].

However, water also has a socio-cultural value. In case of income inequality, water usage rights may be scattered in a way that harms social justice and socio-cultural values of water. It is very likely that people or stakeholders using water will make very bad financial decisions and act irrationally. The lack of knowledge about the market of the buyer or seller wants to trade in water may be the reason. Unconscious market management may ignore the need for environmental water and cause excessive use of water in the excessive market. According to studies on Australia - Murray Darling Basin, which is also one of the most popular water markets, some people who need water very little may stockpile their water rights for purely economic reasons, ignoring the environmental consequences, creating agricultural inefficiency by preventing the use of water by those who need it more. These and similar reasons can create socio-economic, environmental and ecological problems. Traditional water markets can promise weeks or even months of bureaucratic processes for the transaction to take place. [8-12].

The digital system architectures based on blockchain and smart contracts have the potential to maximize the advantages of water markets while minimizing the risks. First of all, it creates a peer-to-peer market for water trade, and automates trade agreements with smart contracts, considering environmental, socio-cultural and ecological rules. Moreover, all data required for an effective water management and market operations is immutable and reliably accessible to economic, environmental policy makers and water traders.

2.2. Trust in Water Systems

Sociologically, trust is the most basic social construct. Every time people interact with each other, a certain level of trust or distrust begins to form. People have a natural tendency to trust and judge the reliability of other individuals or groups of people and things, social and physical systems they interact. Natural processes, on the other hand, have gained trust of humankind because they occur as a result of precise and fixed physics rules and can be tested by experiment-observation. When the air temperature drops below a certain level, the water freezes or as a result of rainfall surface runoff occurs. Thousands of years of hydrological observations and infinite number of test results make this cause and effect relationship reliable. Water systems are hybrid systems that need to be managed together with the natural cycle of water and the sociocultural perception of people. No matter how a person perceives himself, water always flows according to certain physical laws. People, on the other hand, want to survive by manipulating this flow wherever and whenever the water starts to flow [13].

For a well-managed and resilient water system at all scales, there should not be a trust problem between stakeholders, policy makers and the financial and environmental system operators. For customers in urban water systems, it is the most natural right to be informed about all the storage, transmission or treatment processes of the water and the quantity and quality of the water they pay for. All supply chain stages of water from source to tap should be transparent in order to sustain trust in socio-hydrological system.

Similarly, transboundary river systems and inland seas involve stakeholders with unlimited demand who share a water system with a limited capacity. Stakeholders (countries) located in the same river basin may not only provide their agricultural, domestic and industrial water use from the same basin, but also discharge used or treated water to the same basin. If this complexity is combined with a trust issue, conflict between riparian countries is deepened. The transboundary river basin faces a severe drought or the inland sea is teste with a pollution load well above its absorptive capacity as a result of unconscious discharges. In both cases, ecological and hydrological restoration is expensive and very arduous [14-16]. Sustainable and integrated water resources management is a complex process that requires huge effort, but unless socio-hydrological trust in any water system is established, whole optimizations, uncertainty analyses or technical assessments cannot go beyond just theoretical studies.

A simple distributed digital architecture based on blockchain and smart contracts is able to ensure socio-hydrological trust straightforwardly and data security. Recorded data in an immutable manner can help resolve the uncertainty of hydrologically complex multi-stakeholder systems.

2.3. Water Footprint and Virtual Water

The water footprint is an indicator of freshwater use by taking the water used directly and indirectly together. The water footprint has three components: green, blue and grey. A green water footprint is water obtained directly from precipitation. It is a concept especially applicable to the agricultural sector and is related to the water stored in the root zone of the plant and lost by evapotranspiration. The blue water footprint is the water obtained and used from surface and ground water sources. It is valid for all water uses, especially irrigated agriculture, industrial products, domestic use. The grey water footprint is the amount of fresh water required to absorb pollutants to meet certain water quality standards. The grey water footprint considers point source pollution discharged directly into a freshwater source via a pipe or indirectly through runoff or seepage from soil, impermeable surfaces or other diffuse sources [17]. Virtual water is the total water consumed in the production process of an agricultural, industrial product or service. If a country or a region imports or exports a product, it can also virtually import/export water [18].

The water footprint draws attention to the embedded water consumed in the global supply chain of any product that is conceptually a local product. In other words, it underlines the fact that in a world where international trade is valid, water is never a local and domestic source, but rather a global natural resource. This means that one country's consumption habits may be directly related to another country's water scarcity. This point shows that economic policies and water policies should be integrated. Even a country that produces and consumes its own coffee beans is considered to have imported water if it uses imported products or services (energy, production technology, etc.) in any of the production stages. Water footprint can also be included in the policy in the form of water footprint caps and permits. A water footprint cap can be institutionalized at the basin or country scale; this can then translate into maximum water footprint permissions to be granted. On a smaller scale, water footprints can be created for processes and products that will enable companies to formulate water footprint reduction targets for their operations and supply chains. Water footprints indicate that consumption patterns based on raw materials from water-scarce regions may need to change. This encourages companies, investors, governments and consumers to explore how they can make their supply chains more sustainable in terms of water use. After all, relying on an unsustainable supply chain involves many risks and cannot be permanent [19].

The supply chain of products or services in terms of water footprint can be recorded and certified on the blockchain. Countries or companies have the chance to be aware of the investment they pay for or invest in virtual water, especially for water intensive products. Immutable and distributed data about virtual water and water footprint not only provide rationality in investment decisions in agriculture and industry, but also enable producers, consumers and policy makers to take water wise actions.

3. Results and Discussion

Digitally transformed water markets with a blockchain-based architecture offer new advantages by eliminating the disadvantages of traditional water markets. The Smart Water Chain (SWC) architecture provides a transparent and immutable market data availability. It prevents the asymmetric information problem that may occur in traditional water markets (Figure 1).

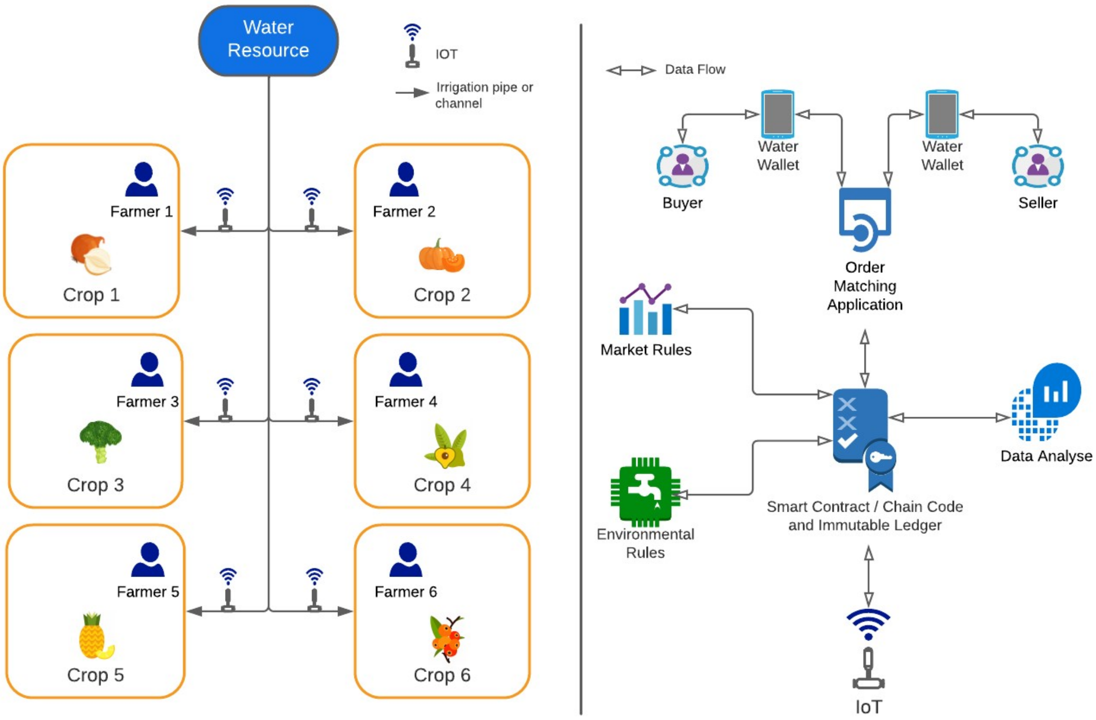


Figure 1. Illustration of an irrigation system and SWC architecture design for blockchain-based water market.

Market actors do not have to trust or distrust each other because every transaction is transparent. Farmers in the same basin system can grow crops that are subsidized at different rates by the agricultural policy maker. They can be sure that all other stakeholders comply with market or environmental rules that are strictly defined by smart contracts or chain codes, and they have maximum knowledge of the market. Farmers can easily access their water wallets, being aware of all market information and willing to trade as buyers or sellers. Water wallets can be thought of as any electronic system that allows a person to make water transactions. This can be any decentralized web or mobile application. SWC architecture conceptually follows these processes:

- Checks the compatibility of the information in the water wallets of the buyer and the seller with the IoT data and reports possible incompatibilities.

- Allows buyer and seller to view offers and match them
- Checks the compliance of the transaction agreed by the buyer and the seller with the environmental and market rules
- If all the requirements are met, the finalized transaction and all related data is recorded on immutable ledger.

The crucial point here is that market data must be transparent (not real identities). It is essential that all stakeholders have access to read the recorded data but not change or modify. The transparency and reliability of the data should not be even a matter of discussion, rather than the system's efforts to create trust between stakeholders. For this reason, the genesis block or the network to be selected is very important. Networks that have adopted the revolutionary differences brought by blockchain technology and that have proven themselves for several natural resource management applications should be selected. Distributed water transaction ledgers may be part of any public blockchain that provide opportunity to work compatible smart contracts and water-related data type. Distributed Ledger Technology (DLT) platforms such as; Ethereum, IOTA and Hyperledger are capable to process real-time water-related data [20].

Although a blockchain-based water trading infrastructure offers uniqueness, the trust and transparency provided by decentralized and distributed architectures also provides resilience for water systems at different scales. Figure 2 is the illustration of a simple urban water system.

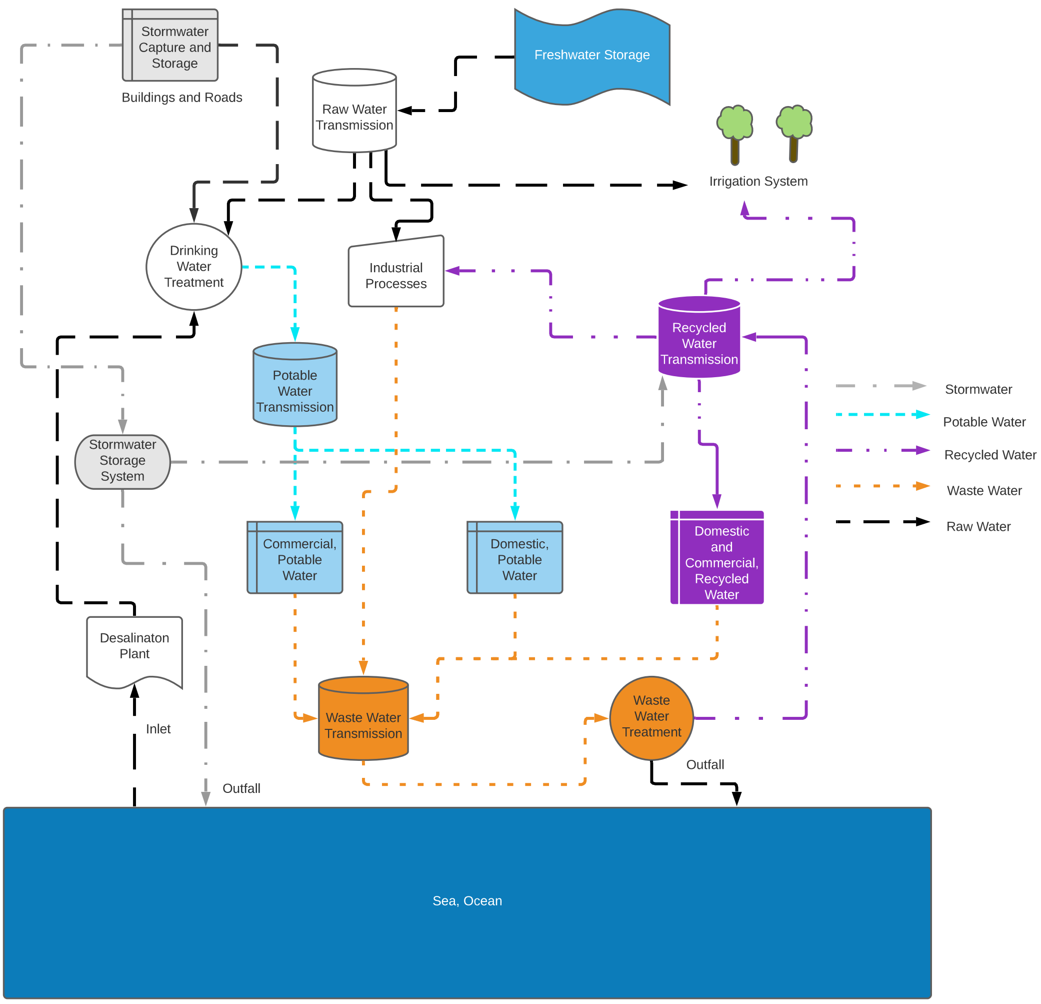
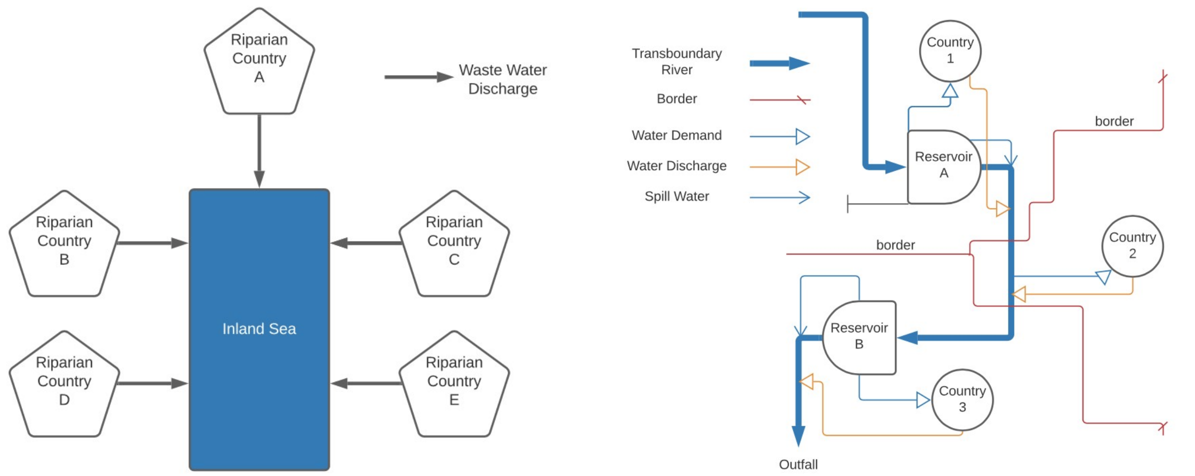


Figure 2. Illustration of simple urban water system.

Each unit where water is physically transmitted, stored or treated also functions as digital twin and measuring, monitoring and sending real-time data about the quantity and quality of water to the distributed water transaction ledger.

In this way, the consumers not only aware of the quantity and quality of consumed potable or industrial water, but also all the water-related data in the system becomes trusted and transparent. Through smart contracts, consumers pay water bills only if the consumed potable or industrial water meets quality standards and whole system meets environmental criteria. All inefficiencies in the system, measures to be taken, climatic trends, and leaks can be reliably analyzed and prevented thanks to immutable data.

Similarly, Figure 3.a and 3.b (may be considered as the Baltic Sea and the Nile Basin) indicated the basic transboundary river basin water cycle and inland sea waste water discharges. Resilience of transboundary river basins or inland sea systems highly depends on trust and coordination between stakeholders and reliable, immutable and transparent environmental data [21]. It is clear that, transboundary water system can be transformed digitally by the agency of blockchain-based algorithms to ensure essentialness for more resilient international water systems.



(a) (b)

Figure 3. Illustration of a (a) wastewater-based polluted inland sea system (b) transboundary river system.

Proposed system architecture is demonstrated in Figure 4.a. All riparian countries can be easily aware of the fact that the transboundary water system or inland they are part of has a layer of trust in terms of water quantity and quality, and that welfare maximization is aimed. Although it is not essential for resilience of every water system, a free market economy may also be applied to these systems in which any water demand and water right, or unit permission to pollution load by discharge can be opened to trade. All regulative red and yellow lines can be drawn with the smart contracts (Figure 4.b).

It is widely recognized that reducing the water footprint should be part of the sustainable water management strategy like carbon footprint. In production systems where process water is one of the main inputs, especially in the textile and beverage sector, the money spent for water footprint and virtual water is vital. The management of the water used in production and the amount and quality of the wastewater generated are correlated with financial sustainability [22]. Likewise, the conscious consumer wants to know the water used and the wastewater generated throughout the entire supply chain of the product. Collecting, combining and presenting water-related data, which is valid for the entire supply chain of a product reaching the consumer, with traditional database architecture, requires a very complex process. With a blockchain-based solution, data in all processes can be collected and made into open access for all consumers in a reliable and transparent way. This is also a way of challenge for brands and companies and can play an encouraging role to prove their environmental sensitiveness. Similarly, the resulting integrated and transparent data helps farmers reduce their water footprint. In addition, water labeling, certification and benchmarking plans can be collaborated on and reports generated on supply chain water footprints and associated impacts of their products.

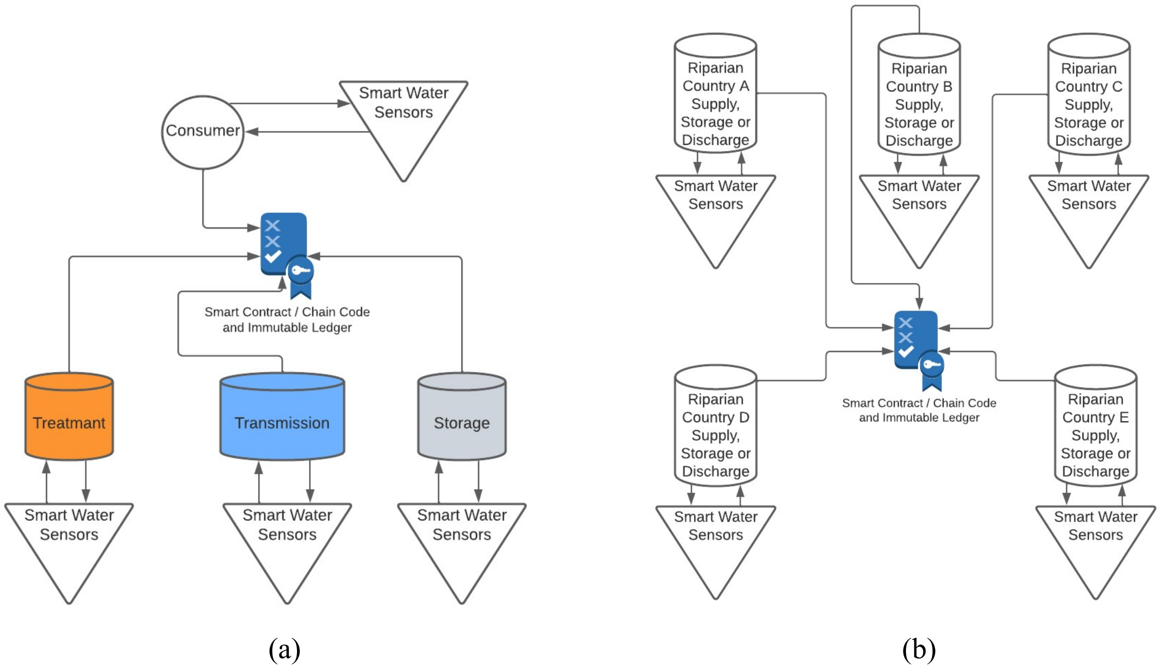


Figure 4. SWC architecture design (a) urban water system (b) transboundary river system / inland sea system.

Countries with high virtual water trade volumes may need more transparent background information on the water impact of the products they import. Thanks to a reliable, real-time and immutable dataset, import/export policies can be reviewed and more rational steps can be taken. Governments can adjust their development cooperation policies according to their desire to promote the consumption and trade of sustainable products. They can analyze their current import/export trends and consider water footprint and economic importance in new policies. Special precautions can be taken for products and services that are considered to be of critical importance in this regard, and the regulation can be modified. All these steps can be taken theoretically with traditional methods. However the bureaucratic and digital collaboration required takes excessive effort [23-24]. A blockchain-based architecture can provide this instantly. As an example, a simple water footprint-oriented supply chain of cup of coffee and SWC architecture can be seen in Figure 5.

An important point to be noted here is that the IoT infrastructure, which plays a key role in data transmission, should be strong. The relevant electronic and digital calibration should be done with precision. It should be known that although it has the potential to provide the highest level of system efficiency, DLT is a set of autonomous data processing and storage architectures. The SWC architecture mentioned here cannot measure data. It uniquely combines the data processing, recording and management system with the physical system. It's a great hydroinformatics tool, but not a flow meter and water quality sensor. Flow meters and water quality sensors are components of the proposed architecture.

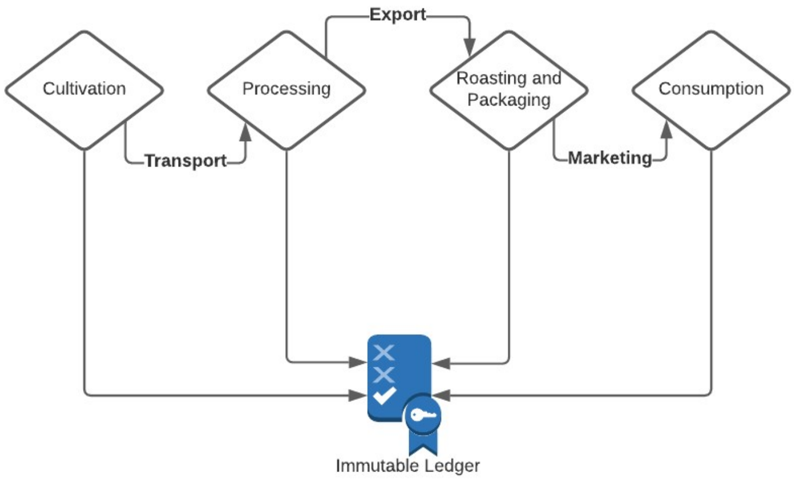


Figure 5. SWC architecture design for water footprint-oriented supply chain.

On the other hand, smart contracts can only be as smart as the professionals who design and code them. The environmental and market rules to be included in the smart contract should be carefully prepared and programmed. Due to the general programming principle and gas fees, it should have maximum application potential with as few lines of code as possible. Once a blockchain-based water market begins to be traded in real time, detected structural errors are nearly impossible to fix.

Another issue discussed during the study is whether architectures should be consisting of public or private blockchains. A private blockchain architecture that is accessible only to a limited number of stakeholders within the basin, city or transboundary water system has been evaluated. However, it is realized that digital water system architectures designed with private blockchain will eventually converge to monopolization, centralization and opaqueness. This goes against the revolutionary potential of blockchain technology and the sociocultural value of water.

4. Conclusion

Water is a commodity that is traded, that is paid to use. Water is the part of socio-cultural life of humankind. Water is also a natural resource, but unlike the usual, it is a two-dimensional natural resource. For efficient use, it should not only be in sufficient quantity, but also be in sufficient quality. Moreover, water does not act as a natural resource that you can leave alone and manage when the time comes. It should be managed continuously in a dynamic, sustainable, rational way. This situation necessitates being aware of the real value of water as a natural resource and having a transparent and reliable management perspective due to its socio-cultural value.

In the 21st century, while every field such as industries, cities, transportation, communication methods, entertainment and sports etc. are rapidly digitalizing, it is impossible for the water industry to act conservatively on this transformation or to limit digital transformation to decision support systems or hydrological models. As a result, the sine qua non of a next generation water management system, directly overlapping with the advantages of blockchain-based distributed algorithms; trust, reliability, immutability, transparency, integration and coordination.

SWC, which combines, smart contracts and decentralized water transaction ledgers, ensures that the inputs and outputs of all components of the urban water system meet environmental standards. The consumers trust the quantity and quality of the water they pay for. Similarly, incentives or penalties in cases where environmental standards are met or not can be regulated by smart contracts. SWC can resolve the issue of trust between all stakeholders who are dependent on the same water resource. SWC can certificate water footprint of any product or service peerlessly. An immutable database of real-time water data provides golden opportunity for data-driven modelling and forecasting.

References

[1] Varfolomeev AA, Alfarhani LH and Oleiwi ZC 2021 Secure-reliable smart contract applications based blockchain technology in smart cities environment *14th Int. Symp. Intelligent Systems* https://doi.org/10.1016/j.procs.2021.04.188

[2] Buterin V 2015 *A Next-Generation Smart Contract and Decentralized Application Platform* https://ethereum.org/whitepaper

[3] Angelakis AN, Vuorinen HS, Nikolaidis C, Juuti PS, Katko TS, Juuti RP, Zhang J and Samonis G 2021 Water quality and life expectancy: Parallel courses in time *Water* **13** 752 https://doi.org/10.3390/ w13060752

[4] Niya SR, Jha SS, Bocek T and Stiller B 2018 *Design and Implementation of an Automated and Decentralized Pollution Monitoring System with Blockchains, Smart Contracts, and LoRaWAN* Zurich Open Repository and Archive, University of Zurich

[5] Dogo EM, Salami AF, Nwulu NI and Aigbavboa CO 2019 Blockchain and Internet of Things-based technologies for intelligent water management system *Artificial Intelligence in IoT. Transactions on Computational Science and Computational Intelligence* https://doi.org/10.1007/978-3-030-04110-6_7

[6] Garrick D, Lane-Miller C and McCoy AL 2011 Institutional innovations to govern environmental water in the western United States: lessons for Australia's Murray-Darling Basin *Economic Papers* **30**(2) 167−184

[7] Wheeler S, Loch A, Zuo A and Bjornlund H 2014 Reviewing the adoption and impact of water markets in the Murray-Darling Basin, Australia *Journal of Hydrology* **518**(A) 28–41

[8] Musgrave W 2008 Historical development of water resources in Australia. Irrigation policy in the Murray-Darling Basin *Water Policy in Australia* ed Crase L (New York: Routledge) chapter 3 pp 28–43

[9] National Water Commission (NWC) 2009 *Australian water markets report* 2008–09, Canberra

[10] National Water Commission (NWC) 2012 *Impacts of water trading in the southern MDB between 2006/7 and 2010/11*, Report, Canberra

[11] Quiggin J 2001 Environmental economics and the Murray-Darling river system *Aust. J. Agric. Resour. Econ*. **45**(1) 67–94

[12] The Economist 2003 *Survey: Liquid assets* 368, 13 Available at http://www.economist.com/node/1906938

[13] Luhmann N 1995 *Social Systems* (California: Stanford University Press) p 127

[14] Stockholm International Water Institute 2013 *Independent Evaluation of the Nile Basin Trust Fund, Final Report* Avaliable at https://documents1.worldbank.org/curated/en/461521468202171071/pdf/892770WP0P09230on0of0NBTF0June02013.pdf

[15] Susskind L 2012 *Water Diplomacy: Creating Value and Building Trust in Transboundary Water Negotiations – Israel and Jordan, From War to Water Sharing* Harvard Law School Daily Blog

[16] Grupper MA, Sorice MG, Stern MJ and Schreiber ME 2021 Evaluating determinants of social trust in water utilities: implications for building resilient water systems *Ecology and Society* **26**(4) 41 https://doi.org/10.5751/ES-12833-260441

[17] Chapagain AK and Hoekstra AY 2004 *Water Footprints of Nations, Volume 1: Main Reports, Value of Water Research Report Series No: 16, UNESCO-IHE* Delft, The Netherland p 80

[18] Schubert H 2011 The virtual water and the water footprint concepts *Acatech Materialien* **14**

[19] Hoekstra AY and Hung PQ 2002 *Virtual Water Trade A Quantification of Virtual Water Flows Between Nations in Relation to Crop Trade* IHE Delft

[20] Pincheira M, Vecchio M, Giaffreda R and Kanhere SS 2002 Cost-effective IoT devices as trustworthy data sources for a blockchain-based water management system in precision agriculture *Computers and Electronics in Agriculture* **180** 105889 https://doi.org/10.1016/j.compag.2020.105889

[21] United Nations Economic Comission for Europe International Network of Basin Organizations

2015 *Water and Climate Change Adaptation in Transboundary Basins: Lessons Learned and Good Practices* p 86

[22] Dong H, Zhang L, Geng Y, Li P and Yu C 2021 New insights from grey water footprint assessment: An industrial park level *Journal of Cleaner Production* **285** doi: 10.1016/j.jclepro.2020.124915

[23] Yu Y, Hubacek K, Feng K, and Guan D 2010 Assessing regional and global water footprints for the UK *Ecological Economics* **69**(5) 1140–1147 doi: 10.1016/j.ecolecon.2009.12.008

[24] Aivazidou E, Tsolakis N, Vlachos D and Iakovou E 2018 A water footprint management framework for supply chains under green market behaviour *Journal of Cleaner Production* **197** 592–606 doi: 10.1016/j.jclepro.2018.06.171