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Mapping the Blockchain Ecosystem in India and Australia: Case Studies

Research Report

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Glossary

ANSI	American National Standards Institute
B2B SaaS	Business-to-business software-as-a-service
BGA	Blockchain Game Alliance
BiTA	Blockchain in Transport Alliance
BIS	Bureau of Indian Standards
CESI	China Electronics Standardization Institute
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
DLT	Distributed Ledger Technology
EEA	Enterprise Ethereum Alliance
EITF	Emerging Issues Task Force
ETSI	European Telecommunications Standards Institute
GDF	Global Digital Finance
IEEE	Institute of Electrical and Electronics Engineers
IIC	Industrial Internet Consortium
INATBA	International Association for Trusted Blockchain Applications
IoT	Internet of Things
ISO	International Organization for Standardization
ITSA	International Token Standardization Association
ITU-T	International Telecommunication Union Telecommunication Standardization Sector
IWA	International Web Association
MOBI	Mobility Open Blockchain Initiative
MSME	Micro, Small and Medium Enterprise
NEO	NEO blockchain platform
NEM	New Economy Movement
NIST	National Institute of Standards and Technology
OASIS	Organization for the Advancement of Structured Information Standards
OSS	Open-Source Software
SA	Standards Australia
SDO	Standards Development Organisation
TDIF	Trusted Digital Identity Framework
TRL	Technology Readiness Level
W3C	World Wide Web Consortium

Definition of Terms

Blockchain: A shared, immutable ledger enabling the recording of transactions and tracking assets in a network.

***De Facto* Standards:** Standards that have become widely accepted and adopted through repeated use and market dynamics, often driven by dominant enterprises or open-source software communities.

***De Jure* Standards:** Standards developed through a formal process by a recognised Standards Development Organisation (SDO) which may be voluntary or mandated through legal codes or regulations in certain jurisdictions.

Digital Identity: The representation of an individual's identity in an electronic form, typically used for authentication and authorisation purposes in digital systems.

Ecosystem Fragmentation: The division or fragmentation of a technology or system into separate and incompatible parts or versions, hindering interoperability and collaboration.

Hybrid Blockchain: A combination of private and public blockchain that allows for selective information sharing to relevant participants, based on the nature of information and the role of participants. Some processes are kept private, and others are public.

Interoperability: The ability of different systems or technologies to work together, exchange information, and use shared resources effectively.

Intellectual Property (IP): Legal rights associated with creations of the mind, such as inventions, designs, trademarks, and copyrights, which can be protected by law.

Non-financial Blockchain: The application of blockchain technology in areas outside traditional financial use cases, such as digital identity, supply chain management, and records management.

OSS (Open-Source Software) Communities: Communities of developers and contributors who collaborate to create and maintain open-source software freely available for use, modification and distribution.

SDOs (Standards Development Organisations): Formal organisations responsible for creating and disseminating technical standards, ensuring quality, interoperability and compatibility.

Self-Sovereign Identity: An approach to digital identity that allows individuals to have their own authority over the information they use to authenticate their identity to various websites, services, and applications on the internet.

Supply Chain: The network of organisations, individuals, activities and resources involved in the production, distribution and consumption of goods or services, including the creation and exchange of value.

Technical Standards: Established guidelines, specifications or protocols that define how a particular technology should be implemented, ensuring compatibility, interoperability and quality.

Technology Readiness Level (TRL): A measure used to assess the maturity and readiness of a technology. TRL 1 signifies the observation of basic principles at the ideation stage. TRL 9 signifies the successful demonstration of an operational system in its intended environment.

Vendor Lock-In: A situation where a customer becomes dependent on a particular vendor's products or services, making it difficult or costly to switch to alternatives.

Introduction: Exploring blockchain applications and standards

This report is the second in a series written for the research project: *shaping blockchain technical standards consistent with Australia and India's shared vision for an open, free, rules-based Indo-Pacific*.

It presents the results and findings of the second phase of the project, based on primary and secondary research. It builds on a baseline understanding of the non-financial blockchain ecosystem in India and Australia developed in the first report titled *Mapping the Blockchain Ecosystem in India and Australia.*[1]

The project focuses on studying the non-financial use of blockchain and relevant technical standards, particularly applications in the non-cryptocurrency space. The non-financial blockchain ecosystem represents an emerging area of opportunity in both India and Australia. The project's initial phase involved mapping the stakeholders and emerging applications in India and Australia. This revealed three primary thematic areas of interest for both countries: digital identity and credentials; supply chains; and records management for resources such as land and water.

To explore these thematic areas further, the project's second phase has focused on presenting three comparative case studies supported by 15 use cases and independent research. These use cases are an avenue to explore the development of relevant blockchain applications, approaches to adopting existing technical standards, and the kinds of standards being considered. Combined, this provides a nuanced understanding of the level of awareness and adoption of blockchain technical standards.

Learnings from studying the use cases and associated technical standards will support the project's third phase by providing a basis to examine the development, adoption, and efficiency of standards. The third phase intends to identify existing gaps to frame recommendations that help build a multistakeholder community and enhance their engagement with standard making at the international level. The report is geared toward achieving the project's objectives of providing recommendations to further the development of blockchain standards that advance Australia and India's interests.

The project's first phase also examined stakeholder awareness and attitudes toward technical standards and standards-making bodies. This demonstrates the need to increase the awareness of standards within the blockchain ecosystem. To further this understanding, the report examines and briefly outlines the role of standards and relevant standards organisations.

This report is organised into four sections:

- Executive summary of key findings
- An overview of the blockchain standards landscape
- Comparative case studies showcasing use cases and associated blockchain technical standards
- Conclusions and next steps.

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Executive summary of key findings

This section presents the report's key findings, drawn from the research, comparative case studies showcasing the use cases, and associated technical standards presented in the report.

The report's Conclusion and Next Steps section discusses each finding in greater detail.

1. Blockchain by itself is neither the only solution to the challenges it proposes to address, nor a complete one. It needs to be implemented alongside strong cyber security practices and robust human rights protections to solve the challenges it proposes to address effectively. Standards, laws and regulations are vital to ensure blockchain technologies are developed to maximise opportunities while minimising risks.

2. The level of understanding and adoption of blockchain technical standards varied among stakeholders. Most stakeholders are aware of certain major standards bodies in the blockchain ecosystem, and in certain cases, existing technical standards and similar frameworks relating to blockchain. However, many stakeholders do not currently participate in standards-making processes, primarily due to the perceived lack of commercial and/or organisational incentives. Some stakeholders (especially those at Standards Development Organisations (SDOs)) also highlighted the lengthy nature of these processes.

3. Perceptions and adoption differed in relation to *de jure* standards (those developed through a formal process) and *de facto* standards (predominantly created by industry groups, communities, and initiatives, including open-source software (OSS) communities).

4. A culture that promotes the uptake of *de jure* standards through government regulations and mandatory requirements plays an important role in driving the adoption of specific standards.

5. Stakeholders operating in sectors the government more closely regulates or providing government services are more likely to engage in *de jure* standards development.

6. Stakeholders involved in standards development are more likely to implement *de jure* standards within their own products.

7. Most use cases engaged on some level with, or had adopted, *de facto* standards established by OSS communities. Stakeholders highlighted the benefit of adopting software and standards by OSS communities, as they were able to resolve issues quickly, for example, security-related issues.

8. The choice of technology and technical standards adopted to tackle challenges, as shown in the case studies, were highly pragmatic. Use cases in both India and Australia favoured standards that align with existing systems and software infrastructure, the objectives of the solutions, and local context.

9. Cost was a key factor in choosing and adopting standards, particularly for Micro, Small and Medium Enterprises (MSMEs). Consequently, *de facto* standards led by Industry groups, communities, and initiatives were generally perceived by stakeholders as more attractive for building more accessible, efficient and effective standards, particularly by MSMEs.

10. Use cases show that SDOs provide the *de jure* standards needed for compliance in regulated sectors and at scale. In contrast, industry groups, communities, and initiatives such as OSS communities provide the *de facto* standards to get things off the ground and keep pace with rapidly evolving technology.

11. Engagement in *de jure* and *de facto* standards processes, and collaboration between them is essential to fostering a thriving blockchain ecosystem. Incentives, governance structures and participation mechanisms are all essential foundations and will be the focus of Phase Three of this research.

Overview of standards landscape

The project's first phase assessed stakeholder awareness (baseline knowledge) and attitudes towards blockchain standards. In the first phase, most stakeholders were broadly aware of the value of standardisation, only some participated in standard-setting processes, and only a few could point to specific standards and standards organisations. This report aims to increase overall awareness by providing a high-level overview of the blockchain technical standards landscape, including standards-development bodies and technical standards.

Benefits of standards

Standardisation in blockchain technology offers several interconnected benefits. It improves interoperability, reduces operational and legal/regulatory risks, and eliminates redundant intermediaries.[2] Blockchain standards assume importance for practical, economic and security reasons.

- ***Practical.*** Standards ensure interoperability and portability, allowing technologies to exchange information with each other and legacy systems across borders. This enables consumers to purchase innovative technologies from overseas confidently and facilitates exporting technology without adjusting specifications for each country, preventing ecosystem fragmentation.

- ***Economic.*** Commercially, standards drive economies of scale, prevent vendor lock-in, unlock network effects, and open new markets. They often embed Intellectual Property (IP), which on the one hand, can be lucrative to IP owners but can pose barriers to disseminating and adopting standards.

- ***Security.*** Strategic considerations involve embedding security, safety, privacy and data governance approaches into technology, enhancing trust. Countries and leading companies that dominate standards discussions shape the agreed specifications, subsequently influencing technology's impact on societies.

Standards can meet the needs of markets by minimising manufacturing and compliance costs and ensuring quality control. Further, they improve market participants' understanding of technologies by building broad consensus on the associated vocabulary and terminology, which facilitates further research and development and enhances the quality of applications.

De facto and *de jure* standards

In general, the process for creating and adopting technical standards takes place through one of the following approaches:

A. ***De facto***: A *de facto* standard is formed when a practice, behaviour or configuration becomes accepted through repetition and use and is driven by market dynamics and dominant enterprises. Such standardisation processes rely on market actors' active and sustained participation, supported by a culture that facilitates such participation. Compliance with *de facto* standards is voluntary.[3] Standards development in OSS communities, industry alliances, associations and consortia are examples of this *de facto* standards development process.

B. ***De jure***: A *de jure* standard is developed through a formal process, under the aegis of a formal SDO. Compliance with *de jure standards* is voluntary but in some cases, can be imposed through a legal code or regulation, making them mandatory in certain legal jurisdictions.[4] The Institute of Electrical and Electronics Engineers Standards Association (IEEE SA), International Organisation for Standardisation (ISO), International Telecommunication Union Telecommunication Standardization Sector (ITU-T) and Organization for the Advancement of Structured Information Standards (OASIS) are examples of voluntary *de jure* standards-development bodies.

Standards-development bodies

The formulation of blockchain-related technical standards, protocols and similar frameworks occurs under the aegis of standards-development bodies. In addition to standards formulation, these bodies also facilitate information sharing among their participants through outputs such as technical reports and survey findings. Such information, even when it does not reach a particular standard, can guide future standard development. In areas of common interest, standards-development bodies often enter into collaborative arrangements with each other to co-develop standards or drive standards-related discourse.

While all standards-development bodies aim to develop standards, each operates under its distinctive structure, membership model, and governance arrangements. Broadly, standards-development bodies can be categorised into SDOs, industry groups, communities, and initiatives. Further, SDOs can be organised geographically into those that operate at international, regional or national levels. Industry groups, communities and initiatives can be organised into open standards organisations, OSS communities, industry alliances or associations, and industry consortia.

International SDOs typically operate within well-defined legal frameworks, with formal leadership and internal governance structures to make and implement decisions. On the other hand, industry groups and communities, particularly OSS communities, rely on voluntary participation and have more flexible leadership roles.

Categorising standards-development bodies (as set out below) is useful for broadly understanding their role in the ecosystem, the motivations behind standards development, and the kinds of standards that each body is responsible for.

Standards-Development Bodies						
Standards-Development Organisations (SDO)			Industry Groups, Communities and Initiatives			
International	Regional	National	Open Standards Organisations	Open-Source Software Communities	Industry Alliances & Associations	Industry Consortia
IEEE ISO ITU-T	ETSI CEN CENELEC	CESI NIST SA BIS ANSI	OASIS EITF	Ethereum W3C Hyperledger R3 Corda NEO NEM Stellar Tezos Hedera	IWA EEA BiTA BGA GDF ITSA INATBA	IIC MOBI BlockStand

Table 1: Sample of organisations involved in blockchain/DLT standardisation5

Table 1 provides an overview of a select group of relevant standards and organisations:

- **International Standards Development Organisations:** At an international level, standards development for blockchain is driven by a small number of organisations. This includes the International Organisation for Standardization (ISO), the International Telecommunication Union (ITU), and the Institute of Electrical and Electronics Engineers (IEEE).
- **Regional/National Standards Development Organisations:** The decisions of major national and/or regional standard-development organisations from jurisdictions with significant technology markets/ecosystems can also shape the standards landscape of other countries. This group includes standards-development organisations in Europe and the USA, and for the purposes of this report national level organisations such as the Bureau of Indian Standards and Standards Australia.
- **Industry Groups, Communities and Initiatives:** Industry groups, communities and initiatives play a crucial role in formulating standards alongside formal standards-development organisations. Practices, protocols or configurations supported by such groups and initiatives often become widely accepted; assuming the character of *de facto* standards. This includes a wide range of groups and initiatives, from the World Wide Web Consortium (W3C) to the Hyperledger Foundation, Enterprise Ethereum Alliance (EEA), and InterWork Alliance (IWA).

Annex A summarises the different types of standards-development bodies relevant to the blockchain ecosystem and briefly describes their respective contributions to developing blockchain-related standards. During our primary research, certain bodies were repetitively identified in numerous consultations with stakeholders as key contributors to the development of blockchain-related standards. Such bodies have been marked with an Asterisk (*).

Annex B lists the blockchain-related committees, sub-committees, working groups and/or focus groups within key bodies with the blockchain-related standards, recommendations and/or any other relevant outputs published by them recently.

Annex C describes the process and stages of standards formulation at the national SDOs in India and Australia.

Comparative case studies: Blockchain applications and associated technical standards

The stakeholder mapping of the Indian and Australian blockchain ecosystems in the project's first phase revealed prominent and emerging use cases for non-financial applications of blockchain technologies. These use cases were thematically categorised to identify three areas of common interest where significant applications are being developed in both countries. These thematic areas are: digital identity and credentials; supply chain; and records management for resources like land and water.

The following section presents three comparative case studies between India and Australia, one for each thematic area identified above. Each case study presents a high-level analysis of the evolution of a thematic area in India and Australia. To show how blockchain technology is being used to address the existing challenges in these thematic areas, the report showcases select blockchain use cases in both countries. These use cases highlight the ways blockchain is being used in a commercial sense and the types of technical standards associated with them. They demonstrate unique blockchain solutions developed by Indian and Australian stakeholders to provide valuable societal, economic, and security benefits that address local challenges.

The understanding of the use cases was developed through a combination of primary research involving stakeholder interviews and desktop research. The validity and accuracy of use cases were verified, where possible, via additional consultations with relevant stakeholders or by cross-referencing publicly available information.

The use cases presented address the following areas:

- an overview of the stakeholder and their application
- blockchain technology's role and why it was chosen
- the kinds of technology and technical standards used
- the stakeholder's involvement in and awareness of standards-making bodies.

Tables 2, 3 and 4 provide a synopsis of the use cases. The tables provide information on the size and type of organisation involved, where the organisation belongs (ownership), the industry sector type, associated technical standards, and Technology Readiness Level (TRL).[6]

The TRL is a progressive scale (1-9) that indicates the level of technological development for an operational system. It begins with TRL 1, which indicates that a system is at an ideation stage adopting basic principles. It ends at TRL 9, which signifies the successful demonstration of an operational system in its intended environment.[7]

The standards category in the table highlights the different standards used for developing a use case. When 'N/A' is indicated, the use case has developed its own blockchain solution and/or no specific standards are mentioned. In the Indian context, 'bespoke standards' indicate that some stakeholders developed their own frameworks or protocols.

Most use cases were from small-scale start-ups in India and Australia, and most standards deployed were from OSS communities such as Hyperledger. The TRL of these organisations was assessed to be between 7-9, indicating that the technology used was small in scale and development or being trialled; a profile that fits with a start-up organisation or early-stage commercial application. This profile and the sample of use cases are reflective of the state of blockchain technology development and its application by organisations in both India and Australia.

While blockchain technologies have many benefits, this report recognises that blockchain by itself is neither the only solution, nor a complete one. Blockchain technologies need to be implemented alongside strong cyber security practices and robust human rights protections to effectively solve the challenges. The role of standards, law, and regulation are important in ensuring that blockchain technologies are developed in ways that maximise their opportunities while minimising the risks to data protection and security.

Endnotes

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1 Theme 1: Digital identity and credentials

Country	Stakeholder	Theme	Size	Ownership	Type	Industry	Standards	TRL
India	Trential	Digital Credentials	Small	India	Start-up	IT Services & Solutions/ Cybersecurity	Hyperledger Indy, W3C VC model	9
	Zupple	Digital Identity & Credentials	Small	India	Start-up	Software solutions	W3C VC model, Bespoke Standards	9
Australia	TrustGrid	Digital Identity & Credentials	Small	Australia/ USA	Corporate	Consultancy	ISO, DIDs, TDIF, PSD2, eIDs, GDPR	8/9
	Type Human	Digital Identity & Credentials	Small	Australia	Start-up	Developer	N/A	7/8

Table 2: Summary of digital ID use cases

India case study

The digitisation of societal, administrative, and professional processes in our daily lives necessitates integrating our offline identities with the digital world. Additionally, multiple identities are emerging from our online interactions. However, even in today's digital landscape, authentication of identities and credentials is often carried out using traditional verification mechanisms. This kind of verification process remains complex involving multiple actors and requires significant time, money, and other resources. The issue is further aggravated by the increasing proliferation of fake credentials, information, and accounts[1] around the globe, causing financial, legal, reputational and security risks for individuals.[2] These concerns show us the need to ensure authenticity, security, and integrity of identity online.

An approach to verifying personal identity online is rooted in verifiable digital credentials that are cryptographically protected and fraud-resistant. They also help verify authenticity instantly. The emergence of 'verifiable credentials' can be attributed to open-source standards such as the World Wide Web Consortium (W3C)[3] model[4] and AnonCreds by Hyperledger Indy.[5] Standardising the format for online identity verification enables a cryptographically secure, privacy-respecting, and machine-verifiable mechanism. This allows individuals to share specific aspects of their identities selectively and enables a verifier to authenticate identity instantly from anywhere.

By enabling the recording and storage of tamperproof credentials through a user-centric approach, decentralised technologies like blockchain have the potential to strengthen digital identities and credentials and make them seamlessly verifiable.

The challenges

Increasing fragmentation and lack of user control

Individuals are required to maintain multiple kinds of digital identities to access varied services or conduct activities online; creating fragmented online personas. User identity managed by multiple isolated systems in conjunction with the lack of effective user control over their information and its movement in the digital ecosystem, creates potential for misuse and identity sprawl.[6]

Cybersecurity concerns

Data security vulnerabilities in digital identity systems can threaten basic human rights such as privacy. These concerns are exacerbated when the entities that aggregate and maintain extensive databases containing personal identity information fall prey to data breaches and cyber-attacks, often resulting in identity theft.[7]

Issuer dependency and centralisation of information

Traditionally, verifiers are required to maintain multiple communication channels and need confirmation from the issuers to verify the credentials they receive. This makes verification time-consuming and complex. Additionally, issuers often use varied formats for processing identity-related information. This often constrains how verification processes occur and results in centralising control with each issuer. Without standardisation of information, information cannot be seamlessly shared by users or verified by entities.

The response

Increased privacy and user control in identity data flows

Digital identities are moving beyond federated or centralised models[8] to a decentralised identity ecosystem that provides users control over access and information sharing. Users interact with the issuers and verifiers in the ecosystem through the verifiable credentials stored in their wallet—that are tamper-proof—created through an adequate verification process. These credentials are linked or attested to the user's personal information, which is kept off the public ledger.[9]

Decentralised storage and access

In the decentralised identity system, once the user has consented to access, the verifier can directly authenticate digital identities or credentials on the blockchain without involving the issuer. This eliminates the need for the verifier to interact with the issuer each time verification is required. This is particularly helpful when the issuer has ceased to exist at the time of verification.

Key metrics

- The blockchain identity management market is estimated to grow by $3.58 billion in five years from 2021–2025.[10]
- By 2026, 1 billion Indians are projected to be smartphone users.[11]
- Digital identity cards, where digital details are loaded onto an identity card, are forecasted to be used by over 4 billion people globally in 2026, from 2.5 billion in 2022.[12]
- In 2020, data shows that 20% of all computer-related crimes in India were identity theft cases.[13]

Use cases

The case study looks at two applications of blockchain used for digital identity and credentials: Credential Manager by Trential, and LegitDoc by Zupple.

Credential Manager by Trential

Trential, previously known as CRUBN, was founded by a team of researchers and engineers at the Indian Institute of Technology (IIT) Kanpur in India. In 2018, the National Security Council launched its flagship National Blockchain Project in collaboration with IIT Kanpur. With the project nearing completion in 2023, Trential emerged to build innovative products across healthcare, education, governance, and financial services and has collaborated with several state governments.

The company developed and implemented a blockchain-based verifiable credentials ecosystem that empowers citizens to regain control over their credentials and allows sharing of credential data while preserving privacy. The solution was launched by the Prime Minister of India at IIT Kanpur and the Minister of Education at convocation ceremonies at the Indira Gandhi National Open University (IGNOU) and the National Institute of Technology Rourkela.

Blockchain's role

Trential's solution includes a credential manager (an application for organisations to create, manage, issue, and verify trusted identity data) and a wallet (a secure way for citizens to receive, store, and share all their digital credentials from a single application). Trential implemented blockchain to develop an immutable, verifiable data registry that contains metadata related to credentials. This ensures the integrity of credentials, making them tamper-proof and allowing sharing of credential proofs in a non-transferable manner. Through an interface layer, the credential manager and the wallet are built on top of a blockchain that adheres to the W3C's verifiable credentials principles.

As part of the solution, IIT Kanpur's IT cell managed the creation of each student's degree, and this database was integrated with Trential's ecosystem. This allowed for verification of students' degrees by a third-party through a simple scan of a QR code. Each degree is uniquely linked to its credentials on the blockchain.[14] The wallet storing the degree is also integrated with Digilocker, India's national digital document wallet. The solution enhances a user's agency by allowing them to control the kind of information they share with third parties for verification purposes. It has been used to create an immutable identity ecosystem that is globally interoperable and eliminates issuer dependency at the time of verification. This solution also allows universities and recruiters to conduct instant background verifications, KYCs, etc.

Trential's verifiable credentials ecosystem is built on the open-source framework Hyperledger Indy,[15] which is considered highly suitable for distributed digital identity systems. Additionally, the wallet designed as part of the solution has been developed to share the digital credential through Near Field Communication.[16] Through this, students can use credentials (stored in the wallet) to gain access to a library, for example, by simply tapping the wallet. This has been piloted at IIT Kanpur.

LegitDoc by Zupple

Zupple, previously known as Cross Forge Solutions, is a software company offering B2B SaaS-based services specialising in web3 innovations and enterprise-grade decentralised solutions.[17] The company works with several state governments: Maharashtra, Karnataka, Chhattisgarh, and Telangana.[18] They have used blockchain to develop verifiable caste certification, traceable identities for distribution of social security entitlements and lead the world's largest implementation for educational credentialing.

Blockchain's role

Zupple developed LegitDoc in 2018 to address security issues around centralised document issuance systems and to create a standard interface for public document verification.[19] LegitDoc is a software application that uses a patent-filed blockchain-based system to issue and verify digital documents.

In 2022, Zupple collaborated with the Gadchiroli district administration (Etapalli Subdivision) in Maharashtra to issue caste certificates through LegitDoc. The certificates are cryptographically stored on a polygon proof-of-stake public blockchain, allowing instant authentication using publicly auditable data.[20] The initial implementation phase included issuing 65,000 caste certificates to citizens through common service centres operating in all villages in the sub-division. The company's implementation of caste certification was recognised in Niti Aayog's 2023 compendium on Best Practices in Social Sector.[21]

Besides this, Zupple's LegitDoc was also selected to collaborate with the Maharashtra State Board of Skill Development to reissue alumni diploma certificates.[22] In 2022, LegitDoc [23] issued 100,000 diploma certificates in Mumbai using Polygon blockchain and cryptography.[24]

The solution's system has two main software applications: one for issuing certificates, and another for verifying credentials. Issuers such as the Sub-Division Officer are registered through the LegitDoc portal either using a hardware wallet or a digital signature pair through the LegitDoc browser extension, where only the public key is shared with LegitDoc. Documents are recorded into the application, and a digital fingerprint (or 'hash') is generated based on certain data fields from the recorded document. The hash is then stored on the blockchain linked to the issuer's digital signature. The issuance application then combines transaction data recorded on the blockchain with the original certificate in a PDF, creating a tamper-proof file shared with relevant recipients. In some cases, like for caste certification, the issuance application generates a QR code that contains blockchain transaction data and data fields from the original caste certificate, which is appended to the side of the certificate for verification purposes.

Issued documents can be verified through the verification interface. The certificate data and blockchain transaction data are used to recreate a unique digital fingerprint to confirm if the same fingerprint exists on the blockchain. The details of the certificate are then displayed to the verifier. The solution enables document verification from anywhere worldwide, within a few seconds.[25]

Zupple's blockchain-based solutions are built using Polygon and Ethereum to leverage the security of public blockchains and adhere to W3C's verifiable credentials standards.[26] The solution is developed using their own framework for storing and verifying documents on the blockchain, accommodating digital access and literacy challenges in India. The company highlighted that clear standards for e-governance are yet to emerge.

Australia case study

The Australian Federal Government has indicated it will introduce legislation in 2023 to build a national Digital Identity System.[27] Digital identity in Australia is an important aspect of the *Digital Economy Strategy 2030*, which, among many actions, aims to migrate 100% of Australian government services online.[28] The digital identity component of that strategy set the objective that digital identity systems should be designed to allow citizens to prove their identity easily and once only, to use a range of government and non-government services.

The Federal Government has invested over $600 million in digital identity initiatives as part of the Strategy, with an additional $161 million committed in the 2021 mid-year budget update[29] and an extra $26.9 million in 2023–24 to expand Digital ID.[30]

The economic benefits of digital identity are estimated at $11 billion annually.[31] Establishing a digital identity allows individuals or entities to have a trusted and verifiable identity that other organisations can rely on for transactions.

The challenge

Limited consensus

There is currently no consensus between Australian state and federal governments on digital identity solutions and their use of blockchain technology. At the federal level, the Digital Identity System that is being developed does not use blockchain technology.[32] Whereas the New South Wales State Government uses a blockchain system to deploy the Digital License system, which it launched in 2019.[33]

The response

National legislation to increase standardisation

In October 2021, the Federal Government released draft legislation to establish the Trusted Digital Identity Framework (TDIF), which builds upon previous efforts to establish a standardised system for digital identity.[34] The TDIF serves as a nationally recognised standard that forms the basis for trust and interoperability within the digital identity ecosystem in Australia.[35] The Federal Government intends to formalise the TDIF and introduce its own Digital Identity System through proposed legislation in late 2023.[36] The legislation aims to address regulatory gaps and encourage participation from state, territory, and private-sector service providers.[37]

Establishes self-sovereign identity

Based on consultations with digital identity blockchain companies, blockchain technology is used for identity and user verification purposes due to its ability to grant individuals control over their data while ensuring security through cryptography. By using blockchain, users can have ownership and agency over their data, removing the need for a centralised authority. The cryptographic features inherent in blockchain technology guarantee the reliability and authenticity of the verification process, aligning with the principles of self-sovereign identity and the evolving standards for verifiable claims and credentials.

Key metrics

- The Australian Federal Government has invested over $600 million in digital identity initiatives.[38]
- The *Digital Economy Strategy 2030* aims to make 100% of Australian Government services available online by 2030.[39]
- The annual economic benefits of digital identity in Australia are estimated at $11 billion.[40]

Use cases

The use cases delve into two applications of blockchain-based Digital Identity solutions in Australia, TrustGrid and TypeHuman.

TrustGrid

TrustGrid is a cloud-based solution that focuses on digital identity and privacy. TrustGrid uses parts of blockchain technology to ensure secure and transparent transactions and interactions within its ecosystem. The TrustGrid system is used to deploy the New South Wales Digital License system.

Blockchain's role

According to an interview with researchers, TrustGrid advised that their technology differs from traditional blockchain systems. They give clients the choice between a complete chain of transactions or a decentralised ledger for their use case. They believe that not everything needs to be stored on the blockchain, addressing changes that do not require immutability. They use an open platform model where data is kept off-chain, ensuring that individuals own their data. Their technology only stores necessary information on the blockchain-based on specific use cases to ensure personal data is not on the system for security purposes.

TrustGrid advised that when developing their technology in 2013, many standards were non-existent. As standards were developed, the team consulted several, including W3C identity standards (DIDs and verifiable claims),[41] authentication standards, ISO standards (particularly related to cryptography), privacy-related standards (such as GDPR), and European standards (such as PSD2 and eIDs). Specifically, the NSW Digital License system was developed by consulting multiple ISO standards and the TDIF. These standards influenced the ongoing development of their technology, ensuring alignment with established frameworks, technical requirements, privacy regulations, and authentication protocols.

The employees of TrustGrid have previously been involved in standards development. TrustGrid, at the time of the interview, was not involved with the standards groups but was investigating getting involved with some of the national-level standards working groups.

TypeHuman

TypeHuman partnered with the Red Cross to develop Ponto, a digital credential platform that uses blockchain to simplify issuing and verifying badges for volunteer and humanitarian workers in Australia.

Blockchain's role

According to an interview with researchers, TypeHuman advised that their technology focused on ensuring users maintain ownership of their own data. They used levels of cryptography provided by blockchain technology, specifically Ethereum keys, to establish decentralised identities (DIDs). The technology was initially developed using blockchain technology to eliminate the need for data ownership by banks or other centralised entities.

TypeHuman highlighted that the creation of frameworks and standards by organisations like W3C helped formalise concepts such as verifiable claims. They describe a process where issuers sign credentials, trusted authorities verify them, and individuals can prove their data's accuracy without relying on the original data source.

Employees at TypeHuman are not currently involved in standards development.

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2 Theme 2: Supply chain

Country	Stakeholder	Theme	Size	Ownership	Type	Industry	Standards	TRL
India	TraceX	Food Supply Chain	Small	India	Start-up	Agriculture and Climate Technology	Hyperledger Fabric	9
	StaTwig	Vaccine Supply Chain	Small	India	Start-up	Healthcare	GS1	9
	TRST01	Provenance Supply Chain	Small	India	Start-up	Agriculture and Climate Technology	Hyperledger Fabric	7
Australia	IndigiLedger	Provenance Supply Chain	Small	Australia	Corporate	Art	N/A	9
	wisecar	Provenance Supply Chain	Small	Australia	Corporate	Transport	Hyperledger Fabric	8/9

Table 3: Summary of supply chain use cases

India case study

The timely delivery of any product to consumers in an economy depends on the efficiency with which the product moves through successive links on its supply chain. Secure, sustainable, and streamlined supply chains are critical to economic growth as well as the general well-being of a nation. This is especially true for supply chains for essential goods and services like food, medicine, water and electricity.

Enhancing the efficiency of supply chains has been recognised as one of the key priorities towards increasing the competitiveness of Indian industries and contributing to the development of the Indian economy.[1] India (and Australia) are part of the Supply Chain Resilience Initiative (SCRI) with the intent to create a virtuous cycle of enhancing supply chain resilience in the Indo-Pacific region.[2] Traditional mechanisms for supply chain management in India are often complex, inefficient and rely on extensive coordination among stakeholders, including regulatory bodies. These elaborate processes, combined with shortcomings in the necessary logistical infrastructure,[3] increase the administrative burden on enterprises, along with the time and cost of operations. Parties do not have visibility on the status of products as they move along the supply chain.[4] This opacity prevents effective product monitoring, both in quality and quantity, and often leads to product wastage as well as reputational loss for enterprises.

In effect, traditional supply chain systems solely act as a means of transporting products and do not play any meaningful role in ensuring transparency and accountability in the ecosystem. However, with increasing consumer awareness on matters such as sustainability, product quality, and authenticity, there is increasing acknowledgment of the need for reliable and trustworthy supply chain systems. Blockchain can be used to address the issues of coordination among stakeholders, providing transparency to internal processes, quality and authenticity of products[5] and reducing corruption in the supply chain.[6]

The challenges

Fractured data sharing

As supply chain systems include multiple stakeholders and involve complex back-to-back processes, delays caused in any one process are likely to have a ripple effect. For example, delays in sharing invoices can impede product delivery. Supply chain information asymmetries can lead to inefficient and fractured data sharing, increasing both cost and time.

Wastage of resources

Accurate and real-time information is often compromised due to a lack of proper communication channels between stakeholders. This lack of visibility on the status of products leads to delays in transportation and discrepancies in storing and managing products. This can affect the quality of products and cause wastage.[7]

Lack of transparency and concerns with quality and authenticity

Fake products are prevalent in every industry. The lack of robust track and trace mechanisms in the supply chain compromises product quality and causes reputational and financial damage.[8] Distribution and manufacturing processes are often opaque and lack a system for maintaining immutable records to check the flow of illegal products in supply chains.[9]

The response

Blockchain can be a catalyst for solving these problems in supply chains. It is useful in creating efficient data sharing among stakeholders, increasing visibility to consumers and providing transparency regarding the quality and authenticity of products.[10]

Enhances efficiency

A blockchain-based supply chain uses smart contracts to automate decision-making and processing. It decentralises record-keeping and decision-making to create an immutable single point of truth.[11] Every input added to the shared ledger is recorded on the blockchain, bearing a unique fingerprint and time stamp. This allows for the real-time seamless data exchange between multiple stakeholders aiding better inventory management and logistics planning.[12]

Assures quality and reduces wastage

Blockchain enables track and trace mechanisms in supply chains to add visibility, identify points of failure, and make decisions on targeted recalls for products with quality concerns.[13]

Builds trust

Blockchain provides reliability, transparency, and irreversibility in the supply chain management process. Immutable and irreversible data recording provides reliable information on products' origin and quality and reduces corruption in their production and distribution.[14] Verification of authenticity of products and proof of origin ensures quality and shows that products are safe to consume, increasing consumer trust.[15]

Key metrics

- The blockchain market in the supply chain is forecast to reach $524 million by 2024, with the Asia-Pacific region set to emerge as the largest, with a revenue of $256 million.[16]
- Logistics cost in India is estimated to be around 13% of gross domestic product (around $400 billion).[17]
- In the food supply chain, from post-harvest up to (but excluding) retail, up to 14% of all food in the world is lost.[18]
- Due to improper shipping, 25% of all vaccines are degraded when they reach their destination. 20% of temperature-sensitive products are damaged during transport due to a broken cold chain.[19]
- In India, counterfeiting in fast-moving consumer goods (including food products) is as high as 25–30%.[20]
- Global sales of counterfeit and pirated goods are estimated to value between $1.7 trillion and $4.5 trillion annually, making counterfeiting at least the tenth largest economy.[21]

Use cases

The case study delves into three blockchain-based supply chain management applications in India: traceability for the Geographical Indication of Tur Dal by TRST01, VaccineLedger by StaTwig, and supply chain solutions by TraceX.

Traceability for geographical indication of Tur Dal (Red Gram) by TRST01

TRST01 (Trust-O-One) is a multi-chain blockchain platform focused on agriculture, climate technology and food. Their solutions include agriculture and food traceability solutions, environmental, social and governance reporting, etc. TRST01 developed a blockchain-based solution for verifying Geographical Indication (GI) tagging for Tur Dal (red gram) from the Tandur region. The Tandur Tur Dal is assigned a GI tag for its unique qualities, one of them being for its protein content, which is known to contain three times the normal protein content in lentils.[22]

This solution was implemented by Professor Jayashankar Telangana State Agriculture University for almost two years, engaging with nearly 100 farmers from the Tandur region. It increased farmers' profits as GI-tagged Tandur Tur Dal retails for a much higher price than normal lentils. Owing to the pilot's success, this solution's application is being considered at a commercial scale.

Blockchain’s role

TRST01 chose blockchain to build traceability and immutability of data in the supply chain for GI tag verification. Traceability helped stakeholders view the geo-location of the harvested product, with additional information about the producer.[23] To verify the GI tag of the Tandur Tur Dal, it was necessary to ensure the details regarding the origin of the pulse were precise, accurate and unalterable. To ensure this, TRST01 geofenced the area growing Tur Dal in the region. It set up an information collection process for various harvesting stages, including checks for purity, colour, variety, etc.

The verified information is recorded on the blockchain and selectively shared with interested stakeholders such as the GI inspection body, the Intellectual Property Rights Department, consumers, and the Telangana State Seeds Development Corporation and Certification Authority. A unique QR code facilitates different levels of information access depending on the type of stakeholder. For example, the GI inspection body has access to more intricate details of the process and origin than a consumer accessing general information, such as batch number or variety, which aids in establishing the product’s authenticity.

Irrespective of the stakeholder category, information proving the authenticity of the GI tag is shared with all stakeholders. This solution addresses information asymmetry and equips consumers to access genuine information on the products they purchase. It also enables suppliers and producers to make decisions regarding batch recalls.

The solution’s architecture is private and displays information to the user through the Hyperledger explorer tool. It was developed using standard software and Hyperledger blockchain protocol standards.[24] The company indicated that blockchain standards are yet to be fully developed for this use case and the overall blockchain ecosystem.

Supply chain solutions by TraceX

TraceX is a blockchain-powered food traceability platform working towards building climate-resilient sustainable supply chains for the future. They have been developing a B2B SaaS[25] subscription for their blockchain-based supply chain technology. They develop supply chain solutions to meet the demand for safe food and solve the emerging climate crisis. The solutions extend to a decarbonisation platform that helps enterprises leverage nature-based solutions[26] to achieve climate action goals. Their solution is used across the food industry in India and internationally. In India, TraceX’s solution is being used by brands such as MilkMantra, Blue Tokai, Organic India, and ITC.

Blockchain’s role

TraceX used a private blockchain framework to build traceability and visibility in the food supply chain through decentralisation, immutability and distributed data sharing. To weave in these benefits, TraceX offers base solutions—TraceGro and TracePro—which solve traceability issues related to a food product's pre- and post-harvesting cycles. This process involves traceability throughout a product's lifecycle and enables tracking of food products’ movements from farm to fork.[27] The solution enables farmers to register themselves with a multilingual and offline application[28] through which their plots of farmland are geo-mapped.

Blockchain creates a common platform to connect all relevant stakeholders (farmers, processors, distributors, retailers, regulators and consumers) and monitor real-time growth, track harvest progress, and trace events through an interactive dashboard. The solution uses public and private keys to securely record product cycle data and allows stakeholder visibility of common data shared in the network.

As products move through the supply chain, transactions, including date, time, process type, etc., are recorded. This information is unalterable due to decentralised data sharing, which prevents data tampering and fraud. At the end of the life cycle of the supply chain, a QR code is generated to showcase the product's journey to consumers. Where companies already employ other software solutions for a part of their supply chain process, components of TraceX's solution can work independently on functions that are not supported. For example, where digitisation may be complete but no traceability solution is deployed. TraceX provides additional solutions such as TraceCo2 and TraceAPI, which can be used with TraceGro and TracePro, depending on client requirements.

This solution was developed on Hyperledger Fabric and uses Mean Stack[29] for its web applications and leverages different components of Amazon Web Services. TraceX is incorporating data analytics and other technologies, such as IoT, as part of its traceability solutions.

VaccineLedger by StaTwig

StaTwig is a blockchain-powered platform that optimises aid distribution and tracking, bringing transparency, efficiency, and accountability to humanitarian operations. In 2019, funding from UNICEF's innovation fund enabled the company to develop VaccineLedger, based on an existing solution that they had piloted in Andhra Pradesh as part of the Smart Village Initiative (by the University of California, Berkeley) and subsequently deployed in other areas such as Telangana, Arunachal Pradesh and Manipur. The company focused on resolving vaccine supply chain-related issues in light of the COVID-19 pandemic.

Having worked with UNICEF and received support from Gavi Infuse[30] for supplying vaccines in developing and under-developed countries, StaTwig is uniquely placed to build this solution. Currently, VaccineLedger is being used in many countries, including Costa Rica and Argentina and has been recognised as a digital public good[31] by the Digital Public Alliance and as a winner in the Trinity Challenge.

Blockchain's role

StaTwig used a blockchain-based supply chain to tackle quality issues, vaccine wastage and counterfeiting. India is positioned as one of the world's largest vaccine manufacturers.[32] Vaccine wastage due to cold chain failure is a continuing challenge that needs attention.[33] To solve this problem, StaTwig created VaccineLedger, which builds visibility of the status of products at all points of the supply chain. Through increased transparency, vaccine manufacturers and suppliers can identify and rectify failure points before vaccine wastage occurs. VaccineLedger acts not only as a traceability solution in the supply chain but also as a solution for proof of vaccine authenticity.

In crafting this solution, the company adopted a product-centric approach to traceability. Each vial is assigned a unique ID that helps record data related to logistics on the blockchain, such as shipping to the airport and customs clearance. Other factors, such as location and temperature, are also recorded through a blockchain-linked web or mobile app. Once recorded on the shared ledger, data cannot be altered and is accessible to all relevant stakeholders.

This blockchain solution is based on a hybrid model giving varied levels of visibility to different stakeholders. It allows individual users to access general information on the vaccine to verify its authenticity and quality. Other stakeholders, such as the manufacturer or government officials, have access to more kinds of information, such as real-time information on the vials' location and temperature.

The data inputted on the status of the vaccines may be done manually by stakeholders or through technologies such as IoT. Smart contracts also play a key role in automating information processing and commencing the next steps in the cycle. The real-time data on the vials' status ensures the cold chain is well maintained.[34] For instance, when information on the cold chain failure point is obtained, emergency reinforcement measures are initiated to prevent depletion in vaccine potency.

The solution was developed using software standards such as WaSP, HTML, CSS, ECMAScript, JSON and REST.[35] For the asset tracking aspect of the solution, GS1 standards are used. The company highlighted the deficiency of adequate blockchain standards and discussed the need for standards for interoperability in blockchain technology. StaTwig is part of various IEEE working groups, including one on blockchain for agriculture.[36]

Australia case study

The provenance of national goods and services has become a global concern for government authorities due to economic impacts, consumer health and safety, and supply chain integrity.[37]

The Australian Government has recognised the significance of traceability in the agricultural sector and is investing over $100 million in agricultural traceability systems.[38] These investments aim to strengthen existing frameworks for food safety, provenance and biosecurity. The government's focus on traceability aligns with the goal of demonstrating product safety, cleanliness and sustainability.

The Australian Agricultural Traceability Alliance was formed to accelerate the agricultural sector's growth to exceed $100 billion in output by 2030. Through this alliance, a draft 10-year National Agricultural Traceability Strategy has been developed by the Federal Department of Agriculture, Fisheries and Forestry. By implementing the strategy, Australia aims to establish a sustainable and enduring approach to national agricultural traceability.[39]

In the context of arts and crafts production, fraudulent goods dilute the economic benefits to communities and undermine aspects of cultural significance. [40]

The growth of Aboriginal and Torres Strait Islander arts and crafts markets has economically empowered artists and communities. In 2019–2020 the sector generated approximately $250 million in sales, supporting around 19,000 individuals.[41]

The challenges

Provenance concerns

The Australian Government has expressed concerns for the provenance of Aboriginal and Torres Strait Islander arts and crafts. In 2021, the Productivity Commission undertook an inquiry into the value, nature, and structure of markets for Aboriginal and Torres Strait Islander arts and crafts and found that rising demand for Aboriginal and Torres Strait Islander art had also led to an increase in the production and sale of inauthentic visual arts and crafts. These products lack any connection to culture or community, are not created by Indigenous artists and lack licensing agreements.[42]

Preservation of cultural heritage

Aboriginal and Torres Strait Islander arts and crafts hold cultural and economic significance in Australia. These artistic practices have spanned thousands of years and contribute to the country's national identity. Today, Indigenous artists are increasingly recognised within the art world and the broader community, with three in four Australians considering them an essential part of the nation's culture.[43]

Lack of supply chain information

Guaranteeing the provenance of high-quality food can form the basis of market advantage, particularly by defining a premium market. This can drive the overall economic growth of the agricultural industry.[44] In the context of food production, pathogens, antibiotics and banned chemicals can expose customers to health risks. An increasingly globalised food supply chain has increased the risk of food fraud. The food industry's supply chain involves multiple intermediaries and processes from the moment the food is collected from its original source to when it arrives at a supermarket or restaurant. However, there is often an absence of transparent information regarding the product's origin and its journey through the supply chain.

The response

Increases traceability and privacy

Blockchain technology proponents say it is well-suited for traceability applications, particularly in supply chains. Blockchain technology could address issues such as counterfeiting and theft by creating digital tokens that are linked to physical items when they are made. These tokens enable the authentication of goods and allow history tracking from their origin to the final recipient. The decentralised nature of blockchain ensures that the information stored cannot be changed, instilling confidence in end users. The linear flow of goods in supply chains aligns with blockchain's capabilities, and the anonymity of transactions between participants helps maintain confidentiality.[45]

Key metrics

- Food fraud estimated costs are $2–3 billion in Australia.[46]
- Australia is investing over $100 million into Australia's agricultural traceability.[47]
- Over 80% of stock images depicting Aboriginal and Torres Strait Islander designs, styles, and motifs are inauthentic.[48]
- 2019–2020 spending on inauthentic Indigenous-style souvenir products totalled $41–54 million.[49]

Use cases

The use cases delve into three blockchain-based supply chain management applications in Australia: Indigilegder, wisecar and BeFAQT.

IndigiLedger

IndigiLedger is a blockchain-based platform aimed at securing and protecting the Indigenous Australian Tourism Souvenir Market. With a focus on providing certainty of legitimacy and authenticity of cultural work, IndigiLedger seeks to ensure that consumers can confidently purchase Indigenous Australian souvenirs knowing their origin and cultural significance.

Blockchain's role

According to written responses provided to researchers by IndigiLedger, blockchain technology emerged as the most suitable solution due to its immutability, transparency, and decentralised consensus features. IndigiLedger aims to establish an unalterable record of ownership, ensuring the legitimacy of Indigenous cultural products in the market.

IndigiLedger advised that during the initial development phase, the project used VeChain, a blockchain platform designed to streamline processes and information flows for complex supply chains. VeChain was chosen primarily due to its start-up incentive program that included a grant and other initiatives to support start-ups.

When IndigiLedger began developing its product, they were unaware of any comprehensive standards in the blockchain industry, so the project did not adhere to any specific international or technical standards. However, the team advised that their system aligns with the principles of the ERC721 standard, which governs the creation and management of unique, non-fungible assets on the Ethereum blockchain.[50]

wisecar

wisecar is a mobile app that helps you manage all your car-related documents, due dates, and expenses in one place. The app allows for the traceability of all car-related document management, ensuring the supply chain of the vehicle and its related documents.

Blockchain's role

According to an interview with researchers, wisecar uses blockchain technology to enhance security and create trust by facilitating information sharing between employees and their organisations for car-related expenses. Using blockchain technology in wisecar ensures transparency and traceability throughout the entire car-related document management process.

wisecar uses the Hyperledger Fabric framework hosted in its cloud.[51] Hyperledger Fabric was used as a framework as wisecar wanted a private blockchain network to ensure their network complied with Australian privacy regulations. A public network was not necessary for the product that they provided. The focus was on maintaining privacy and restricted access rather than a publicly accessible blockchain solution.

wisecar employees were not involved in standards development.

BeFAQT by UTS and Food Agility CRC

The Blockchain enabled Fish provenance and Quality Tracking (BeFAQT) system was designed by the University of Technology Sydney (UTS) to resolve fish supply chain challenges, including lack of fish origin and quality information within fish supply chains.

Blockchain's role

The system enables fishermen to secure the origin of the fish they catch and track the supply chain of it through IoT devices, while e-eye and e-nose technologies assess the freshness of the fish samples at a fish market. The blockchain-enabled app and online platform provides buyers with trusted and transparent data on provenance and quality.

Blockchain provides a provable way to demonstrate fish provenance and ensure the integrity of supply chain data. Blockchain allows fishermen to prove the catch's location and the cold chain's maintenance. It enables automated catch recording that reduces paperwork and improves real-time information sharing. The transparent and immutable nature of blockchain enhances trust among the buyers and stakeholders of the seafood industry.

The UTS research team advised that they decided to use Ethereum in the BeFAQT system development process. This use of Ethereum indicates that the system aligns with the Ethereum ecosystem and its technical standards.

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3

Theme 3: Resource management

Country	Stakeholder	Theme	Size	Ownership	Type	Industry	Standards	TRL
India	Zebi	Land Records Management	Small	India	Start-up	Developer	BIP-0032	7
	Trential	Land Records Management	Small	India	Start-up	Developer	Hyperledger fabric, pBFT consensus algorithms	8
	Centre for Development of Advanced Computing	Land Records Management	Large	India	Government	IT R&D	N/A	7
Australia	Civic Ledger	Water Trading	Small	Australia	Research Services	Agriculture	ISO/TS 23635 Ethereum	7
	Botanical Water Exchange	Water Trading	Small	Australia/ UK	Innovator	Agriculture	Hyperledger Fabric	9

Table 4: Summary of resource management for land and water use cases

India case study

India struggles with a complex and inefficient land records system.[1] Land matters (including procedures and processes related to registration, revenue, and geographical mapping) are determined independently by each of the 28 states. The current system primarily operates on the presumption of ownership, established through registering a sale deed that records transactions related to property transfer.[2] This approach does not provide conclusive land titles, leading to ambiguity and disputes.

Information related to land records is fragmented as several state authorities store records for different purposes. Lack of coordination between various state departments creates inconsistencies in documentation. To address these concerns, digitisation efforts were made at a national level to move away from paper records post-2008. Schemes like the Digital India Land Records Modernization Programme were introduced to modernise and update the land records system by digitising all records, maps, textual and spatial data. However, owing to a myriad of challenges—such as a lack of adequate historical records, state capacity constraints, and a multiplicity of actors—the scheme has not made significant progress.[3]

On average, it takes around 20 years to resolve land disputes.[4] These long-standing disputes burden the courts and adversely affect sectors and individuals that rely on the property economically or socially. Literature highlights that security of land ownership rights can allow for more streamlined access to formal credit, and facilitate efficient distribution of economic opportunity.[5] One way forward is to use technological interventions such as blockchain, where necessary and appropriate, to address existing issues related to fragmented record keeping, involvement of numerous actors, and lack of transparency.

The challenges

Siloed government departments

Record keeping varies within and across different state departments and is often not harmonised, causing the system to operate in a largely fractured manner. For example, the Revenue Department manages Records of Rights and taxation records. Land title registration records are administered by the Department of Stamps and Registration[6] , and land surveys are maintained by the Survey Department. This is compounded by governance at different levels (village, circle, and taluk levels) each adopting documentation processes.[7]

Poor record management and incomplete digitisation

The disharmony between a multiplicity of actors can lead to unsystematic maintenance or sharing of information. As a result, property documents are often plagued by discrepancies and ambiguity of property details. This can result in conflicting records affecting ownership authentication.[8] The existing system is further complicated due to disparate levels of digitisation adoption, making it difficult to verify information accurately.

Risks and harms of the existing system

Individuals are burdened with having to verify information maintained by various state departments.[9] This can be particularly difficult for individuals from lower socio-economic strata having poor literacy levels and no access to resources to support them. Lack of clear ownership over land risks any long-term opportunity to generate legal and stable income from it. This may jeopardise access to formal credit from financial institutions. Minimal control and transparency also exposes the system to unchecked corruption without an accompanying accountability mechanism.[10]

The response

There is a pressing need to develop a system for conclusive land titles and a clear digitalisation strategy. Technological interventions such as blockchain could help address some concerns such as double registration, use of inauthentic documentation, and fraudulent and corrupt transactions.

Establishing a single source of truth

Blockchain can be tailored to only allow information sharing between the relevant entities or authorities and presents a singular version of information recorded. Any changes to these records appear in real-time as a separate entry to update existing records.[11]

Maintaining accuracy and immutability

Blockchain records are digitally signed with a unique fingerprint and time-stamped to create a tamper-proof trail of information relating to a plot of land.[12] As changes to records are visible to all entities, no property record can be retrospectively altered or deleted. This can ensure greater visibility, accuracy, and security of documents and could potentially reduce the creation of fraudulent records.

Ensuring authenticity of records, transparency, and privacy

Permissioned blockchains allow for varied levels of access. Only authorised entities can alter information, ensuring that actions are attributable to maintain authenticity and accountability.[13] A single source of truth and digital fingerprints/traceability can help maintain transparency and create trustworthiness. Authentication on the blockchain uses cryptography, ensuring a user's identity is verifiable to allow privacy and security.[14]

Disintermediation

Permissioned blockchains ensure only the relevant stakeholders/authorities are involved in property transactions on the blockchain. Through this, intermediaries can be eliminated, which can help reduce arbitrariness and corruption in processes.[15]

Key metrics

- In 2019, 66% of all civil cases were land or property related.[16]
- Conflict over 2.5 million hectares of land impacts investments worth $200 billion.[17]
- 31.78% of land conflicts relate to a lack of legal protection of land rights.[18]

Use cases

The case study further delves into three applications of blockchain used for land records management - Zebi Chain by Zebi, Kaveri Blockchain by Trential, and Property Registration Management System by Centre for Development of Advanced Computing, Hyderabad.

Zebi Chain by Zebi

Zebi is a full-stack core-blockchain company that has developed a public and enterprise-grade private blockchain for liability and productivity management, fraud deterrence and remote work management. Zebi developed a nationally acclaimed blockchain solution (Skoch and Digital India awards) for the Andhra Pradesh Capital Regional Development Authority (APCRDA) to create a tamper-proof land registry.[19] Andhra Pradesh (AP) is the first state in India to use blockchain-enabled security for land records in its capital Amravati.[20] Notably, the blockchain solution consolidated greenfield land through a land pooling scheme.[21]

Blockchain's role

This blockchain solution employed a hybrid architecture integrating public and private blockchain to create visibility and transparency for public users. It provides the relevant government departments or nodes, access to view, input and modify land records, such as: adding parties or properties, merging or updating properties, and requesting current owner details or property history. The system ensures these functions are carried out only by authorised government departments or nodes, including the registration, revenue, municipal, survey, and forest departments.

The APCRDA database was used to input existing data held by government departments into the blockchain. The blockchain solution accommodates about 58 attributes that include static features such as property ID, geo-coordinates, survey number, and dynamic (changing) features such as owner ID, subdivided property ID, and litigation status. All events related to the property are chronicled, including mutation of property, filing of a court case on a property, death of an owner, and building construction approvals. Zebi used smart contracts and created a range of APIs[22] that facilitate reading and writing data on the blockchain. The system allows authorised nodes to search for specific data (attributes and records) as required.

Through the public blockchain, users can view property records displaying relevant information related to a parcel of land stored on the private blockchain. Information is also displayed as a blockchain certificate and includes a QR Code. When scanned, this code provides all information related to the property at that given time. The information presented to the user also includes Geographic Information System coordinates, including parcel images (parcel, block, and colony location maps) and longitude and latitude coordinates.

The solution uses existing software standards, including cryptography and BIP-0032 to generate public-private key pairs. The company also highlighted that standards that gain popularity often emerge from the software development community.

Kaveri Blockchain by Trential

Trential, previously known as CRUBN, was founded by a team of researchers and engineers at IIT Kanpur in India. In 2018, National Security Council launched its flagship National Blockchain Project in collaboration with IIT Kanpur.[23] With the project nearing completion in 2023, Trential emerged to build innovative products across healthcare, education, governance, and financial services and has collaborated with several state governments.

The company developed and implemented a blockchain-based solution called 'KAVERI Blockchain' for the Centre for e-Governance (Karnataka)[24] to digitise and verify land records in Karnataka. They also implemented the solution with Karnataka's Centre for Smart Governance and the Centre for Development of Advanced Computing (C-DAC). Trential successfully deployed blockchain-based land records in six districts' sub-registrar's offices in Karnataka[25] , with approximately 15,000 records stored on the blockchain.

Blockchain's role

Trential relied on blockchain to create an auditable trail of property records secured with irrefutable identity proof built through stakeholder consent. This solution specifically focused on agricultural land in Karnataka. The solution was integrated into C-DAC's land registration system 'KAVERI' to record property transactions on the blockchain. The solution ensures that the parties' consent is immutably stored to record any changes to rights, titles and interests of a property, and ownership verification through smart contracts. The system was integrated with UIDAI for Aadhaar KYC and Aadhaar eSign services to ensure parties' identities. It supports 50 types of property transactions, including transfer, partial transfer and exchange of ownership, cancellation of transfer, partition or rights, recording of encumbrance, and record correction.

A public-permissioned blockchain was used to ensure relevant authorities have access to the system, such as IIT-Kanpur, the Centre for e-Governance, the Department of Revenue and the Ministry of Finance in Karnataka. Before rolling out, the solution was audited by Standardisation Testing and Quality Certification. This framework gives the public access to read data stored on the blockchain. The identities of parties of the transaction are verified through Aadhaar biometric sensors (iris and fingerprint) authentication. As part of the blockchain solution, the project introduced a digital wallet system that functions through a smartcard and a key to store property records.[26] Individual property owners are given a smartcard with a signature to validate blockchain records and a key to secure these details. The card is used with a 4-digit pin and has recovery processes if the pin is lost or forgotten. The card and key can be accessed at a local sub-registrar office kiosk and verified against details stored in the KAVERI database through an e-KYC process using Aadhaar biometrics.[27] The corresponding property transactions are stored on the blockchain post-verification. Through this card, the solution aims to empower property owners with a secure mechanism to transact and reduce future cases of rejection. To carry out transactions, both the purchaser and seller can access records at the kiosk to verify the property's authenticity. Simultaneously, the sub-registrar corroborates the information and registers the sale through a master key. During the testing phase, this project reportedly issued 781 smartcards.[28]

This blockchain solution uses Hyperledger Fabric[29] with Practical Byzantine Fault-Tolerant (pBFT) consensus algorithms and existing software standards related to the solution's components. The company observed that there are currently no set national or international standards for land records management and many other use cases. To introduce global standards for a use case, it must evolve to an extent that allows for the framing of standards.

Property Registration Management System by Centre for Development of Advanced Computing (C-DAC), Hyderabad C-DAC is the premier organisation of the Ministry of Electronics and Information Technology (MeitY) for research and development in information technology, electronics and associated areas.[30] It established its Hyderabad centre in 1999 to conduct research and development (R&D) and training, and to operate as a knowledge centre to strengthen its work areas.[31] The centre's R&D focuses on high-performance computing and quantum computing, strategic electronics, cyber security and software technologies.

C-DAC, Hyderabad designed and developed a blockchain-based Property Records Management System (PRMS) with the support of the Telangana state departments of Information Technology, Electronics and Communications, Stamps and Registration, and the National Informatics Centre. In 2018, C-DAC piloted the solution in the Shamshabad district of Telangana that can be scaled to the entire State. The solution received a Skoch Governance Gold award[32] and has been published as a global use case in ISO/TC307 Blockchain and Distributed Ledger Technologies standards.[33]

Blockchain's role

C-DAC developed PRMS using blockchain to establish a secure database with immutable records to ensure transparency across departments, citizens' trust in government, and protect owners' rights. The solution was designed to provide ownership provenance and address existing issues such as duplicated property sales and fake registrations. The Sub-Registrar Office and Revenue, Survey and Settlement departments were authorised to access and use the system. Other departments could also use the system to obtain tamper-proof registration data.

PRMS was integrated with Telangana's property registration system—'CARD'—to input data onto the blockchain. Registration data from 2008–2018 was inputted onto the blockchain. The registration process involved two phases: check slip generation, and final document number generation. Check slip generation took place at the time of registration, where necessary checks related to taxation and payment were conducted to create an internal report called a check slip report. The solution then pulls near real-time data of check slips and regular document transactions and appends it to the blockchain.

The check slip record verifies the property's current owner details with the blockchain ledger and notifies the Sub-Registrar's Office of any mismatch. It also provides a reliable encumbrance certificate search without any manual intervention. The solution is designed to store the unique fingerprint of the final registered document on the blockchain to curb fake registrations.

C-DAC observed that blockchain standards for this use case are yet to be developed. They emphasised that since blockchain primarily operates for data storage, there is a need for data-related standards such as data privacy and data preservation. They highlighted that organisations such as the International Organization for Standardization and the Bureau of Indian Standards are contemplating these subjects' standards.[34]

Australia case study

The World Economic Forum has identified water as among the 20 emerging markets that will transform economies and drive growth and sustainability in the coming decades.[35] Water scarcity is increasing globally, causing challenges for cities and regional agriculture.[36] Scarcity increases competition for water resources both domestically and internationally.

The challenges

Fragmented regulation, complicated rules, lack of transparency, and lack of trust

Water trading is a potential solution to scarcity, as it can contribute to water use efficiency.[37] Within water trading markets, a range of water entitlements and allocations can be bought and sold to achieve allocative and productive efficiencies.[38] However, in many jurisdictions, water trading is challenged by fragmented regulation, complicated rules, lack of transparency, and lack of trust.

Murray-Darling Basin

Much of Australia's water trading is centred on the Murray Darling Basin (MBD), a large geographic area in south-east Australia, which crosses five state and territory jurisdictions that each enact their own process and rules for allocating water. The MDB water market is complex and influenced by various factors, including weather, commodity markets, and water policy.[39] Price differs across jurisdictions, over time, and according to the details of specific entitlements. There are more than 150 classes of water entitlement in the MDB, with irrigation infrastructure operators creating and maintaining trading rules within their jurisdiction.[40]

The response

Increases transparency and trust

Proponents of blockchain technology solutions in water markets argue that it would enable water markets to become transparent, trusted, automated, verifiable, and accountable. Smart contracts could capture the metadata around water licences, ownership, and allocation, then automate licence tracking, trades, and transactions.

Establishes an immutable register of transactions

A blockchain water market could provide a publicly accessible, immutable register of all trades; a peer-to-peer marketplace integrated with existing systems of record, and a curated information supply chain that assures smart contracts that automate (to the greatest degree possible) trade activity.[41]

Improves efficiency

Proponents of this solution say it can drive greater efficiencies in the system, reducing the time it takes to complete a trade and improving general understanding of water quality and flow.[42]

Key metrics

- Water markets in Australia had an estimated turnover of $6 billion in 2020–21.[43]
- One-third of Australia's water trading occurs in the Murray Darling Basin,[44] responsible for 40% of Australia's agricultural production.[45]
- Irrigated crops make up about 30% of the value of Australia's agricultural production,[46] delivering $3–4.3 billion to annual GDP.[47]
- MDB attracts visitors worldwide, with tourism earning around $11 billion each year.[48]

Use cases

The use cases delve into two blockchain-based resource management solutions applications in Australia: Water Ledger by Civic Ledger, and Botanical Water Exchange.

Water Ledger by Civic Ledger

Water Ledger is a pilot blockchain-based platform developed by an Australian-based company, Civic Ledger, that automates issuing water entitlements and allocations.

Blockchain's role

In an interview, Civic Ledger advised the company chose to work with blockchain technology for the Water Ledger project because their owners recognised that blockchain technologies may meet five key requirements for water markets that were inefficient in Australian water markets: price discoverability, ownership, audited history, liquidity, and authority.

Civic Ledger advised that it used the Ethereum technical standards and deployed them through the Hedera distributed network.[49]

Civic Ledger also referred to international standards when developing the Water Ledger platform. They referenced the ISO Standard, ISO/TS 23635: Blockchain and Distributed Ledger Technologies: Guidelines for Governance.[50]

Civic Ledger employees are directly involved with standards-development bodies and worked closely on the ISO/TC 307: Blockchain and Distributed Ledger Technologies standard.

Botanical Water Exchange by Botanical Water Technologies and Fujitsu

Botanical Water Technologies (BWT) uses its technology to harvest and purify water for food production. To ensure secure water trading, BWT collaborated with Fujitsu to develop a blockchain platform.

Blockchain's role

The BWT website advises that the company chose to work with blockchain technology, specifically Fujitsu's Track and Trust, because they needed a system to track and certify water production. Blockchain's decentralised ledger provided a solution. Unlike a traditional database, blockchain ensures data consistency and trust, removing operational frictions. Water source certifications and transactions become easier and less susceptible to manipulation.

By leveraging blockchain, the BWT claims it saves money on auditing, reduces costs, minimises intermediaries, and enhances trust in the system.

Fujitsu's blockchain solution, Track and Trust, uses Hyperledger Fabric. While Hyperledger Fabric provides a default Certificate Authority service for Public Key Infrastructure management, Botanical Water Technologies implements an Azure Key Vault-based solution.

Azure Key Vault ensures the security of secrets and keys by employing industry standards, algorithms, key lengths, and hardware security modules (HSMs) – specifically FIPS 140-2 Level 2 validated HSMs. The Ingress Controller, which operates within the customer's Azure Kubernetes Service, runs in its dedicated pod, and is supported exclusively by Standard_v2 and WAF_v2 SKUs.

Furthermore, the Fujitsu Track and Trust blockchain solution uses Azure-secured storage to store and trade company-related documents. Azure Storage automatically encrypts data using 256-bit AES encryption, one of the strongest block ciphers available and complies with the FIPS 140-2 standard. The AES standard is also defined in FIPS PUB 197: Advanced Encryption Standard and ISO/IEC 18033-3: Block ciphers.

The digital certificates used within this system adhere to the X.509 standard, containing a set of attributes associated with the certificate holder.

Based on publicly available knowledge, employees of BWT have not been involved in standards development. BWT has adopted a blockchain solution that adheres to internationally accredited standards rather than developing a new solution and engaging in standards directly.

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Conclusions and next steps

At a high level, the findings of this report highlight the varied understanding and adoption of blockchain technical standards. Further, the research revealed that the adoption of standards can be driven by:

1. practicality
2. government regulation
3. the specific nature of each Blockchain application.

Basis for adopting blockchain

In each case study, blockchain's immutability has been relied on to create and maintain accurate and tamper-proof records. All use cases highlighted that this helps provide transparency and aids in verifying authenticity. Blockchain was used to establish a single source of truth for multiple stakeholders and helps avoid fragmentation of information between participants in the relevant ecosystem.

Blockchain was used for similar purposes across different use cases in India and Australia. For example, findings show that blockchain was used to ensure ownership and control of data through use-centric digital identity systems. Similarly, a common objective was addressing concerns of counterfeiting and fraud in traditional supply chains through traceability. Whereas, for record management, blockchain is being used in both India and Australia to achieve the common goal of creating trust among varied stakeholders and increasing process efficiency.

The findings show that, for both stakeholders in India and Australia, blockchain was used in a privacy preserving manner to protect sensitive and/or personal information collected. Some stakeholders used a hybrid blockchain—a combination of private and public blockchain—to allow for selective information sharing to relevant participants, based on the nature of information and role of the participant. Other stakeholders took a flexible approach in using blockchain for information collection to ensure only specific information requiring immutability was stored on the blockchain, and other data was maintained off-chain.

Awareness of standards

Most stakeholders are aware of certain major standards bodies in the blockchain ecosystem, and in certain cases, existing technical standards and similar frameworks relating to blockchain. However, many stakeholders do not currently participate in standards-making processes, primarily due to the perceived lack of commercial and/or organisational incentives. Some also highlighted the lengthy nature of such processes, especially at SDOs. These findings are consistent with those of the first report.

Adoption of standards

Rationale for the use of *de jure* Standards

The findings show that the sector may influence attitudes towards standards adoption the organisation is working in. Adoption of *de jure* standards (those developed through a formal process) are driven by mandates and incentives by state agencies, through legal or contractual terms or due to client requirements.

Across the case studies, only a few adopted formal standards. The reasons given were:

- existing standards were redundant or irrelevant to their specific context
- there was a lack of awareness
- standards did not suit the objectives of their solutions
- standards were under development.

For example, while standards relating to privacy and data management existed in recent years, many technical solutions to meet or exceed the standards had already been developed (either before the introduction of the standards or during their development).

The findings show that a culture that promotes the uptake of *de jure* standards through government regulations and requirements plays an important role in driving the adoption of specific standards. Stakeholders involved in standards development are more likely to implement these standards within their own products.

In the Indian context, to progress meaningful and active participation with SDOs, stakeholders advised that participants adopt a meticulous, collaborative, and constructive approach. This would require, *inter alia,* thoroughly understanding the scope and the prior work of the relevant ISO committee, identifying points of convergence and divergence with other participants, and providing solution-oriented inputs.[1]

In the Australian context, use cases more regulated by the government, such as healthcare, water trading, and government-issued digital identity credentials, show that stakeholders operating in sectors that are more closely regulated by the government, or provide government services, also show a greater likelihood of engaging with SDO working groups. This could be due to the necessity of ensuring regulation compliance in the sector. For example, Civic Ledger is an Australian company that offers services to citizens, industries, and governments. Within the water market industry in Australia, they have developed Water Ledger, a product that uses blockchain technology to facilitate water trading. Given that the water market industry is tightly regulated, engaging in SDO working groups is important for ensuring compliance with formally accredited standards.

Rationale for the use of *de facto* standards

The case studies show that adopting *de facto* standards, predominantly created by industry groups, communities and initiatives, may be driven by the accessibility and availability of OSS. Some stakeholders highlighted the benefit of adopting software and standards by OSS communities, due to their quick support for resolving issues such as security.

Most use cases were engaged on some level with, or had adopted, *de facto* standards established by OSS communities. Examples of OSS community standards in the blockchain ecosystem include: Hyperledger Fabric and Indy, W3C's Decentralised Identifiers (DIDs) v1.0, Ethereum's ERC-20, and Tezos' TZIP-7: Fungible Asset (FA1:2).

The choice of technology and technical standards in the case studies were highly pragmatic. Use cases in India and Australia favoured standards aligned with their existing systems, software infrastructure, the objectives of their solutions, and local context. For example, some stakeholders tailored their solutions and conceptualised new frameworks to ensure the inclusivity of diverse stakeholder needs. Compatibility and seamless integration were key factors in selecting standards. Examples include the use of BIP-0032 by an Indian stakeholder and the adoption of Hyperledger Fabric by many Indian and Australian stakeholders due to its alignment with their development needs.

Role of standards-development organisations and industry groups, communities and initiatives

SDOs, industry groups, communities and initiatives play an important role in the blockchain industry. SDOs provide stability and broad-based quality assurance due to their consensus-based protocols involving the participation of as many as 168 national bodies at present.[2] On the other hand, industry groups, communities and initiatives, due to their flexible governance structures and proximity to an industry, are more suitably placed to gauge and respond to the evolution of technology. Accordingly, they develop standards, implementations and frameworks that respond to the market's needs and aim to achieve interoperability.

Industry groups, communities and initiatives also offer the advantages of lower costs for research and development, shorter periods for standards development and lower costs of adoption; these advantages are particularly relevant for small and medium enterprises in the ecosystem. Findings from the first report indicate that the blockchain ecosystem consists of many MSMEs. Use cases show that cost is a critical factor in choosing and adopting standards for MSMEs. Consequently, industry groups, communities and initiatives are generally perceived as more attractive for building more accessible, efficient and effective standards, particularly by such enterprises.

While SDOs and industry groups, communities, and initiatives can complement each other in certain aspects, they also compete for relevance. Collaboration between SDOs and industry groups, communities, and initiatives is often hindered by their differences in governance structures and mechanisms for direct participation.

In the standards ecosystem SDOs, industry groups, communities, and initiatives should play complementary roles. Use cases show that SDOs provide the standards needed for compliance in regulated sectors and at scale, while industry groups, communities, and initiatives such as OSS communities provide the standards to get things off the ground and keep pace with a rapidly evolving technology.

Next steps

The research findings highlight that engagement in *de jure* and *de facto* standards organisations, and collaboration between them, are essential to fostering a thriving blockchain ecosystem. Incentives, governance structures and participation mechanisms are all essential foundations, and will be the focus of Phase Three of this research.

Learnings from Phases One and Two provide the foundation for the project's third and final phase. Phase Three will examine interactions between standards development and adoption and the use and efficacy of standards. The third phase intends to identify existing gaps to frame recommendations that help build a multistakeholder community and enhance their engagement with standard making at the international level.

For further information, or to participate in Phase Three, please contact: ccg@nludelhi.ac.in or techpolicydesign@anu.edu.au.

Annex A: Standards Development Bodies for Blockchain

This Annex presents an overview of significant standards development bodies and those set out in the Overview of the Standards Landscape.

* Standards-development bodies marked with an Asterisk (*) were repetitively identified in numerous stakeholder consultations as key contributors to developing blockchain-related standards. Others listed were identified through secondary research.

Major international standards-setting bodies

Globally, three main international standard-development organisations drive the adoption of blockchain-related standards. These include: the International Organisation for Standardisation (ISO), the International Telecommunication Union (ITU), and the Institute of Electrical and Electronics Engineers Standards Association (IEEE).

A. International Organisation for Standardisation (ISO)*

The ISO is a non-governmental organisation that develops voluntary, consensus-based standards for global adoption.[3] It established the Technical Committee 307 (ISO/TC 307) for blockchain and distributed ledger technologies in 2016. ISO/TC 307 currently comprises 44 participating members, i.e., national standards bodies and 20 observing members, with Standards Australia (the organisation representing Australia at the ISO) serving as the secretariat. Currently, it has 13 working groups, including advisory groups, working on specific remits. Since its inception, ISO/TC 307 has published 11 standards covering various topics, including vocabulary, reference architecture, privacy considerations, and governance guidelines. Five more standards are currently under development.[4]

As part of its standards development mandate, ISO also advances research on new areas or technology for standardisation by facilitating information sharing among its community through Technical Reports.[5] Unlike outputs related to technical standards that outline specific rules, guidelines, conditions or requirements formed that are based on consensus and a public consultation process, Technical Reports are initial working drafts that may lead to the development of a standard but may not be a part of the final standards output. Essentially, they enable the circulation of information to guide future standardisation[6] by providing information to stakeholders regarding technical research, findings of surveys, and other state-of-the-art developments on standards on a certain subject.

B. International Telecommunications Union Telecommunication Standardization Sector (ITU-T)*

The ITU-T, a division of the International Telecommunication Union, develops international standards for ICTs, termed ITU-T Recommendations, in collaboration with other standards-development bodies like ISO and IEEE-SA.[7] Its membership comprises nation-states and private-sector enterprises, although only states have voting rights.[8] The Focus Group on Application of Distributed Ledger Technology (FG DLT) was created in 2017 to analyse DLT-based applications and services. It submitted Technical Specifications and Reports covering definitions, reference architecture, and use cases in 2019.[9] The ITU-T has since continued its work on DLT and blockchain, with four ITU-T Recommendations relating to the subject published in May 2023.[10]

C. Institute of Electrical and Electronics Engineers Standards Association (IEEE SA)*

Under the IEEE, the IEEE-SA focuses on sector-driven standards development without the formal representation of government stakeholders. It has a dedicated IEEE Blockchain Initiative and the IEEE Blockchain Technical Community to facilitate standards development. Thirteen blockchain-related standards have been published, covering cryptocurrency exchanges, IoT data management, e-contracts, and supply chain finance. Additionally, over 50 other blockchain-related standards are under development.[11] Generally, standards development at IEEE-SA is primarily driven by industry and technology experts, who are considered more efficient in formulating standards.

In contrast, ISO frames standards through a democratic process, with each member country represented by one member having one vote. However, ISO also draws inputs from a wide range of stakeholders, including technical experts and representatives from industry, academia, lawyers, and civil society through the national standard bodies and therefore has lengthy processes. Often in areas of common interest, the IEEE enters into collaborative arrangements with the ISO to co-develop standards through joint working groups.

Regional and national standards-development organisations

Australia and India are members of the ISO and are represented by their respective national standards organisations; Standards Australia, and the Bureau of Indian Standards (BIS). Besides these, it is important to consider the influence of other major national and regional SDOs from jurisdictions like Europe and the USA. These institutions, such as the European Telecommunications Standards Institute (ETSI), the European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardisation (CENELEC), StandICT, the National Institute of Standards and Technology (NIST), and the American National Standards Institute (ANSI), can shape the standards landscape in other jurisdictions as well. Regional bodies have been covered in Annex A.

A. Bureau of Indian Standards (BIS)*

BIS is an autonomous body set up by the Ministry of Consumer Affairs, Food and Public Distribution under the BIS Act, 2016 (which came into effect in October 2017) for harmonious standards development in India. The Minister-in-charge acts as the BIS' ex-officio President. As the national standards body, BIS represents India at the ISO and participates in ISO technical committees through its national mirror committees. It follows the Code of Good Practice for the Preparation, Adoption, and Application of Standards under the World Trade Organisation Technical Barriers to Trade Agreement.

The BIS has a Governing Council and an Executive Committee that oversee the development and implementation of standards. BIS set up a sectional committee for blockchain and distributed ledger technologies, LITD 29, in 2017, the national mirror committee for ISO TC/307.[12] To date, the LITD 29 has published two standards on blockchain vocabulary and privacy considerations. Five other blockchain-related standards, which the ISO has adopted, are presently under BIS' consideration as draft standards. Notably, blockchain has been recognised as a key area requiring standardisation in BIS' Standards National Action Plan 2022-27.[13]

In general, BIS develops indigenous standards, but for emerging technologies such as blockchain, it directly adopts international standards formulated at the international level by the ISO. The typical process of standard formulation at BIS and its stages is set out in Annex C.

B. Standards Australia (SA)*

Standards Australia is a non-governmental standards development body representing Australia at the ISO. It was incorporated in 1999, replacing the Standards Association of Australia, a body incorporated by Royal Charter in 1922.[14] SA's relationship with the Australian Government is governed by a Memorandum of Understanding executed in 2018.[15] The SA is headed by a Board of Directors, assisted by four committees in performing its duties. The Standards Development and Accreditation Committee, open to external members, is primarily responsible for developing Australian national standards within SA.[16]

At the international level, SA is the Secretariat for the ISO Technical Committee 307 (ISO/TC 307) for blockchain and distributed ledger technologies.

In formulating standards, like the BIS, the SA also follows the Code of Good Practice for the Preparation, Adoption, and Application of Standards. It has a mirror committee, IT-041, for blockchain and distributed ledger technologies. To date, the committee has published two standards on vocabulary and privacy considerations.[17]

C. National Institute of Standards and Technology (NIST)*

NIST, part of the US Department of Commerce, is responsible for developing and deploying standards. Their blockchain standardisation efforts began with the NISTIR 8202, providing an overview of blockchain technology. Recent focus areas include industrial applications, blockchain-based identity systems, and enhanced distributed ledger technologies.[18]

D. American National Standards Institute (ANSI)*

ANSI is a private, not-for-profit organisation coordinating the development of voluntary consensus-based standards in the USA. The Accredited Standards Committee X9 (ASC X9), an ANSI-accredited committee for financial services, approved the ANSI X9.138-2020 standard on distributed ledger technologies terminology. ASC X9 also published a technical report on the blockchain risk assessment framework.[19]

E. European Telecommunications Standards Institute (ETSI)

ETSI is an independent, non-profit organisation that develops globally applicable standards for information and communication technologies, including telecommunications, broadcasting, and related areas. Their prominent standards cover 5G, IoT, network security, and intelligent transport systems. ETSI has published two standards titled ‘blockchain’: ETSI GR IPE 012 V1.1.1 (2022-08): IPv6 Enhanced innovation (IPE); and IPv6-based Blockchain and ETSI GR IP6 031 V1.1.1 (2020-11): IPv6 Security, Cybersecurity, Blockchain.[20]

F. European Committee for Standardization (CEN)

CEN is the European Committee for Standardization, an association that unites the National Standardisation Bodies of 34 European countries. It is one of the three officially recognised European Standardization Organizations responsible for developing voluntary standards at the European level, alongside CENELEC and ETSI.[21]

G. European Committee for Electrotechnical Standardization (CENELEC)

CENELEC, the European Committee for Electrotechnical Standardization, is an association that brings together the National Electrotechnical Committees of 34 European countries. It is one of the officially recognised European Standardization Organizations responsible for developing voluntary standards at the European level, alongside CEN and ETSI. CENELEC focuses on preparing voluntary standards in the electrotechnical field, promoting trade, creating new markets, reducing compliance costs, and supporting the development of a Single European Market.[22]

H. China Electronic Standardization Institute (CESI)

CESI is a prominent standards organisation in China dedicated to standardising electronic technologies and industries. It operates under the administration of the Ministry of Industry and Information Technology (MIIT) of the People's Republic of China. Based on publicly available knowledge, CESI has published 13 blockchain standards.[23]

Industry groups, communities, and initiatives

Industry groups, communities and initiatives, including developer communities, play a crucial role in formulating standards alongside formal SDOs. Some notable industry groups and initiatives include:

A. World Wide Web Consortium (W3C)*

W3C is an international standards community focused on developing common standards for the World Wide Web. Notably, in 2016, it conducted a blockchain workshop and distributed ledgers for an early scoping of specific aspects that may require standardisation, focussing on non-financial use cases.[24] Specific standards and guidelines are currently being discussed within various W3C community groups, such as the Blockchain Community Group.[25]

B. Hyperledger Foundation*

Hyperledger Foundation is an open-source community established by the Linux Foundation to develop tools, frameworks, and libraries for enterprise-level use cases, proofs-of-concept and applications of blockchain. Hyperledger Fabric is one of their prominent frameworks, designed for scalable blockchain solutions across industries.[26]

C. Enterprise Ethereum Alliance (EEA) *

EEA is a collaboration of industry stakeholders aiming to promote the use of Ethereum blockchain technology in enterprise operations. It includes global enterprises, service providers, collectives, start-ups, and innovators. The EEA focuses on developing standards for using Ethereum's capabilities in enterprise-grade applications. Some of the most common token standards are ERC-20, ERC-721, ERC-777 and ERC-1155.[27]

D. R3 Corda

R3 Corda is an open-source blockchain platform for enterprises. It ensures secure and private transactions, allows for the automation of agreements through smart contracts, and is interactable with other existing systems for interoperability. It is predominantly used by the finance, supply chain, healthcare, and insurance industries. Corda is compatible with emerging standards such as ISO20022 and ISDA CDM.[28]

E. NEO

NEO is an open-source, community-driven platform founded in China in 2014. NEO is a blockchain platform that aims to digitalise assets and identities through smart contracts, with the goal of building a smart economy. NEO has established and joined several industry groups to establish standards.[29]

F. NEM (New Economy Movement)

NEM is an open-source blockchain platform and cryptocurrency that aims to create a new economic system. It offers Proof-of-Importance consensus, smart assets, and smart contracts. NEM has standards known as Technical Reference standards, which provide specifications and guidelines for developers. These standards ensure compatibility between NEM-based applications and tokens.[30]

G. Stellar

Stellar is an open-source network for fast, low-cost payments and asset issuance. Stellar is a decentralised network owned by the public, running on blockchain technology. Stellar conforms to several standards to ensure interoperability. The Stellar Development Foundation has established the Stellar Payment Protocol (SEP-0006), which provides a common format for payment requests and integration with wallets and exchanges. Stellar has also established the Stellar Asset Transfer Protocol (SEP-0012) for token creation and management.[31]

H. Tezos

Tezos is an open-source blockchain that enables peer-to-peer transactions and the deployment of smart contracts. It operates through proof-of-stake consensus and its cryptocurrency is called ‘tez’. Tezos has established a standardisation process called the Tezos Improvement Proposal (TZIP). TZIPs are proposals for improvements. A TZIP document suggests new features, tools, or standards to improve Tezos. Key TZIP standards include TZIP-7: Fungible Asset (FA1:2), and TZIP-10: Wallet Interaction and TZIP-12: Multi-Asset/NFT (FA2).[32]

I. Hedera

Hedera is a decentralised public ledger with a unique consensus algorithm. A council of organisations governs it and offers tools for developers to build real-time web3 applications.[33]

J. Organization for the Advancement of Structured Information Standards (OASIS)

OASIS is a non-profit consortium that develops and promotes open standards for exchanging information and interoperability across various industries and technologies. OASIS focuses on developing standards for web services, security, electronic publishing, cloud computing, and many other areas.[34]

K. The Internet Engineering Task Force (IETF)

The Internet Engineering Task Force (IETF) is an open standards organisation responsible for developing voluntary standards for internet users, network operators, and equipment vendors. The IETF operates based on open processes, allowing anyone to participate and contribute to its work. The IETF publishes its technical documentation as Requests for Comments, which are freely available and cover various aspects of internet standards.[35]

L. The InterWork Alliance (IWA)

The InterWork Alliance (IWA) is a non-profit organisation that simplifies digital value exchange and facilitates collaboration among businesses. They develop standards for using digital tokens to represent different types of assets, including physical, digital, and conceptual ones. These standards can be applied to various technologies, including blockchain.[36]

M. The Blockchain in Transport Alliance (BiTA)

BiTA is an organisation that brings together companies to develop open-source and royalty-free data standards for the global supply chain. BiTA aims to promote interoperability among participants in the supply chain by leveraging talent and resources from its members. Its vision is to provide open-source standards that empower blockchain-enabled global commerce, and its mission is to produce, publish, and certify these standards as a global community.[37]

N. The Blockchain Game Alliance (BGA)

BGA is dedicated to promoting blockchain in the game industry and establishing industry standards. They raise awareness, drive adoption, and foster collaboration to develop common standards and best practices for integrating blockchain technologies in games. They emphasise the importance of standards and interoperability to facilitate widespread adoption and knowledge sharing, ensuring blockchain technology's overall success across different industry companies and structures.[38]

O. Global Digital Finance (GDF)

Global Digital Finance (GDF), now known as GBBC Digital Finance, is the largest industry association for blockchain technology and digital assets. GDF collaborates with industry leaders to develop market standards, best practices, and governance standards for using cryptocurrencies and digital assets. Their mission is to promote the adoption of these standards through engagement with industry, policymakers and regulators.[39]

P. The International Token Standardization Association (ITSA)

ITSA establishes market standards for blockchain and DLT-based tokens. They address the challenge of identifying and classifying tokens in the growing fields of DeFi, NFTs, and cross-chain operations. They have published two main blockchain standards: The International Token Identification Number (ITIN) for safe identification of tokens in DeFi and NFTs; and The International Token Classification (ITC) for classifying tokens based on different dimensions.[40]

Q. International Association for Trusted Blockchain Applications (INATBA)

INATBA is a global forum for DLT developers and users to interact with regulators and policymakers. INATBA has a standards committee that is engaging with blockchain standards. It has a Liaison Category A in ISO TC307 and ITU-T.[41]

R. The Industry IoT Consortium (IIC)

The IOC comprises over 90 companies and is dedicated to advancing the adoption of a reliable and secure IoT ecosystem. The IOC has published standards on the use of blockchain in Industrial IoT projects.[42]

S. Mobility Open Blockchain Initiative (MOBI)

MOBI is a global non-profit consortium focused on smart mobility and creating identification standards. Their Supply Chain working group evaluates blockchain benefits in supply chain management. They develop interoperability standards for operational efficiency, visibility, provenance, tracking, and authenticity of parts and vehicles.[43]

T. BlockStand

BlockStand is an EU-funded consortium to strengthen European leadership in global blockchain standardisation. It was launched on 18 May 2023 with four founding EU consortium partners. It supports the participation of European experts in blockchain standardisation activities and ensures that internationally used standards reflect European values. BlockStand creates a web-based platform for resources on blockchain standardisation, offers funding for experts' involvement, and establishes an online community to support implementation and collaboration in the blockchain field.

Annex B: Mapping of Technical Standards

Annex B presents a preliminary list of blockchain-related technical standards, technical recommendations, technical reports, and other relevant outputs published by the select major international and national SDOs described in the Overview of the Standards Landscape. This list will form the basis of consultation in Phase Three of this research and will be updated and revised in the final report.

S. No.	Entity	Relevant committee/ working group/ focus group/ study group (if any)	Relevant outputs (standards/ technical recommendations/ technical specifications/ technical reports)
1.	**International Organization for Standardization**	**Technical Committee 307 (ISO/TC 307) – Blockchain and distributed ledger technologies** **Working groups** 1. AG 1 Strategic Business Plan Advisory Group 2. AG 2 Liaison Advisory Group 3. AG 3 Digital currencies, 4. AHG 2 Guidance for Auditing DLT Systems 5. AHG 3 Representation of physical assets as non-fungible tokens (NFT) 6. AHG 4 DLT and carbon markets 7. CAG 1 Convenors coordination group 8. JWG 4 Joint ISO/TC 307 – ISO/IEC JTC 1/SC 27 WG: Security, privacy and identity for Blockchain and DLT 9. WG 1 Foundations 10. WG 3 Smart contracts and their applications 11. WG 5 Governance 12. WG 6 Use cases 13. WG 7 Interoperability	**Standards by Technical Committee 307**[44] 1. Vocabulary: ISO 22739:2020 2. Reference architecture: ISO 23257:2022 3. Privacy and personally identifiable information protection considerations: ISO/TR 23244:2020 4. Taxonomy and ontology: ISO/TS 23258:2021 5. Security management of digital asset custodians: ISO/TR 23576:2020 6. Guidelines for governance: ISO/TS 23635:2022 7. Overview of existing DLT systems for identity management: ISO/TR 23249:2022 8. Overview of interactions between smart contracts in blockchain and DLT systems: ISO/TR 23455:2019 9. Use cases: ISO/TR 3242:2022 10. Overview of trust anchors for DLT-based identity management: ISO/TR 23644:2023 11. Identifiers of subjects and objects for the design of blockchain systems: ISO/TR 6039:2023

S. No.	Entity	Relevant committee/ working group/ focus group/ study group (if any)	Relevant outputs (standards/ technical recommendations/ technical specifications/ technical reports)
2.	**International Telecommunications Union - Telecommunication Standardisation Sector (ITU-T)**	**Focus Group on Application of Distributed Ledger Technology (FG DLT)**	**Outputs delivered by FG DLT[45]** Technical Specifications: 1. FG DLT D1.1: DLT terms and definitions 2. FG DLT D3.1: DLT reference architecture 3. FG DLT D3.3: Assessment criteria for DLT platforms Technical Reports: 1. FG DLT D1.2: DLT overview, concepts, ecosystem 2. FG DLT D1.3: DLT standardization landscape 3. FG DLT D2.1: DLT use cases 4. FG DLT D4.1: DLT regulatory framework 5. FG DLT D5.1: Outlook on DLTs Other ITU-T Recommendations[46] 1. ITU-T Y.2345 (05/2023): Scenarios and requirements of network resource sharing based on distributed ledger technology 2. ITU-T M.3366 (04/2023): Requirements for management of blockchain system 3. ITU-T X.1412 (04/2023): Security requirements for smart contract management based on the distributed ledger technology 4. ITU-T X.1411 (03/2023): Guideline on blockchain as a service (BaaS) security 5. ITU-T Y.3082 (03/2023): Mobile network sharing based on distributed ledger technology for networks beyond IMT-2020: Requirements and framework 6. ITU-T X.1410 (03/2023): Security architecture of data sharing management based on the distributed ledger technology 7. ITU-T Y.4560 (03/2023): Blockchain-based data exchange and sharing for supporting Internet of things and smart cities and communities 8. ITU-T Y.4910 (03/2023): Maturity model of digital supply chain for smart sustainable cities 9. ITU-T Y.2247 (01/2023): Framework and requirements of network-oriented data integrity verification service based on blockchain in future networks

S. No.	Entity	Relevant committee/ working group/ focus group/ study group (if any)	Relevant outputs (standards/ technical recommendations/ technical specifications/ technical reports)
3.	**Institute of Electrical and Electronics Engineers Standards Association (IEEE SA)**	**IEEE Blockchain Technical Community (BCTC)**	**Standards**[47] 1. IEEE 2418.7-2021: IEEE Standard for the Use of Blockchain in Supply Chain Finance 2. IEEE 2418.10-2022: IEEE Standard for Blockchain-based Digital Asset Management 3. IEEE 2418.2-2020: IEEE Standard for Data Format for Blockchain Systems 4. IEEE 2142.1-2021: IEEE Recommended Practice for E-Invoice Business Using Blockchain Technology 5. IEEE 3801-2022: IEEE Standard for Blockchain-based Electronic Contracts 6. IEEE 2144.1-2020: IEEE Standard for Framework of Blockchain-based Internet of Things (IoT) Data Management 7. IEEE 2140.2-2021: IEEE Standard for Security Management for Customer Cryptographic Assets on Cryptocurrency Exchanges 8. IEEE 2140.5-2020: IEEE Standard for a Custodian Framework of Cryptocurrency 9. IEEE 2143.1-2020: IEEE Standard for General Process of Cryptocurrency Payment 10. IEEE 3205-2023: IEEE Standard for Blockchain Interoperability Data Authentication and Communication Protocol 11. IEEE 2146.1-2022: IEEE Standard for Entity-Based Risk Mutual Assistance Model through Blockchain Technology 12. IEEE 2140.1-2020: IEEE Standard for General Requirements for Cryptocurrency Exchanges 13. IEEE 2140.4-2023: IEEE Standard for Distributed/ Decentralized Exchange Framework using DLT (Distributed Ledger Technology)

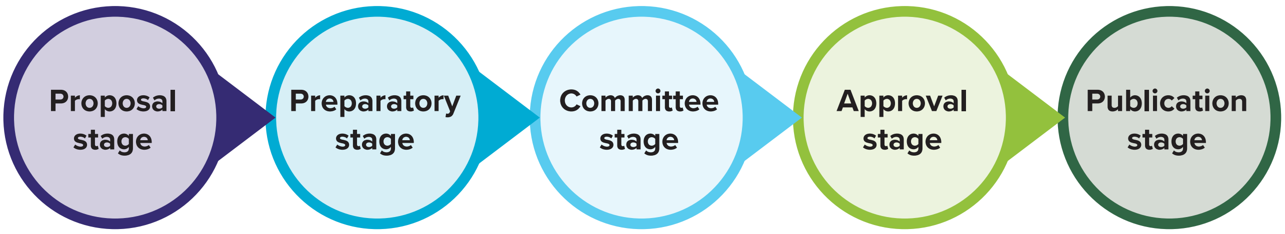
S. No.	Entity	Relevant committee/ working group/ focus group/ study group (if any)	Relevant outputs (standards/ technical recommendations/ technical specifications/ technical reports)
4.	**Bureau of Indian Standards (BIS)**	**Sectional Committee: LITD 29 Blockchain and Distributed Ledger Technologies (Mirror committee for ISO TC/307)** Panels within LITD 29 Blockchain and Distributed Ledger Technologies:[48] LITD 29: P1 Foundations LITD 29: P2 Security, Privacy and Identity LITD 29: P3 Smart Contracts LITD 29: P4 Non Functional Requirements LITD 29: P5 Governance LITD 29: P6 Use Cases	**Standards:** 1. IS/ISO 22739: 2020 Blockchain and distributed ledger technologies—Vocabulary 2. IS/ISO/TR 23244: 2020 Blockchain and distributed ledger technologies—Privacy and personally identifiable information protection considerations **Draft Standards:** 1. LITD 29 (20727) Blockchain and distributed ledger technologies—Taxonomy and Ontology (identical ISO/TS 23258:2021) 2. LITD 29 (20728) Blockchain and distributed ledger technologies—Reference Architecture (identical to ISO 23257:2022) 3. LITD 29 (20729) Blockchain and distributed ledger technologies—Overview of existing DLT systems for identity management (identical to ISO/TR 23249:2022) 4. LITD 29 (20730) Blockchain and distributed ledger technologies—Guidelines for governance (identical to ISO/TS 23635:2022) 5. LITD 29 (20731) Blockchain and distributed ledger technologies—Use cases (identical to ISO/TR 3242:2022)
5.	**Standards Australia (SA)**	**Committees:** IT-041, Blockchain and Distributed Ledger Technologies (Mirror committee for ISO TC 307)[49] **Working Group:** ISO/TC 307, Blockchain and Distributed Ledger Technologies[50]	**Standards:** 1. AS ISO 22739: 2020: Blockchain and distributed ledger technologies—Vocabulary[51] 2. SA TR ISO 23244: 2020: Blockchain and distributed ledger technologies—Privacy and personally identifiable information protection considerations[52]

S. No.	Entity	Relevant committee/ working group/ focus group/ study group (if any)	Relevant outputs (standards/ technical recommendations/ technical specifications/ technical reports)
6.	**American National Standards Institute (ANSI)**	Accredited Standards Committee X9 Inc. (ASC X9)—develops and publishes standards, technical reports and white papers for the financial services industry in the US. Distributed Ledger and Blockchain Technology Study Group (under ASC X9)—has a liaison agreement with ISO TC307. X9A Subcommittee—Electronic and Emerging Payments X9A1—DLT Work Group X9A3—Blockchain Auditing Work Group	**Standards (by X9A Electronic and Emerging Payments Subcommittee):** ANSI X9. 138-2020 Distributed Ledger Technologies (DLT) Terminology **Technical Reports (X9A Electronic and Emerging Payments Subcommittee)** 1. ASC X 9 TR 54-2021: Blockchain Risk Assessment Framework 2. ASC X9 TR 41-201x: Framework for Auditing a Blockchain within a Distributed System *[Note: Listed as a 'Current Standard Project' in the 'Program of Work' published by the ASC X9 in December 2019.]* **Study Group Report:** Distributed Ledger and Blockchain Technology Study Group Report (2018)

Annex C: Process and Stages of Standards-Formulation at BIS and SA

Bureau of Indian Standards (BIS)

The BIS standards formulation process typically comprises the following stages: (a) proposal stage, a standard is proposed; (b) preparatory stage, the relevant committee prepares a working draft; (c) committee stage, the preliminary draft is circulated within the committee; (d) approval stage, the draft is circulated for public comments; and (e) publication stage, the standard is notified in the Official Gazette [*See below figure*].[53]



- NWIP
- Can be proposed by any individual, organization or technical committee

- Working draft
- Prepared by BIS Technical committee

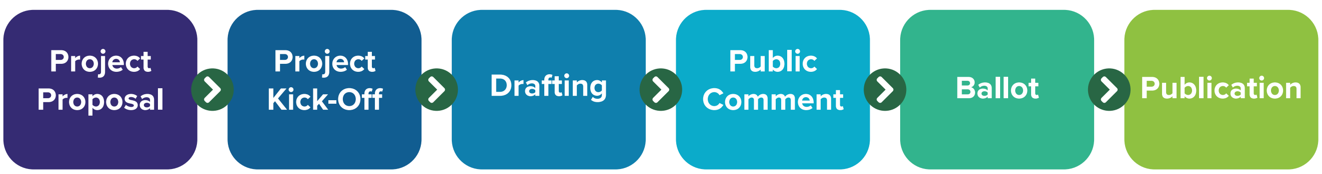
- Preliminary draft
- Narrow circulation of draft within committee for feedback/comments

- Wide circulation draft
- Wide circulation of draft for public comments

- Indian standard
- Notification in gazette

Standards Australia (SA)

The SA standards formulation process typically comprises the following stages: (a) proposal stage, a proposal is made to develop, revise, or amend a standard; (b) project kick-off stage, approved proposals are assigned to a technical committee, and a kick-off meeting is held; (c) drafting stage, working groups within the technical committee provide the technical content for the standard; (d) public comment stage, drafts are open for public comment for nine weeks, with feedback considered by the committee; (e) ballot stage, the final draft is voted upon by committee members to reach consensus; and (f) publication stage, once approved by the Standards Development and Accreditation Committee (SDAC), the standard is ready for publication [*See below figure*].[54]



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