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A Blockchain Architecture for Hourly Electricity Rights and Yield Derivatives

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Abstract

The article presents a blockchain-based architecture for decentralized electricity trading that tokenizes energy delivery rights and cash-flows. Energy Attribute Certificates (EACs) are implemented as NFTs, while buy/sell orders are encoded as ERC-1155 tokens whose *tokenId* packs a time slot and price, enabling precise matching across hours. A clearing smart contract (Matcher) burns filled orders, mints an NFT option, and issues two ERC-20 assets: PT, the right to consume kWh within a specified interval, and YT, the producer's claim on revenue. We propose a simple, linearly increasing discounted buyback for YT within the slot and introduce an aggregating token, IndexYT, which accumulates YTs across slots, redeems them at par at maturity, and gradually builds on-chain reserves—turning IndexYT into a liquid, yield-bearing instrument. We outline PT/YY lifecycle, oracle-driven policy controls for DSO (e.g., transfer/splitting constraints), and discuss transparency, resilience, and capital efficiency. The contribution is a Pendle-inspired split of electricity into Principal/Yield tokens combined with a time-stamped on-chain order book and IndexYT, forming a programmable market for short-term delivery rights and yield derivatives with deterministic settlement.

Keywords: decentralized electricity markets; peer-to-peer energy trading; blockchain; smart contracts; tokenization; energy attribute certificates (EAC); market design; electricity derivatives; order book; distribution system operator (DSO)

JEL Classification: D47; D44; Q41; L94; Q42; Q48; G13; L51

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1. Introduction

Centralized electricity trading systems (ETS) deliver high operational speed, standardized procedures, and integration with financial institutions. In Ukraine, for example, day-ahead and intraday trading is executed under a single operator (the state-owned Market Operator) via platforms such as XMtrade, where participants submit orders to a central server that processes, clears, and reports transactions [4,10]. This architecture simplifies administration and technical support, scales well for a fixed set of market roles, and provides a familiar user experience.

However, centralized ETS also exhibit structural limitations: a single point of failure; dependence on the integrity and technical competence of the operator; constrained flexibility as the number of participants and product types grows; increased exposure to cyberattacks; and challenges in embedding innovative trading instruments for risk transfer [1,2]. As the share of renewable generation rises and small and medium-sized independent power producers (IPPs) and prosumers enter the market, the need for more dynamic, open, and programmable infrastructures becomes pressing [1,2].

A decentralized trading architecture built on distributed ledgers and smart contracts offers an alternative design space [2,3,6]. In such systems, market rules are encoded as programmatic controls; execution is deterministic and auditable; and state changes are immutably recorded on-chain, reducing reliance on a central authority while increasing transparency and resilience [2,3,6]. In addition, decentralized financial (DeFi) protocols demonstrate how self-regulating mechanisms—fee schedules, incentive designs, and automated clearing logic—can be expressed directly in code, enabling markets to adjust to supply–demand conditions and minimizing scope for discretionary intervention [2,4]. This opens the door to native derivative instruments for price insurance and liquidity management in electricity trading.

This article proposes a blockchain-based conceptual framework for decentralized electricity markets that is functionally comparable to centralized platforms yet aims to surpass them in flexibility, verifiability, and operational resilience. The approach combines: 1) a time-stamped on-chain order book realized with ERC-1155 multi-tokens that encode both price and delivery slot in the token identifier; 2) tokenization of delivery rights and cash-flows into ERC-20 Principal Tokens (PT)—rights to consume kWh in a specified interval—and Yield Tokens (YT)—claims on the producer's revenue; and 3) Energy Attribute Certificates (EACs) as NFTs that bind provenance and other attributes of generated electricity to delivery rights [7–9,11]. The design adapts the Pendle-style split of a yielding asset into principal and yield legs to short-term electricity delivery and introduces a simple, deterministic intra-slot discounted buyback for YT to keep settlement rules transparent and programmable [5].

Research gap. While prior work on blockchain in energy has examined certificate tracking, bilateral P2P matching, and general decentralization benefits [1–3], the literature still lacks: a fully on-chain, time-granular order book tailored to hourly (or sub-hourly) delivery; a principal/yield split adapted to commodity delivery rights with deterministic intra-slot settlement; an aggregating yield instrument (IndexYT) that transforms short-lived YT cash-flows across slots into a liquid, reserve-backed asset; and an oracle-mediated policy layer that aligns Distribution System Operator (DSO) constraints (e.g., transfer/splitting limits, curtailment handling) with on-chain execution [1–3,5–11].

Addressing these gaps would improve price discovery, liquidity, and risk transfer in short-term electricity markets.

Contributions. This work: introduces a time-stamped ERC-1155 order-book that matches bids/asks by price and delivery slot and records execution on-chain; defines a PT/YT tokenization of electricity delivery rights and producer revenue as ERC-20 claims, with a deterministic intra-slot discounted buyback for YT; implements EAC-as-NFT to verifiably attach provenance and attributes to delivery rights, supporting composite settlement workflows; proposes IndexYT, an aggregating instrument that accumulates YT across slots and builds reserves over time to improve liquidity; and specifies an oracle interface for DSO policy controls to enforce grid and compliance constraints programmatically.

Together, these elements outline a programmable market architecture that preserves the administrative clarity of centralized schemes while enhancing transparency, fault tolerance, and capital efficiency [1–11].

2. Materials and Methods

This is a conceptual systems-design and token-engineering study that formalizes market functions for short-term electricity trading on a public ledger.

We proceed in three steps:

1) requirements elicitation from current Ukrainian day-ahead/intraday practices (order intake, matching/clearing, reporting, settlement) to identify mandatory roles, artifacts, and timing constraints [10,11];

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2) standards mapping that assigns core objects to widely used token standards—ERC-20 for PT and YT, ERC-721 for EACs, and ERC-1155 for time-stamped order-book positions—so that price and delivery slot are encoded in the token identifier and all state transitions are auditable [7–9,11];

3) mechanism design that specifies matching invariants (price–time priority, partial fills), deterministic clearing/settlement flows for PT and YT (including the intra-slot discounted buyback for YT inspired by Pendle-style yield separation [5]), and an oracle interface through which the DSO can activate policy toggles (transfer/splitting limits, curtailment handling) in a transparent manner [2–6,11]. The design choices are illustrated via stylized hourly scenarios (UAH/kWh), ensuring conservation of value across all cash-flow legs without relying on confidential datasets.

The design is fully specified through standards [7–9], public documentation [5,6], and market rules [10,11]. Pseudocode for the Matcher, ERC-1155 order-books, and PT/YT issuance, along with parameter tables for examples, can be provided upon request; no proprietary data or code were required. Ethical approvals and informed consent are not applicable.

3. Results

3.1. Pendle Architecture: Dividing a Yielding Asset into PT and YT

Modern decentralized finance of a derivative instrument (DeFi) is an existing financial cryptocurrency system that offers a large number of tools for making a profit: staking, farming, lending, liquidity pool. However, there is a fundamental problem: the inability to directly trade future income. Traditionally, a user who places an asset in a staking or lending desk can only wait for profit or withdraw the asset early, losing future returns. This reduces capital efficiency, restricts access to liquidity, and makes it impossible to form a secondary market for income. The solution to this problem was offered by the Pendle protocol, which allows tokenizing the yield, i.e. turning it into a separate trading asset that can be sold, bought, transferred, or used in DeFi operations.

The first step of the protocol is to wrap the original yielding asset (e.g., stETH) in a special standardized token SY (Standardized Yield Token). The SY acts as a "wrapper" representing the full value of the asset along with the future yield. In the protocol, all assets are processed through SY, which allows for standardized interaction regardless of the source of income.

Further, SY is automatically divided into two components:

- PT (Principal Token) - a token that represents the "body" of the asset, i.e. the amount that will be returned after the maturity date (expiry). PT does not generate income, but only guarantees the return of the asset.
- YT (Yield Token) is a token that contains all future profits accrued until the expiry date. It is YT that allows you to make money on growing yields.

What is the relationship between $SY = f(PT, YT)$. The simplest understanding of function f is sum of PT and YT, but authors propose to reduce the Pendle model to a system of differential equations for formalization. This approach allows us to describe the dynamics of the cost of PT and YT tokens as functions of t time, which change under the influence of the yield rate and time discontation. The following system of differential equations is used purely as a conceptual token-engineering formalization of SY/PT/YT flows over time. It is not calibrated to empirical electricity price dynamics, and developing such stochastic models lies outside the scope of this paper. This is important because the interdependence of the components *SY, PT, YT* can be considered as a constrained problem in the form of a balance equation:

$$SY(t) = PT(t) + YT(t)$$

The original SY asset grows by accumulating yield with an instant rate of $y(t)$. Instant yield rate $y(t)$ — the rate of increase in the value of the SY income asset over time, which acts as an analogue of Annual Percentage Rate (APR).

The PT — token is the discounted value of the asset that approaches SY at maturity, with an effective discount rate of $r(t)$. The effective discount rate of $r(t)$ is the rate of convergence of the value of PT to SY when approaching the maturity date.

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The YT token reflects the difference between the current SY and PT value, and therefore decreases to zero over time.

$$\frac{dSY(t)}{dt} = y(t)SY(t)$$

$$\frac{dPT(t)}{dt} = r(t)PT(t)$$

$$\frac{dYT(t)}{dt} = y(t)SY(t) - r(t)PT(t)$$

with initial conditions

$$SY(0) = SY_0, PT(0) < SY_0, YT(0) = SY_0 - PT(0)$$

and marginal conditions at maturity $t = T$

$$P(T) = SY(T), YT(T) = 0.$$

The producer-seller (user) can choose how to dispose of these tokens:

- If a user sells YT, he or she actually gives up income but receives SY for it. This is equivalent to fixing the profit "here and now".
- If the user sells PT, he gives up the principal amount of the asset, but retains the right to all the income (YT) and receives liquidity in the form of a SY token that can be exchanged for ETH or another asset.
- If he holds both PT and YT, he keeps the entire SY - a full yielding asset that can be "deployed" into the original asset (for example, stETH) after expiration.

All trading between these tokens is realized through the SY/PT financial market, where the price of PT changes according to the time to expiry. The closer to the end of the electricity supply period, the more expensive PT becomes. Since $SY = f(PT, YT)$, changes in the price of PT automatically affect the price of YT

Figure 1 shows how the value of the revenue token YT decreases over time: at the beginning of the period, SY = 1.00 ETH, PT = 0.95 ETH, so YT = 0.05 ETH. As the income accumulates, SY grows, but PT rises in price faster due to the decrease in the discount, so the difference (the price of YT) gradually disappears. Before expiry, YT is almost worthless and at maturity is equal to zero.

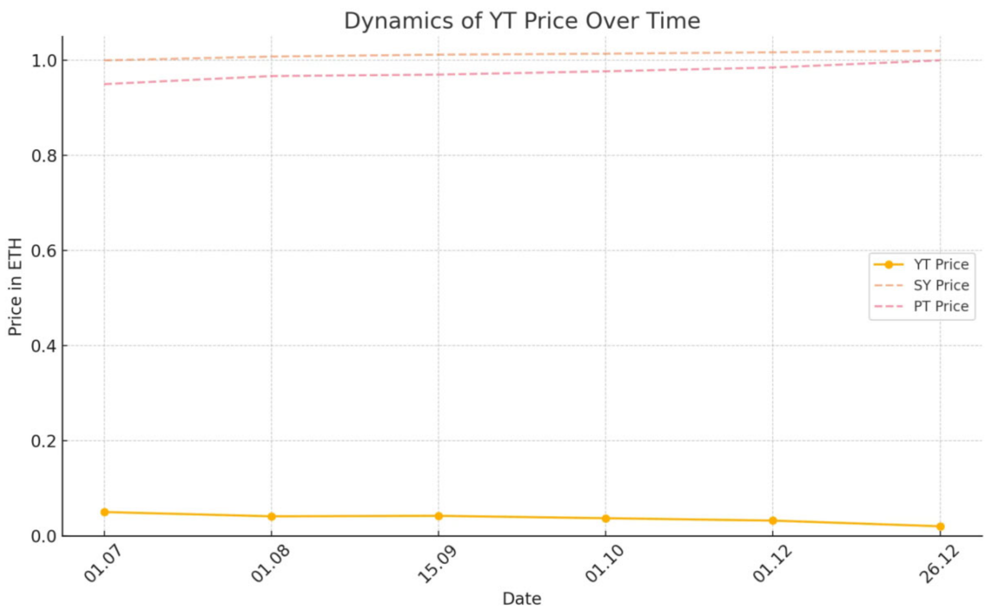

Figure 1. Graphical display of the dynamics of SY, PT, YT values.

The Pendle protocol proved that the separation of the underlying asset (PT) and the future income (YT) creates a yield market. The principle is simple: if an asset generates income, it can be separated and tokenized. In ETH staking, Pendle allows you to choose whether to keep the principal or the income. This approach can be adapted to the electricity market, where the producer generates future cash flows. We propose to formalize supply obligations in the form of PT and YT tokens, which are adapted to the commodity nature of energy. This PT/YT mapping is architectural rather than a calibrated pricing model; it structures programmable short-term delivery rights and revenue claims without treating electricity as a conventional yield-bearing financial asset. In the revised model, we propose:

- PT (Principal Token) - a token representing the right to receive a certain amount of electricity in a given time interval (for example, 1 PT = 1 kWh from 16:00 to 17:00), possibly linked to an EAC (Energy Attribute Certificate);
- YT (Yield Token) - a token representing the producer-seller's income from the sale of PTs, i.e. the future profit that will be received upon the fact of energy consumption.

When a producer tokenizes a future energy supply, it issues a pair of PT and YT:

- PT is an obligation to the consumer-buyer, which is realized in the form of future electricity supply and the right for the consumer to receive electricity (kWh).
- YT is the obligation to the producer-seller to receive the corresponding monetary revenue (UAH) generated from delivering that same amount of electricity in the specified time slot.

The producer can retain YT (ensuring future profits) either by selling it at a discount, attracting liquidity in advance, or by selling it to other market participants.

This creates the preconditions for a secondary market for energy performance obligations, where:

- consumers can freely transfer or sell their PTs, which allows for flexible planning and load balancing;
- investors invest in YT to receive a predictable income from the transaction;
- producers get new tools for liquidity and risk management;
- the system as a whole becomes open, transparent, and programmable.

Thus, energy contracts turn into liquid tokenized assets, where each kilowatt of electricity becomes part of a decentralized commodity and financial market.

3.2. Decentralization of the Purchase and Sale of Electricity

In classical centralized or decentralized exchanges, trading is carried out through a bilateral order book (Bid/Ask), where each order contains only the price and volume. This approach is effective for fungible assets such as tokens, stocks, currencies, but is limited for electricity, as it is physical in nature, consumed in real time, and not fungible between different time intervals. The energy available from 14:00 to 15:00 is not equivalent to the energy available from 20:00 to 21:00, and its price is constantly changing under the influence of supply, demand, peak loads, and local conditions. In the classic order book model, there is no possibility to specify a time slot, which leads to inaccurate matching of orders, reduced trading efficiency, and makes it impossible to create a full-fledged market for short-term electricity supply contracts.

To solve this problem, a modified model of the exchange cup is needed, where each order fixes not only the volume and price, but also a specific time interval for delivery. This will ensure an accurate match between suppliers and consumers, balance supply and demand in real time, and create a flexible pricing mechanism. In a decentralized architecture, this logic is implemented at the level of smart contracts that automatically process orders based on time, volume, and price, eliminating the limitations of traditional exchange models and creating the basis for a scalable, transparent, and efficient electricity market.

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In the extended architecture of the tokenized energy market, the main element is a glass of orders in the form of tokens, implemented through two separate smart contracts of the ERC1155 standard [9]:

- BidERC1155 - a contract containing bids from energy producers (offer);
- AskERC1155 - a contract containing bids from consumers (demand).

Each order for purchase or sale in this system is represented as a unique ERC1155 token, the tokenId of which encodes the parameters of a particular trading position, including the time slot of delivery (for example, 13:00-14:00) and the desired price per 1 kWh.

tokenId = (uint256(timestamp) << 128) | uint128(price)

- timestamp - the unix timestamp of the start of delivery. For example, Tue, 22 Jul 2025 19:00:00 will be encoded in 1753210800, which means delivery from 19:00 to 20:00
- price - the desired price in kopecks (for example, 102 for 1.02 UAH/kWh).
- << - bit shift to the left
- | - logical OR
- uint256()/uint128() - conversion of variable types.

The number of ERC1155 tokens on a participant's balance sheet under a certain tokenId reflects the amount of energy that the participant is willing to buy or sell under specific contract conditions - for example, 1 kWh in a certain time slot at a fixed price. Thus, each token in the system represents a specific trading position. The key element of the system is the Matcher contract (or Gateway), a coordinating smart contract that has the authority to change the state of both ERC1155 glasses and is responsible for all clearing and transaction logic. The Matcher scans the available tokens in both cups, identifies the orders that match the parameters (price and time), and automatically performs the match. In case of a successful match, the Matcher burns the order tokens, records the transaction, deposits funds, and issues an NFT option along with a pair of financial tokens - PT (right to consume) and YT (right to producer income). Here's an example of an extended glass:

Bid Book (energy sale):

- (13:00-14:00, 1.05 UAH) - Producer1: 40, Producer2: 24, Producer3: 50
- (13:00-14:00, 1.04 UAH) - Producer1: 50, Manufacturer2: 55
- (13:00-14:00, 1.03 UAH) - Producer1: 40, Manufacturer2: 20
- (12:00-13:00, 1.05 UAH) - Producer1: 40, Manufacturer2: 24, Manufacturer3: 50
- (12:00-13:00, 1.04 UAH) - Producer1: 50, Manufacturer2: 55
- (12:00-13:00, 1.03 UAH) - Producer1: 40, Producer2: 20

Ask Book (energy purchase):

- (13:00-14:00, 1.02 UAH) - Consumer1: 20
- (13:00-14:00, 1.01 UAH) - Consumer1: 20, Consumer2: 70
- (13:00-14:00, 1.00 UAH) - Consumer1: 20, Consumer2: 70
- (12:00-13:00, 1.02 UAH) - Consumer1: 20
- (12:00-13:00, 1.01 UAH) - Consumer1: 20, Consumer2: 70
- (12:00-13:00, 1.00 UAH) - Consumer1: 20, Consumer2: 70

Market analysis:

- For the slot 12:00-13:00:
  - Minimum selling price: 1.03 UAH/kWh;
  - Maximum purchase price: 1.02 UAH/kWh;
  - No match, but possible matching under market conditions.

Example of a transaction:

Producer1 wants to sell 15 kWh of energy in the 12:00-13:00 slot at a price of 1.02 UAH/kWh.

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The Matcher sees that there is a matching request from Consumer1 for 20 kWh at this price in Ask Book. The matcher contract conducts a match:

1. An NFT option is created in which the:
   - Producer: Producer1
   - Buyer: Consumer1
   - Time: 12:00-13:00
   - Volume: 15 kWh
   - Price: 1.02 UAH/kWh
2. Consumer1's bid in the Ask Book is reduced from 20 to 5 kWh.
3. Matcher issues:

   15 PT to the wallet of Consumer1 - this is the consumer's right to receive energy.
   15.3 YT (15 × 1.02 UAH/kWh) to the wallet of Producer1 - the expected income of the producer.
4. Consumer1 transfers 15.3 UAH to the contract YT - this is the payment for energy.

3.3. Examples of the Creation and Implementation of PT, YT, and IndexYT

The PT token (Principal Token) is a digital representation of the consumer's right to receive a certain amount of energy in a specific time slot. Each PT token is an ERC20-compliant asset representing the consumer's right to receive a certain amount of electricity in a specific time slot. Technically, the PT does not contain all the data about the interval, price, or supplier, but refers to the corresponding NFT option, which contains the full terms of delivery:

- time slot (startTime, endTime)
- volume of energy
- price;
- seller.

The consumer's balance in PT tokens directly indicates how many kilowatt-hours of energy the consumer is entitled to consume in accordance with the associated NFT option. Thus, PT is an easily tradable legal instrument that delegates the entire logic of a contractual obligation to the option level.

For example, if balanceOf(<consumer address>) returns a value of 20, it means that the consumer is entitled to receive 20 kWh of energy in the time slot specified in the PT contract.

Owning a PT gives the user the right to receive the corresponding amount of electricity from a specific supplier, which is fixed in the NFT option and in the specified time slot. The fact of fulfillment of the obligation is confirmed by the distribution system operator.

Since PT is a transferable asset, it can be freely used for further circulation. In particular, the token holder can sell it directly to another person on the over-the-counter (OTC) market or place it in the Ask exchange cup as an offer for sale, indicating the desired price per kilowatt-hour and the corresponding delivery time slot. This opens up the possibility for speculative or investment use of PT. Even if the user does not plan to consume electricity personally, they can sell their PT tokens on the secondary market.

In addition to the basic function of representing the right to consume electricity, PT is a programmable token that allows for flexible configuration of its behavior in accordance with the policies of the power system. In particular, PT can be used to set restrictions on transmission (rebalancing) or sales, which are activated depending on the state of the grid or the distribution system operator's policy.

These restrictions are implemented through the oracle, a trusted data source that provides the smart contract with up-to-date information on the technical state of the grid (e.g., energy shortage or surplus, critical load in the region, etc.) or other policy parameters. Based on this data, the PT token can automatically prohibit or authorize such actions:

- transfer of the token to another consumer (i.e., load rebalancing between locations)

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- sale of PT on the secondary market;
- dividing the token into small parts (if necessary, to limit microtrading).

Thus, PT is not only a legal but also a technically controlled element in the energy infrastructure. It ensures compliance with regulations and balance in the grid without centralized manual intervention, using automated rules and adaptive logic for access to consumption rights.

PT token life cycle.

1. Creation (Mint)

- A PT is created after successful matching of an application in the decentralized electricity market, when a consumer agrees to purchase energy in a certain slot.
- At the time of the transaction, the Matcher:
  - Issues an NFT option, which fixes the seller's obligations;
  - issues a PT to the consumer in the amount corresponding to the ordered amount of kWh.

2. Ownership

After creation, the PT token becomes the property of the consumer and is stored in his wallet. The PT is a digital representation of the right to receive a certain amount of electricity in a specific time slot, which must be delivered by the supplier specified in the NFT option.

The user can flexibly manage his right to receive electricity: store it until delivery, transfer it or rebalance it among other consumers depending on the need and policies of the electricity distribution operator, and sell it on the secondary market, fixing the value at the current price.

3. Utilization.

When the time slot specified in the PT arrives (startTime ≤ now < endTime), the token becomes active and enters the use phase. This does not necessarily mean physical consumption of electricity in real time.

The PT is not a direct mechanism for physical delivery, but rather a tool for accounting for the capacity of energy obligations to be fulfilled by the producer specified in the option. After the end of the slot (now ≥ endTime), the distribution system or an external operator verifies the fact of delivery (or lack thereof).

Electricity Yield Token

The Yield Token (YT) is an ERC-20 token that reflects the producer's right to receive payment for the electricity supplied. It is generated simultaneously with the creation of the PT when the Matcher contract compares the Bid and Ask, it issues the consumer PT (the right to receive electricity) and the producer an equivalent amount of YT, which preserves the liquidity paid by the buyer.

YT is created so that the producer has flexibility in choosing a financial strategy. He can either wait until the delivery and receive full payment or redeem YT at a discount to get instant liquidity.

Buyback at a discount

The original Pendle model created the YT token for assets that gradually accumulate income in real time, such as rebase tokens like stETH, whose balance automatically increases in users' wallets. In Pendle's model, YT serves as a dynamic representation of a variable yield that grows every second, depending on how much income is still left to be earned.

A simplified alternative is offered - the discount redeem mechanism, which sets a time-varying redemption price for YT. The price of YT increases linearly from a certain initial value (for example, 95% of the face value) to the full 100% of the value at the end of the slot. This approach maintains a simple logic for producers, allows them to capture a discounted profit immediately after the transaction, and does not require a complex curve or constant revaluation of tokens as in the Pendle protocol.

The price depends on the discountα and the time frame from the beginning of the slot t_0 and the end of the slot t_e

$$P_{YT}(t) = \alpha + (1 - \alpha) * \frac{t - t_0}{t_e - t_0}$$

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Thus, at the start of the slot, YT is allowed to be exchanged for liquidity at a discount ofα (e.g.,α α = 0.95), since $t = t_0$, and as the period approaches the end ($t \rightarrow t_e$), the discount disappears and the price approaches the face value (Figure 2), i.e., $P_{YT}(t_e) = 1$

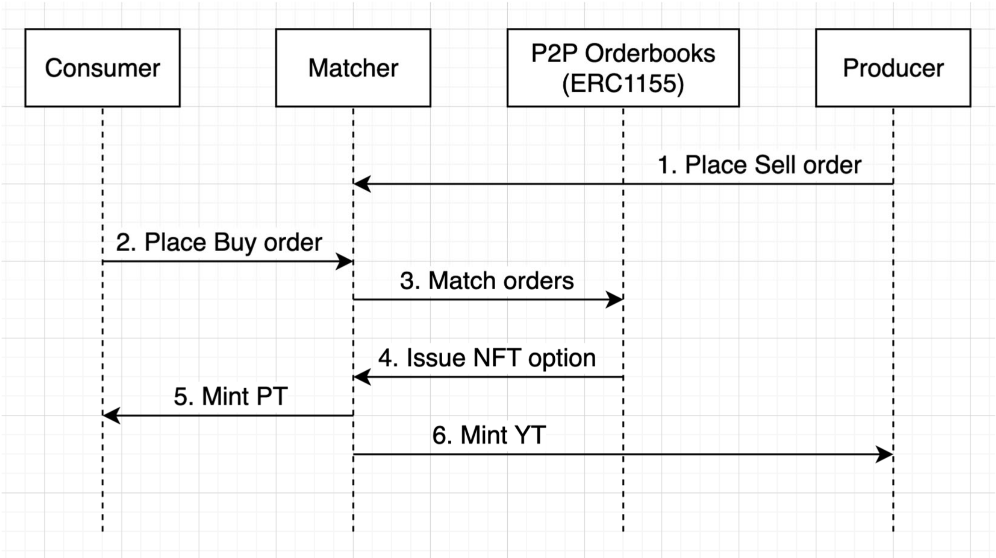

Figure 2. Simplified illustration of decentralized energy market flow.

<u>Example 1: One producer holding YT until the end of the period</u>

The producer sells 100 kWh for the slot 16:00-17:00 for 1.20 UAH/kWh and receives 120 YT = 100 kWh *** 1.2 UAH /** kWh and holds it until the end of the slot, expecting full payment.

Input data:

- Slot start: t_0 = 16:00
- End of the slot: t_e = 17:00
- Early discount: α = 0.95, which means a 5% discount
- Initial liquidity: x = 120 UAH
- Quantity of YT: y = 120 YT

The price of YT changes over time in the slot from 16:00 to 17:00. This is shown on the graph.

The producer did not sell 120 YT during the entire slot, holding them until 17:00, when the discount disappeared and each token became worth 1.20 UAH. As a result, he redeemed all the tokens and received UAH 120 from the funds reserved in the contract, fulfilling the obligation to supply 100 kWh in the 16:00-17:00 slot. There was no trading on the secondary market, so the discount remained only theoretical and did not affect the producer's final income. This is an example of direct supply, when the producer receives full payment without intermediate transactions.

<u>Example 2: A producer sells YT, but some tokens are not redeemed by the end of the period</u>

Time	Participant	Action	Number of YT	Price P_{YT} (UAH/YT)	Amount (UAH)	Comment
16:00	The product	Buys UAH from YT	120	0.95	+114.00	Received UAH immediately
16:00	Trader1	Buys YT	40	0.95	-38.00	The price is fixed

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16:15	Trader2	Buys YT	60	0.9625	-57.75	According to $P_{YT}(t)$
17:00	Trader1	Buys UAH from YT	40	1.00	+40.00	Profit +2 UAH
17:00	Trader2	Buys UAH from YT	60	1.00	+60.00	Profit +2.25 UAH
17:00	-	Excess funds	-	-	1.75 UAH	The balance was formed

IndexYT

The Yield Token (YT) is a token that gives the electricity producer the right to receive payment for the delivery in a certain time slot. Its main feature is a limited lifecycle and low liquidity until maturity, when it can be converted into full value. This limits the use of YT in DeFi. To solve this problem, we propose the IndexYT token, which accumulates YT from different slots in a single pool. The user transfers YT to the IndexYT contract, where they are stored until the end of the period. After maturity, the IndexYT contract buys back liquidity and forms a reserve that ensures all IndexYT tokens in circulation. At the beginning of the period, YT is traded at a discount α , as the revenue has not yet been realized. This gives the producer the opportunity to immediately sell YT at a discount and receive liquidity. The IndexYT issuance formula is proposed:

$$IndexYT = YT * (1 - \frac{\alpha}{2})$$

The IndexYT token issuance formula is a balanced compromise between the electricity producer and the financial system.

On the one hand, the producer receives better terms than if he immediately redeemed YT at a discount - instead of $YT \cdot \alpha$, he receives a secured and liquid token whose value is $YT * (1 - \frac{\alpha}{2})$, which is usually more profitable. This incentivizes the producer to transfer YT to IndexYT and thereby receive a liquid asset before the actual delivery of energy. On the other hand, the system ensures that YT is redeemed in full at face value after the delivery period is over. Until then, YT tokens are stored in the IndexYT contract, which gradually accumulates liquidity. When the period ends, the contract redeems the liquidity from YT at 100% of its value, and the proceeds replenish the IndexYT reserve. This allows the IndexYT token issuance to remain balanced and the token itself to have liquid coverage.

Thanks to the issuance formula, where each IndexYT token is issued at a discount $\frac{\alpha}{2}$, the total supply of IndexYT grows slower than the amount of liquidity entering the contract. This means that for every unit of liquidity, less than one unit of token is issued, which creates an excess of value in the system. Over time, this ensures the growth of the internal price of one IndexYT token and turns it into an investment asset that accumulates the profitability of many YTs and becomes an attractive investment tool.

When withdrawing liquidity or exiting the investment, the owner burns N IndexYT tokens and receives a share of the total pool:

$$Liquidity = N * \frac{TotalLiquidity}{TotalSupplyIndexYT}$$

This mechanism guarantees a transparent and fair distribution of liquidity (Figure 3), and IndexYT becomes a liquid, diversified, and attractive derivative instrument for investors.

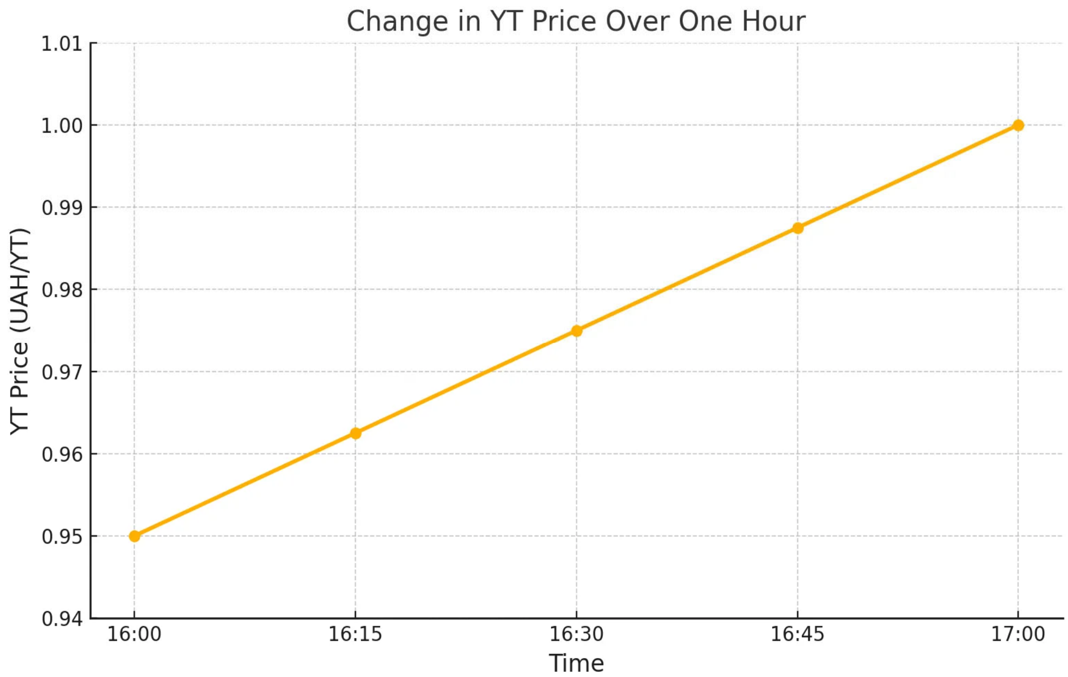

Figure 3. Graphical representation of the YT price for the period from 16:00 to 17:00.

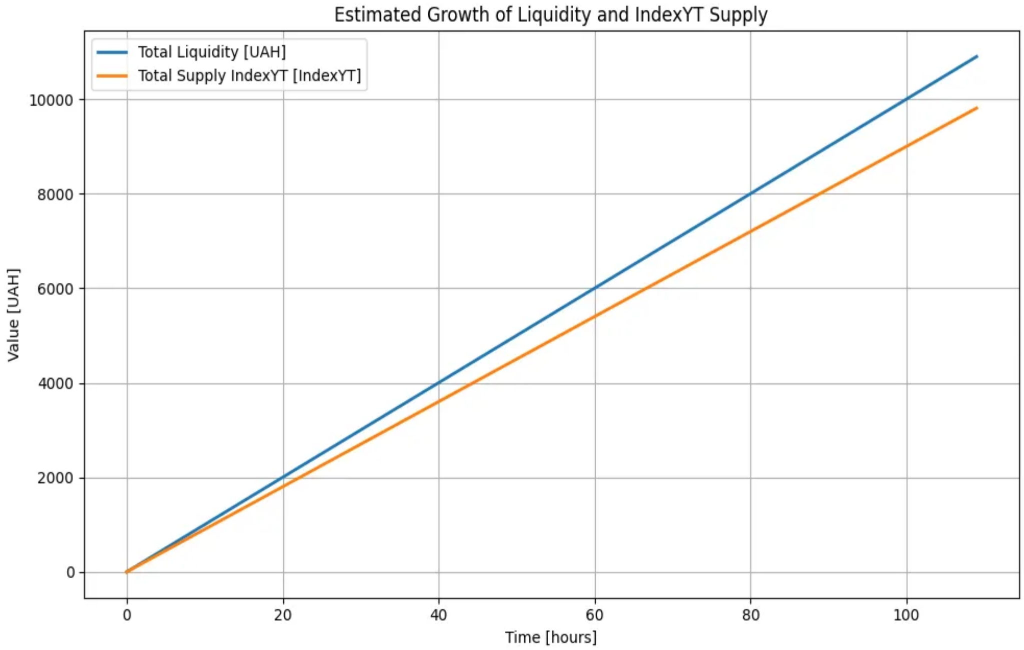

Figure 4. Graphical display of liquidity (UAH) and the total amount of IndexYT.

4. Discussion

Positioning to prior work. Compared with centralized platforms [4,10], the proposed architecture replaces operator-mediated workflows with auditable, rule-based smart contracts [6]. Relative to earlier blockchain-in-energy studies emphasizing certificates or bilateral P2P matching [2], our design integrates a time-granular order book and a PT/YT split tailored to commodity delivery—with EAC-as-NFT binding provenance to settlement [7–9,11]. Adapting Pendle-style yield separation [5] to electricity introduces a deterministic intra-slot buyback that preserves programmability while avoiding complex continuous revaluation.

Implications. The ERC-1155 order book enables accurate price discovery per time slot; PT creates a liquid claim on delivery that can be rebalanced or traded; YT and IndexYT open risk-transfer and liquidity pathways for producers and investors; and the oracle-mediated DSO layer provides levers to enforce grid and compliance constraints in real time. Collectively, these mechanisms improve transparency, resilience, and capital efficiency [1–3,5–11]. The modular separation of orders, PT/YT rights, options, and IndexYT introduces additional structural complexity compared with minimal market designs. In practical deployments, several components can be consolidated or abstracted to reduce implementation overhead while preserving transparency and formal verifiability.

Scalability and cost considerations. Practical deployment must also account for economic efficiency: issuing large numbers of NFT/PT/YT instruments per hourly slot and per small energy unit on an L1 chain may be prohibitively expensive. Realistic implementations would therefore rely on L2 environments, sidechains, or aggregation strategies—such as larger PT lots or netting within balancing groups—to achieve feasible operating costs. A full economic evaluation of platform choice and transaction-cost structures is left for future research.

Limitations. Practical deployment must address: 1) metering latency and oracle trust, including robust signing and fraud-proofs; 2) market-microstructure risks (MEV/front-running) in public chains; 3) non-delivery and curtailment policies that ensure fair loss allocation; 4) regulatory/AML compliance for fiat settlement; and (v) throughput and fees on the chosen L1/L2. These are engineering and governance challenges rather than conceptual blockers; 5) The architecture does not model intra-hour load volatility and assumes that real-time balancing and deviation settlement are handled by existing DSO/TSO mechanisms.

Regulatory considerations. Given the high level of regulation in the electricity sector, practical deployment must align with ISO/TSO and DSO requirements, metering and billing standards, and licensing rules. The on-chain layer is intended as a complement to existing infrastructure, and its integration with regulatory processes remains an essential area for future development.

Consumer impact. Potential effects include improved price transparency, flexible resale of consumption rights, access to basic hedging tools, and the possibility to participate in localized markets through tokenized consumption rights and localized EAC certificates. Recent trends toward the regionalization of energy markets – including local energy communities and microgrids – create demand for infrastructures that can represent localized delivery rights and certificates. The proposed architecture can naturally support such settings by tokenizing consumption rights (PT) and EAC-backed provenance at the level of feeders, campuses, or community microgrids, while gateways interface them with national day-ahead and intraday platforms. These benefits are balanced against risks such as product complexity, reliance on aggregators, and increased short-term volatility. Broader social implications remain for future study.

Future work. Priorities include: 1) agent-based simulations using real load shapes and tariffs to quantify liquidity/volatility; 2) pilot integrations with metering back-ends and EAC registries [11]; 3) privacy-preserving settlement (e.g., aggregation or ZK proofs) for sensitive consumption data; 4) exploring non-linear or market-adaptive YT buyback curves; and 5) empirical evaluation of different execution venues (order book vs. AMM hybrids) under MEV-aware designs [6–9].

Roadmap. A possible deployment path includes: (i) pilot sandbox trials within microgrids or large corporate consumers; (ii) gateway-based integration with existing day-ahead/intraday platforms rather than full replacement; and (iii) gradual expansion of tokenized products and derivatives following evaluation of pilot results.

5. Conclusions

In this paper, we have developed a concept of a decentralized electricity trading system that can replace centralized platforms in the future with a number of advantages, namely transparency, lack

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of a single administrator, censorship resistance, and automated rule enforcement. The first key component of the architecture is the NFT Energy Attributes Certificate, which is issued through a new decentralized exchange cup via the Matcher smart contract, which calls the ERC1155 BidOrderBook and AskOrderBook contracts. This makes it possible to build an open certificate market that is fully stored on the blockchain. The second component is the tokenization of energy consumption rights by Principal Token (PT) in the form of ERC20 tokens, which are fungible assets that reflect the amount of electricity in a particular time slot. They can be transferred between users and used to rebalance consumption portfolios, which creates the preconditions for a dynamic secondary market for energy rights. The third innovative element is the introduction of yield derivatives - Yield Token (YT). The article describes how producers can issue YTs representing future profits, receiving liquidity in advance through a discounted redemption mechanism. This allows for the formation of financial products based on electricity generation, including universal income indices IndexYT, which can be aggregated by source, time slot or region. Thanks to IndexYT's special issuance formula, the total volume of IndexYT tokens grows more slowly than the liquidity flowing into the index token, which creates an internal premium in the token price. Thus, IndexYT becomes an investment asset whose value increases over time along with the accumulated yield of YT tokens.

The conceptual model of a decentralized electricity trading system can be the basis for a startup to develop a platform for concluding smart contracts for electricity and derivative instruments using existing blockchain technologies in the electricity market.

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