

Lumin: Blockchain-based Solar Energy Management System

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1. Introduction

Saudi Arabia is making a groundbreaking **investment of $266 billion** in solar energy as part of its Vision 2030 initiative[4]. This ambitious strategy includes major projects such as NEOM, KAUST, and Red Sea Global, positioning the nation as a leader in renewable energy. However, the rapid expansion and modernization of the energy sector comes with significant challenges. One of the critical issues is cybersecurity. Global industry faces annual **losses** of approximately **$10 billion** due to cyberattacks, with the energy sector being particularly vulnerable. As energy projects become more complex and interconnected, the risks of cyber threats and data breaches escalate, leading to potentially severe financial and operational impacts. **Lumin,** our proposed solution, addresses these pressing challenges by offering a blockchain-based decentralized solar energy management system. By utilizing blockchain technology, it ensures that all transactions within the solar energy management system are transparent and tamper-resistant. This enhances trust and integrity in the handling of energy resources. Additionally, traditional energy management systems rely on centralized platforms, which can be susceptible to cyberattacks. Lumin's decentralized approach reduces this risk by distributing data and processes across a blockchain network, minimizing the impact of potential security breaches. Moreover, the proposed product supports Saudi Arabia's Vision 2030 goals by promoting the adoption of renewable energy and facilitating an **efficient and secure management and exchange of solar energy resources**, contributing to the nation's renewable energy targets.

2. Problem Statement

This section demonstrates the main challenges facing current traditional solar panel systems[8]. As shown below, **Figure 1** illustrates the vulnerable components, which are explained further in the following:

- **Data Tampering:** Collecting information from solar panels and smart meters can lead to incorrect decisions in energy management, making the system unreliable.
- **Energy Surpluses and Shortages:** Imbalances between energy production and consumption in centralized systems can result in unutilized surpluses or shortages, affecting overall performance.
- **Centralized Control Systems:** These are vulnerable to cyberattacks, and if compromised, could lead to a complete system shutdown, jeopardizing energy security.

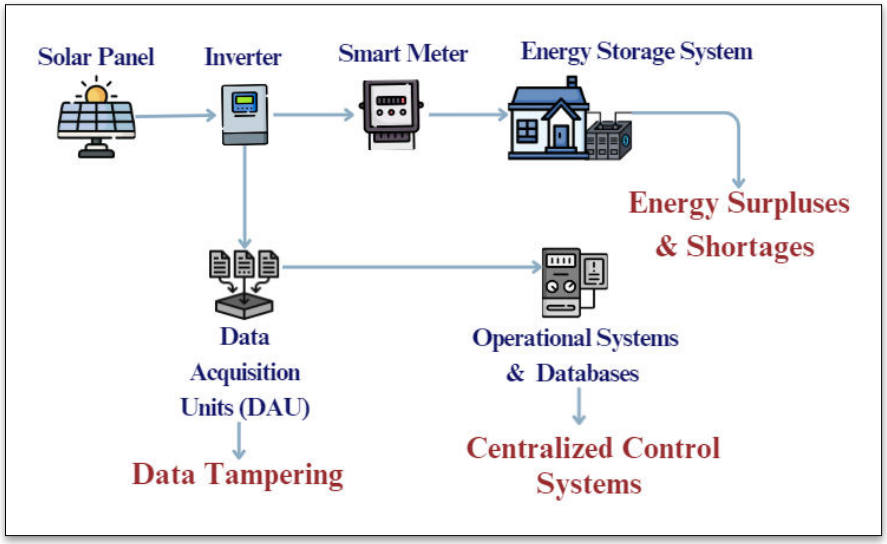


Figure 1: *Key Challenges in Traditional Solar Panel Systems*

3. Objectives

The main objective of this project is to address the challenges presented by the current energy management systems. The proposed solution aims to provide a **decentralized control system** to minimize single points of failure while enabling a **peer-to-peer energy trading** system to facilitate direct energy trading between consumers and producers, enhancing energy distribution efficiency. Additionally, Systems' **transparency** is Ensured by showing that all transactions are visible and verifiable on the blockchain, reducing opportunities for fraud and error.

4. Methodology

This section explains the utilized tools for the project's development and the system's flow and inner working.

4.1 Tools:

Lumin utilizes various resources to achieve its objectives, including:

- **Ganache:** A personal blockchain for Ethereum development, used by LUMIN to create a local blockchain environment for testing and deploying smart contracts.

- **Truffle:** A development framework for Ethereum, helping LUMIN streamline smart contract compilation, deployment, and testing processes**.**

- **Solidity:** Essential for smart contract development; although it's a programming language, it is fundamental in constructing the platform's blockchain logic.

- **MetaMask:** A tool for managing digital assets and interacting with the Ethereum blockchain, crucial for LUMIN users to securely manage their energy tokens.

- **Python (PyQt5):** Used for data processing, integrating various components of the platform, and building the user interface (UI).

- **Ethereum:** The underlying blockchain platform that powers LUMIN's decentralized operations, enabling secure, transparent, and tamper-proof energy trading.



Figure 2: *Key Tools Utilized by LUMIN.*

4.2 System Flow:

The project follows a structured methodology where transactions are initiated through Lumin's interface, executed via smart contracts, and represented as blocks on the blockchain[1]. The process includes the following steps, and illustrated in **Figure 3**:

1. **Transaction Initiation:** A new transaction is requested.

2. **Smart Contract Execution:** Lumin directly interfaces with the smart contract to start the transaction.

3. **Transaction Completion:** The transaction is completed and reflected on Lumin's interface.

4. **Chain Inclusion:** A new block is created and added to the blockchain.

5. **Block Propagation:** The transaction is broadcasted to the network for validation.

6. **Transaction Completion:** The transaction is successfully reflected through Lumin's interface.

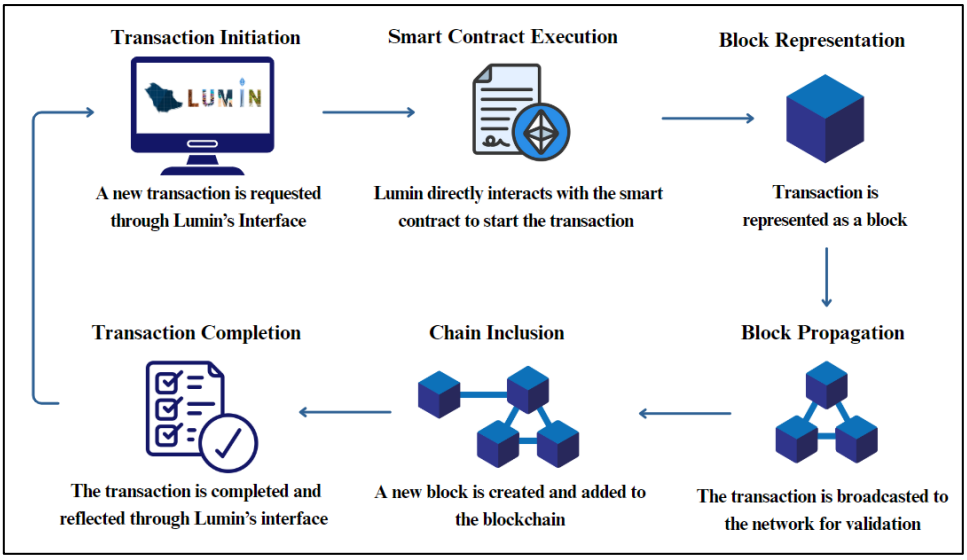


Figure 3: *The LUMIN Transaction Flow*

5. System Design

This section illustrates some of the features provided through Lumin's interfaces:

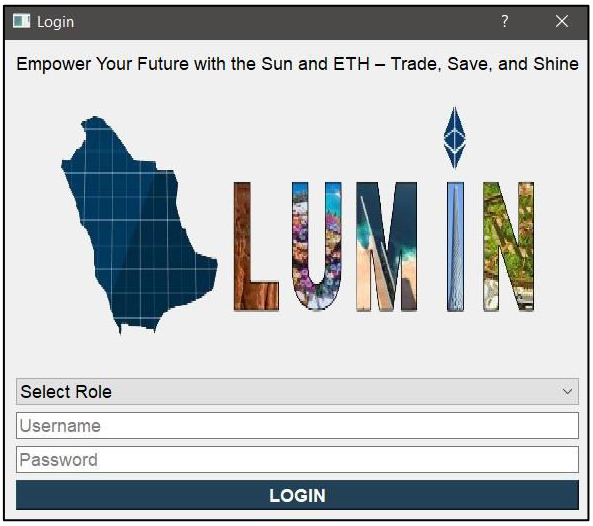


Figure 4: *Log in Interface*

5.1 Log in Interface:

Figure 4 shows the first interface of the program is the login interface, which showcases the LUMIN logo and invites users to "Empower Your Future with the Sun and ETH," emphasizing sustainable energy management through innovative technology. It offers two user roles: Managers and Normal Users. Managers can oversee transactions and panels, while Normal Users can trade, save, and manage their solar energy resources.



Figure 5: *User Dashboard Interface.*

5.2 User Dashboard Interface:

Figure 5 shows the dashboard and user info page, displaying user-specific information, including the user's name, Ethereum balance, and details of the selected solar panel. The panel information section provides key metrics such as capacity, energy balance, efficiency, and current energy level, with a visual bar indicating the energy level percentage. The panel status is shown as "Active". Additionally, there is a scatter plot graph displaying the relationship between temperature and power output at various solar elevations, offering insights into panel performance under different conditions. The "Logout" button allows the user to exit the system.

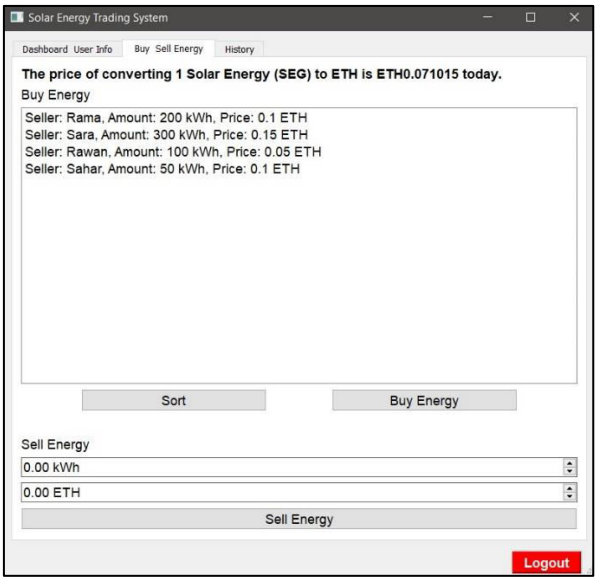


Figure 6: *Energy trading Interface.*

5.3 Energy trading Interface:

Furthermore, **Figure 6** illustrates the energy trading interface, designed to facilitate energy transactions. In the **buy section**, users can browse available offers and select their preferred option to purchase solar energy[3]. The system allows users to allocate the purchased energy across different panels they own, ensuring it doesn't exceed the capacity of the chosen panel, as shown in **Figure 5**.

In the **sell section**, users can specify the amount of energy they wish to sell, set a price, and choose the panel from which the energy will be sold, as depicted in **Figure 6**. The system verifies that the selected panel has the specified amount of energy before completing the offer process.

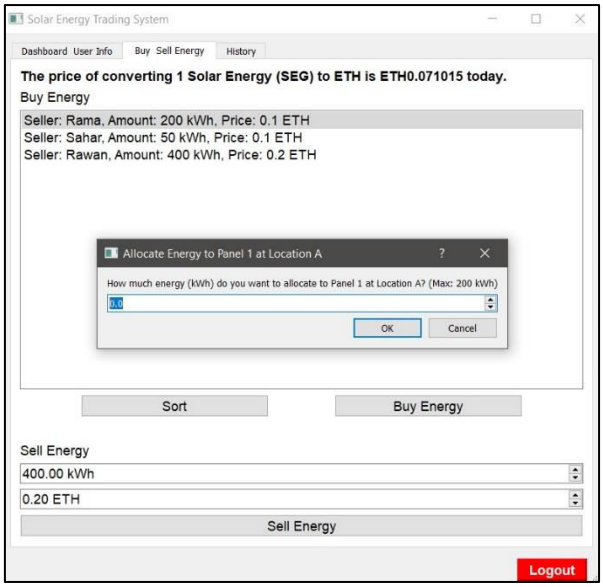


Figure 7: *Choosing the Panel and the Amount While Buying.*

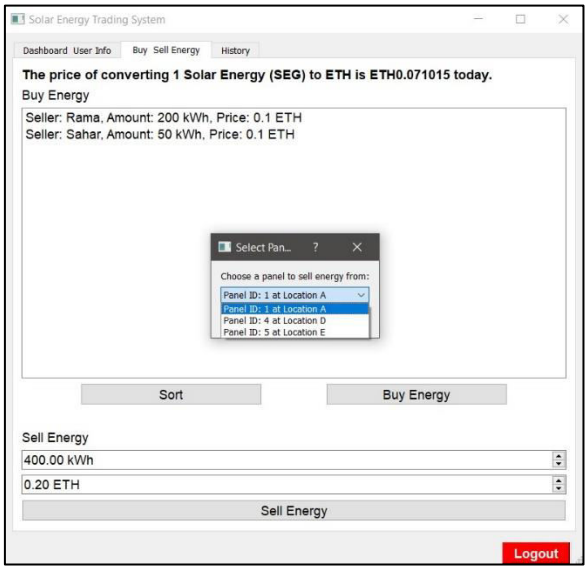


Figure 8: *Choosing the Panel to Take Energy from to Offer.*

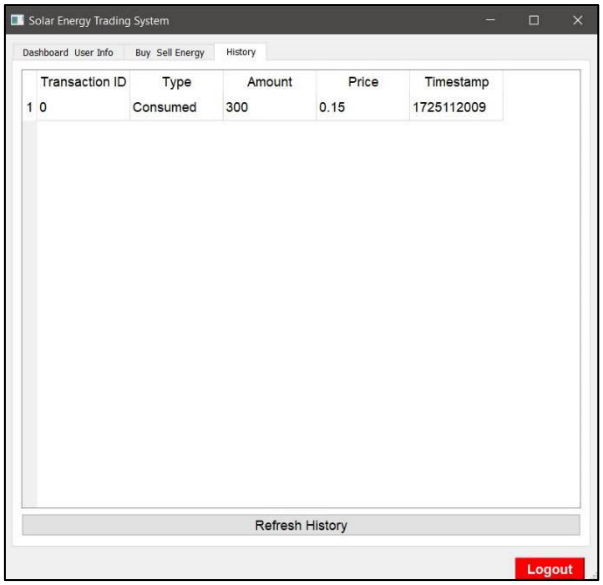


Figure 9: *Transactions History Interface.*

5.4 Transactions History Interface:

Figure 7 & Figure 8 explains how users can choose how much energy to allocate for each solar panel. While Figure 9, the history page, provides a detailed record of each transaction, including whether the user was **consuming energy** (purchasing energy from another user) or **producing energy** (selling energy to another user). The interface also shows the **price** at which each transaction occurred and the **time** the transaction was completed, allowing users to easily track and review their energy trading activities over time.

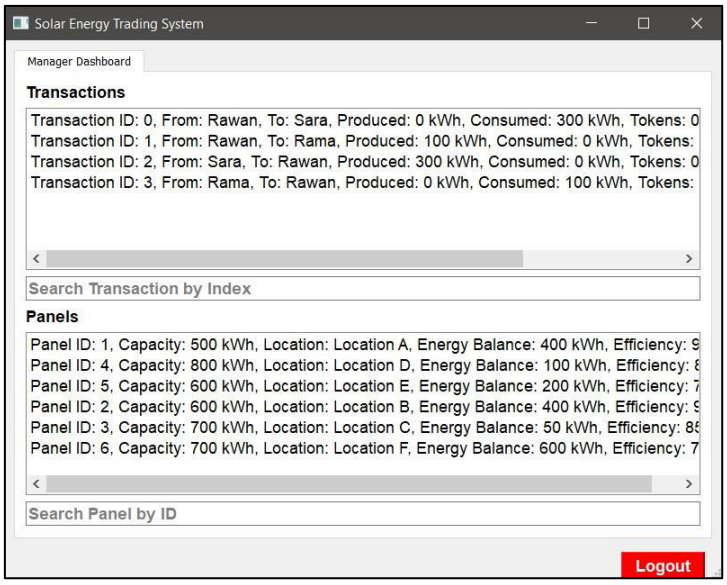


Figure 10*: Manager Dashboard Interface.*

5.5 Manager Dashboard Interface:

Moving to the manager dashboard interface, **Figure 10** shows the manager's view of a comprehensive overview for administrators to monitor and maintain system activities. Managers can view all **transactions** and their specific details, including the **from-user** and **to-user** involved, the **type** of transaction (whether it is **consuming** or **producing** energy), the **amount** of energy traded, the **price**, and the **time** of the transaction.

Additionally, managers can access detailed information about the **solar panels** belonging to users they are connected to and responsible for. This includes panel **capacity**, **energy balance**, and **efficiency**. The dashboard also offers search functionalities to easily locate specific transactions by their **index** or search for panels by their **ID**. This allows managers to efficiently oversee the system for **monitoring** and **maintenance** purposes, ensuring optimal performance and reliability.

6. Security Features

Aligning with the objectives of our training program, three main security features are ensured throughout the development of this project. Namely, integrity, non-repudiation, and privacy. the security features provided by this project are further explained below:

6.1 Integrity:

System and data integrity are provided by relying on the immutable nature of blockchain, which constitutes the architecture of our system. This feature ensures that once a transaction is logged on to the blockchain, it cannot be altered or tampered with later. This provides a high level of trust in the data and ensures its accuracy across the entire system.

6.2 Nonrepudiation:

The system ensures that a user cannot deny or claim they didn't perform a specific action within the system. Whether it's buying, selling, logging in, or any other operation, everything is recorded as a transaction receipt on the blockchain. This means all actions can be traced and verified at any time.

6.3 Privacy:

Due to the rising concerns regarding users' privacy, Lumin anonymizes users' identity on two levels, showing its importance:

6.3.1 Front-End Level:

The user's full name is only visible through their personal accounts, meanwhile, their alias is used to place their bids on the market. Preserving users' anonymity and privacy.

6.3.2 Back-End Level:

The system is linked to a blockchain address, meaning operations are recorded and protected using a string of characters rather than by their real name, boosting the security and privacy of the data.

7. Conclusion & Future Work

All in all, Saudi Arabia's shift towards renewable energy caused major intities to contribute with huge investments for a seamless migration. That with the rising concerns of the rapid cyberattack, a secure, efficient and user-friendly solution was proposed to address existing limitations in alignment with Saudi's 2030 vision. The proposed solution, Lumin, offers an enhanced energy management system that successfully applies blockchain technology. Addressing the critical security challenges in the energy sector, paving the way for a secure and efficient renewable energy future in Saudi Arabia.

As we look to the future, we are excited to expand the capabilities of our blockchain-based solar energy management system. We aim to support additional renewable energy sources, such as wind and hydro, to broaden our impact and enhance sustainability. Additionally, artificial intelligence (AI), will be employed to strengthen system security, protect against emerging threats, and implement predictive maintenance for timely repairs, reduced downtime, and selling recommendations. Our plans also include extending our operations to new regions and forging strategic partnerships with leading tech firms and research institutions. These efforts will help us drive innovation, enhance our technology, and accelerate growth, contributing to a more sustainable energy future globally.

8. References

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9. Appendix

9.1 Logo Inspiration

The LUMIN logo reflects the integration of advanced technology with key Saudi Arabian projects. Each element of the logo symbolizes the project's connection to initiatives that align with Saudi Arabia's Vision 2030[5], such as NEOM, Tuwaiq Mountain, representing the determination of the Saudi people, KAUST Academy[6], and King Salman Energy Park (SPARK)[7]. The use of the Ethereum blockchain platform further emphasizes the project's commitment to innovative digital solutions for energy challenges.

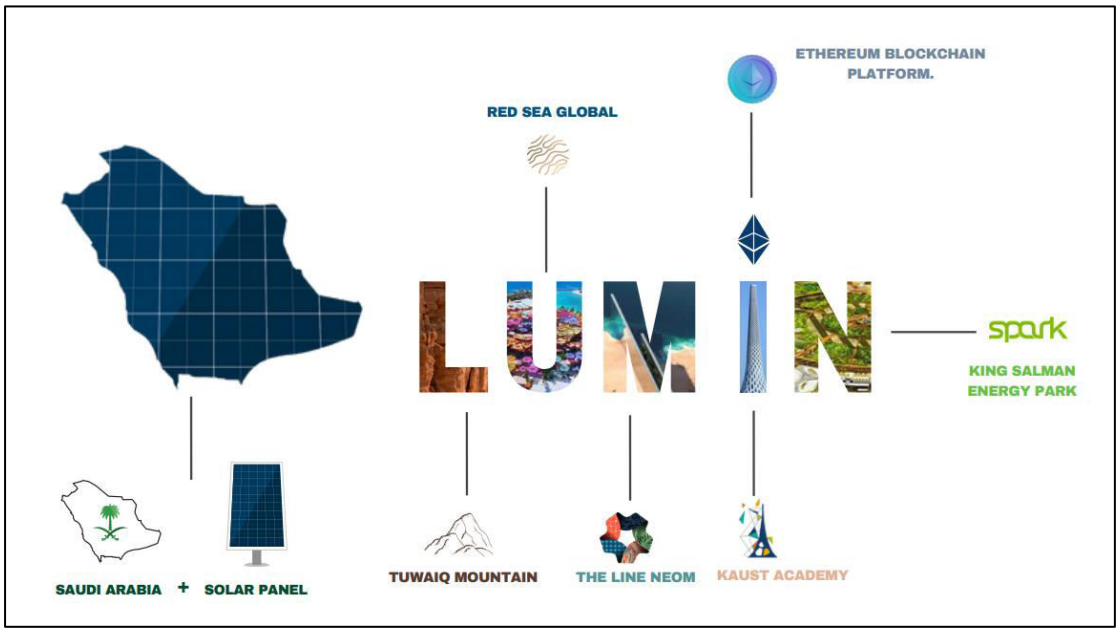


Figure 11: *LUMIN's Integration with Key Saudi Arabian Projects and Technologies.*