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Original Article

# AI Governance Models Using Blockchain-Based Transparency Mechanisms

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## Abstract

*AI is making major changes in business, government, and society, but its rapid expansion has also brought up a lot of moral, clear, and responsible problems. It is vitally crucial to have solid governance frameworks in place as AI systems become more self-sufficient and start to make significant choices. Traditional ways of keeping an eye on things don't function well with AI technology that is decentralised, crosses borders, or isn't obvious. Blockchain technology is a good place to start when it comes to making AI governance models better because it is open, unchangeable, and has decentralised trust.*

*This article talks about how to include blockchain-based tools for transparency in AI governance frameworks. Blockchain can create unchangeable audit trails, decentralised systems for making decisions, and smart contracts that automatically enforce regulations. These traits could help with some of the biggest issues with AI governance, such as how hard it is to comprehend algorithms, how hard it is to hold individuals accountable, and how power is concentrated among a small group of AI stakeholders.*

*Blockchain technology is used in a number of AI governance frameworks. First, keeping explicit development records on a blockchain can make it easier to find things, which implies that people who aren't working on the project can check AI models, training datasets, and development procedures. Second, smart contracts can make sure that norms and morals are observed without any help. Third, blockchain-based decentralised AI governance consortia can help make decisions that are open and include a lot of different people. Finally, public audit trails based on blockchain can make people more responsible, especially in sensitive areas like healthcare, banking, and public administration.*

*There are still challenges in the actual world, even with these benefits. It's challenging to keep track of AI judgements in real time since blockchain doesn't scale well. When private AI data is stored on immutable ledgers, it can be hard to keep it private. That's why we need privacy-preserving methods like zero-knowledge proofs. Blockchain systems and AI platforms need to function together, and it's challenging to regulate decentralised models.*

*Future research should focus on making blockchain solutions that make AI governance more private, architectures that can be scaled up and used with other systems, and real-world case studies that show how blockchain and AI can function together in governance. To preserve rights and cope with new risks, legal and regulatory frameworks need to change. They also need to support these new concepts.*

*In conclusion, using blockchain to make things more clear is a promising strategy to make AI governance better. By making AI systems more accountable, transparent, and open to input from stakeholders, blockchain can help people trust them more and decrease the dangers that come with them. People from different professions, like technology, law, and policy, need to work together to make this happen.*

## Keywords

*AI governance, blockchain, openness, responsibility, smart contracts, decentralised decision-making, AI ethics, traceability, privacy-preserving technologies, and public trust altering industries, governments, and society. But as AI systems becoming more powerful and independent, people are more worried about how accountable, open, and ethical they are. This research paper looks at how blockchain technology, which is known for being unchangeable and having decentralised trust mechanisms, could improve AI governance models. Adding blockchain-based transparency tools to the processes of building and deploying AI could make AI systems easier to track, hold accountable, and trust. The paper talks about what other people have said about the topic, recommends various ways to govern it, and talks about challenges that happen in the actual world and what research could be done in the future.*

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## Introduction

Artificial intelligence (AI) technologies have spread so quickly to practically every sector of society that they have revolutionised how people make decisions, how services are delivered, and how organisations work. AI systems are currently helping to run significant parts of healthcare, banking, transportation, and public administration. They offer degrees of efficiency, predictive power, and automation that have never been seen before. But as AI systems become more widespread in important circumstances, they also raise new, tough difficulties for government, especially when it comes to ethics, accountability, transparency, and justice.

There have been a number of high-profile events in the previous few years that have made it evident that we need to take control of AI right soon. Some examples are biassed AI hiring tools that disadvantage minority groups, credit-scoring algorithms that are hard to understand and make it harder for individuals to secure loans, and AI-driven surveillance systems that violate people's right to privacy. These events indicate that AI can make social problems worse without meaning to, break basic rights, and work without clear means to hold individuals accountable if it is not kept in check. It's challenging to understand AI systems, especially those that use machine learning and deep learning, because they don't explain how they make judgements or who is to blame when something goes wrong.

Governance mechanisms that were made for making decisions about conventional software or people don't necessarily function well for controlling AI technologies. AI systems are hard to grasp, do their jobs on their own, and are always learning and changing. This makes it exceedingly challenging for businesses, authorities, and society as a whole to cope with them. It is also tougher to govern because AI development is happening all over the world and is not centralised. Many countries work together to make AI models, and they train them on different sets of data. They are then utilised in regions with very different laws and moral standards.

This broken ecosystem makes it challenging to create standard, enforceable AI governance frameworks and leaves gaps in regulation. Blockchain technology has become a viable approach to fix these challenges with AI governance. Blockchain was first made to serve cryptocurrencies, but it includes qualities that make it a viable choice for strong AI governance. These include decentralisation, transparency, immutability, and resistance to manipulation. Blockchain can make the AI lifecycle more accountable and traceable by retaining records of AI development processes, decision-making events, and compliance procedures that can't be changed.

This study looks into whether blockchain technology could be used in AI governance frameworks to help with big problems like power imbalances, accountability, and transparency. It looks at how blockchain-enabled audit trails, decentralised oversight mechanisms, and smart contracts might aid with better monitoring, automatic enforcement of ethical principles, and higher public trust in AI systems. It is becoming clearer and clearer that we need real-time monitoring, contact with stakeholders, and flexible regulatory regimes as AI systems change swiftly. AI systems can change how they work after they are used because they can keep learning. That means that static, retrospective governance models aren't good enough. We need governance systems that are flexible and proactive enough to keep up with how AI changes.

Another key issue is the gap between power and information. A lot of the time, no one else is paying close attention to the proprietary AI models, training datasets, and algorithms that big tech companies have. People are worried about monopolistic behaviour, a lack of public accountability, and the possibility that AI may be used for espionage, influencing politics, or making money because of this concentration of power.

Blockchain's decentralised nature allows AI ecosystems distribute power more fairly by letting different groups keep an eye on things and making them less reliant on centralised authorities. Regulators, civil society groups, and the public can help keep an eye on, check, and enforce rules for AI development and use by using transparent, unchangeable ledgers and programmable smart contracts.

Adding blockchain to AI governance also fits with global policy trends that stress Responsible AI. The European Union's AI Act, the OECD AI Principles, and UNESCO's Recommendation on the Ethics of AI are all examples of how the world is coming together to agree on the need for enforceable governance frameworks. You can use blockchain as a technical platform to put these policy suggestions into effect. It can prove that AI is acting in a way that is both legal and moral right now, with proof.

Bad governance has significantly greater repercussions when AI is used in crucial industries like healthcare, transportation, energy, and public safety. It's easy to see how high the stakes are when AI-powered healthcare tests are inaccurate, self-driving cars make blunders, or smart city monitoring systems infringe people's privacy. Open and accountable governance models are no longer optional; they are critical to make sure that AI technologies are deployed in ways that are safe, ethical, and good for society as a whole.

*Table 1. The main concerns with AI governance and how blockchain can help solve them*

| AI Governance Challenge | Description | Potential Blockchain Solution |
|---|---|---|
| Lack of Transparency | AI decision-making often functions as a "black box" | Immutable audit trails of AI processes |
| Accountability Gaps | Difficulty attributing responsibility for AI outcomes | Decentralized records linking actions to accountable parties |
| Fragmented Regulatory Environments | AI development and deployment span multiple jurisdictions | Cross-border, tamper-proof compliance records |
| Power Concentration | Proprietary control of AI models by a few tech giants | Distributed oversight and verification through blockchain |
| Dynamic, Evolving AI Behavior | AI systems adapt after deployment, complicating oversight | Real-time monitoring via blockchain-enabled data logs |
| Privacy Concerns | Tension between transparency and individual data protection | Privacy-preserving blockchain architectures (e.g., zero-knowledge proofs) |

This article attempts to overcome these challenges with governance by bringing together what we already know about AI and blockchain governance, offering beneficial approaches to connect the two, and pointing out areas where more research and policy work is needed. The following part of the literature review looks at all the academic work that has been done on the connection between AI governance and blockchain technology.

## Literature Review

AI governance is a hot topic in the commercial world, in public policy, and in academic study. This shows that AI technologies are having a wider and bigger effect on people all around the world. In this case, governance is the laws, institutions, regulations, and instruments that make sure that AI is developed and used in a way that is moral, legal, and in keeping with society's values. The AI4People project, which was led by Floridi et al. (2018), was the first to create a full set of ethical rules for AI governance. Their ideology is founded on five basic ideas: doing good, not doing harm, freedom, fairness, and being able to explain things. These rules make it clear that AI systems must be open, responsible, and created with people's health and safety in mind. Floridi et al.'s work is the starting point for later efforts to put AI governance into action.

Jobin, Ienca, and Vayena (2019) looked at more than 80 AI ethics standards from around the world and found that there was a lot of agreement on important rules for how to run AI, such as privacy, justice, human oversight, and responsibility. But their study also found that there were some serious difficulties with the ways they planned to put things into action and make sure they were followed. There are big holes in making sure that AI is made and used in a moral way because most suggestions are not legally required. Blockchain technology has also becoming more popular as a way to help fix difficulties with AI governance that are still going on. In 2018, Zheng et al. wrote a long paper about what blockchain can do. They focused on its strengths in managing trust in a decentralised way, keeping data that can't be modified, and automating jobs with smart contracts. These features are a good fit for the need for AI ecosystems to have means to govern themselves that are open and can't be changed.

A new study is beginning to explore into how blockchain and AI can work together to govern. Binns (2020) studied the tension between AI's ability to explain itself and its need for openness. He suggested adopting blockchain-based audit trails to maintain track of AI development processes and decision-making events in a form that can be checked. Wright and De Filippi (2015) also came up with the idea of "Lex Cryptographia," which envisions blockchain as a decentralised regulatory framework that can enforce norms and agreements through code that runs on its own. Recent studies have added to this conversation by looking into how blockchain can be utilised in real life to make AI governance better. Casino et al. (2019) looked into how blockchain may make AI systems more trustworthy in a lot of different ways, such sharing data, checking models, and making them easier to audit. Their experiment highlights how vital blockchain is for ensuring sure data is correct, which is really significant because AI needs large, high-quality datasets.

Rauchs et al. (2020) studied how blockchain could make it easier to audit and more open AI-driven systems in the financial technology (FinTech) area. Their study demonstrates that data that can't be changed can help keep an eye on things like algorithmic trading, credit rating, and fraud detection. In the healthcare industry, things have also been doing well. Yue et al. (2016) highlighted how blockchain might make sharing data safe, open, and under the control of the patient. This is something that all ethical, AI-driven healthcare apps should include. Their work shows how blockchain can protect privacy and hold people accountable when there is a lot of sensitive data. There are still

a lot of legal, moral, and technical issues that need to be worked out. Scalability is a huge problem because AI and blockchain can be demanding on computers. One more thing that hasn't been figured out yet is how to get multiple AI models and blockchain systems to work together. Also, the legal status and approval of blockchain-based governance systems vary greatly from place to place, making it hard to create models that function everywhere.

Things are considerably more problematic since people are worried about their privacy. Blockchain's openness and inability to be changed are good for accountability, but they may not be in line with data protection laws like the General Data Protection Regulation (GDPR), especially when it comes to the "right to be forgotten." Zyskind et al. (2015) have suggested privacy-preserving blockchain architectures, like zero-knowledge proofs, as possible ways to solve this problem. Blockchain is becoming even more relevant for AI governance as international policies change. The European Commission's AI Act from 2021 highlights how important it is to have governance frameworks that can be enforced and technology tools that can ensure openness, responsibility, and human oversight. Blockchain gives these policy aims a technical foundation to build on.

***Table 2. Key Books and Articles on Blockchain Integration and AI Governance***

| Study/Author | Focus Area | Key Contribution |
|---|---|---|
| Floridi et al. (2018) | AI Ethics and Governance Framework | Proposed AI4People ethical principles for transparent, accountable AI |
| Jobin et al. (2019) | Global AI Ethics Guidelines | Analyzed 80+ guidelines; identified consensus and enforcement gaps |
| Zheng et al. (2018) | Blockchain Capabilities | Surveyed blockchain's potential for decentralized, tamper-proof governance |
| Binns (2020) | AI Transparency and Explainability | Suggested blockchain audit trails to enhance AI decision transparency |
| Wright & De Filippi (2015) | Blockchain and Decentralized Governance | Introduced "Lex Cryptographia" for blockchain-based rule enforcement |
| Casino et al. (2019) | Blockchain for AI Trust and Data Integrity | Reviewed blockchain's role in enhancing AI data sharing and verification |
| Rauchs et al. (2020) | Blockchain for AI Governance in FinTech | Examined blockchain's role in auditing AI-driven financial technologies |
| Yue et al. (2016) | Blockchain for AI-Enabled Healthcare | Demonstrated secure, transparent data sharing for AI healthcare applications |
| Zyskind et al. (2015) | Privacy-Preserving Blockchain Architectures | Proposed decentralized, privacy-preserving data management frameworks |
| European Commission (2021) | AI Regulation and Policy | Introduced the AI Act highlighting enforceable, technical governance tools |

To sum up, the research makes it clear how to use blockchain and AI governance together, but there aren't enough real-world instances of this operating on a wide scale yet. Technologists, lawyers, ethicists, and lawmakers need to work together across sectors to fill in these gaps. This study helps us learn more by putting together existing information, suggesting beneficial ways to run things, and pointing out significant areas that need more investigation in the future.

The next parts will deal about blockchain-based governance models that have been offered and the technological, legal, and organisational issues that need to be fixed so that ethical, open, and responsible AI systems can work on a broad scale.

## Methodology

### *A. The Research's Design and Method*

This study employs a qualitative, exploratory approach to find out more about how blockchain technology and AI governance operate together. We picked the qualitative method since the subject is complex, always changing, and covers a lot of ground, such as law, technology, ethics, and policy. The study doesn't intend to draw broad statistical generalisations. It doesn't want to do that; it wants to make in-depth conceptual discoveries and frameworks that may be used to guide future research, policy-making, and technology progress. With a qualitative study, we can better understand how blockchain can be used in AI governance to make things more open, accountable, and decentralised. This strategy makes it easy to put together information from a lot of different places, like peer-reviewed academic research, company reports, technical white papers, and policy papers from other countries. We can be sure that the conclusions are based on current scientific knowledge and are still applicable in real-world policy and technology settings by using three separate sources.

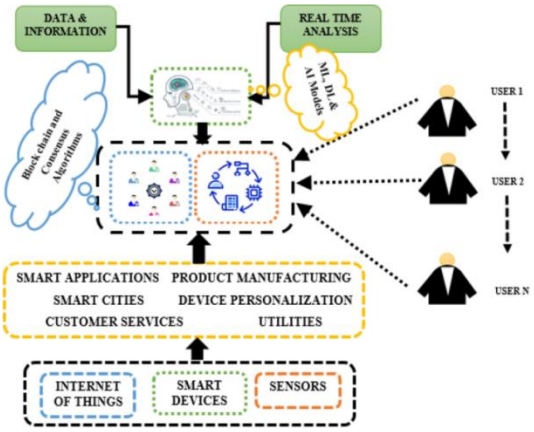


***Figure 1. Blockchain-Enhanced Machine-Learning Architecture***

### *B. Where the Data Came from and how it was Gathered*

The study's three main sources of data are academic literature, policy reports, and white papers from the business world. Academic literature includes peer-reviewed journal articles, conference proceedings, and scholarly publications that talk about AI ethics, governance frameworks, and blockchain applications. We looked through significant databases like Scopus, Web of Science, and Google Scholar to discover publications from the last 10 years that were relevant. Reports on policy from international organisations, government agencies, and regulatory bodies give us essential information about new rules for how to run a business, how to act morally, and how to follow the law. Papers from the European Commission, the OECD, UNESCO, and national AI initiatives from the US, China, and the EU are all relevant examples. Blockchain and AI research groups, technology companies, and blockchain consortia all create industry white papers that show real-world instances of the issues and opportunities that come up when trying to merge blockchain and AI governance. These papers talk about the newest developments in AI and blockchain technologies, as well as industry trends, test initiatives, and pilot programs. There were some requirements for what might be included in the document selection process. It had to be related to AI governance, blockchain applications, or both; it had to have been published in the recent 10 years; and it had to be in English. There were a number of reasons for not include opinion pieces, blog posts that weren't peer-reviewed, and ads that weren't extremely technical or academic.

### *C. A Plan for Comparing and Analysing*

We developed a methodology for comparative analysis to thoroughly look at the reports and literature we found. You can use this method to uncover major distinctions, common themes, and conceptual overlaps between different governance models and technical proposals. It was notably helpful to use comparative study to see how blockchain's primary qualities, such immutability, transparency, and decentralisation, fit with or solve problems that are already known in AI governance. We used conceptual mapping methods to put together essential design elements, governance ideas, and technology mechanisms that have been mentioned in the literature. After that, these elements were put together into a conceptual framework that explains how blockchain may assist enhance the way AI is managed.

***Table 3. Below shows the major ideas and design elements that were uncovered during the analysis:***

| Theme | Design Element | Description |
|---|---|---|
| Transparency | Immutable Audit Trails | Blockchain provides tamper-proof records of AI development, training, and deployment processes. |
| Accountability | Decentralized Compliance Monitoring | Stakeholders can participate in verifying adherence to ethical and legal standards. |
| Data Integrity | Secure, Verifiable Data Sharing | Blockchain ensures the integrity and provenance of datasets used in AI systems. |
| Explainability | Transparent Decision Logs | AI decision-making processes can be documented and traced through blockchain-based records. |
| Decentralization | Distributed Oversight Mechanisms | Blockchain reduces reliance on centralized authorities for AI governance. |
| Privacy Preservation | Zero-Knowledge Proofs and Encryption | Blockchain architectures can incorporate privacy-preserving technologies to balance transparency with data protection. |

### *D. Making Structures for Ideas*

This study builds on the ideas that were used to construct conceptual governance models that employ blockchain technology to keep an eye on AI. These frameworks stress the need for openness, the ability to be audited, and making decisions in a decentralised way. These models use blockchain's technical features, such as

smart contracts and distributed ledgers, to try to put ethical principles, laws, and social norms into action. For instance, the conceptual framework says that smart contracts on the blockchain might be used to autonomously enforce standards for AI development. These smart contracts might incorporate rules for conduct or ethics, and if someone breaks one of these rules, the system could automatically check for compliance or stop the system from being used. The technique also suggests putting unchangeable audit trails in the AI development pipelines. This would permit independent entities, including regulators or civil society groups, make sure that the training data, algorithm updates, and decision-making processes are all right.

### *E. Problems with putting it into action and its limits*

There are some concerns and limitations with the frameworks that are being presented for AI governance, even though they do give some ideas on how to deal with these issues. First, both AI and blockchain technologies have a lot of trouble growing. AI systems, especially those that use deep learning, need a lot of processing power. A lot of blockchain platforms, especially those that use proof-of-work consensus methods, also need a lot of computer power. Combining these technologies could make resource needs worse and raise concerns about how long they will last. Second, there is still a huge problem with interoperability. AI systems and blockchain platforms don't use the same technological standards, thus it's challenging to combine them. If there aren't any standard protocols and interfaces, adopting blockchain-based AI governance in real life might not work well all the time.

Third, there are still uncertainties regarding how the law and rules apply to blockchain-based governance structures. Blockchain's decentralised and immutable nature can sometimes conflict with present norms, especially when it comes to legislation about protecting personal data like the General Data Protection Regulation (GDPR). For example, the idea of the "right to be forgotten" doesn't make sense because blockchain keeps data forever. Finally, we need to think about how socially acceptable it is to use blockchain to govern AI. People still don't know much about AI and blockchain technology, and there are still concerns about privacy, tracking, and algorithmic control. If proposed governance models don't incorporate all stakeholders and make their points clear, they may not be accepted or perceived as legitimate.

### *F. In short*

In short, this study uses a qualitative method that combines diverse kinds of literature, looks at policies, and compares and contrasts ideas. The research carefully looks into and finds essential themes, governance principles, and design elements for combining blockchain with AI governance. People are coming up with new ideas for governance models that emphasis on transparency, responsibility, and decentralised monitoring to remedy faults with the ones we have now.

The study does, however, say that these frameworks won't work properly until technical, legal, and social issues are fixed. To test, refine, and grow blockchain-based AI governance systems in the real world, we need more research and pilot projects.

## Blockchain-Based AI Governance Models

Adding blockchain technology to AI governance is a huge step towards building AI systems that are open, responsible, and trustworthy. This part talks about four primary ways that blockchain can make AI governance better. Each one solves a different problem, such as not being open, not being responsible, or having too much control. These models employ blockchain's unique qualities, including being unchangeable, decentralised, and automated, to make valuable tools for keeping an eye on how AI is growing and being used.

### *A. Open AI Development Records*

One of the main challenges with AI governance is that people don't talk about how AI is made. Some people term AI models "black boxes," which makes it hard to know how they were produced or where they might be biassed. Deep learning and neural networks are two types of models that are very good at this. Adding blockchain to this process can help keep track of AI model development in a way that can't be changed and has a time stamp. These records can provide details about training datasets, changes to algorithms, and the results of tests. Blockchain's distributed ledger technology makes sure that these records can't be modified or deleted after they are produced. This lets you look back over the history of an AI system's life cycle, from when it was first made to when it is still being changed. Independent auditors, regulators, and other interested parties can look at these records to make sure that AI models are both technically and morally sound.

These kinds of explicit records are very crucial in domains like healthcare, criminal justice, and financial services, where biassed or wrong AI outputs can have big impacts on society. By making a permanent, tamper-proof record of development operations, blockchain makes it easier to keep an eye on things and detect problems early.

To make sure that AI development is open and honest, Table 1 highlights some of the data pieces that might be kept on a blockchain:

| Data Element | Description |
|---|---|
| Model Version History | Records of all AI model versions and updates |
| Training Dataset Sources | Documentation of datasets used, including origins and characteristics |
| Algorithmic Changes | Detailed logs of algorithm modifications |
| Testing and Validation Results | Results of AI performance tests and bias assessments |
| Developer Contributions | Records of contributions by individual developers |

These blockchain-based development records hold people accountable by showing how AI models have changed over time in a way that can't be modified. This helps regulators do their jobs better and makes people trust them more.

### *B. Smart Contracts that Follow the Rules*

Another innovative technique to leverage blockchain in AI governance is to employ smart contracts to make sure that AI follows the law and is moral. Smart contracts are pieces of code that operate on a blockchain and automatically follow particular rules or conditions. Smart contracts can interact with AI systems to make sure that AI acts in a way that is both legal and moral. They can achieve this by becoming independent ways to enforce the law. For instance, a smart contract may be set up to watch what an AI system does and step in if it makes proposals that break the rules, like advising hiring people based on their race or gender or telling self-driving cars to do things that are unsafe. In these cases, the smart contract can send out alerts, limit the use of the AI system, or even apply fines, all without needing any cooperation from people.

This automated enforcement solution makes governance better by providing real-time compliance checks and making it less reliant on centralised oversight bodies. Smart contracts also maintain track of enforcement efforts in a clear way. This lets you look back at what happened and make governance frameworks better all the time.

**Table 4. Shows potential ways that smart contracts could be used to regulate AI:**

| Application Area | Smart Contract Function |
|---|---|
| AI Hiring Systems | Enforce non-discrimination rules for candidate selection |
| Autonomous Vehicles | Restrict operation under unsafe conditions |
| AI-Powered Financial Trading | Limit risky transactions beyond regulatory thresholds |
| AI-Enabled Medical Diagnosis | Require human review for high-risk medical decisions |

Smart contracts are a means to make sure that AI is used properly that can grow and work on its own. They do this by writing code that follows moral and legal rules. This works great when people are watching and there are rules in place.

### *C. Groups for Decentralised AI Management*

A few huge businesses are in charge of most of the work on AI. This has made people worried about monopolistic conduct, a lack of public scrutiny, and the chance that AI will be used in ways that are not intended. Blockchain lets people from different backgrounds work together to build decentralised AI governance consortia. These organisations can include AI developers, politicians, civil society organisations, and communities that are affected by AI. These groups use blockchain's decentralised technology to make the process of making decisions open and fair.

People who have a stake in AI systems can help define rules, policies, and means to enforce them through blockchain-based voting systems. Keeping records of decisions on the blockchain makes everything clear and accountable. This makes it tougher for anyone to edit things or leave them out. Decentralised AI governance consortia promote inclusivity by making sure that a wide range of opinions are heard, especially those that have been left out of technical advancement in the past. They also make systems stronger by giving more people control and making them less reliant on a few main causes of failure.

***Table 5. Ooutlines a few different ways that blockchain-based AI governance consortia could be set up and what they could do:***

| Governance Function | Blockchain Application |
|---|---|
| Policy Development | Transparent proposal submission and voting processes |
| Standards Setting | Immutable recording of technical standards and updates |
| Compliance Monitoring | Decentralized verification of AI system compliance |
| Dispute Resolution | Blockchain-based arbitration records and outcomes |

### *D. Public Audit Trails for AI Decisions*

Responsible AI is that you should be able to explain and check the decisions made by AI systems, especially in vital sectors like healthcare, finance, and public safety. But a lot of AI models are too sophisticated and hard to understand to be properly checked. Blockchain fixes this by keeping public records of AI decisions that can't be modified. This model uses a blockchain to keep track of the crucial inputs, outputs, and reasoning steps of AI systems. This makes a record that can't be modified and has a time stamp that regulators, auditors, and those who are affected may look at on their own. This kind of openness makes people more responsible and gives investigators the proof they need to look into AI decisions that are unfair or cruel. The European Union's AI Act specifies that high-risk AI systems must have paperwork and be able to be traced. Public audit trails enable corporations comply these new standards. Using blockchain's immutability can help organisations prove that they are obeying the regulations and decrease their legal and reputational concerns.

***Table 6. Demonstrates some frequent pieces of data that can be discovered in AI audit trails that are based on blockchain***

| Data Element | Description |
|---|---|
| Input Data Snapshots | Records of data provided to AI systems |
| AI Model Outputs | Logged results or decisions produced by AI systems |
| Reasoning or Decision Steps | Where applicable, documentation of AI reasoning processes |
| Human Oversight Actions | Records of human interventions or approvals |
| Incident Reports | Documentation of errors, biases, or rule violations |

Blockchain improves AI governance, develops trust in the public, and gives people means to keep getting better and hold themselves accountable by making audit trails that can be checked and can't be modified. These blockchain-based models reveal how to make AI governance better in the real world. They talk about essential topics like openness, responsibility, and getting stakeholders involved, all of which are needed for AI systems to be ethical, trustworthy, and helpful for society.

## Practical Challenges and Limitations

Blockchain-based AI governance solutions could make things far more open, accountable, and decentralised. But it's vital to look closely at a variety of real-world challenges and limitations to make sure that these models are not only theoretically sound but actually work in the real world. Some of these obstacles are scalability, data privacy, interoperability, and the complexity of governance. Each of these concerns has its own set of technical and operational issues that need to be fixed before the deployment can work.

### *A. Ability to Grow*

When it comes to AI governance on the blockchain, scalability is still a huge problem, especially when you consider about how much data AI systems make. Ethereum and Bitcoin are two public blockchains that usually have problems executing transactions rapidly. For instance, the Ethereum network can process roughly 30 transactions per second (TPS). AI systems employed in things like self-driving cars or real-time financial trading, on the other hand, can make hundreds of data points every second. Because of this mismatch, it's very hard to log and check AI judgements in real time on blockchain networks.

To make transactions safer, several blockchains use consensus methods like Proof of Work (PoW) or Proof of Stake (PoS). However, these methods also make it take longer to confirm transactions. This makes the problem of scalability even worse. Because of this, blockchain may not be able to be used in AI governance models that need real-time monitoring and quick auditability until scalability is much improved.

Some of these difficulties might be easier to solve with new Layer 2 scaling technologies like state channels and rollups. These methods let transactions happen off-chain while still retaining the security promises of the blockchain they are built on. But integrating these kinds of solutions to AI systems makes things more complicated and requires strict rules for interoperability.

***Table 7. A comparison of the data needs of AI systems and the scalability of blockchain***

| Parameter | Blockchain (Ethereum) | AI Systems (Real-Time Applications) |
|---|---|---|
| Transactions per Second (TPS) | ~30 TPS | Up to 10,000 data points/second |
| Data Storage Cost | High | Variable, often large-scale |
| Latency | Moderate to High | Ultra-Low Required |
| Scalability Solutions | Layer 2, Sharding | High-Performance Computing |

Blockchain has some amazing governance features, but because it has challenges with scalability, it needs careful architectural planning and hybrid models to make sure it can be used in real life.

### B. Keeping Information Private

Data privacy is another huge issue with AI governance based on blockchain. This is largely because blockchain technology can't be changed and is available to everyone. AI systems often handle incredibly private data, like health records, financial information, and proprietary algorithms. Putting this kind of information directly on a public blockchain is a huge legal and privacy problem. The "right to be forgotten" is a key aspect of the General Data Protection Regulation (GDPR) and other regulations like it. This goes against the basic idea of blockchain, which is that data should never change. It is illegal and unlawful to edit or delete anything that has been recorded on a blockchain, especially when it comes to sensitive AI outputs or datasets.

Zero-knowledge proofs (ZKPs) and secure multi-party computing (SMPC) are two new cryptographic methods that might help with these issues. For instance, ZKPs let humans check that an AI system's outputs are true or that it respects ethical principles without disclosing the data that was used to make the choice.

This lets you build audit trails for AI decisions that can be reviewed while yet keeping anonymity. Another option is to keep sensitive AI data off-chain and just store cryptographic hashes or proofs on the blockchain. This keeps the data safe and lets you check it without showing what it is. But this model relies on external storage systems that need to be safe and reliable so that data can't be modified.

*Table 8. Issues with blockchain data privacy and how to fix them*

| Challenge | Description | Potential Solution |
|---|---|---|
| Immutable Data Storage | Inability to delete or alter stored information | Off-Chain Storage, ZKPs |
| Public Visibility of Transactions | Exposure of sensitive AI data on public ledgers | Encryption, Privacy-Preserving Protocols |
| Regulatory Compliance (GDPR) | Conflicts with "right to be forgotten" | Selective Disclosure, Data Minimization |

In the end, blockchain can make things more transparent, but because it has privacy problems, AI governance needs to have strong technical protections and strict rules that are in line with them.

### C. Working Together

Blockchain and AI governance frameworks need to be able to function together smoothly in a lot of different technology environments for them to work successfully together. AI systems usually deal with sophisticated networks that include outdated IT systems, cloud platforms, and a lot of proprietary algorithms. When you add blockchain to this situation, it might pose technological challenges that make it tougher for systems to operate together and share information. It is hard for blockchain platforms and AI components to work together since there are no standard rules for how data is formatted, how smart contracts are executed, or how systems talk to one other. For instance, AI models that were trained on proprietary frameworks would not work well with verification systems or audit tools that are based on blockchain.

A lot of blockchain networks also don't work well with each other, which makes it challenging to keep track of them all. For example, an AI system that works in more than one area might connect to a lot of different blockchain networks, each with its own rules for how to establish consensus, how to structure data, and how to run things. This spread makes it harder to create governance models that are explicit and work well together.

The Interledger Protocol (ILP) and blockchain interoperability platforms like Polkadot and Cosmos are trying to fix these issues by making it easier for various chains to communicate and share information in a consistent fashion. Also, people in the AI business are starting to look into common data formats and APIs that could assist link AI with blockchain.

*Table 9. Issues with and fixes for blockchain-based AI governance that make it challenging for systems to work together*

| Interoperability Challenge | Description | Potential Solution |
|---|---|---|
| Legacy System Integration | Incompatibility with existing IT infrastructure | API Development, Middleware Solutions |
| Cross-Blockchain Communication | Fragmentation across different blockchain networks | Interledger Protocol, Polkadot, Cosmos |
| AI-Blockchain Data Standardization | Lack of common data formats for AI and blockchain | Industry Standards, Open Data Protocols |

Interoperability is necessary for blockchain-based AI governance to work in the real world. This will require a lot of work from lawmakers, standard-setting groups, and technological developers.

### *D. Hard to Understand Governance*

Decentralised governance models based on blockchain make things more transparent and include more people, but they also make governance a lot harder. It can be inefficient, get stalled, and be simple for powerful people to control when decisions are made on a blockchain. Some people have said that Decentralised Autonomous Organisations (DAOs) might be used to run AI systems that leverage blockchain. DAOs use token-based voting and smart contracts to let groups make decisions, but they often have difficulties including low voter turnout, decisions that don't go anywhere, and a few big token holders having too much influence. These issues make it harder for the government to be fair and democratic. Also, blockchain and AI systems are hard to understand, which makes it challenging for those who aren't experts to get involved in a meaningful way. If governance interfaces aren't easy to use and people don't know enough about technology, decentralised governance could leave some people out and privilege those who are good with technology. Also, governance chores like modifying the rules for how AI can be used, settling conflicts, or updating the rules for smart contracts can be boring and take a long time, especially when a lot of different people need to agree. In high-stakes AI applications like healthcare or vital infrastructure, delays in making governance decisions can have big repercussions.

***Table 10. Issues concerning how hard it is to govern blockchain-based AI oversight***

| Governance Challenge | Description | Potential Solution |
|---|---|---|
| Low Participation in Decision-Making | Limited engagement from stakeholders | Incentive Mechanisms, User-Friendly Platforms |
| Concentration of Influence | Dominance by large token holders or technical elites | Governance Token Caps, Quadratic Voting |
| Technical Barriers to Participation | Complexity excludes non-experts | Education Initiatives, Simplified Interfaces |

People are looking towards hybrid governance models that mix decentralised elements with centralised monitoring, expert advisory groups, and technical education programs to get past these challenges. These kinds of projects strive to establish a balance between openness, inclusion, and running things well when it comes to leveraging blockchain to manage AI. In the end, blockchain-based AI governance has a lot of promise, but it will be challenging to make it work in the real world because of problems with scalability, privacy, interoperability, and the complexity of governance. These issues need to be fixed in order to create a safe, open, and fair AI governance ecosystem.

## Future Research Directions

Blockchain technology and AI governance are two fields that are just beginning to work together. They have a lot of promise, but there are also some significant holes that need to be plugged. To make sure that blockchain-based AI governance systems operate, are safe, and can evolve, a lot of research needs to be done in a few key areas. This section talks about four significant areas where greater research could assist build AI governance frameworks that are powerful and dependable, and that use blockchain technology.

### *A. Creating Blockchain Architectures that Protect Data for AI Governance*

One of the most essential things researchers want to do is come up with blockchain designs that keep people's information private while still letting AI do its job. Bitcoin and Ethereum are two examples of classic blockchain systems that use public ledgers that anybody can see. These ledgers are not safe places to keep sensitive AI-related data like secret decision outputs, training datasets, or proprietary methodologies. This means that there is an urgent need for research into privacy-preserving systems that can interact with blockchain platforms. Some new technologies, including as zero-knowledge proofs (ZKPs), homomorphic encryption, and private smart contracts, seem like they could help with these issues. But these technologies are still new, and not much research has been done on how they could be used to manage AI. Future research should focus on making these systems perform better and be able to handle more data while yet maintaining privacy robust. In addition, it's necessary to think about the pros and cons of privacy, openness, and the ability to audit in AI governance systems that employ blockchain. Finding the right balance is vital so that privacy protections don't get in the way of the accountability and oversight that blockchain is designed to provide.

| Research Focus | Description | Current Status |
|---|---|---|
| Zero-Knowledge Proof Integration | Application of ZKPs to AI-related blockchain transactions | Limited real-world deployment |
| Homomorphic Encryption for AI Data | Secure computation on encrypted AI inputs/outputs | Largely theoretical, early-stage |
| Confidential Smart Contracts | Smart contracts with encrypted logic and data | Experimental prototypes exist |

### *B. Making systems that can evolve and collaborate with other systems to record AI judgements in real time*

It is also crucial to study how to make blockchain systems that can grow and work with other systems. These systems should be able to record AI decisions as they happen. As AI takes on more and more significant jobs, like driving self-driving cars, trading markets, and detecting health concerns, it becomes more and more necessary to be able to swiftly and reliably record AI system outputs for transparency and accountability. Public blockchain networks often can't handle a lot of transactions at once since they have low throughput and significant latency. Bitcoin can process roughly seven transactions per second (TPS), while Ethereum can handle between 15 and 30 TPS. This isn't enough for AI systems that need to work right away. So, more research needs to be done on Layer 2 scaling solutions like state channels and sidechains, as well as new blockchain protocols like Polkadot and Cosmos that are all about making different blockchains work together.

To make it easier for multiple AI systems, blockchain platforms, and traditional infrastructure to work together without any difficulties, we also need standardised data formats and interfaces. Research should focus on making open, industry-wide standards for documenting AI decision data on blockchains, based on what we've learnt from initiatives like the IEEE P7000 series on AI ethics and governance.

| Research Focus | Description | Current Status |
|---|---|---|
| Layer 2 Blockchain Scaling | Off-chain transaction processing for speed and efficiency | Growing adoption in DeFi |
| Interoperable Blockchain Protocols | Cross-chain communication for AI governance data | Early-stage development |
| AI-Blockchain Integration Standards | Common formats for AI decision data on blockchains | Fragmented, no universal standard |

### *C. Look at the Laws and Rules that Help Keep an Eye on AI based on Blockchain.*

AI governance needs to follow the rules and laws for it to work. Politicians and policymakers have a hard time figuring out what to do, though, because blockchain and AI work together. The European Union's AI Act and other AI guidelines don't say much about how blockchain can make things more open, accountable, and decentralised. Most laws for blockchain, like those for cryptocurrencies and digital assets, don't support AI governance applications in the same way. To figure out how legislation might change to make it easier to employ blockchain-based AI governance systems responsibly, more research is needed. This involves figuring out how privacy rules like the General Data Protection Regulation (GDPR) operate with blockchain records that can't be modified and hold data from AI systems. Also, research should look into the legal status and decision-making capacity of decentralised governing bodies that are made up of blockchain consortia. Researchers should also look at how things are done in different places to determine the best ways to conduct things and any holes in the rules. To make sure that blockchain-based AI governance systems perform well across borders, countries will need to work together. This is especially true now that AI is being made and used all over the world.

| Research Focus | Description | Current Status |
|---|---|---|
| AI Act and Blockchain Synergies | Alignment of EU AI regulations with blockchain solutions | Limited consideration to date |
| GDPR and Immutable Blockchain Records | Reconciliation of privacy rights with data immutability | Ongoing legal debate |
| Legal Status of Decentralized Consortia | Governance authority of blockchain-based AI groups | Largely undefined |

### *D. Examples from real life of how AI governance works with blockchain*

There are a lot of ideas about how to use AI on the blockchain, but not enough study has been done in the real world to see how these concepts operate. It is also vital to use case studies of current projects to evaluate theoretical frameworks, discover real-world difficulties, and make recommendations based on facts. Some case studies that could be useful are AI-focused blockchain consortia like the Ocean Protocol, which uses blockchain to share data and train AI, and initiatives like SingularityNET, which combines AI services with decentralised governance systems. We can learn a lot about how well the system works, how stakeholders engage with each

other, how hard it is to scale up, and what the legal challenges are by looking closely at these and other similar projects. Future research should incorporate both technical performance evaluations and qualitative investigations of governance processes and stakeholder views from a variety of sectors. These kinds of studies will assist refine models and shape laws by looking at both the technical and social-political sides of AI governance through blockchain.

| Case Study Focus | Description | Current Status |
|---|---|---|
| Ocean Protocol | Blockchain-based data sharing for AI development | Active, growing ecosystem |
| SingularityNET | Decentralized AI marketplace with governance mechanisms | Operational, mixed adoption |
| AI Governance Pilots in Public Sector | Government-led blockchain AI oversight initiatives | Very limited, early experimentation |

## Conclusion

How to regulate Artificial Intelligence (AI) systems is one of the main concerns of the digital age. It's becoming clearer and clearer that utilising AI technology without the right standards or oversight is dangerous as they become more independent, sophisticated, and used in key decisions in areas like healthcare, banking, transportation, and national security. The fact that AI development is largely happening in a few huge organisations, as well as algorithmic opacity, bias, lack of accountability, and privacy concerns, all illustrate how crucial it is to have robust, unambiguous, and enforced AI governance frameworks. This research looks into how blockchain could help fix the flaws with how AI systems are run. Blockchain performs a great job of meeting the primary demands for good AI supervision, which are decentralisation, immutability, transparency, and tamper-resistance. By adding blockchain-based transparency tools to the processes of building, deploying, and running AI, stakeholders can make AI more accountable, traceable, and trustworthy, while also minimising the risks that come with AI that is not clear and not controlled. The proposed models, such as open AI development records, smart contracts for ethical compliance, decentralised AI governance consortia, and public audit trails for AI judgements, show how blockchain may make essential ideals about governance like openness, responsibility, fairness, and inclusiveness a reality. These models illustrate how to make sure that AI systems act in a way that is moral, lawful, and in line with what society thinks is right.

Blockchain has a lot of potential for AI governance, but there are still a lot of challenges with it. Scalability is still a major technical concern, especially when you think about how much data AI systems make and how fast AI-powered apps need to run. There are still privacy difficulties, though, because the immutability and openness of blockchain can conflict with data protection rules like the General Data Protection Regulation (GDPR), especially when it comes to the right to be forgotten. Making ensuring that AI systems, legacy infrastructure, and different blockchain platforms can all function together adds even more difficulties that need to be fixed. People with a lot of technical knowledge or a lot of tokens can also take over decentralised governance structures, which can be hard to grasp and get bogged in decision-making.

People from different professions, like technology, law, ethics, and policy, need to work together to fix these difficulties. Technologists need to keep coming up with innovative blockchain architectures that safeguard privacy, ways to reach consensus that can grow, and standards that work with AI governance. Legal experts and lawmakers need to amend the rules so that blockchain-enabled monitoring is possible while still maintaining basic rights and dealing with knotty questions of jurisdiction. Ethicists and social scientists need to make sure that governance models reflect society's values, keep people safe, and get people involved in democracy. To get the most out of blockchain-enhanced AI governance, future research is very vital. To test theoretical models, figure out what doesn't work in the real world, and make policy proposals based on facts, we need real-world examples of things like the Ocean Protocol and SingularityNET. We need to look into privacy-enhancing technology, scalable blockchain infrastructures, and changes to the law in order to make responsible AI governance function on a wide scale.

As AI impacts enterprises, economies, and society, effective governance is no longer an option; it is important to make sure that new technologies are good for people and do as little harm as possible. Blockchain technology can make AI governance much better if it is utilised responsibly and ethically. It can make AI systems more open, responsible, and open to feedback from all stakeholders. Everyone in society has a responsibility to make sure that AI is run appropriately. People's rights need to be protected while also allowing for new ideas. To do this, governments, business leaders, technologists, civil society groups, and the public all need to work together. Blockchain isn't a cure-all, but it's a crucial aspect of this combined effort since it helps build trust, transparency, and democratic oversight in the age of AI.

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