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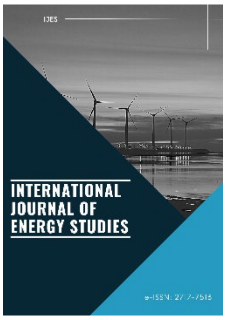

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International hydrogen market meets blockchain: A new frontier in trade

Sofya Morozova[a*], Arif Karabuga[b], Zafer Utlu[c]

[a] Halic University, Faculty of Business Administration, Istanbul, Türkiye, ORCID: 0009-0003-8485-1530

[b]Istanbul Atlas University, Faculty of Engineering and Natural Science, Istanbul, Türkiye , ORCID: 0000-0002-9349-7049

[c]Istanbul Atlas University, Faculty of Engineering and Natural Science, Istanbul, Türkiye , ORCID: 0000-0003-1981-9107

*(*Corresponding Author: sofyatoo1@gmail.com)*

Highlights

- Difficulty of blockchain is its customization under international regulations.
- Government ministries have highest interest and power.
- Blockchain comparable with trade mechanism.
- AI is needed to close blind gaps inside a smart contract structure.

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ABSTRACT

This research investigates the convergence of the nascent hydrogen market and blockchain technology. Driven by renewable energy policies, hydrogen demand has surged across traditional industries, expanding the overall market. However, hydrogen trading remains a relatively new sector in need of growth and investment. By examining the interplay between trade mechanisms and blockchain within the existing international regulatory landscape, including World Trade Organization frameworks, this study explores the feasibility of blockchain integration. Stakeholder analysis highlights the government as a pivotal actor in this emerging ecosystem. At the same time, to enhance the efficacy of smart contracts, the integration of artificial intelligence is proposed.

Keywords: Hydrogen market, Energy trading, Blockchain

1. INTRODUCTION

Concern over sustainable energy production methods has grown quickly as the effects of climate change and environmental degradation become more noticeable. The United Nations Sustainable Development Goals (SDGs) and the Kyoto Protocol have been instrumental in shaping international climate policy, to decrease emissions a switch to clean energy sources is needed. Renewable energy such as solar, wind, hydropower, and geothermal paved the way to a carbon-neutral future, they showed a sustainable alternative to fossil fuels. The renewable energy industry is starting to recognize hydrogen as a major player of the energy trading market. It has the capacity to be a very important energy carrier due to its adaptivity. Generally, hydrogen is dedicated to clean energy, energy security, and decarbonization. Hydrogen can be produced from different resources like natural gas which is a prime source of hydrogen production, nuclear power, and renewable energy solar and wind. Hydrogen and fuel cells have the potential to be used in nearly every industry, including transportation, business, industry, housing, and power generation that can significantly impact the energy strategy. More nations are implementing policies that actively support the development of hydrogen-based solutions across a range of economic sectors [1], which is evidenced by the trend of rising international investment in hydrogen infrastructure and technology.

The hydrogen market is waiting for substantial growth in the coming years. By 2050, clean hydrogen demand could soar to 125–585 million tons annually [2]. Research by Yusaf et al. [3] suggested a potential increase in global hydrogen demand, with estimates ranging from 73 to 568 million tons by 2050. Xu et al. [4] found that as hydrogen usage expands, so does the market, predicting a value of $36.17 billion by 2025. Despite rising usage, hydrogen prices are expected to decline. Another forecast anticipates the market reaching $32.7 billion by 2060, achieving half its growth within 15 years, from 2045 to 2060. While market size and demand for hydrogen are on an upward trajectory, certain challenges slow down progress. For instance, the verification process for hydrogen origin certificates and carbon recordkeeping complicates supply chain management, adding costs, labor, and time due to numerous intermediaries.

Blockchain and similar advanced technologies could significantly enhance carbon accounting and green certification processes [5]. This is particularly vital for green hydrogen, which is produced emission-free from renewable energy sources. Independent verification of hydrogen sources is crucial for stakeholders to gain recognition for their role in producing carbon-neutral hydrogen.

Blockchain's support for hydrogen can boost continued innovation and collaboration among nations, contributing to a cleaner, more sustainable future in line with the SDGs and the principles of the Kyoto Protocol. Currently, as the energy sector evolves, so does the digital landscape. Since blockchain's introduction in 2008, it has revolutionized trade and currency. The demand for blockchain technology is escalating, with its application extending across various sectors. In 2021, global spending on blockchain solutions was $6.6 billion, and it's anticipated to hit $19 billion by 2024, according to summary report [6] on Statista, which is an online platform providing statistics and market data across various industries, also predicts that the blockchain market will reach $39.7 billion by 2025 [7].

It could be an opportunity to consider adapting the traditional hydrogen market and blockchain in parallel. There is a proposal to use this to close the existing shortcomings and complexity of the system, at the same time expand the network and increase the number of investments and participants could accelerate the global adoption of hydrogen. The existing literature does not provide enough description of smart contracts application within international policies and which policies are used for hydrogen. In the introduction, an examination of the scale and predictions for the hydrogen market, as well as the rapidly increasing usage of hydrogen, is intended. Subsequently, the article will provide a detailed description of blockchain technology and its applications, and will address the role of smart contracts in concluding trade agreements. Artificial Intelligence and its role in blockchain are also mentioned, but only with the goal of deepening the complexity of the hybrid smart contract. Trade and regulatory policies for energy trading are provided, as well as a brief stakeholder analysis. The article ends with reflections and future opportunities in the field.

For this research, secondary data was utilized, including academic papers, industry reports, and government statistics on blockchain implementation. Relevant theoretical frameworks or models, such as supply chain analysis or energy economics, were referenced to understand the dynamics and challenges of the hydrogen market. The conclusion discussed potential limitations and biases in the research methodology. Power interest stake holder analisys (PISA) was asssest for the blockchain hydrogen market. This analysis identified key influencers who have the most vested interest in the hydrogen market. PISA provides a more in-depth understanding of individual stakeholders' motivations and potential actions in the assesst field.

Additionally, the study explored the potential of integrating blockchain technology with the traditional hydrogen market. It was suggested that this combination could address existing shortcomings and complexities, expand the network, and attract more investments and participants, ultimately accelerating the global adoption of hydrogen. Usage of Artificial Intelligence algorthims was also discussed as it is a topic of hybrid smart contracts. However, the existing literature lacks sufficient detail regarding the application of smart contracts within international policies specifically for hydrogen.

2. BLOCKCHAIN TECHNOLOGY

Blockchain is a decentralized digital ledger where data is stored in blocks that are linked together cryptographically. This makes it difficult to tamper with or alter the data without affecting the entire chain. Each block contains information about previous and subsequent blocks, creating an unchangeable record and resolves the issue of duplicate digital content, also known as double-spending. In the comprehensive study by Tripathi et al. [8], distinguish the evolution of blockchain into three distinct waves. The first wave of blockchain technology began in 2008 with the introduction of Bitcoin, which was created by the so-called Satoshi Nakamoto [9]. This innovative digital currency disrupted established financial paradigms with its decentralized ledger system.

Figure 1 illustrates the schematic work of the blockchain's hashes, so it seems that every next block is connected by hashes with the previous one.

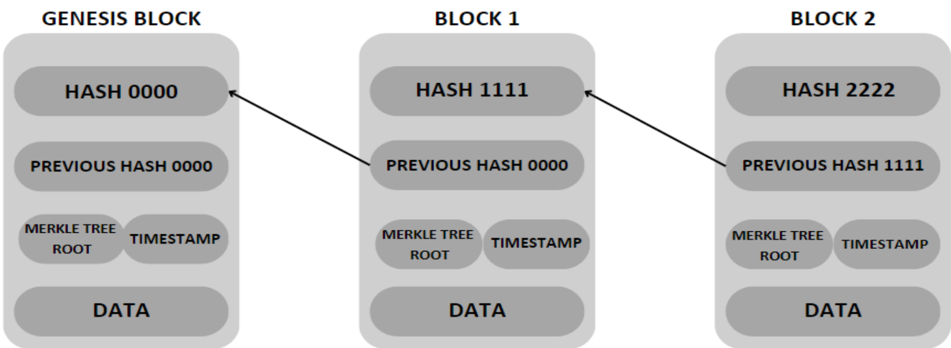


Figure 1. Blockchain's hash schematic review

The second generation introduced smart contracts, expanding its use beyond currency. The third wave saw blockchain applied to various sectors like healthcare and governance. Blockchain is valuable when decentralization, multiple parties, transparency, and data sharing are needed. It benefits sustainability by improving data traceability, supply chain management, and reducing costs.

Bitcoin is the original cryptocurrency and has a strong reputation for security and decentralization. However, its energy consumption for mining has raised concerns. Ripple is designed for fast and efficient cross-border payments. It could be a good option for international hydrogen trades. There are also energy-specific cryptocurrencies like SolarCoin [11] that focus on incentivizing renewable energy production and consumption. Ethereum has several advantages that make it a suitable platform for hydrogen trade on blockchain. Its ability to execute self-executing contracts without intermediaries is crucial for automating transactions and ensuring transparency in hydrogen trades. Ethereum has a large and active community of developers, which means there are abundant resources and support available for building and maintaining hydrogen-related applications. Python can be used to develop tools and applications that interact with the Web3 environment, which is a decentralized internet infrastructure powered by blockchain technology. However, the primary programming language for writing smart contracts on Ethereum is Solidity.

It was shown in Figure 2, showcasing the technology's versatility and potential to streamline services across multiple domains. It was concluded that blockchain usage can be reasonable when decentralization is needed, multiple parties are contributing to the network, and there is a need for transparency and datasets just the same as in the trading market. Supply chain management, energy systems, and carbon credit trading are just a few of the ways that blockchain technology has been suggested to help achieve sustainable development. The integration of blockchain contributes to real-time data and traceability, supports supply chain management and overall lowers financial costs.

Figure 2. Smart Contracts in the industry

2.1. Smart Contracts and Energy Trade

The adoption of blockchain technology in the energy domain is set to revolutionize renewable energy transactions. According to the study by Li et al. [12], blockchain platforms not only offer fault tolerance but also enable the implementation of "smart contracts." These contracts encode the terms of energy purchase and sale, allowing them to be automatically executed within a blockchain-based trading framework. This innovation is expected to drastically cut down on the costs and time associated with energy trading transactions. Furthermore, a decentralized smart grid powered by blockchain could adjust to fluctuations in supply and demand almost instantaneously, processing payments in a matter of minutes. Addressing the challenges associated with energy transactions could reduce the expenses related to green energy, enhance energy efficiency, contribute to the battle against climate change, and facilitate the precise monitoring of energy usage and production at an unprecedented level of detail. This could lead to a more sustainable and efficient energy landscape, promoting the use of renewable resources and supporting global environmental goals. Further, Table 1 shows links connecting trade mechanism and implementation of blockchain.

Table 1. Trade Mechanism and Blockchain

Trade Mechanism	Blockchain Solution	Result
cross-border transactions	custom procedures within smart contracts immutable records [13]	reduction of time needed for procedures
stakeholder's interest	decentralized wide spread system with a secure organized structure	increasing number of participants
payment proceeding	secure transactions without financial intermediaries, solves double-spending problem [8]	prevention of loss and fraud
trade system	decentralized transparent system	establishment of common trading platform
security and risk management	transparency within shared data	investment and decision making
supply chain management	enforcement of smart contracts that traces production and market operations	transparent and stable environment
data management	collects, stores data inside blockchain	easy access to historical data available

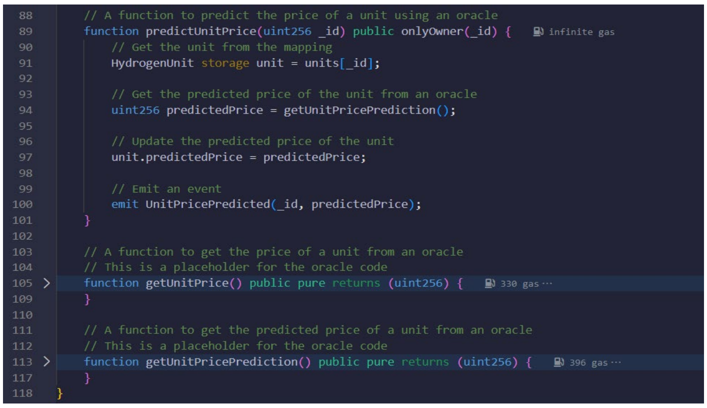
A real-world example of blockchain technology is being used in the LO3 Energy project Brooklyn Microgrid (BMG) [14]. The Brooklyn Microgrid, which was started as experemental project in 2017, has used blockchain to track energy generation, consumption, and trading within the local grid. This provides a high level of transparency for all participants, increasing trust and facilitating peer-to-peer energy transactions. They have created a permission data platform called Exergy that facilitates the creation of regional energy markets for the exchange of energy across the current grid infrastructure. Through this platform, neighbors who own solar panels can buy P2P back extra energy from homeowners in a peer-to-peer exchange. The community's energy transactions are safe, open, and effective thanks to the usage of the private blockchain [14]. Smart contracts built on Ethereum are the foundation of the platform; they offer an unchangeable ledger of every transaction made on the network, including who bought and sold what and how much energy was consumed [15]. P2P energy trading powered by blockchain encourages the use of renewable energy sources and helps to grow a shared economy. Blockchain technology has been widely adopted for peer-to-peer energy trading in such projects like Volt Markets, Verv, SunContract, Power Ledger, mentioned companies use Ethereum to run smart [16, 17, 18, 19, 20].

2.2. AI for Smart Contracts

Artificial intelligence (Al) can be defined as a software technology that performs complex operations — like those of the human brain, identifying the best option among different alternatives [21]. As a branch of artificial intelligence, machine learning (ML) focuses on creating algorithms that can analyze, interpret, and predict data to make decisions. Deep Learning (DL) is a subfield of machine learning (ML) that analyzes massive amounts of data by employing multi-layered artificial neural networks, or "deep structures." In forecasting and data analysis, future trends are predicted using ML and DL methods based on historical data. Utilizing AI applications built on foundation models or machine learning (ML) can provide your company with a competitive advantage. A business can meet customer expectations now and in the future by automating tasks like cybersecurity, supply chain management, and customer service and integrating customized AI models into workflows and systems [22]. AI integration into the smart contract structure is needed to provide prediction, market information, and automation of agreements. AI will support smart contracts as its inseparable part. Machine learning models offer enhanced reliability for data and predictions. Analyzing and predicting hydrogen production can be made more secure and efficient by integrating blockchain technology with AI-supported management systems [23]. By leveraging machine learning, we can predict hydrogen production, enabling market participants to make better-informed decisions. Additionally, predictive analytics assists companies and traders in assessing future demand for hydrogen units, leading to more precise pricing in the market. Including AI or its ML will support market participation and interest increase. Blockchain applications can gain improved control over data and predictive analytics by integrating AI algorithms. For instance, clean hydrogen supply and demand are forecasted using artificial intelligence models. McKinsey's Global Energy Perspective 2023 [24] presents scenarios in which artificial intelligence (AI) assists in forecasting the adoption of green and blue hydrogen, taking into account elements such as cost-competitiveness, technological advancement, and policy enforcement. The application of AI can lead to a rise in automation and enhance the forecasting of various aspects of the green economy, including the production of renewable energy and hydrogen demand [24].

This integration promotes a more responsive and interactive trading environment and enables more accurate forecasting in big data analytics. Blockchain technology combined with AI has the potential to create a more transparent, safe, and efficient market where people can use technology to make more informed decisions. In a P2P energy trading system, AI can dynamically adjust prices based on real-time supply and demand data. For example, in a microgrid with a surplus of solar energy, AI can lower prices to incentivize consumption. Smart contracts can then automatically facilitate these trades, ensuring efficient and transparent transactions [25].

To get AI price prediction to smart contract a special function called oracle is needed. Figure 3 illustrates an example of such a function. Oracles allow smart contracts to receive data from outside the blockchain, creating a hybrid type of smart contracts. For the presentation, the Remix Ethereum IDE and the Solidity programming language were used.



```
    // A function to predict the price of a unit using an oracle
    function predictUnitPrice(uint256 _id) public onlyOwner(_id) {    infinite gas
        // Get the unit from the mapping
        HydrogenUnit storage unit = units[_id];

        // Get the predicted price of the unit from an oracle
        uint256 predictedPrice = getUnitPricePrediction();

        // Update the predicted price of the unit
        unit.predictedPrice = predictedPrice;

        // Emit an event
        emit UnitPricePredicted(_id, predictedPrice);
    }

    // A function to get the price of a unit from an oracle
    // This is a placeholder for the oracle code
    function getUnitPrice() public pure returns (uint256) {    330 gas ...
    }

    // A function to get the predicted price of a unit from an oracle
    // This is a placeholder for the oracle code
    function getUnitPricePrediction() public pure returns (uint256) {    396 gas ...
    }
}
```

Figure 3. Smart Contract function to get AI price prediction

Nethertheless, reliable data is essential for AI algorithms to produce accurate results. In the energy market, data can be fragmented, inconsistent, or difficult to access. AI models can be complex and difficult to understand, making it challenging to explain their decision-making processes and reability with blockchain. This can be a concern in regulated industries where transparency and accountability are crucial.

3. POWER-INTEREST STAKEHOLDER ANALYSIS

Stakeholder analysis plays a critical role for economists and market participants in the traditional energy market model and does so in the newly introduced system with blockchain smart contracts. Blockchain technology has been actively investigated by the EU for the energy markets. The goal of initiatives like "Blockchain for Energy" is to improve the efficiency and transparency of energy trading. Several blockchain projects, including those aimed at integrating renewable energy sources and enhancing grid management, have received funding from the European Commission's Horizon 2020 program [26]. Blockchain is being investigated by the Australian government as a means of tracking and managing renewable energy certificates (RECs) [28]. This would support the expansion of clean energy and help to maintain the integrity of the market for renewable energy.

The establishment of hydrogen trading means understanding economic conditions and policies, the parties involved, and their interest, benefits, and risks. Under general stakeholder analysis, we can understand and predict the intentions of the market participants and how blockchain technology could be adopted for energy, narrowly hydrogen, and trading.

The following categories of institutions may be regarded as core decision-makers planning policies and energy transition. These groups influence policy, implementation, and the integration of community perspectives:

1. Government Ministries: Overseeing energy, transport, and environmental policies.
2. Regulatory Bodies: Enforcing sector regulations.
3. Energy Sector Companies: Both public and private, including renewable energy developers.
4. Infrastructure Operators: Managing electricity distribution and transmission.
5. Research Institutions: Contributing knowledge and innovation.
6. Community Representatives: Ensuring local interests and needs are addressed.

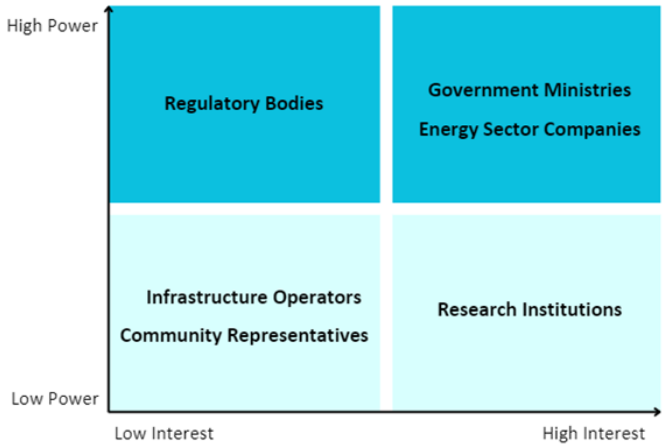


Figure 4. The power-interest grid in energy transition

According to the power-interest grid method that focuses on institutions as core decision-makers in energy policy and transition. This grid categorizes stakeholders according to the power and the interests they hold over the project's success. This method was chosen to show key players and decision makers of the energy market. Figure 4 illustrates:

1. Government Ministries: High Power – High Interest

They have the power to decide on policies, and since the results have an instant effect on national objectives, they have a high level of interest in them. So, it should be noted that they propose policies applied to national and political goals. Ministries are responsible for resource allocation, security, and economic growth.

2. Regulatory Bodies: High Power – Medium Interest

They have a large influence on how policies are carried out by enforcing rules and guaranteeing compliance. They are setting standards and monitoring of accuracy and fairness of the applied policies.

3. Energy Sector Companies: High Power – High Interest

Both public and private companies, including renewable energy developers, have a high interest in policies that affect their operations and profitability. Companies connect energy policies with infrastructure development.

4. Infrastructure Operators: Medium Power – High Interest

They oversee key infrastructure and have a strong interest in policies that impact its upkeep and operational effectiveness, they maintain infrastructure.

5. Research Institutions: Low Power – High Interest

Even though they might not directly control policy, their contributions to knowledge and innovation have the potential to do so over time. Researchers propose innovative ideas, address problems, and development of technological and social applications.

6. Community Representatives: Medium Power – Medium Interest

They appeal to the needs and interests of the local community, which has power, particularly when policies directly affect those communities, giving feedback to introduced policies.

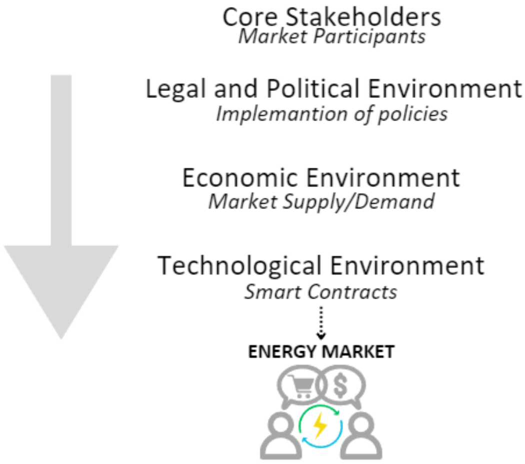


Figure 5. Market environment with Smart Contract implementation

On Figure 5 summary of market aspects is represented: core decision makers and wide social environment, legal and political environment, economic, technological environment are shaping the perspective of the energy market, and its rules under which blockchain will run smart contracts for hydrogen trade. The established stakeholders' roles in a future hydrogen market will completely change [29]. Opportunities exist in the political, ecological, and economic spheres. Political action during the market ramp-up should prioritize allocating the limited hydrogen supply to heterogeneous demand and focusing on the economic disparity between low-carbon hydrogen and fossil fuel alternatives. There must be opportunities for both financial and physical trade for a competitive, liquid hydrogen market to develop. In addition, a long-term plan needs to be considered in order to ensure that the hydrogen market is both competitive and nondiscriminatory in the future. For successful implementation of the blockchain market environment should be clearly understood, wrong implementation of the policies could collapse the market at the early phase without opportunities for a long run. Government ministries should form public-private partnerships to fund blockchain pilot projects and provide regulatory sandboxes. Offering financial incentives and grants can encourage companies to adopt blockchain technology. Clear regulations are essential to support blockchain adoption while ensuring market integrity. Energy companies should form consortia to share knowledge and best practices. Community feedback mechanisms can help build trust and ensure that projects align with local needs.

4. HYDROGEN MARKET WITHIN BLOCKCHAIN

Discussion on the hydrogen market should be started from introduction to the traditional energy market and its landscape. A small number of large-scale producers, in other words monopolies, and suppliers have controlled the majority of energy resources, including coal, oil, and natural gas, in the traditional energy market, which has been primarily centralized. For hydrogen to seek investors, trading globally should be considered on the research basis. All international trade is subject to agreements under the General Agreement on Tariffs and Trade (GATT) and the World Trade Organization (WTO). The multilateral trading system, initiated by GATT and expanded by WTO, has eliminated protectionism and facilitated global business operations. This has led to the growth of corporations, supply chains, and global networks, as well as the standardization of regulations and reduction of trade barriers. In-depth multilateral GATT or WTO negotiations regarding the energy market have not occurred frequently due to monopolies in the energy sector. The trading model that governs natural gas is what determines the trade's significance in this market. Supply and demand dynamics control prices in the market-driven model, but government intervention is necessary in the state-driven model. A multilateral pact that was signed in 1994 with the aim of improving the energy market – the Energy Charter Treaty (ECT), is outside of the GATT/WTO framework, ECT is the only multilateral agreement that uniquely defines and regulates energy trading [30]. The comprehensive coverage of all aspects of energy trade, including safeguarding foreign investments in the sector, facilitating global energy trade, and assisting energy efficiency makes this agreement crucial. Basically, the international energy market depends on several regulations and policies (Figure 6): GATT, WTO, ECT and Regional Trade Agreements (RTA) that can vary by location, affecting how energy commodities are traded globally. The United Nations Convention on Climate Change (UNFCCC) and Kyoto Protocol are also subjects of energy trade, although indirect. UNFCCC long-term policy supports reduction of greenhouse gas emissions that naturally shifts usage from fossil fuel to renewable energy sources and so creates change in market demand. Kyoto Protocol and its cap-and-trade mechanism encourages market innovation and the adoption of cleaner technologies.

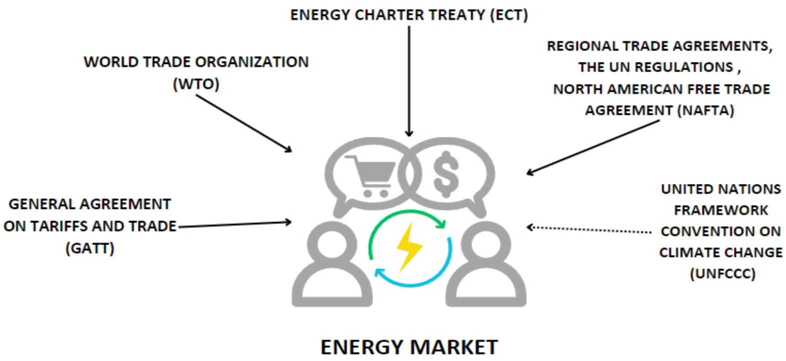


Figure 6. Legal frameworks and regulations that affect international energy trade

Hydrogen trading is a subject of energy trade policies and is also being addressed by various international organizations such as WTO and UNFCCC. WTO oversaw hydrogen influence on global decarbonization and recognized it as an important strategic tool under renewable energy [18]. The European Energy Exchange (EEX) to promote rapid ramp-up of the hydrogen market has been publishing the first global market-based hydrogen index since 2023. Thus, as a trading platform for hydrogen, EEX has developed the HYDRIX [31] that reflects price transparency, facilitating the trading of hydrogen and its stock demand. HYDRIX serves as a benchmark for the hydrogen market, providing a clear and objective measure of the price of hydrogen. Traders can use HYDRIX to discover the fair market price of hydrogen, ensuring that transactions are conducted at a transparent and equitable price.

Smart contracts can track and verify the authenticity and quality of hydrogen, ensuring it meets the required standards. This is crucial for protecting intellectual property rights and maintaining the integrity of the hydrogen supply chain, as outlined in the WTO's Agreement on Trade-Related Aspects of Intellectual Property Rights. Furthermore, smart contracts ensure that all trading partners in the hydrogen market are treated equally by maintaining a transparent and immutable record of trade transactions. This aligns with GATT's principle of non-discrimination, thereby promoting fair trade practices. Moreover, blockchain can manage and verify trade data for hydrogen, ensuring accuracy and compliance with GATT's rules on trade data reporting. This reduces errors and enhances the reliability of trade information. Finally, blockchain provides a transparent ledger for energy transactions, ensuring that all parties have access to the same information. This supports the ECT's goal of promoting transparency in energy markets, facilitating trust and cooperation among stakeholders [32].

Hydrogen market for efficient and effective operation requires establishment of a reliable trading system where hydrogen units can be traded. However, the hydrogen market is experiencing slow development and limited adoption due to existing policies, the complex process of hydrogen certificate verification, lack of transparency, and the absence of a widespread trading mechanism. Blockchain technology within its software nature closes these gaps providing a decentralized, tamperproof, reliable platform. In assessment of Blockchain's potential to enhance transparency, efficiency, and compliance in hydrogen production, storage, and distribution systems is based on findings from extensive literature reviews and particular case studies, such as "HydroChain" and "H2-Share" [33]. According to the findings, blockchain technology has the potential to greatly improve hydrogen certification and traceability, support stable peer-to-peer energy trading platforms, and fortify market dynamics by facilitating better logistical operations. Notable obstacles to its full adoption, however, include scalability, interoperability among various blockchain systems, and the requirement for flexible regulatory frameworks.

Developing optimized blockchain solutions that can successfully integrate with current technologies will require a multidisciplinary approach and proactive collaboration among stakeholders to address these challenges. Dong et al. [34] proposed the concept of hydrogen credits (HC) as a way to enhance hydrogen economy. Under the suggested HC framework, HCs can be traded in a global H2 economy setting. As a result, an international regulatory framework is taken into consideration when building the HC issuance framework. The worldwide recognition of credits can be guaranteed by the International Executive, which is the highest authority in credit issuance. The planned H2 project is able to abide by national laws and carbon reduction regulations thanks to the designated operation entity and designated national authority. As the project developer, the project participant is a major player in the HC market and is the owner of the issued HCs.

Another example of blockchain usage for energy trade is Grid+, a pioneering blockchain energy company disrupting the traditional wholesale energy distribution model. By targeting inefficient retail services like billing and metering, Grid+ proposes a direct user-to-grid connection via a blockchain-based platform. This eliminates intermediaries, potentially reducing consumer bills by 40%. Utilizing Ethereum, Grid+ empowers users to buy energy at desired prices, fostering a more equitable, stable, and cost-effective energy market [35].

An Australian company called Power Ledger has created and managed microgrids using blockchain technology. By enabling direct energy transactions between community members, Power Ledger's platform lessens dependency on the central grid and fosters energy independence [36]. Energy transactions are made more efficient by smart contracts, which do away with middlemen and cut administrative expenses. Blockchain-powered microgrids can reduce the impact of disruptions and improve energy security by supplying backup power during blackouts.

5. RESULTS AND DISCUSSIONS

According to the research, blockchain technology shows compatibility with the trading mechanism. Thus, the core features of smart contracts offer cross-border transactions, fair payment proceedings and solving of double spending issues, common trading decentralized platform without intermediaries, security and data management. Smart contracts creating a unified security system have every chance to win the trust of key stakeholders. Smart contracts demonstrate needed in hydrogen market prerequisites for their further improvement and application as automatic trading contracts. Smart contracts within Artificial Intelligence algorithms could make contracts truly smart; AI could be used by developers to provide information inside the blockchain and automate the system with forecasts for the future state of the market.

Conducting stakeholder analysis for the hydrogen market is necessary. Understanding the power and interest distribution of government institutions and corporations allows us to determine the next steps of implementing policies, technologies and hydrogen distribution. Under a power-interest grid method, the highest interest and power belongs to government ministries and energy sector companies, one will suggest the future direction of hydrogen trade, others will implement infrastructure including smart contracts platform. Decisions of core stakeholders create a wave that goes to the legal and political environment, then economic and technological.

Nevertheless, the main difficulty of blockchain implementation is customization of its use under existing regulations. Energy trading operates within a complex framework that encompasses a pyramid of rules and global regulations. It was found that while all forms of trade fall under the scope of the World Trade Organization (WTO), the trade of energy resources is distinctly governed by the Energy Charter Treaty (ECT), that covers foreign energy investment, trade and efficiency. Additionally, this sector is influenced by both local agreements like Regional Trade Agreements and international conventions concerning carbon emissions. Thus, hydrogen trading is governed by WTO and UNFCCC convention. Introduced regulations collectively have a significant impact on the market demand for sustainable energy sources, such as hydrogen, being a promoter of switch to renewable energy.

6. CONCLUSIONS

Hydrogen market in its ramp edge phase needs further investment, technological and legal support to establish a common widespread trading system. There are questions of how exactly blockchain technology will be implemented under existing policies, will blockchain change these policies or not. The need of policy maker professionals and smart contract engineers and their future collaboration is obvious. Nevertheless, hydrogen is a highly efficient energy source that plays a key role in the modern environment under renewable energy and decarbonization regulations.

Future studies should explore ways to customize blockchain technology to comply with existing regulations. Additionally, further analysis of stakeholder power and interest, particularly in government and energy sectors, could provide insights into the implementation of policies and technologies for the hydrogen market. This could help pave the way for broader acceptance and integration of blockchain technology in the energy trading market.

NOMENCLATURE

AI - Artificial Intelligence
DL - Deep Learning
ECT - Energy Charter Treaty
EEX - European Energy Exchange
GATT - General Agreement on Tariffs and Trade
HC - Hydrogen Credits
ML - Machine Learning
P2P – Peer-to-Peer
SDGs - The United Nations Sustainable Development Goals
UNFCCC - United Nations Convention on Climate Change
WTO - World Trade Organization

DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Sofya Morozova: Wrote the manuscript.

Arif Karabuga: Collected the data, wrote the manuscript.

Zafer Utlu: Supervised the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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