First steps in the implementation of a COAP and Blockchain server for green hydrogen certification.

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Abstract. In the face of rising concerns about climate change, the energy sector is undergoing a digital transformation. IoT and Blockchain technology has emerged as a promising solution to ensure security, traceability, and efficiency in energy management, particularly in certifying the origin of energy. Various projects in the energy sector are discussed, highlighting how these initiatives are transforming the way energy is produced, distributed, and consumed. The paper focuses on the work done to implement a central node for handling received hydrogen gas flow measurements using the COAP protocol and the initial steps in the implementation of a blockchain node.

Keywords: Blockchain, Renewable Energy, COAP, Energy Certification.

1 Introduction

Climate change is one of the major concerns of our time due to its significant impact on the environment and people's lives. Strategies for mitigating climate change vary across countries but generally center around the shift away from fossil fuels. As nations assume to achieve climate neutrality, green hydrogen and information management have emerged as crucial components [1]. In this transition, digitization plays a vital role, transforming the traditional energy distribution and trade models. This shift towards a 'digitized' paradigm goes beyond energy alone, extending to the data associated with generation, distribution, trading, and usage. Gathering, storing, analyzing, and publishing information according to clear standards, such as security, traceability, processing speed, and data transfer, becomes critical [2]. Therefore, the tools used must be adaptable to a decentralized energy sector that aims for sustainability in network energy sourcing.

A significant number of companies are working on various components of hydrogen certification systems, such as sensors, data transfer, data storage, visualization, and analysis. Some of these companies include My-Oli, Youki Energy, Spherity, Riddle and Code, UTE, Theben, and Power Plus Communication. In Europe, there is a notable rise in research groups, such as the DENA (German Energy Agency), which collaborates with a network of companies and universities to design, conceptualize, and implement certification systems. Also, the University of Palermo in Italy is particularly focused on traceability and certification of hydrogen [3]

This leads the research group to the concept of 'Certification of Origin', a requirement that is gaining traction among governments and industries committed to sustainability through energy with a verifiable renewable origin. In this context, Argentina's existing cost advantages in sustainable hydrogen production make it an ideal candidate for implementing smart sensors and blockchain technology for certification at the point of origin. This paper aims to explore these issues in detail, specifically looking at how IoT technology in complement with blockchain technology can serve as a critical tool for sustainability.

This paper is structured as follows: it explores digitalization in the energy sector, details a central node setup for data handling using the IoT COAP protocol, and assesses blockchain's role in ensuring security and traceability. Test results validate the system's feasibility and application in future applications.

2 Digitalization in the Energy Sector

The certifiable hydrogen generation system involves the interaction of four key players: the sustainable electrical energy source, the electrical distribution network, the electrolyzer, and hydrogen storage facilities for export. Directly connecting sustainable electricity generation to the electrolyzer is the easiest method to certify, but this setup risks leaving electrolyzer plants idle during adverse weather conditions. To certify this option, intelligent sensors are required to continuously measure electrical generation and consumption, associating it with hydrogen generation at any given moment to ensure the energy corresponds with the renewable energy certificate.

Emerging technologies like IoT, AI, and blockchain are leading to the energy sector digitalization. IoT devices provide real-time data on energy handling and use, while AI algorithms offer advanced analytics and predictive insights to optimize energy use. Blockchain technology ensures secure and transparent recording of energy transactions, further enhanced by smart contracts for automated and self-executing transactions. All these technologies together are changing how energy companies operate, making things more transparent, efficient, and automated. This makes it harder for bad actors to manipulate data and helps automate the record-keeping of energy transactions, leading to a more sustainable and reliable energy system [4].

However, the transition to a digitalized energy sector is not without challenges. Technical limitations, such as old infrastructure, must be addressed. Workforce adaptation and training in new digital tools are crucial, requiring the energy industry to invest in skill development for all stages of the energy value chain. Finally, successful digitalization demands political reforms and social acceptance. Government support and approval to research and development on the energy sector are crucial for rapid and effective implementation [5]. Despite these challenges, embracing digitalization is crucial for a more sustainable and responsive energy future.

3 Internet of Things (IoT) system

3.1 General Aspects of the System

This paper describes an Internet of Things (IoT) system designed for the certification of the origin of green hydrogen. The primary objective is to ensure the traceability and authenticity of the produced green hydrogen, facilitating its origin certification through a secure and efficient system. A block diagram of the system is presented in **Fig. 1**, followed by a brief description of each block operation.

- Hydrogen Flow Sensor: This sensor measures the amount of hydrogen produced and sends the data to the ESP-32 microcontroller.
- ESP-32 Microcontroller: Acts as a CoAP (Constrained Application Protocol) client, receiving data from the sensor and transmitting it to the data server. The ESP-32 is chosen for its low power consumption, Wi-Fi connectivity, and adequate processing capacity for IoT applications [6].
- Data Server (Raspberry Pi 4): Acts as a CoAP server, developed in Python v3.12. It receives and stores the data sent by the ESP-32 in a MySQL database. The Raspberry Pi 4 is selected for its processing power, storage capacity, connectivity, and low cost, making it ideal for server applications in small IoT projects [7].
- Blockchain Node: This server is analyzed in depth in Section 4.

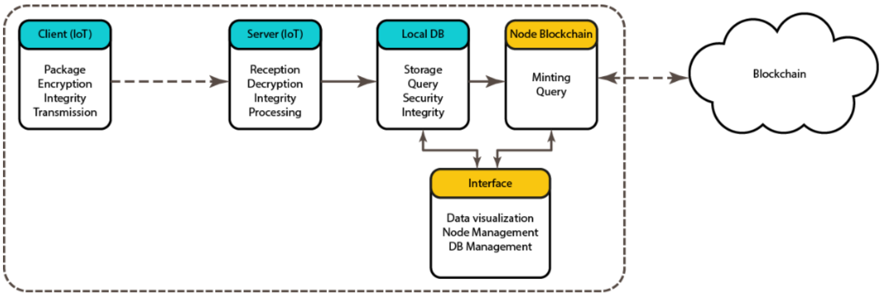

Fig. 1. – Flow Meter Data Communication and data storage

3.2 IoT protocol selection

In the following section, the comparative advantages of Constrained Application Protocol (CoAP) over other protocols, such as HTTP, MQTT, and AMQP, are outlined, highlighting its suitability for our implementation. These advantages illustrate why CoAP is ideal for communication between the ESP-32 microcontroller and the Raspberry Pi 4, ensuring efficient use of bandwidth and power. [8]

Comparative Advantages of CoAP.

- Efficiency: CoAP uses UDP instead of TCP, reducing overhead and power consumption. This makes it more suitable for resource-constrained devices compared to HTTP and AMQP, which have higher bandwidth and power consumption requirements.
- Optimization for Constrained Networks: CoAP is designed to perform well in networks with high latency and low bandwidth, outperforming MQTT in these specific environments.
- Simplicity: Its lightweight request-response design makes it easy to implement and maintain in IoT devices, unlike the greater complexity of AMQP.
- Compatibility: CoAP is compatible with RESTful models, facilitating integration with existing web systems in a more efficient manner, like HTTP but with greater efficiency.
- Encryptable: CoAP supports DTLS (Datagram Transport Layer Security), providing confidentiality, integrity, and authentication, like the security offered by HTTPS. However, while HTTPS (HTTP over TLS) relies on TCP, adding overhead and latency, DTLS is designed to operate over UDP, maintaining CoAP's efficiency and performance advantages [9]

4 Blockchain Technology

Blockchain technology, a decentralized ledger that records transactions without the need for a central authority, is increasingly being recognized for its potential in the energy sector [10]. In blockchain, an ever-expanding chain of records, is created, with each block containing transaction data, a timestamp, and a hash pointer that links it to the previous block. The use of hash values ensures tamper-proof capabilities, making it difficult to alter any block without changing all subsequent blocks. So, it allows multiple users to access the same information source, and all actions taken on the blockchain are verifiable, instilling confidence among all participants in the system. These unique features make blockchain an appealing solution for efficient digital energy payments, secure data storage, energy trading among stakeholders, and ensuring data privacy [11].

Blockchain technology has expanded its scope beyond cryptocurrencies, finding valuable applications in the energy sector, particularly using smart contracts. These are self-executing contracts coded to automatically execute and verify transactions once certain predetermined conditions are met. This feature minimizes the likelihood of errors or fraud [12]. In the energy context, one of the main objectives is to certify the origin of generated energy. Using data from smart meters, smart contracts can automatically validate power generation, making easier the verification process [13]. The introduction of green certificates, which are electronic credentials for businesses that use renewable energy, has raised security concerns about the origin of that energy. Blockchain improves these concerns by treating each phase of the energy lifecycle as an individual transaction, facilitating point-to-point certification [14]. This methodology transforms an otherwise unclear system into a transparent, traceable registry that includes both consumers and producers.

In addition to facilitating "point-to-point" certification, the integration of blockchain technology with smart contracts and smart meters also opens new chances for innovation within the energy sector. It offers possibilities for real-time energy pricing, dynamic grid management and peer-to-peer energy trading and certification. These expanded applications not only enhance data integrity and network security but also empower consumers with more control over their energy data, paving a new era of decentralization and democratization in energy systems.

4.1 Assessing and Selecting Blockchains for Energy Certification

In the energy sector, numerous project companies are leveraging blockchain technology and other distributed ledger systems as their primary development tools. They aim to gain a competitive edge by offering solutions and unique features to enhance various segments of the energy value chain.

All these competitors have different approaches to rethink the different steps of the energy sector's chain of value, but with one common denominator: the blockchain technology (or a similar distributed ledger system) as the main tool. Some focus on distribution and sales, providing secure and traceable means to buy and sell energy produced from renewable sources. However, few solutions address the need for tamper-proof certification of renewable energy sources, and even fewer tackle this need specifically for renewable hydrogen production. For instance, TEO and PowerLedger specialize in digital certificates for tracing energy origins, but they offer their solution only for a fee without general platform access. This limitation makes it difficult to evaluate the software for potential pilot projects and impedes further analysis based on available documentation. On the other hand, the Energy Web (EW) blockchain platform offers a well-documented set of open-source development tools (referred to as an SDK, or "software development kit") that can be used across various stages of the energy process, from generation to consumption. Additionally, this platform offers a sandbox environment, enabling the evaluation of pilot projects before actual implementation. These features make EW an excellent candidate for a more comprehensive analysis within this research work. It's noteworthy that the Energy Web platform does hold back some more sophisticated features, available via a Software as a Service (SaaS) model, which are tailored for hydrogen certification under their "Green Proofs" solution.

5 Test Results

5.1 Central node implementation

The implementation of the central node, housed in a Raspberry Pi 4, involved several steps detailed below:

1. Operating System Installation (pi OS): Raspberry Pi OS, an optimized version of Debian for the Raspberry Pi, was downloaded and installed. This choice was made

due to its extensive support and active community, which facilitate problem resolution and the implementation of new functionalities.
2. Python Update: Python was updated to version 3.12 to ensure compatibility with the latest libraries and functionalities required for the project.
3. Installation of Apache and MySQL:
   - Apache was installed as a web server to host the system's administration and monitoring interface.
   - MySQL was installed as a database server, providing robust and reliable storage for the data generated by the hydrogen flow sensor.
4. Installation of the CoAPthon3 Library: The CoAPthon3 library by Tanganelli was used to handle the CoAP protocol in Python, enabling efficient and effective communication between the client and server.
5. Development of the CoAP Server: The CoAP server was developed in Python using the CoAPthon3 library. The server's design allows it to receive data sent by the ESP-32 client, process it, and store it in the MySQL database. Extensive testing was conducted to ensure that all methods (GET, POST, PUT, DELETE) functioned correctly, guaranteeing the system's robustness and reliability.

5.2 Testing the COAP protocol

The initial tests consisted simply of observing the data frame sent between the two points. For this purpose, a PC and an ESP32 was used as the client and the Raspberry Pi (assigned IP address 192.168.1.98) acted as the server, with both using Python as the programming language.

The test procedure involved performing a GET request on the "basic" resource available on the server, followed by a PUT request to modify this resource, and finally, another GET request to verify the correct modification of the resource.

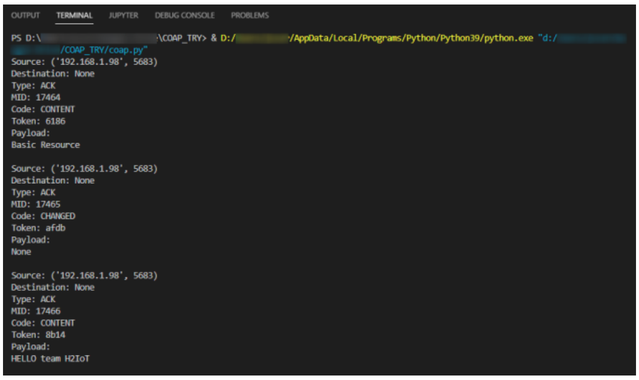

Fig. 2. - Client Console: Response to GET and PUT Methods

Subsequently, functions for encoding and decoding JSON frames and storing them in the database were implemented. The result is shown in **Fig. 3**, where the generated records in the database can be observed.

The tasks performed have yielded satisfactory results. Communication between the client and the server was established without issues, and the data was correctly stored in the database.

sensor_id	timestamp	flow_rate	temperature	latitude	longitude	origin_certification
sensor_1	2024-06-22 18:50:33	23.4897	22.8979	40.7128	-74.006	H2_green
sensor_1	2024-06-22 18:50:46	20.2146	28.9514	40.7128	-74.006	H2_green
sensor_1	2024-06-22 18:50:47	10.4843	25.2059	40.7128	-74.006	H2_green
sensor_1	2024-06-22 18:50:48	10.2296	29.0019	40.7128	-74.006	H2_green
sensor_1	2024-06-22 21:00:00	28.3	12.5	40.7128	-74.006	Green

Fig. 3. - Database Management Capture: MyPhpAdmin

5.3 Testing the security layer of Energy Web

The Energy Web provides a complete development package, called “EW-DOS”, which is structured as a “Stack” ecosystem, formed by 3 main layers:

1. **Trust layer**: this component provides security to the entire stack functionality. It heavily relies on blockchain's distributed ledger technology to securely validate transactions.
2. **Utility layer** This layer offers a suite of services that facilitate the development of decentralized applications (dApps), including tasks like ID management and blockchain interaction.
3. **Toolbox layer**: This is where developers can access a wide array of tools and libraries to create apps more specific for every use-case within the energy ecosystem. "Green Proof" is the best example of this kind of tools available in this layer.

This research will delve into the functionalities of the Trust layer to understand how this security aspect of the system functions. The security layer of Energy Web is composed of numerous nodes that serve as connection points within a blockchain's peer-to-peer network. These nodes execute the blockchain protocol, allowing them to interact with other peers, access the blockchain ledger, and conduct transactions. Different types of nodes exist based on how much blockchain information they synchronize. For instance, full nodes maintain a complete copy of the blockchain ledger and update it in real-time, light nodes store only the essential data needed for specific transactions, and archive nodes keep a historical record of the blockchain's states. To evaluate the functionality of Energy Web's tools, a full-node instance was deployed on the Volta test network, enabling the implementation of smart contracts and certification tools.

On the hardware side, the system requires a multi-core CPU, at least 4GB of RAM, and an SSD with a minimum of 150GB of free storage space to hold a fully synchronized copy of the blockchain. It's worth noting that such hardware specifications are common in an average domestic computer, distinguishing it significantly from the high-end nodes used in Bitcoin mining. On the software side, given that Energy Web's architecture is embedded in the Ethereum platform, the "OpenEthereum" client becomes essential for aligning the specifications of the Volta chain with the local node.

During the synchronization process, the software provides a real-time display of the blocks being locally recorded, as well as a count of the blocks still pending import. During this phase, it was observed that an Ethernet connection with a 300Mb download rate was too slow for synchronizing the node, taking approximately three days to complete. Once this process is complete, the local copy of the blockchain becomes available for additional development and operational activities. Moreover, the local node will stay up to date by continually integrating new blocks generated by other network nodes.

The implementation of a private node allows the transactions generated to be more direct and secure and eases the self-verification process of the transactions. Also, a local node is not subject to speed restrictions, which can be beneficial if development requires many requests to the blockchain [15]. By setting up a "full node" on the Volta test network within the Energy Web platform, the value of having open-source code and clear documentation becomes evident. These hands-on experiences with node deployment have proven critical for understanding the system's performance and requirements. This practical knowledge equips this team to confidently move forward with implementing additional advanced layers within the Energy Web framework.

6 Conclusion

The digital transformation of the energy sector is increasingly imperative as the global community addresses climate change and transitions from fossil fuels to renewable energy sources. Among a range of facilitating technologies, IoT system and blockchain technology together emerge as a significant enabler of transparency, security, and efficiency across the entire energy supply chain. Its utility extends from straightforward point-to-point certification to complex smart contract functionalities.

The development and implementation of the CoAP server and client have proven to be highly effective for the real-time communication needs of resource-constrained microcontrollers. The initial tests validated the correct transmission and storage of data, confirming the reliability of the protocol. The comparative analysis, which evaluated alternatives such as HTTP, MQTT, and AMQP, highlighted CoAP's advantages in terms of efficiency, simplicity, and performance in high-latency and low-bandwidth networks, underscoring its suitability for IoT applications.

Through an in-depth analysis of blockchain-based solutions, Energy Web emerged as a notable candidate. With its well-documented open-source development tools and sandbox environment for pilot project evaluation, Energy Web offers a holistic solution that is both accessible and sophisticated. The platform also offers advanced features through a Software as a Service (SaaS) model, addressing specific requirements like renewable hydrogen production.

The implementation of a full node on Energy Web's Volta test network served as a practical example, providing valuable insights into the functionality and requirements of the platform. In addition to imparting technical knowledge, the process shed light on the hardware requirements for running a node.

Next steps in the research agenda include the initiation of robust pilot projects to evaluate blockchain's real-world efficacy, proactive dialogue with regulatory bodies to shape a favorable policy landscape, and targeted public awareness campaigns to dissipate misconceptions in blockchain's benefits. Additional steps include exploring diverse funding mechanisms, such as public grants and venture capital, and forming strategic partnerships with key stakeholders in the energy ecosystem. These concerted efforts aim to enhance the broader understanding and acceptance of blockchain's role in facilitating a more sustainable energy future.

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