

Proof of Useful Intelligence (PoUI): Blockchain Consensus Beyond Energy Waste

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Abstract—Blockchain technology anchors decentralized systems by enabling secure, transparent data management across distributed networks, powering a wide range of applications — from foundational cryptocurrencies like Bitcoin to the recently emerging tokenization of real-world assets (RWAs), such as property and commodities. However, its scalability and environmental sustainability depend on consensus mechanisms that maintain network integrity without imposing excessive computational or energy burdens. Proof of Work (PoW), a prevalent mechanism seen in Bitcoin, relies on miners performing energy-intensive cryptographic computations to ensure robust security, yet driving significant resource demands. In contrast, Proof of Stake (PoS) selects validators based on the amount of cryptocurrency they stake, as exemplified by Ethereum post-Merge, providing a markedly more energy-efficient option than PoW. While PoW excels in delivering decentralized security through computational effort, it does so at the cost of high energy consumption; PoS, meanwhile, enhances participation accessibility and reduces resource use but introduces potential centralization risks due to wealth concentration among larger stakers. The rapid rise of artificial intelligence (AI) models, with their substantial energy consumption, underscores a growing strain on computational resources. Hence, it inspires us to propose a new consensus mechanism, namely, Proof of Useful Intelligence (PoUI). PoUI is a hybrid consensus mechanism where workers execute AI-based tasks, such as natural language processing or image analysis, to earn coins, which are then staked to secure the network, seamlessly integrating security with real-world utility. This system leverages decentralized functional nodes, i.e., job posters who submit tasks, market coordinators who oversee jobs distribution, workers who perform computations, and validators who ensure accuracy, all orchestrated by smart contracts for task execution and reward allocation. Our energy analysis benchmarks PoW at 3.51 kWh/miner, PoS at 0.1 kWh/validator, and PoUI at 0.6 kWh/worker — yielding a 97% energy reduction from PoW while adding value. Simulations further demonstrate that PoUI’s dynamic reward adjustment regulates worker participation in the job market, which subsequently encourages a sufficient number of validators in the network.

I. INTRODUCTION

Blockchain technology has revolutionized decentralized systems by enabling secure, intermediary-free transactions, fundamentally reshaping trust in digital environments [1], [2]. Introduced by Satoshi Nakamoto in 2008 as Bitcoin’s foundation, blockchain is a distributed ledger where transactions are cryptographically linked into blocks, replicated across a network of nodes, and secured without centralized control. This architecture ensures immutability and transparency,

driving applications beyond cryptocurrencies such as supply chain traceability and digital identity management, to enhance accountability and efficiency. One of the blockchain’s recent applications is the tokenization of real-world assets (RWAs), like real estate and art, which leverages blockchain to fractionalize ownership, boosting liquidity and democratizing access to high-value markets [3].

The stability of blockchain networks hinges on consensus mechanisms, i.e., protocols that ensure network agreement, but their energy demands pose significant challenges. Proof of Work (PoW) is the Bitcoin’s core mechanism that exemplifies this issue. It relies on energy-intensive cryptographic computations, which are estimated to be at 181.67 terawatt-hours (TWh) annually in 2025 [4] to secure the network — a burden that continues to spark environmental concerns [5], [6], [7]. PoW diverts vast resources to puzzles offering no practical utility beyond security. As blockchain adoption grows across diverse domains, the inefficiencies of PoW have intensified the need for sustainable consensus alternatives that balance security with tangible benefits [8].

The rapid emergence of artificial intelligence (AI) models, such as Large Language Models (LLMs) for text and image generation, has introduced a parallel challenge: their substantial power consumption [9]. Running LLMs demand vast computational resources, often exceeding hundreds of megawatt-hours per model, rivaling the energy intensity of PoW-based blockchains. This confluence of energy-hungry technologies inspires us to reimagine PoW’s wasteful computations. Hence, we propose Proof of Useful Intelligence (PoUI), a consensus mechanism that leverages AI models to perform valuable AI tasks while securing the blockchain, transforming PoW’s inefficiencies into productive outcomes.

At the core of PoUI is a decentralized marketplace that orchestrates task distribution and execution across the network. This marketplace involves four key roles: market coordinators, nodes with sufficient stake and reputation that manage job clusters and match tasks with workers; job posters, who submit tasks to the marketplace; workers, who execute tasks using AI models; and validators, who ensure the integrity of communications and task outcomes. Tasks are designed to be divisible into smaller, manageable chunks to enable flexible participation without real-time constraints. Upon completion, smart contracts automate payments, transferring compensation

from job posters to both market coordinators and workers, incentivizing engagement and ensuring fairness.

PoUI re-imagines blockchain consensus as a dual-purpose system that secures the network and creates tangible value through AI. This paper is structured as follows. In Section II, we explore traditional PoW and PoS mechanisms alongside recent advancements in Proof of Useful Work (PoUW) and Proof of Intelligence (PoI). Next, in Section III, we delve into the roles of functional nodes, illustrated with a simplified example. We then compare the energy consumption of PoW, PoS, and PoUI in Section IV with some assumptions. Following this, Section V discusses the market mechanism designed to regulate the number of workers effectively in processing the jobs with some simulation results. Finally, we present our conclusions in Section VI, underscoring PoUI's role as a pioneering step toward socially impactful blockchain technology.

II. RELATED WORK

Consensus mechanisms are critical to blockchain networks, enabling decentralized nodes to agree on the state of the ledger while ensuring security and trust. Various mechanisms have been developed, each balancing trade-offs in energy use, decentralization, and utility. This section examines the prominent consensus mechanisms with our proposed Proof of Useful Intelligence (PoUI).

A. Proof of Work (PoW)

PoW is the consensus mechanism used in Bitcoin, and it requires miners to solve computationally intensive cryptographic puzzles to validate transactions and add blocks to the blockchain. The first miner to solve the puzzle is rewarded, securing the network through this competitive process. The key advantages of PoW are its proven security as it relies on computational effort to make it highly resistant to attacks. Additionally, the mechanism is straightforward and widely understood.

However, PoW has significant drawbacks. The vast computational power required consumes enormous amounts of energy, often with no value beyond network security, raising environmental concerns. Additionally, mining has increasingly concentrated in the hands of large entities with specialized hardware, undermining decentralization. In contrast, PoUI offers significant energy efficiency, using only 0.6 kWh per node versus PoW's 3.51 kWh, while generating valuable AI-driven outputs (see Section IV). It also promotes broader participation through its job market, reducing centralization compared to PoW's hardware-driven model.

B. Proof of Stake (PoS)

PoS offers an alternative by selecting validators based on the amount of cryptocurrency they hold and stake, rather than their computational power. This reduces the need for energy-intensive calculations as compared to PoW. Also, it potentially broadens accessibility by eliminating the need for expensive hardware.

Yet, PoS has its own limitations. Validators with larger stakes are more likely to be chosen, which can centralize power among the wealthiest participants. Issues like the "nothing-at-stake" problem, where validators support multiple chains, pose new vulnerabilities. By contrast, PoUI extends beyond PoS's security-only framework, employing AI models to deliver practical outcomes like text and image generation. Its marketplace structure fosters inclusivity by compensating a wide range of participants, countering PoS's tendency toward wealth concentration (see Section III).

C. Proof of Useful Work (PoUW) and Variations

PoUW is first introduced in [10] with the aim to replace the computationally wasteful PoW used in systems like Bitcoin. The paper outlines a system where the computational efforts of miners are redirected toward training machine learning (ML) models, thereby producing socially beneficial outcomes rather than merely solving cryptographic puzzles.

Generally, the miners compete to train ML models, submitting their solutions to a smart contract that evaluates the quality of the work based on predefined metrics, such as model accuracy or loss on a validation dataset. Then, the miner producing the best model wins the block reward, consisting of both the client's payment and standard blockchain incentives.

Some variations of PoUW are observed in different implementations. For instance, [11] leverages computational power for decentralized applications (dApps), while [12] focuses on training deep learning models, requiring model performance to exceed a predefined threshold for block validation. Additionally, [12] applies PoUW to combinatorial optimization problems, such as scheduling and vehicle routing. However, these implementations have notable limitations. The approaches in [10] and [12] are constrained to ML and deep learning tasks, demanding specialized hardware and expertise, which restricts participation to well-resourced nodes. Similarly, [12] targets niche optimization problems, limiting its applicability and contributor pool. While [11] supports a broader range of dApps, it lacks a cohesive framework for task allocation and reward distribution, reducing its scalability and efficiency.

In contrast, our proposed PoUI addresses these shortcomings by introducing a decentralized job market that supports a diverse range of AI-driven tasks, from natural language processing to public goods contributions (e.g., verifying open datasets). Unlike the specialized focus of [10], [12], and [13], PoUI leverages widely accessible AI models, lowering barriers to entry and broadening participation. Furthermore, PoUI's market coordinators and smart contract-based task management provide the unified coordination absent in [11], ensuring efficient task distribution and reward allocation. By integrating a PoS-based validator selection with dynamic reward adjustments, PoUI enhances inclusivity and scalability, offering a more versatile and socially impactful consensus mechanism compared to existing PoUW implementations.

D. Proof of Intelligence (PoI)

PoI is a consensus mechanism that leverages computational resources for AI-related tasks, such as neural network inference, to secure the blockchain while producing valuable

outputs [14]. In PoI, nodes compete to execute predefined AI tasks, with the best-performing node (e.g., based on model accuracy) earning the right to validate the block. This approach reduces energy waste compared to PoW by redirecting computational effort toward practical applications.

PoI's task scope, however, is often limited to specific ML frameworks. It requires specialized hardware and expertise, which may restrict participation and scalability. Additionally, its consensus relies solely on task performance, potentially favoring computationally powerful nodes and risking centralization. In contrast, our proposed PoUI introduces a decentralized job market supporting diverse AI-driven tasks, from text generation to public goods contributions, and integrates a PoS-based validator selection to enhance inclusivity and decentralization (see Section III).

III. PoUI NETWORK ARCHITECTURE

In the following, we elaborate on the architecture of the PoUI network and the corresponding functional nodes.

A. Functional Nodes in the PoUI Network

The PoUI consensus mechanism operates through four types of functional nodes, each performing distinct roles to support the network's operation, security, and utility. These functional nodes are:

- **Job Posters:** Nodes that submit tasks to the network for execution.
- **Market Coordinators:** Nodes responsible for coordinating job postings and managing the work completed by workers.
- **Workers:** Nodes that perform the tasks using AI models such as LLMs or similar computational resources.
- **Validators:** Nodes responsible for validating the work and adding blocks to the blockchain.

In the following, we detail the role and operation of each functional node within the PoUI ecosystem.

1) *Job Posters:* Job posters are functional nodes that initiate the process by submitting tasks to the job market, which is managed by market coordinators. These tasks require computational services, typically provided by AI models, such as text and image generation and may even contribute to public goods (e.g., verifying Wikipedia entries).

Tasks are categorized into two types, i.e., private jobs, which benefit the job poster directly, and public good jobs, which provide value to the broader community. For private jobs, job posters are typically required to pay a fee in the network's currency to incentivize workers and cover operational costs. Conversely, for public good jobs, this payment may be waived, with rewards potentially subsidized by the network (e.g., through block rewards or a community fund) to encourage contributions to societal benefit. Each job submission includes detailed specifications, such as:

- **Job Type:** The category of task (e.g., image processing).
- **Job Description:** A detailed explanation of the task requirements.

- **Job Validity Period:** The duration for which the job remains available before it is removed from the market if not accepted.
- **Runtime Requirements:** The estimated computational time or resources needed to complete the task once accepted.

2) *Market Coordinators:* Market coordinators are the functional nodes that manage the job market and facilitate interactions between job posters and workers. When a job poster submits a task, its validity is evaluated by the coordinators; if accepted, the task is added to the job queue — a decentralized list of available tasks. Job queues are synchronized across all coordinators to ensure consistency in the network's task list. The history of job posters, including metrics like submission frequency and task quality, is recorded and tracked by coordinators to maintain reliability and prevent abuse.

3) *Workers:* Workers are functional nodes equipped with AI models or similar computational resources, tasked with executing the jobs listed by market coordinators. Workers review the job listings and select tasks they are interested in and capable of completing.

When a worker accepts a job, a smart contract is established among the market coordinator, the job poster, and the worker. This smart contract governs the task execution process, including deadlines, quality requirements, and reward distribution. Upon successful completion of the tasks, both workers and market coordinators earn coins as rewards.

While it is possible for a group of workers to form a cluster to secure and execute jobs collaboratively, similar idea on collaborative computation has been found in [15], [16] and will not be discussed in this paper.

4) *Validators:* Validators are functional nodes responsible for ensuring the integrity of the work performed by workers and securing the blockchain by adding validated blocks. Validators are selected using PoS mechanism, where nodes with higher stakes have a greater likelihood of being chosen. Validators perform a critical role in verifying the quality and correctness of workers' outputs before these are included in the blockchain. Notably, a validator can also act as a worker, enabling flexible participation when the demand for workers is high. However, it cannot validate its own work to avoid conflicts of interest and preserve trust.

B. Centralization Risks and Mitigation

The PoS-based validator selection risks centralization if active workers accumulate disproportionate coins to increase their stake and influence. To address this, we adopt existing methods such as (i) applying stake caps to limit the maximum coins stakable per validator, preventing dominance by high-earners [17]; and (ii) adding random selection adjustments to give less-staked nodes better odds [8]. These measures ensure balanced participation and preserve decentralization across the validator pool.

C. Security Against Malicious Attacks

AI-driven tasks in PoUI, such as text or image generation, lack a single correct answer, making the network vulnerable

to malicious attacks. These include fraudulent tasks by job posters, low-quality outputs by workers, or collusion between nodes to approve invalid work. PoUI mitigates these risks with the following measures:

- 1) Task Screening: Market coordinators check submitted tasks for legitimacy based on job poster history and task relevance, rejecting suspicious tasks to prevent fraud.
- 2) Output Verification: Validators use frameworks like MCP [18] or CodeAct [19] to assess AI output quality. Multiple validators review subjective tasks, requiring majority agreement for approval to counter low-quality submissions.
- 3) Collusion Prevention: Validators are randomly assigned to tasks and cannot verify their own work. Smart contracts log all decisions transparently to detect collusion.
- 4) Reputation System: Nodes earn reputation scores based on honest behavior. Malicious actions, like submitting fraudulent tasks or invalid outputs, lower scores, reducing rewards or access to tasks.

These strategies ensure PoUI's resilience against malicious attacks, maintaining network trust. Future work will explore advanced attack detection to further enhance security.

D. Incentive Structure and Dynamic Reward Balancing

In PoUI, workers complete jobs from job market to earn coins. These coins can then be staked by workers to qualify as validators under the PoS mechanism, creating a pathway for active contributors to gain influence in the network. Besides, the workers and validators may sell the coins to the job posters to fund new tasks or exchange for other resources, enhancing liquidity within the ecosystem.

To ensure a balanced ecosystem, the rewards earned by workers are dynamically adjusted based on job demand (see Section V). Specifically, when the number of pending jobs in the market exceeds a predefined threshold, workers' rewards are increased to incentivize task completion and clear the backlog. Conversely, when the job queue is low, rewards for workers are reduced, reflecting lower demand. This dynamic adjustment mechanism ensures the network adapts efficiently to varying workloads, encouraging workers to remain active and maintain system throughput.

E. Example

Fig. 1 depicts the simplified workflow of the PoUI consensus mechanism across four key stages, i.e., job posting, job acceptance, job completion, and reward distribution.

In the first stage, as shown in Fig. 1(a), a job poster initiates the process by submitting a task to the job market. The job poster sends the job details, including specifications such as job type, description, validity period, and runtime requirements, to the market coordinator. The market coordinator, responsible for managing the job market, evaluates the task's validity and, if accepted, adds it to a decentralized job queue, making it available for a worker to access.

Once the job is listed, the second stage, depicted in Fig. 1(b), involves a worker searching for and accepting a job. The

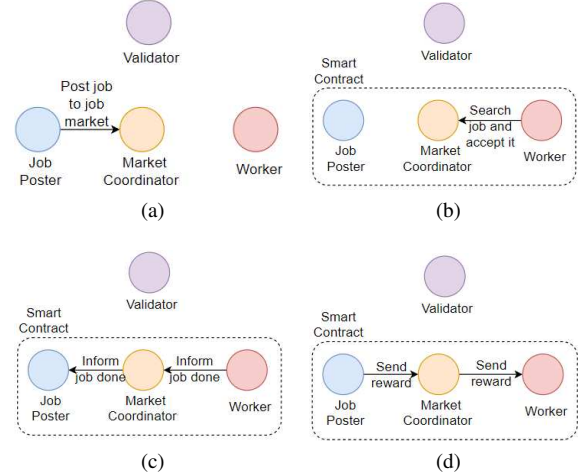


Figure 1: Workflow of the PoUI consensus mechanism: (a) Job poster submits a task to market coordinator, (b) Worker searches and accepts a job, establishing a smart contract, (c) Worker informs market coordinator of job completion, validated by validator, (d) Job poster sends rewards via smart contract to market coordinators and worker.

worker interacts with the market coordinator to browse the job queue, selects a task based on its interest and capability, and accepts it. Upon acceptance, a smart contract is established among the job poster, market coordinator, and worker. This smart contract governs the task execution process, enforcing deadlines, quality requirements, and reward distribution.

In the third stage, shown in Fig. 1(c), the worker completes the assigned task and informs the market coordinator of the job's completion. The market coordinator then notifies the job poster that the task is done. Throughout this process, validator oversees the interactions, ensuring the integrity of the communications and verifying the quality of the worker's output before it is recorded on the blockchain.

Finally, in the fourth stage, illustrated in Fig. 1(d), the reward distribution occurs. Upon validation of the completed task, the smart contract triggers the payment process. The job poster sends the reward to the market coordinator, who then distributes the coins to the worker for task execution and retains a portion as a coordination fee.

F. Practical Issues in Smart Contract Integration and Development

Integrating PoUI into existing smart contracts or developing new ones presents practical challenges due to its unique AI-driven task management and node interactions. Below, we outline the key challenges to the implementation.

- Integration with Existing Smart Contracts: Existing platforms like Ethereum use Solidity for smart contracts, which may not support PoUI's job market or reputation system natively. A middleware layer, such as an oracle or off-chain coordinator, could bridge PoUI's task validation (e.g., using MCP) with on-chain execution, but this increases latency and costs. Additionally, PoUI's multi-node interactions (e.g., task screening, output verification)

Table I: Energy characteristics of Bitmain Antminer S21 Pro for PoW.

Parameter	Value	Unit
Hash Rate, H	234	TH/s
Energy per Hash, E_{hash}	15	J/TH
Power Consumption	3510	W
Energy per Hour, $E_{\text{total}}^{\text{PoW}}$	3.51	kWh/miner

require complex contract logic may cause gas fees to increase. Optimizing contract functions, such as batching validator approvals, potentially mitigate this issue.

- New Smart Contracts: New contracts must encode PoUI's dynamic reward adjustments (Section V) and reputation system (Section III.C). Subjective AI output validation requires multiple validator inputs, complicating contract logic. Besides, managing a decentralized job queue and validating AI tasks on-chain could overload networks with high transaction volumes. Off-chain computation for task screening or output scoring, with results hashed on-chain, may improve scalability.
- Common Challenges: Contracts must enforce anti-collusion and reputation penalties robustly to prevent exploits. It requires rigorous audit and formal verification. PoUI contracts need to interact with external AI models or data (e.g., for public good tasks), necessitating secure oracles or APIs, which adds complexity.

These practical considerations highlight the trade-offs in deploying PoUI. While integration with existing systems offers faster adoption, new contracts enable tailored functionality. Future work will explore optimized contract designs and layer-2 integrations to enhance PoUI's scalability and cost-efficiency.

IV. ENERGY CONSUMPTION ANALYSIS OF PoW, PoS, AND PoUI

As blockchain technology scales, the energy efficiency of the consensus mechanisms grows increasingly important. We evaluate the energy consumption of each consensus mechanism through the following equation,

$$E_{\text{tot}} = E_{\text{sec}} + E_{\text{use}}, \quad (1)$$

where E_{sec} represents the energy essential for upholding blockchain consensus and integrity, while E_{use} represents the energy devoted to computations that produce valuable outputs beyond the essential task of securing the network.

To provide a standardized reference for the energy consumption analysis, we present the energy characteristics of the Bitmain Antminer S21 Pro [20], a modern mining rig used in PoW-based blockchains like Bitcoin in Table I. We now explore the energy consumption of PoW, PoS, and PoUI using Eq. 1.

A. Proof of Work (PoW)

PoW secures the network by leveraging miners to solve complex cryptographic puzzles, a process that demands substantial energy expenditure. The security energy per miner over one hour is modeled as,

$$E_{\text{sec}}^{\text{PoW}} = H \times E_{\text{hash}} \times 3600, \quad (2)$$

where, H is the hash rate per miner (hashes per second), E_{hash} is the energy per hash (joules per hash), and 3600 is the number of seconds in an hour. Since PoW performs no useful work beyond security, $E_{\text{use}}^{\text{PoW}} = 0$, and thus the energy per miner per hour is $E_{\text{total}}^{\text{PoW}} = E_{\text{sec}}^{\text{PoW}}$.

Using the Bitmain Antminer S21 Pro specification from Table I, the security energy is,

$$\begin{aligned} E_{\text{sec}}^{\text{PoW}} &= (234 \times 10^{12}) \times (15 \times 10^{-12}) \times 3600 \\ &= 3.51 \text{ kWh/miner}. \end{aligned} \quad (3)$$

Thus, $E_{\text{total}}^{\text{PoW}} = 3.51 \text{ kWh/miner}$, reflecting PoW's high energy demand compared to alternative mechanisms.

B. Proof of Stake (PoS)

PoS secures the network by selecting validators based on staked cryptocurrency. The security energy per validator over one hour is modeled as,

$$E_{\text{sec}}^{\text{PoS}} = P_{\text{val}} \times t, \quad (4)$$

where P_{val} is the power consumption per validator (watts), t is time in hours. Since PoS performs no useful work beyond security, $E_{\text{use}}^{\text{PoS}} = 0$, and thus the total energy per validator over one hour is,

$$E_{\text{tot}}^{\text{PoS}} = E_{\text{sec}}^{\text{PoS}}. \quad (5)$$

Assuming $P_{\text{val}} = 100 \text{ W} = 0.1 \text{ kW}$ for an Ethereum-like validator node (e.g., a standard PC) and $t = 1 \text{ hour}$,

$$\begin{aligned} E_{\text{sec}}^{\text{PoS}} &= 0.1 \text{ kW} \times 1 \text{ hour} \\ &= 0.1 \text{ kWh/validator}. \end{aligned} \quad (6)$$

Thus, $E_{\text{tot}}^{\text{PoS}} = 0.1 \text{ kWh/validator}$, a 97% reduction compared to PoW's 3.51 kWh/miner, highlighting PoS's energy efficiency.

C. Proof of Useful Intelligence (PoUI)

We assume that a PoUI worker operates at high utilization to maximize computational efficiency. To provide a concrete estimate, we consider typical values for a GPU server equipped with an NVIDIA A100 GPU, a common choice for LLM inference. The A100 draws approximately 250–400 W depending on its configuration, with system components (e.g., CPU, memory, cooling) contributing to a total active power consumption, denoted as P_{act} of 500 W during full utilization [21]. Over one hour, this corresponds to an energy consumption for useful work of $E_{\text{use}}^{\text{PoUI}} = 0.5 \text{ kWh/worker}$. For security energy, we adopt the staking energy consumption from Eq. 6, where $E_{\text{sec}}^{\text{PoUI}} = 0.1 \text{ kWh/validator}$.

When validators also act as workers, they share hardware. The total energy per node over one hour is modeled as

$$E_{\text{tot}}^{\text{PoUI}} = \kappa_{\text{sec}} E_{\text{sec}}^{\text{PoUI}} + \kappa_{\text{use}} E_{\text{use}}^{\text{PoUI}}, \quad (7)$$

Table II: Energy consumption per node over one hour.

Mechanism	$E_{\text{sec}}(\text{kWh/node})$	$E_{\text{use}}(\text{kWh/node})$	$E_{\text{tot}}(\text{kWh/node})$
PoW	3.51	0	3.51
PoS	0.1	0	0.1
PoUI	0.1	0.5	0.6

where κ_{sec} and κ_{use} are weighting factors representing the proportion of effort allocated to security (validation) and useful work (task execution), respectively. When a node focuses solely on validation, $\kappa_{\text{sec}} = 1$ and $\kappa_{\text{use}} = 0$, yielding

$$\begin{aligned} |E_{\text{tot}}^{\text{PoUI}}|_{\text{val}} &= (1)(0.1 \text{ kWh}) + (0)(0.5 \text{ kWh}) \\ &= 0.1 \text{ kWh}. \end{aligned} \quad (8)$$

When a node performs both task execution and validation concurrently, $\kappa_{\text{sec}} = 1$ and $\kappa_{\text{use}} = 1$, and hardware overlap resulting in:

$$\begin{aligned} |E_{\text{tot}}^{\text{PoUI}}|_{\text{wrk+val}} &= (1)(0.1 \text{ kWh}) + (1)(0.5 \text{ kWh}) \\ &= 0.6 \text{ kWh}. \end{aligned} \quad (9)$$

D. Comparative Analysis

This section analyzes the energy consumption profiles of PoW, PoS, and PoUI based on the metrics from Section IV-A - IV-C with a summary provided in Table II.

- 1) Energy Efficiency in Security: PoW consumes the highest security energy at 3.51 kWh/miner, driven by intensive cryptographic puzzle-solving. In contrast, PoS and PoUI achieve 0.1 kWh/validator, a 97% reduction, due to staking-based mechanisms that eliminate mining.
- 2) Utility Through Useful Work: PoW and PoS have no useful work energy ($E_{\text{use}} = 0$). PoUI allocates 0.5 kWh/worker for AI tasks, adding value while maintaining efficiency.
- 3) Total Energy and Trade-Offs: PoW's 3.51 kWh/miner (Table II) is entirely for security, offering no utility. PoS's 0.1 kWh/validator is the lowest but lacks useful output. PoUI's 0.6 kWh/node, with 0.1 kWh for security and 0.5 kWh for useful work, achieves an 83% reduction from PoW while surpassing PoS in utility (Table II).

V. POUI MARKET MECHANISM

The PoUI consensus mechanism combines useful work with the PoS-like staking process. In this section, we elaborate the mechanism to regulate an adequate number of workers in preserving the stability of job market.

A. Dynamic Reward Adjustment

The PoUI consensus mechanism implements a dynamic reward adjustment strategy to maintain an optimal balance of workers based on the number of pending jobs. We assume that job quantities are normalized, such that one job requires one worker to complete within a single interaction, denoted as time step i . However, jobs of varying complexity, specifically those requiring multiple interactions, are split into an equivalent number of normalized jobs to ensure compatibility with this model.

The number of jobs in the market fluctuates over time due to varying demand. We assume an informed analysis is conducted to derive the required number of workers in the network, denoted as $\tilde{w}$, representing the target worker count. The total number of available workers in the network at time step i is denoted as w_i , with the assumption that worker availability is unconstrained. With α denoting the sensitivity of the reward to the disparity between target and current worker counts, the subsequent equation formalizes a dynamic adjustment process that modifies the worker reward r to align participation with job demand, i.e.,

$$r_{i+1} = \begin{cases} r_i \left[1 + \alpha \left(\frac{\tilde{w} - w_i}{w_i} \right) \right] & \text{if } \frac{|\tilde{w} - w_i|}{w_i} \geq \Delta \\ r_i & \text{otherwise.} \end{cases} \quad (10)$$

Here, the adjustment occurs when the relative difference between the current and target number of workers exceeds a predefined threshold Δ , i.e., $\frac{|\tilde{w} - w_i|}{w_i} \geq \Delta$. In such a case, the next reward r_{i+1} increases if the number of workers is insufficient ($\tilde{w} > w_i$), encouraging participation, or decreases if workers are excessive ($\tilde{w} < w_i$), optimizing resource allocation. If the difference falls below Δ , the reward remains unchanged, ensuring stability for minor fluctuations.

Simulation is detailed in Subsection V-B to validate this mechanism.

B. Simulation Setup

We assume that the job market requires a target worker count of $\tilde{w} = 250$ to maintain stability. For this simulation, the network starts with an initial worker count of $w_0 = 100$, and the maximum number of workers is capped at a sufficiently large value. The dynamic reward adjustment, formalized in Eq. 10, uses parameters $\alpha = 0.2$ (sensitivity to worker disparity) and $\Delta = 0.05$ (adjustment threshold). We execute 200 simulation steps to assess the system's behavior under these conditions.

To model how workers respond to these reward adjustments, we define their participation dynamics as follow. The number of workers in the next interaction, denoted as w_{i+1} , adapts to reward changes based on the utility function:

$$w_{i+1} = w_i \beta \left(1 + \frac{r_{i+1} - r_i}{r_i} \right) + N \quad (11)$$

where $\beta = 1$ represents the workers' sensitivity to reward variations, and $N = \text{random} \left(-\gamma w_{i+1}^{(c)}, \gamma w_{i+1}^{(c)} \right)$ introduces random values as noise, with $\gamma = 0.05$ defining the range of random fluctuations in the worker count. This model assumes that most workers respond sensitively to reward adjustments, capturing realistic participation dynamics.

C. Result

Fig. 2 illustrates the dynamic behavior of the PoUI consensus mechanism over 200 time steps, capturing the trends in worker rewards (blue line), the number of workers (red line), and the target worker count (dashed red line at 250 workers). The simulation evaluates how the dynamic reward adjustment

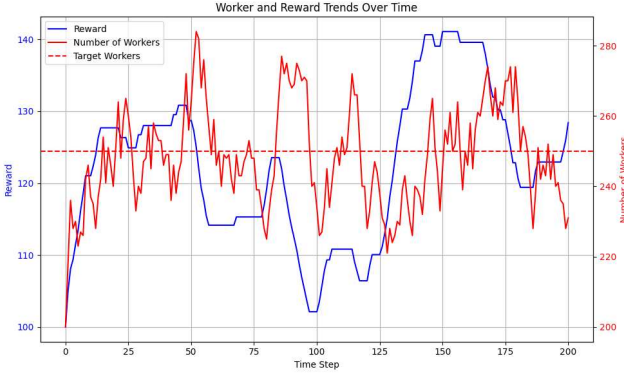


Figure 2: Worker and reward trends over 200 time steps in the PoUI simulation, illustrating the dynamic adjustment of rewards (blue) and the corresponding number of workers (red) relative to the target worker count of 250 (dashed red line).

strategy influences worker participation in response to varying job demands, with parameters set as $\alpha = 0.2$, $\beta = 1$, $\gamma = 0.05$ and $\Delta = 0.05$.

Initially, the network starts with 100 workers, significantly below the target of 250. As a result, the reward increases sharply in the first 25 time steps, peaking at approximately 140, to incentivize worker participation. This adjustment effectively drives the number of workers upward, reaching the target around time step 25. However, the number of workers fluctuates around the target throughout the simulation, driven by the noise term N in the utility function 11, which models realistic variations in worker participation.

Generally, the reward trend responds to these fluctuations, decreasing when the worker count exceeds the target (e.g., around time step 50) to discourage excessive participation, and increasing when the worker count falls below the target (e.g., around time step 100) to attract more workers. Despite these oscillations, the system demonstrates overall stability, as the number of workers generally remains close to the target of 250, with deviations typically within ± 20 workers. The reward stabilizes around 120 after the initial adjustment phase, indicating that the dynamic reward mechanism effectively balances worker participation with job demand.

The result highlights PoUI's ability to adapt to varying network conditions through its reward adjustment strategy. The mechanism successfully maintains the worker count near the target, ensuring efficient job processing while avoiding over- or under-participation. However, the observed fluctuations suggest that fine-tuning parameters such as α (sensitivity to worker disparity) could further reduce variability and enhance system stability in future implementations.

VI. CONCLUSION

The PoUI consensus mechanism represents a significant advancement in blockchain technology by integrating the energy-efficient staking principles with the productive potential of useful computational work. Unlike Proof of Work (PoW), which expends substantial energy (e.g., 3.51 kWh per miner per hour) on security alone, PoUI achieves a dual-purpose

design, securing the network with minimal energy (0.1 kWh per validator) while dedicating additional resources (0.5 kWh per worker) to run AI models for valuable tasks. This balance reduces energy waste by approximately 83% compared to PoW, while surpassing PoS in utility. Due to page limitations, several aspects such as the detailed mechanism of the functional nodes, extended comparisons, broader simulation scenarios, etc. could not be explored in depth in this paper and will be revisited in future work.

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