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A Blockchain-Based E-Recapitulation System for Indonesia'S Presidential Election

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Abstract. Blockchain-based e-recapitulation systems benefit the recapitulation process compared to centralized e-recapitulation systems by introducing accessibility, anonymity, auditability, immutability, inclusivity, privacy, security, transparency, and trust. This paper designed and implemented a blockchain-based e-recapitulation system with an exploratory case study of Indonesia's presidential election. The case study demonstrates the development of the blockchain-based e-recapitulation system and the evaluation of the system on the Ethereum blockchain. The e-recapitulation process in Indonesia involves numerous manual steps by human staff in the field. The recapitulation process consists of six tiered starts from the bottom up: polling station, village / sub-district, district, regency/city, province, to national, with 820,161 polling stations and over 204 million registered voters nationwide for the 2024 presidential election. The real-case deployment of the blockchain-based e-recapitulation provides a solution to the issues of a centralized e-recapitulation system run by the Indonesia General Commission. It also serves as an alternative to improve the overall quality of the recapitulation process for significant events like the presidential election. This paper further employs necessary smart contracts in the Ethereum blockchain and calculates the gas fee required for the e-recapitulation process based on the case study.

Keywords: Blockchain, E-recapitulation, Ethereum, IPFS, Presidential election

1. Introduction

Recapitulation is a crucial part of the election process after the voting to consolidate and verify the results from the polling stations. Recapitulation involves aggregating and reconciling votes in different precincts or districts to determine the election outcome. The e-recapitulation system in a presidential election streamlines the process using electronic devices or specialized software to collect and summarize real-time voting results. This technology reduces the time-consuming and error-prone task of manually collecting and collating vote counts from individual polling stations (Sihite & Salman, 2019). The information is securely transmitted to a system, ensuring up-to-date and accurate information on voting results. Implementing an e-recapitulation system in a presidential election can enhance the speed and accuracy of result dissemination, allowing for quicker decision-making and reducing uncertainty (Djuyandi et al., 2019). Additionally, the e-recapitulation system improves the integrity and security of the election process by leveraging encryption and robust cybersecurity measures to safeguard the transmission and storage of voting data against unauthorized access or tampering. This increased security instills confidence among voters, candidates, and stakeholders in the legitimacy of the electoral outcome.

In transforming election systems, numerous blockchain-based e-voting systems, i.e. (Christyono et al., 2021; Goyal & Kumar, 2021; Mark et al., 2021) successfully utilize blockchain technology as a distributed and decentralized ledger, providing real-time and tamper-proof vote aggregation. The blockchain is a secure and immutable repository for storing voting data, allowing election officials, political parties, candidates, and the public to independently verify the accuracy of recorded votes. This increased transparency fosters confidence in the integrity of election results and reduces suspicions of electoral fraud and manipulation (Anitha et al., 2023; Jafar et al., 2021). The decentralized nature of blockchain technology ensures that no single entity or central authority controls the voting data, distributing data across multiple nodes in the network (Buterin, 2014; Nakamoto, 2008). Thus, blockchain-based e-recapitulation can potentially leverage existing election systems, specifically where the election cannot be held online. Manual voting processes in elections can use the e-recapitulation system as integral for the election process. The disadvantages of the e-voting system potentially increase disenfranchisement and raise security concerns on the current infrastructure (Darmawan, 2021; Park et al., 2021). In addition, public sector reforms and public servant training need addressing to ensure readiness and sustainability (Hapsara et al., 2017).

The Indonesia presidential election is a significant democratic event where eligible citizens exercise their right to vote and elect their President and Vice President every five years. The election process involves multiple stages, including campaigning, debates, and voting day, where registered voters head to their designated polling stations to cast their ballots. The election is overseen by the General Election Commission (KPU) of Indonesia, ensuring the integrity and fairness of the process. The KPU announced 204,807,222 registered voters for the 2024 presidential election, with 1,750,474 abroad and 820,161 polling stations nationwide (Humas KPU, 2023). The House of Representatives (DPR) has agreed on IDR 76.6 trillion to implement the 2024 elections (DPR RI, 2022). The presidential election voting process is scheduled to start on 14 and 15 February 2024, with 35 days recapitulation process until 20 March 2024 (KPU, 2023). The 2024 presidential election will be held on-site without e-voting or e-recapitulation. Although simulations on e-voting have been deployed on a smaller scale, the government of Indonesia and DPR have opted to refrain from using e-voting for presidential elections due to their lack of legal basis. KPU has developed information systems to assist the election process since 2014, e.g., Situng and Sirekap (Kustiasih, 2021).

A study on the e-recapitulation system in (Djuyandi et al., 2019) proposed using the e-recapitulation system for the general election in Indonesia to transform the manual system, which is costly, less accountable, less effective, and less efficient. The study highlighted the importance of e-recapitulation in modernizing the electoral system, in this case, in Indonesia. Another study (Seftyanto et al., 2019) designed an electronic election system with Hyperledger blockchain based on a case study in Indonesia.

The study revealed four major problems of the 2019 Indonesia general election: logistic distribution, counting duration, inconsistent ruling, and recapitulation error. A similar study (Anitha et al., 2023) on the design of blockchain-based voting systems emphasized the benefits of blockchain technologies to voting and election processes: better security and transparency with lower cost and shorter waiting time. Multiple studies (Alvi et al., 2022; Anwar ul Hassan et al., 2022; Fatrah et al., 2019; Hjalmarsson et al., 2018; Tanwar et al., 2023; Taş & Tanrıöver, 2021; Yi, 2019) on e-voting and e-election systems alone suggested the importance of digital transformation for better voting or election systems. A review article by (Jafar et al., 2021) on the topic presented seven future research directions, i.e., scalability (processing overheads), user identity, transaction privacy, energy efficiency, maturity, acceptability, and user adoption (political resistance).

This paper intends to deploy blockchain-based e-recapitulation to support the digital transformation of the Indonesia presidential election. Existing articles on e-voting and e-recapitulation, both blockchain-based and not, are evaluated to reveal the state-of-the-art and present the research gap. The novelty and contributions of this paper are to exploit blockchain technologies for e-recapitulation and deploy the blockchain-based e-recapitulation system for the Indonesia presidential election. The dataset from the 2019 Indonesia presidential election dataset is used to test and evaluate the blockchain-based e-recapitulation system. The rest of this paper is organized as follows. Section 2 reviews related works and literature that underpins this study: e-recapitulation and blockchain-based e-recapitulation. Section 3 describes the research methods: case study description and the development of the blockchain-based e-recapitulation system. Section 4 presents the use case deployment results with discussions on key findings. Finally, Section 5 concludes this paper with some recommendations for future work.

2. Related Works

Numerous studies on blockchain-based e-voting systems have been proposed in recent years from 2018-2023: (Anwar ul Hassan et al., 2022; Christyono et al., 2021; Hjalmarsson et al., 2018; Seftyanto et al., 2019; Tanwar et al., 2023; Wicaksana et al., 2021) and particularly a blockchain-based e-recapitulation system in (Djuyandi et al., 2019). Integration of blockchain technologies to enhance parts of the election process studied by (Alvi et al., 2022; Anitha et al., 2023; Fatrah et al., 2019; Taş & Tanrıöver, 2021; Yi, 2019) focus on ensuring the security and transparency of blockchain-based e-voting systems. A review article published in 2023 on blockchain for e-voting systems summarized the security requirements for voting systems: auditability, accuracy, democracy or singularity, vote privacy, robustness and integrity, lack of evidence, transparency and fairness, availability and mobility, verifiable participation or authenticity, accessibility and reassurance, recoverability and identification, and voters verifiability (Jafar et al., 2021). Table 1 compares the existing studies on blockchain-based e-voting and e-recapitulation systems and related blockchain-based solutions for election.

Table 1: Comparison of blockchain-based e-voting systems

Year	Ref	Focus	Blockchain	Results
2023	(Tanwar et al., 2023)	E-voting	Ethereum	This paper discusses core components, challenges, and opportunities in using blockchain technology for confidentiality, authentication, access control, trust, and reputation. It also discusses the Election Dapp database, verifying votes twice, and maintaining voter anonymity. Future research aims to explore blockchain integration with edge computing and handling security and data integrity issues.
2023	(Alvi et al., 2022)	Digital voting	Ethereum 2.0	A blockchain-based digital voting system using smart contracts aims to ensure voter engagement, credibility, and fairness in elections. The system involves three smart contracts. The encrypted cast votes are stored as a hash, reducing costs and

				preventing voter identification. Voters can verify their vote using a unique vote ID, allowing them to vote globally. This method aims to increase voter numbers and achieve democracy in every region.
2022	(Anwar ul Hassan et al., 2022)	Liquid democracy	Hyperledger Fabric	This paper introduces a blockchain-based electronic voting system using smart contracts for secure, cost-effective elections while preserving voter anonymity. The system offers democratic countries a new way to transition from pen-and-paper elections to a more efficient, secure, and transparent method. The study addresses legal and technical constraints that may hinder blockchain's use in electronic voting.
2022	(Anitha et al., 2023)	Transparent voting	Ethereum	The decentralized voting system utilizes blockchain and smart contracts for efficient and transparent voting. It uses candidate or voter information, manages voting methods, and enhances validation and assignment phases. The project plans to integrate Machine Learning with facial recognition, improving security and preventing duplicate and forged votes. Additionally, two-factor authentication is included to avoid proxy votes.
2021	(Christyono et al., 2021)	E-voting	Ethereum (Proof-of-Authority)	The study developed an electronic voting system using a website, database, and the Go Ethereum blockchain. The system architecture combines the web and database servers with the blockchain's peer-to-peer network, ensuring secure and transparent audits. Testing revealed that genesis block configurations, including the PoA algorithm and sealer number, impact blockchain performance.
2021	(Wicaksana et al., 2021)	Secure and auditable e-voting	Ethereum	The e-voting system on the Ethereum blockchain was tested using real-world data from the 2019 Jelupang regional representative election in Indonesia. Short block time can cause block losses in mining, while high block time delays users. The system can commit around 23 transactions per second, with 15,725 votes committed within 12.75 minutes. The total time required to create all blockchain accounts was 13.4 hours.
2021	(Taş & Tanrıöver, 2021)	Manipulation prevention model	Ethereum	This work proposes a double-layer security model to prevent manipulations during elections and election results. The model ensures voter privacy, no central authority is needed, and distributed voting structures. Simulation results show that the system works as intended, with valid voter ballots recorded as transactions. Even when a node becomes inoperable, the system continues functioning, and election results are announced without data loss.
2019	(Djuyandi et al., 2019)	E-recapitulation	N/A	Indonesia's IT development has significantly increased in the past decade, leading to e-recapitulation technology to streamline the election management process. This technology transforms the manual system into an accountable, effective, and efficient system. However, e-recapitulation requires officials to be honest and fair, and data must be secured to prevent

				interference. Support for mature facilities and infrastructure is crucial, as well as cultural and political consensus among executive body members. Focus group discussions suggest that e-recapitulation technology can provide more security and minimize post-election conflicts caused by fraud in the vote-counting process.
2019	(Seftyanto et al., 2019)	E-election	Hyperledger	The proposed electronic election system utilizes blockchain technology to address issues in Indonesia's 2019 General Election, ensuring secure voting and increasing participant trust. The design secures votes from voting booths to candidate declarations, enhancing participant trust and security.
2019	(Fatrah et al., 2019)	E-voting	N/A	Proposed Proof of Concept Blockchain-based voting system aims to improve election transparency, voter privacy, and voter count by allowing eligible voters to participate and audit. With guaranteed security, no additional security section is needed.
2019	(Yi, 2019)	Securing e-voting	N/A	A blockchain-based e-voting scheme meets essential requirements, with blocks linked by signatures. Voters can vote according to a candidate's list or choose their preferred candidate. The system is public and not encrypted. However, blockchain uses ECC public key cryptography, which is not secure against quantum computer attacks. Future research should focus on quantum computer attack countermeasures.
2018	(Hjalmarsson et al., 2018)	E-voting	Ethereum (Proof-of-Authority)	This paper introduces a blockchain-based electronic voting system using smart contracts for secure, cost-efficient elections while ensuring privacy. The technology overcomes limitations and adoption barriers, ensuring election security, integrity, and transparency. The Ethereum private blockchain supports hundreds of transactions per second, but additional measures are needed for larger countries.

Although using blockchain as an immutable ballot may seem promising, the technology does little to solve the fundamental issues in elections, in which blockchain introduces additional vulnerabilities (Park et al., 2021). In addition, the Indonesian government does not have the legal basis to conduct an e-election. Various information systems have been developed and tested by the KPU in recent years. These information systems aim to assist the recapitulation process, and manual recapitulation problems in Indonesian elections have been identified by (Djuyandi et al., 2019). Thus, this study aims to develop a blockchain-based e-recapitulation system instead of a voting system for the case study of the Indonesia presidential election. This study continues previous work on blockchain-based e-voting systems for the Indonesia presidential election conducted in 2020 (Christyono et al., 2021).

3. Methods

3.1. Requirement Analysis

The 2024 Indonesia presidential election will be held manually by KPU, as is calculating and recapitulating the vote counting results. The vote counting results are carried out in stages (Humas KPU, 2023): polling station (TPS), village / sub-district, district, regency/city, province, and national. The KPU schedules the recapitulation process for the 2024 presidential election to start on 15 February 2024 until 20 March 2024, which totaled 35 days (KPU, 2023). It is still unclear whether or not the KPU will

utilize information systems to assist and digitalize the recapitulation process. As of the 2019 presidential election, the KPU uses Situng (vote count information system) to facilitate the public in obtaining information regarding the results. The Situng was later replaced by Sirekap (vote counting results recapitulation system) in 2020 to boost real-time transparency.

The Situng information system is used by KPPS (the voting organizing group) officers as a tool to report the recapitulation results at the polling stations. Form C1 is a certificate of vote counting results issued officially by KPU. The C1 form is physically distributed by the KPU to each polling station and filled by the KPPS officers during the vote tallying and recapitulation process on election day. KPPS officers are expected to manually input the C1 results into Situng, including uploading and submitting the proof of form C1 to Situng. KPU still determines election results based on the multilevel manual recapitulation. The information recorded in the C1 form is polling station, village / sub-district, district, regency/city, province, number of legitimate votes for each candidate, number of illegitimate votes, total of legitimate votes, total votes, polling place, and date, name, and signature of all KPPS officers and each candidate's witness.

Manual data input of the C1 form into Situng introduces the risks of human error and malicious intent that potentially harm the integrity and accountability of the election results. Several cases of discrepancy between form C1 data in the field and in Situng are proven to have occurred in the 2019 presidential election, and one of them is at TPS 93 Bidara Cina shown in Fig. 1. Thus, the KPU launched Sirekap to replace Situng. The KPPS officers at the TPS no longer need to manually input the data into Sirekap. Sirekap only takes photographs of the physical C1 form at the polling stations. Hence, Sirekap reduces the complexity of manual data input that existed in Situng. This is achieved by implementing optical character recognition (OCR) and optical mark recognition (OMR) to extract information from the C1 form photograph automatically. However, several problems occurred while using Sirekap in the 2020 regional head elections, as reported in (Rizkiyansyah, 2020; Wardy, 2020): slow upload progress due to several reasons and failing information extraction.

The major problem with Sirekap is the unavailability of real-time vote tally and recapitulation processes accessible to the general public. The KPU's publication portal functions to publish the vote tally process at each TPS, but it cannot be accessed when the process is in progress. This signifies the failure of Sirekap to enhance the election process further and assist stakeholders in the recapitulation process of an election. Furthermore, cases where the information system could not be accessed forced the recapitulation process to be repeated manually. The readiness of reliable and secure information technology infrastructure for transforming the whole process is vital for the future of electronic-based election systems. Otherwise, the proposed information technology solutions become an additional burden to bear by the stakeholders without clear advantages, as experienced in Situng and Sirekap KPU. Table 2 summarizes the problems and associated pain points in the existing Indonesia e-recapitulation process.

Table 2: Problems and pain points in Indonesia's e-recapitulation process

Problems	Pain points
Recapitulation results discrepancy	Manual input by humans and centralized access control contribute to data integrity loss and distrust, which requires additional effort to recheck and fix any discrepancies.
Poor accessibility, availability, and transparency	The correctness and deliverables of information system functionality are falling behind expectations, which causes the general public to be unable to view and follow the recapitulation process in real-time.
Non-standard recapitulation process	Inconsistency in troubleshooting problems during the recapitulation process confuses the quality of the results as various manual approaches are used to complete the recapitulation process.
Centralized business process	The centralized architecture combined with existing problems further questions the system's suitability as data are still modifiable in the database after the recapitulation.

3.2. Design

The digital transformation proposed in this study adheres to the existing business process and technological landscape. The blockchain-based e-recapitulation system addresses the problems and pain points summarized previously and introduces and enhances accessibility, auditability, immutability, inclusivity, privacy, security, transparency, and trust. The system's stakeholders are KPU and KPPS, and the architecture design is semi-decentralized to comply with government regulations and legal basis. The workflow of the e-recapitulation system for Indonesia's presidential election is shown in Fig. 1.

KPU logs into the system using the pre-registered wallet via Metamask. After verification, the system proceeds to KPPS wallet address registration, displaying an error message upon wallet address mismatch. During the wallet registration process for all TPS (KPPS), the system checks a file containing the wallet address and TPS identifier for each wallet address. Upon successful registration, the system stores the wallet address and TPS ID for the KPPS officer in the blockchain, and the wallet address of each officer is also stored in the database. Smart contract to be deployed at system initialization by KPU contains functionalities shown in Fig. 2.

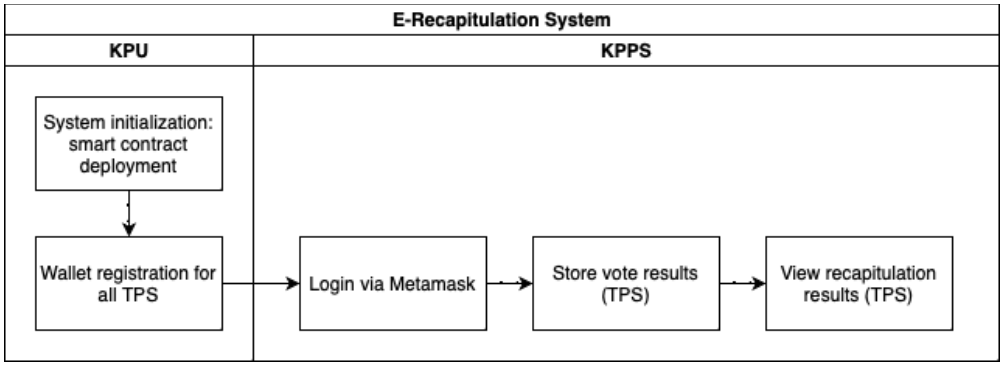

Fig. 1: E-recapitulation system workflow

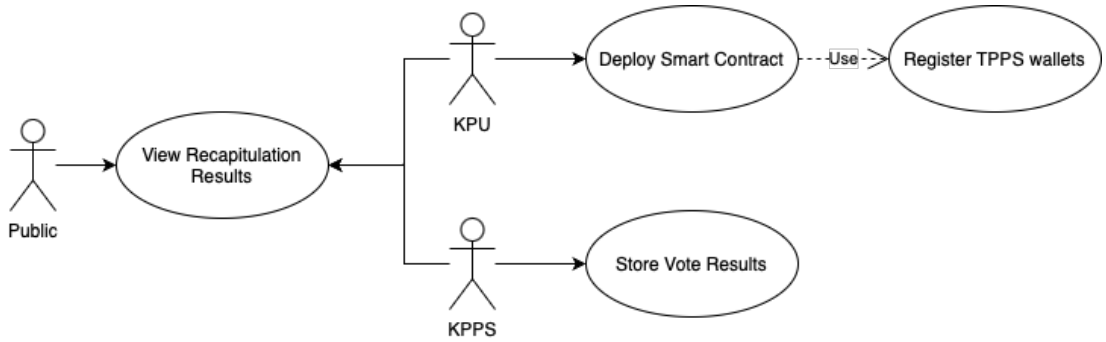

Fig. 2: E-recapitulation system use-case diagram

The smart contract deployment triggers the system to register all KPPS wallet addresses required for the recapitulation process. Each KPPS wallet address could access functions within the smart contract to store vote results and view the recapitulation results per TPS. Store vote results can only be executed once by each KPPS wallet address for the respective TPS. This design eliminates the possibility of further modification by KPPS on the recapitulation results. KPPS could only access the smart contract through the pre-registered wallet addresses managed and distributed by KPU.

In the store vote results use-case, the KPPS inputs vote results on form C1 into the system parameters: TPS identifier (polling station), number of legitimate votes for each candidate, number of illegitimate votes, total of legitimate votes, total votes, and the image of form C1. The system validates the input and verifies the correctness of the input automatically. The image of form C1 is uploaded and saved in IPFS (InterPlanetary File System). Upon completing the process, the system retrieves the path to the form C1 image in IPFS, commonly called the Content Identifier (CID), and stores all vote results

information along with the CID into the blockchain. The system keeps the transaction hash in the database.

The view recapitulation results use-case allows KPU, KPPS, and the general public to view the recapitulation results in real-time on each TPS. This feature is accessible on the system without requiring a login. The recapitulation results are retrieved from the blockchain by querying the TPS identifier. The information displayed includes the wallet address of the KPPS responsible for the TPS and the transaction hash for the TPS on the blockchain. The data flow within the system is illustrated in Fig. 3.

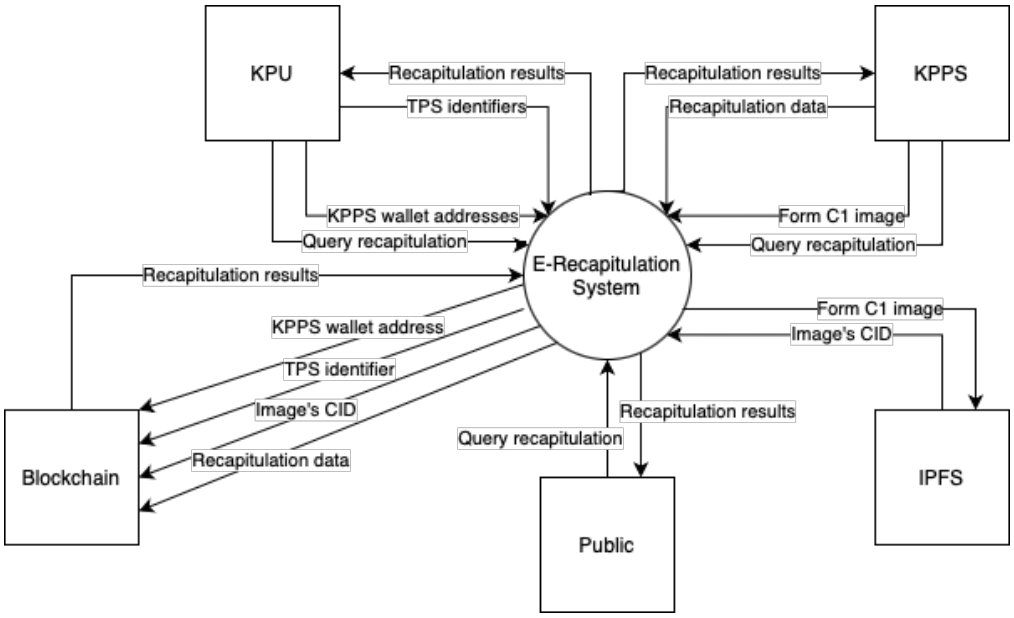

Fig. 3: E-recapitulation system data flow diagram

The local centralized database system is still required to serve as a support subsystem for the blockchain-based e-recapitulation system. The information in the database is strictly related to metadata necessary for the recapitulation process, e.g., provinces, regencies/cities, districts, villages / sub-districts, and polling stations (TPS). No recapitulation-related data and information have to be stored in the database. The relational structure of the database is shown in Fig. 5.

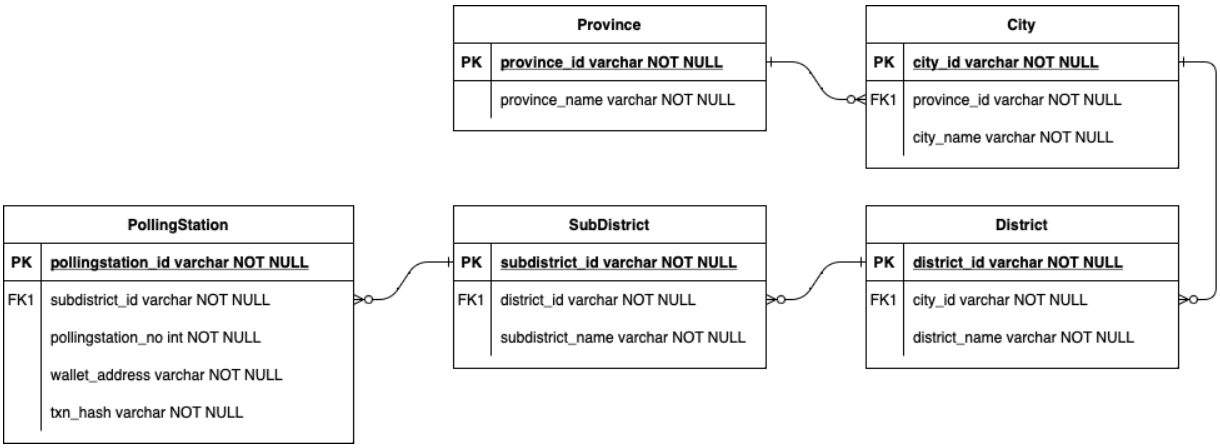

Fig. 4: E-recapitulation system entity relationship diagram

3.3. Implementation

The blockchain system chosen for implementing and deploying the smart contract is Ethereum for its Turing-complete and public permissionless type of blockchain. Programming the front end of the e-

recapitulation system uses ReactJS (Meta Open Source, 2023) and ExpressJS (OpenJS Foundation, 2017) to provide end users with a responsive graphical user interface accessible via web browsers. Remix (Remix, 2022) integrated development environment (IDE) is used to code the smart contract with Hardhat (Nomic Foundation, 2023) to deploy it to the Ethereum Sepolia Testnet (Etherscan, 2023). The front and back-end integration use Web3JS (*Web3.Js - Ethereum JavaScript API*, 2016) with the Infura (ConsenSys, 2023) application programming interface (API) to connect with the IPFS (Protocol Labs, n.d.). Fig. 5 shows the graphical user interface of the e-recapitulation system landing page for KPU and KPPS, where the pre-registered wallet address must be used to access the system.

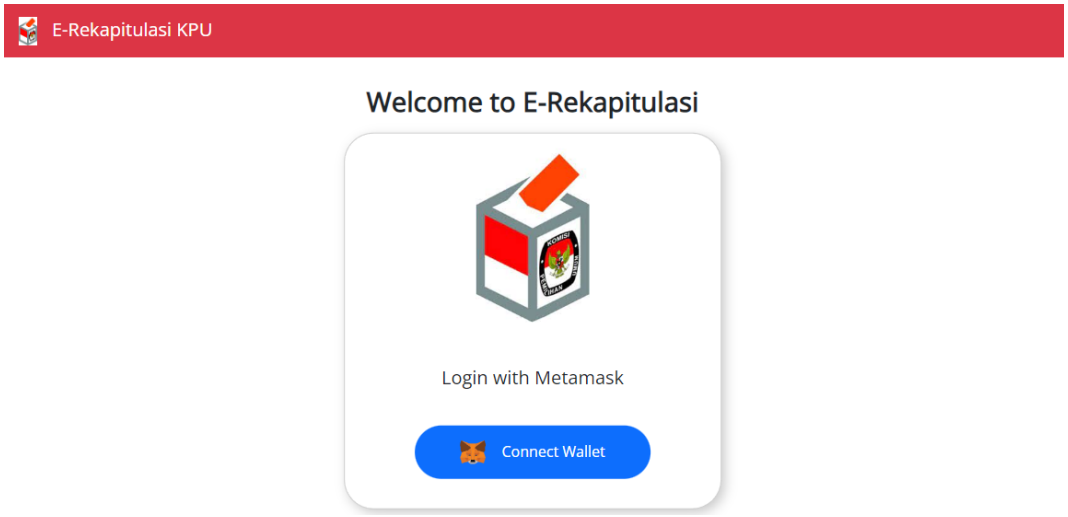

Fig. 5: E-recapitulation system landing page

The process after login differs for KPU and KPPS. KPU officers must register all KPPS wallet addresses into the system while KPPS officers store vote results. A JSON file containing a complete list of KPPS wallet addresses can be uploaded into the system for KPU officers to deploy the recapitulation smart contract. This feature is implemented in the backend—the front end for KPPS and the public focus on recapitulation-related processes only. Fig. 6 shows the input form of the e-recapitulation system for KPPS officers after KPU successfully registers all of the KPPS wallet addresses.

Fig. 6: E-recapitulation system input form

The field in the input form follows the field in the C1 form; trivial information, i.e., the location of the polling station, is not required as it is available on the database. KPPS officers must put the correct TPS identifier and voting-related information into the form. The system processes automatic checking on the correctness of the given information to assist KPPS officers in avoiding incorrect inputs. After the KPPS officers completed the input form and provided the C1 form image, the process continued to the submission of this information into the blockchain. None of the data is stored in the database; the information inputted is stored in the blockchain along with the C1 form image in the form of the CID produced by IPFS. The C1 form image in PNG or JPEG file formats is uploaded and stored in the IPFS. Pushing transactions into the blockchain causes the Metamask to pop up a confirmation modal for the KPPS officers to evaluate the gas fee (transaction cost), as illustrated in Fig. 7.

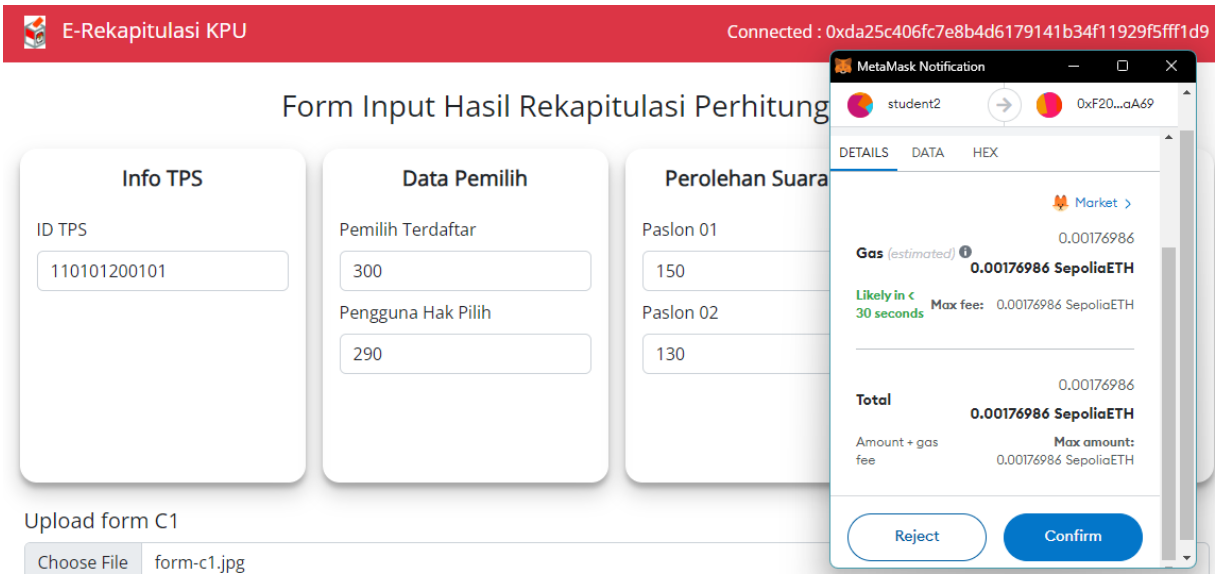

Fig. 7: Transaction confirmation

The blockchain returns with transaction hash upon successful transaction confirmation. This transaction hash is stored automatically in the database for record-keeping purposes. KPPS officers could access the transaction hash through Etherscan to investigate the transaction status in the Ethereum blockchain further. These processes are displayed in Figures 8 and 9, which indicate the completion of the recapitulation process for the TPS.

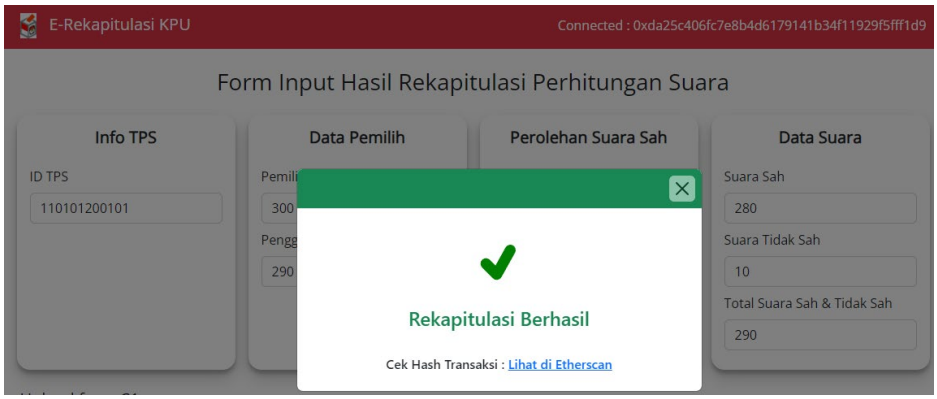

Fig. 8: Completion of submit vote results by KPPS

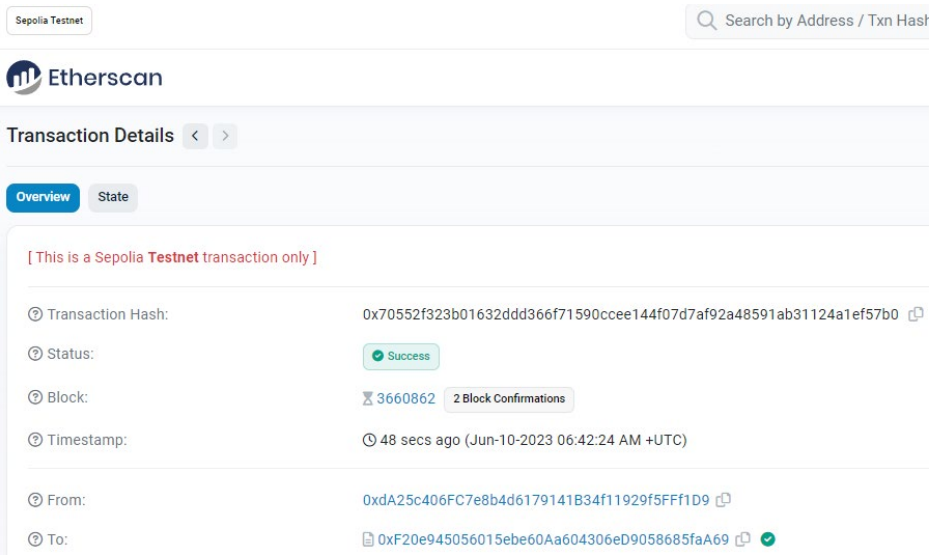

Fig. 9: Recapitulation transaction details viewed in Etherscan

3.4. Testing

The white-box testing method is used to verify and validate the use cases and functionalities of the system with a focus on login for KPU and KPPS officials, KPPS wallet address registration, store vote results, and view recapitulation results. Augmented data are produced based on the 2019 Indonesia presidential election for testing and evaluation purposes. The test cases are listed in Table 3, and the developed blockchain-based e-recapitulation system in this study has passed all scenarios.

Table 3: Test-cases for the e-recapitulation system

Focus	Scenario	Expected Outcome
KPU login	Login using the correct wallet	Login success
	Login using incorrect wallet	Login failed
KPPS wallet address registration	Input file with the correct format (JSON)	System proceeds with wallet registration
	Input file with incorrect format	System rejects the file
	Confirm transaction on Metamask	Transaction pushed into the blockchain
	Cancel transaction on Metamask	Transaction cancelled
	Register wallet for the first time	Wallet successfully registered
	Register wallet for the second time	Registration failed with error message
	Register wallet with non-KPU wallet	Registration failed with error message
KPPS login	Login using the correct wallet	Login success
	Login using incorrect wallet	Login failed
Store vote results	Fill correct data on the input form	Form auto-check accepts the data
	Fill incorrect data on the input form	Form auto-check rejects the data with error message

	Confirm transaction on Metamask	Transaction pushed into the blockchain
	Cancel transaction on Metamask	Transaction cancelled
	Submit vote results for the first time	Submission success
	Submit vote results for the second time	Submission failed with error message
	Submit using unknown wallet	Submission failed with error message
View recapitulation results	Access landing page (national level)	Landing page is accessible for public and display all provinces
	Choose province	Display all regencies and cities in the selected province
	Choose regency / city	Display all districts in the selected regency/city
	Choose district	Display all villages and sub-districts within the chosen districts
	Choose village / sub-district	Display all polling stations (TPS) within the chosen village / sub-district
	Choose polling station (TPS)	Display the recapitulation results for the chosen TPS

4. Results and Discussion

As a means for demonstration and proof of concept, the developed blockchain-based e-recapitulation system uses an Indonesian territory dataset from GitHub, available at https://github.com/emsifa/api-wilayah-indonesia. There are 34 provinces in the 2019 Indonesia presidential election. The electronic recapitulation results at the national level for all provinces are displayed in Fig. 10. Users can access this page publicly. Each province links to the regencies/cities and so forth down to the polling station (TPS) shown in Fig. 11. Fig. 11 displays a page display that shows the recapitulated data at the TPS selected by the user on the previous page. This page displays the province's name, regency/city, district, village/sub-district, TPS number, and identifier. In addition, there is a table that shows the recapitulation results, such as the number of voters, the number of votes for each candidate, and the number of valid and invalid ballots. Then, there is a table containing the URL for checking transaction hashes on the Etherscan web, the URL for checking the wallet address of the KPPS officer, and the URL for checking the C1 form image.

E-Rekapitulasi KPU

Hasil Rekapitulasi Perhitungan Suara Pemilu Presiden & Wakil Presiden RI 2019

Wilayah	Wilayah
ACEH	NUSA TENGGARA BARAT
SUMATERA UTARA	NUSA TENGGARA TIMUR
SUMATERA BARAT	KALIMANTAN BARAT
RIAU	KALIMANTAN TENGAH
JAMBI	KALIMANTAN SELATAN
SUMATERA SELATAN	KALIMANTAN TIMUR
BENGKULU	KALIMANTAN UTARA
LAMPUNG	SULAWESI UTARA
KEPULAUAN BANGKA BELITUNG	SULAWESI TENGAH
KEPULAUAN RIAU	SULAWESI SELATAN
DKI JAKARTA	SULAWESI TENGGARA
JAWA BARAT	GORONTALO
JAWA TENGAH	SULAWESI BARAT
DAERAH ISTIMEWA YOGYAKARTA	MALUKU
JAWA TIMUR	MALUKU UTARA
BANTEN	P A P U A
BALI	PAPUA BARAT

Fig. 10: E-recapitulation results for the 2019 Indonesia presidential election – all provinces

E-Rekapitulasi KPU

<< Back to Main Menu

Hasil Rekapitulasi Perhitungan Suara Pemilu Presiden & Wakil Presiden RI 2019

ACEH - KAB. ACEH SELATAN - Bakongan - Keude Bakongan - 01

Data Pemilih dan Penggunaan Hak Pilih

ID TPS: 110101200101

Uraian	Jumlah (L + P)
Pemilih Terdaftar (DPT)	300
Pengguna Hak Pilih	290

Uraian	Suara Sah
Paslon 01	150
Paslon 02	130

Uraian	Suara Sah
Jumlah Seluruh Suara Sah	280
Jumlah Suara Tidak Sah	10
Jumlah Seluruh Suara Sah dan Tidak Sah	290

Cek Rekapitulasi	URL
Cek Hash Transaksi	Lihat Transaction Hash
Cek Wallet Address KPPS	Lihat Address KPPS
URL Form C1	Lihat form c1

Fig. 11: E-recapitulation results for the 2019 Indonesia presidential election – Aceh province

Three links are provided to view the transaction details in Ethereum, the KPPS wallet address, and the uploaded form C1. These guarantee accessibility and transparency of the recapitulation results to the general public in real time, including the immutability aspect of the recapitulation results stored in the system, which ensures integrity. Any modifications to the recapitulation results, including the C1 form, would create a new transaction that mismatches the existing transaction. Furthermore, the smart contract can only be run through the e-recapitulation system, which implements an access control list by limiting the execution to only one for each KPPS wallet address. This limitation is coded in the recapitulation smart contract. Fig. 12 shows the content of transaction details viewed in Etherscan. Users can check the correctness of the transaction and the conformity with the recapitulation process

for the chosen polling station.

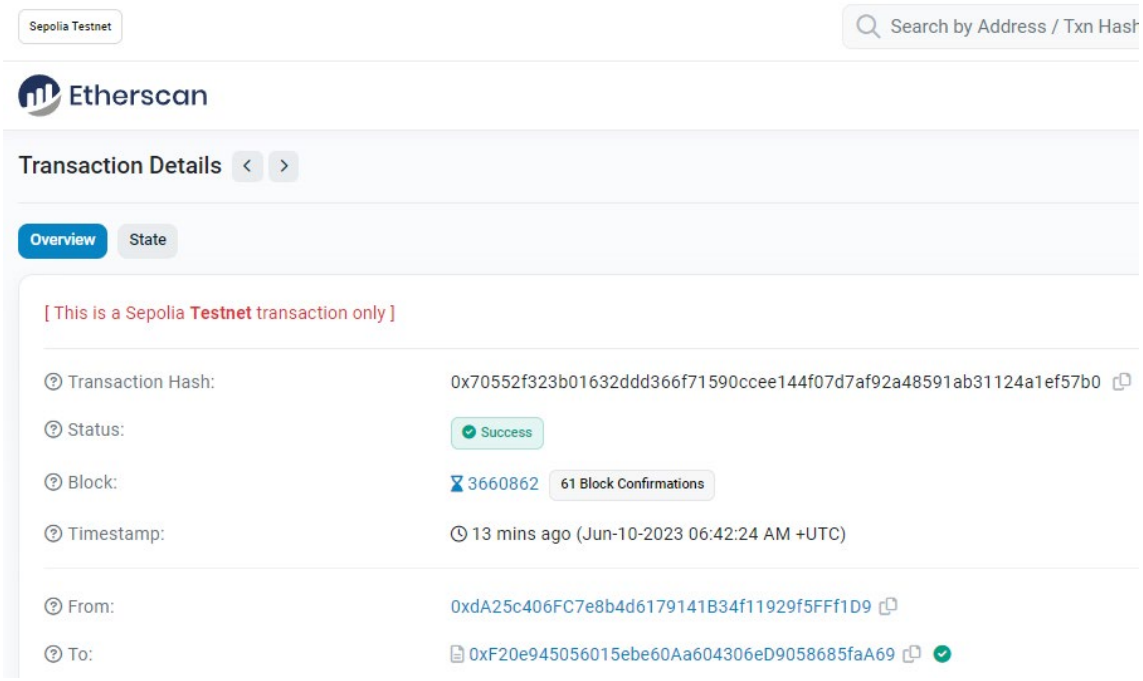

Fig. 12: Etherscan view on TPS recapitulation transaction details

Moreover, users can track the activity of KPPS officers for the chosen TPS in the recapitulation process. The link to the KPPS wallet address reveals the wallet overview, including transaction details from and to the wallet address. The wallet details can be explored with Etherscan, as shown in Fig. 13. Thus, the public can assess the recapitulation processes conducted by the KPPS officers responsible for the particular TPS.

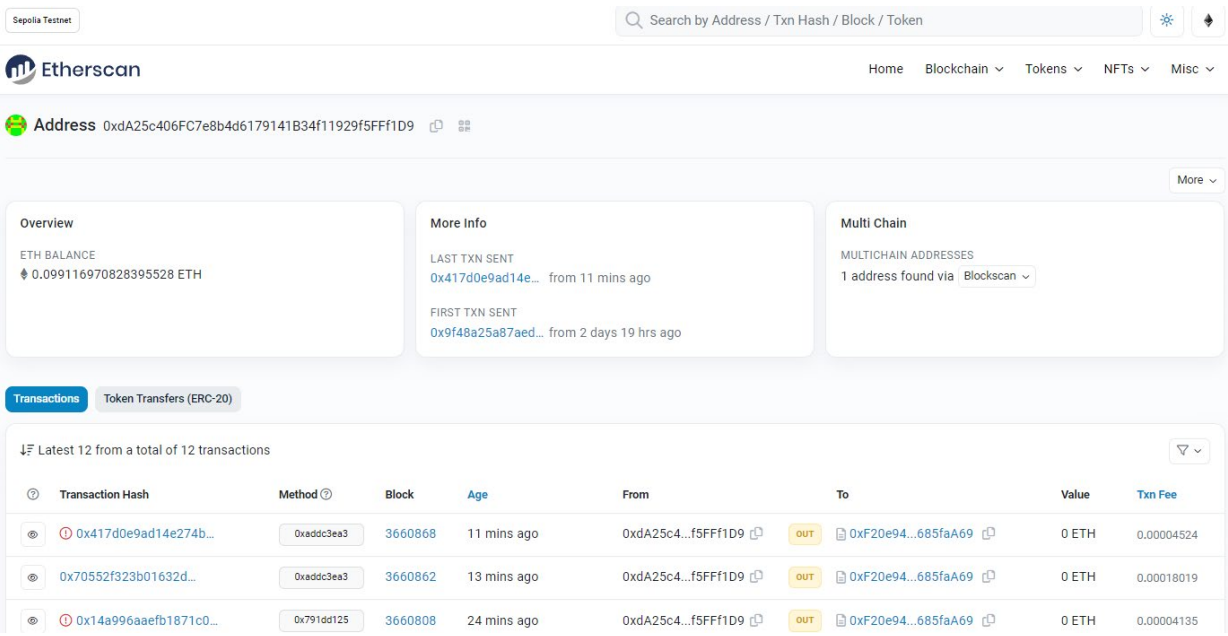

Fig. 13: Etherscan view on KPPS wallet address

The public can view the stored C1 form for each TPS in the IPFS through the e-recapitulation system. This mechanism enables auditability of the recapitulation processes and results and bolsters public trust in the system. The public can access all C1 for all TPS through the system. The use of IPFS

maintains a decentralization degree of the overall business process and system architecture. The availability of recapitulation results, including the C1 form, accessible by the public through not only the e-recapitulation system but also the Ethereum blockchain explorer, such as Etherscan, promotes inclusivity in the design and implementation of a blockchain-based recapitulation system.

The nature of blockchain technologies provides anonymity, privacy, and security simultaneously, in contrast with centralized technologies, where extra measures have to be applied to provide anonymity, privacy, and security. The design and implementation of this study protect the identity and unnecessary details of KPPS officers' data and information to focus more on the recapitulation processes and results. Using the Ethereum wallet address gives anonymity and privacy to election officers working in the field. However, for security reasons, the KPU can check and track down KPPS officers for misconduct and malicious activity investigations. Furthermore, in general, the security of the blockchain-based e-recapitulation system in this study relies on the Ethereum blockchain for access control (login) through the Ethereum wallet and recapitulation of the main features through the smart contract.

5. Conclusions

The blockchain-based e-recapitulation system developed in this study contributes to solving the problems in the manual recapitulation process of Indonesia's presidential election. Any legal basis in Indonesia does not support electronic or online voting with the initiative of KPU to assist the recapitulation process electronically using information systems. The blockchain-based e-recapitulation system presents an approach where a semi-decentralized system architecture is proposed instead of a fully centralized information system for the recapitulation. Moreover, blockchain (Ethereum) and related decentralized technology (IPFS) are incorporated to deliver accessibility, anonymity, auditability, immutability, inclusivity, privacy, security, transparency, and trust for e-recapitulation. The deployment of the recapitulation smart contract on the Sepolia test net and the e-recapitulation system have been tested thoroughly for the correctness of functionalities using the white-box method. The system is run using augmented data from the 2019 Indonesia presidential election for specific polling stations (TPS) to demonstrate the feasibility and goal of this study.

The limitation of this study is the evaluation of the gas fee required for the recapitulation process due to the unavailability of ETH for deployment and testing in the Ethereum mainnet. Another limitation is the legal basis and election mechanisms regarding the recapitulation in the Indonesian presidential election case study. It includes the mandatory use of printed physical form C1 for each TPS used for vote tallying and recapitulation. Suggestions for future works are evaluating the gas fee on the Ethereum mainnet, including parameters, i.e., transaction or block confirmation time, and the optimization concerning the trade-off between cost and performance. Further improvement in Indonesia election laws would open more possibilities in the e-recapitulation process, i.e., the use of digital form C1 directly.

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