Srcful: A community-driven decentralized virtual power plant

Abstract—**The energy sector is confronting significant challenges, including a reliance on non-renewable fossil fuels, the centralization and inefficiency of energy distribution networks, and a lack of transparency and trust in energy transactions, driving a high demand for innovative approaches to tackle these issues. In this paper, we introduce Srcful, a Decentralized Virtual Power Plant (DVPP) that addresses these issues by leveraging Distributed Energy Resources (DERs) and a global network of IoT devices in a peer-to-peer format. Srcful utilizes a dual-incentive blockchain mechanism, "Proof-of-Source" and "Proof-of-Control," to motivate DER owners to participate actively in the network. We detail an in-depth exploration of Srcful's architecture along with its native cryptocurrency, the SRC-token, highlighting the strategic use of data and active incentivization of participants. These aspects aim to enhance platform participation and generate mutual benefits for DER owners and energy companies while promoting a shift towards more sustainable and efficient energy systems underpinned by principles of decentralization, decarbonization, and democratization. This paper contributes to the ongoing scientific discourse on Decentralized Physical Infrastructure Networks (DePINs), emphasizing their potential role in transforming the global energy sector.**

Index Terms—**Blockchain, Solana, Virtual Power Plant, Energy Systems, Decentralized Energy Management, Renewable Energy, DePIN, Helium, Proof of Control, Proof of source, Internet of Things (IoT), Data Monitoring**

I. Introduction

THE energy sector, characterized by its complexity and multifaceted nature, faces significant challenges. These include a reliance on non-renewable fossil fuels, which contributes to environmental degradation and is unsustainable in the long term; the centralization and inefficiency of energy distribution networks, which can lead to losses and reliability issues; and a pervasive lack of transparency and trust in energy transactions, which hampers the development of fair and open markets [1], [2]. Paramount among these challenges is the difficulty in balancing demand and response within the grid. This balance is crucial for the reliability and sustainability of energy systems, as mismatches can lead to outages and instability [3], [4]. Addressing these concerns necessitates a paradigm shift toward more sustainable and efficient energy systems, with an emphasis on the adoption of decentralized models [5]. The proliferation of renewable energy generation acts as a catalyst for this shift, inherently leading to a more decentralized power production landscape. This decentralization arises from the geographically dispersed nature of renewable resources, in contrast to the centralized configuration of conventional large-scale power plants. As the proportion of renewable energy sources increases, power generation becomes more distributed. This shift helps to address some of the sector's central challenges, such as reducing reliance on non-renewable fossil fuels, mitigating the inefficiencies of centralized distribution, and enhancing transparency and trust by diversifying energy production and enabling local control and ownership [3], [4], [6].

Blockchain technology emerges as a transformative agent in this context. By leveraging blockchain, there is an unprecedented opportunity to facilitate this transition towards a more resilient, equitable, and transparent energy paradigm [7]. Blockchain provides a secure and transparent way to record transactions and service provisions via DePINs, Decentralized Physical Infrastructure Networks [8].

DePINs enable a trustless environment where all parties —service providers and users— can interact directly without the need for traditional centralized authorities. This decentralization is key, allowing for a more resilient and efficient infrastructure network that is less susceptible to single points of failure and more responsive to the dynamic needs of the community. On the other hand, DePINs leverage cryptocurrency-based incentive systems to create a reward framework, enticing Distributed Energy Resources (DERs) owners and providers to contribute to crowd-sourced physical infrastructure services and fostering decentralized options over conventional facilities [9]. Within the spectrum of DePINs, Helium stands out as a forefront operating as a decentralized peer-to-peer global wireless network tailored for Internet of Things (IoT) device communication.

Building upon the transformative potential of blockchain within the energy sector, the proposed solution, harnesses the power of DePINs through the Helium network and the robust capabilities of the Solana blockchain to create a harmonious energy ecosystem [10]. The Helium Network, leveraging the Solana blockchain, incorporates specific tokens for Internet of Things (IoT) and Mobile connectivity, referred to as IOT and MOBILE tokens, respectively, alongside the Helium (HNT) token. This arrangement underscores a proof-of-participation model. Network participants achieve consensus through the demonstration of their active engagement in the

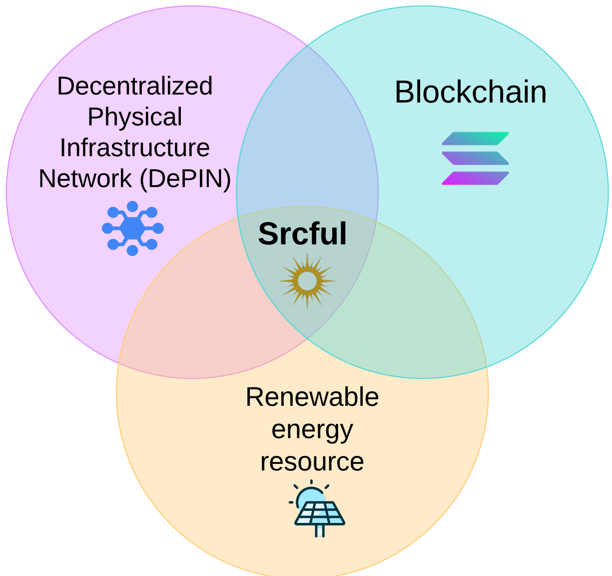

Fig. 1. Conceptual overview of the Srcful platform

network's coverage maintenance. This involvement is verified via regular checks of the device's geographic location, facilitating a proof-of-coverage (PoC) algorithm. The PoC algorithm plays a crucial role in recognizing and validating the contributions of participants towards maintaining and expanding the network's coverage. [11] [12]. The Solana blockchain is a high-performance blockchain platform known for its exceptional processing speed and efficiency, enabling thousands of transactions per second with minimal transaction costs. It employs a unique consensus mechanism called Proof of History (PoH), alongside Proof of Stake (PoS), to achieve its remarkable scalability making it an attractive option for decentralized applications and financial systems [13].

Srcful is designed to address the challenge of demand-response balance in the grid by enabling real-time, decentralized energy transactions that are both secure and scalable [10]. The Srcful platform employs the SRC-token, a cryptocurrency designed specifically for the platform which enables efficient and transparent energy transactions within the Srcful platform. The conceptual overview of Srcful, depicted in Figure 1.

This paper aims to maintain an academic perspective, examining the theoretical underpinnings and practical implications of the SRC-token within a broader context of blockchain applications in the energy sector.

The main contributions of this study are as follows:

- We propose that blockchain and decentralized physical infrastructure networks (DePIN) can act as needed transformative accelerators in the energy sector.
- We demonstrate the architectural overview of a decentralized virtual power plant based on renewable energy sources.
- We propose two main incentive mechanisms: proof of source (PoS) and proof of control (PoC).
- We provide an open-source hardware solution for energy gateway.

Section II describes our proposed solution. It presents the system overview and a detailed examination of the Srcful Energy Gateway. We then discuss the pivotal role of the SRC-token within our ecosystem and introduce the novel concepts of Proof-of-Source and Proof-of-Control. This section also presents the Srcful Data Platform and data monitoring features. In Section III, we shift the focus to the broader implications of our solution. We investigate the generation and utility of data, the mechanisms in place to reward individuals through incentives, and the benefits such incentives offer energy companies. Additionally, we consider this innovation's sustainable aspects and position relative to competitors and other stakeholders within the energy sector. Section IV provides the conclusion and presents a clear vision of how the proposed solution stands to revolutionize the energy landscape.

II. Proposed Solution

Srcful presents a decentralized virtual power plant (DVPP) solution based on wireless network for IoT devices. The primary goal of this solution is to create a community-powered energy system by leveraging DERs. Srcful's unique system operates with a dual incentive mechanism utilizing Proof-of-Source and Proof-of-Control rewards for DER owners who contribute to the network.

A. *System overview*

The architectural overview of Srcful, depicted in Figure 2, showcases the energy and data flows around the Srcful platform. By connecting their solar panels or battery to the Energy Gateway, Srcful members can join the network, which utilizes Solana-based blockchain technology to facilitate secure transactions and ensures system integrity. The Srcful Energy Gateway offers authorization, control, and rewards, while saving production and security data on the Srcful data platform that includes programmatic access to the data via Srcful API. The Gateway measures the amount of green energy produced, which, upon validation, rewards members with SRC-tokens. These tokens open avenues for participation in the energy marketplace and offer the authority to influence network operations.

B. *Srcful Energy Gateway*

Central to Srcful solution is its Energy Gateway (eGW), embedded with a Raspberry Pi 4, LoRaWAN module and a Crypto Authentication Unit (ATECC608B) [14]. The eGW is shown in Figure 3. The crypto chip provides a unique digital identity to each DER integrated into the network. LoRaWAN Helium network node enables a wireless connection to the LoRaWAN network via the

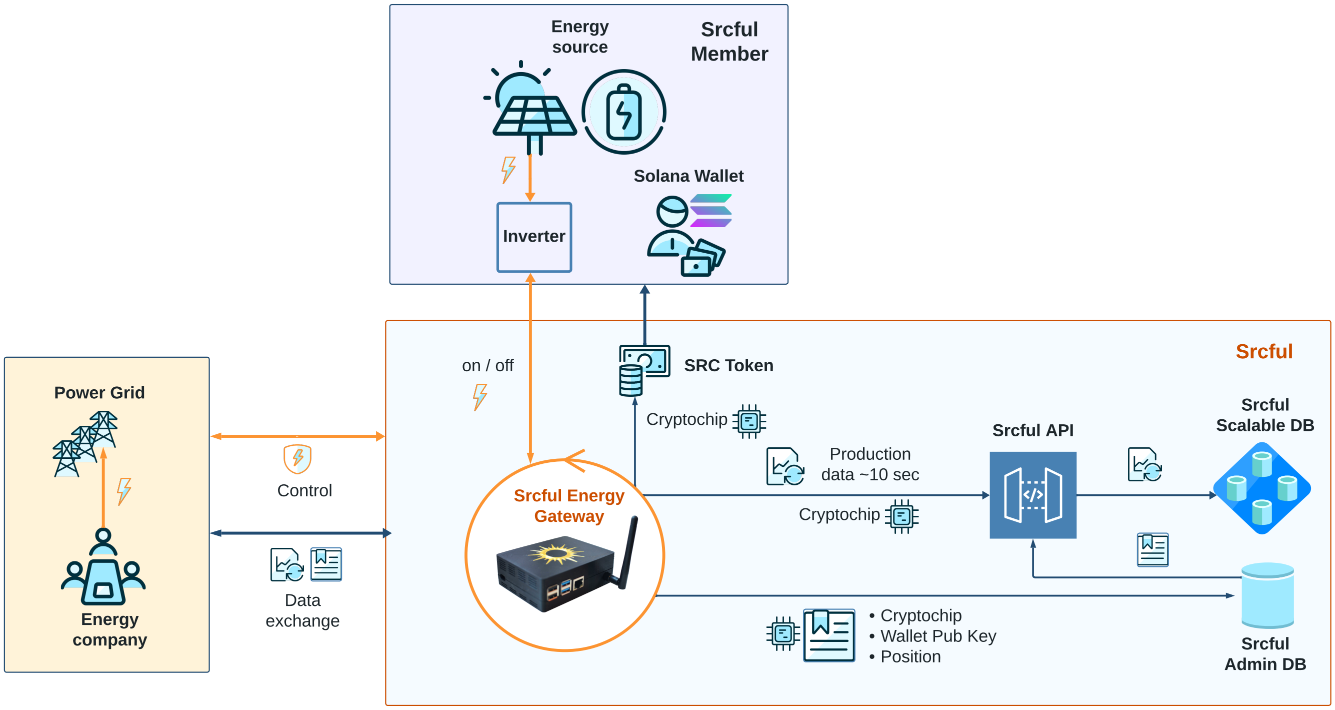

Fig. 2. Architectural overview of the Srcful platform

Helium network, which is designed to support low-power, long-range IoT applications. Helium network is utilized to collate anti-gaming on the network and verify location of the specific node. In addition to the Helium network, the eGW also utilizes Wi-Fi and Ethernet protocols for data transfer and communication with the Srcful API and the inverter. Each Srcful eGW can also directly communicate with photovoltaic inverters or any battery storage systems using the Modbus protocol for data and control signal exchange.

The Srcful eGW is compatible with over 50% of inverters on the market including widely-used brands such as Sungrow, Huawei, and SolarEdge. All the hardware used for the eGW is available open source and guidelines on DIY assembly are provided in [15].

C. Srcful Token

Srcful token is called SRC-token [16] which is a Solana Program Library (SPL) Token-2022 generated on the Solana blockchain [17]. SRC-token presents a utility token engineered specifically for the Srcful platform, with Solana chosen for its beneficial attributes, such as speed, efficiency, and robust community engagement. The token supply is capped at 250 billion units. The tokens are released progressively, targeting rewards, initially serving beta testers and early adopters.

The tokenomic distribution plan by Srcful details a long-term strategy for distributing the total supply of SRC-tokens. This plan intends to create equitable distribution promoting decentralization and facilitating wider platform adoption. It designates a specific percentage of tokens for categories such as Proof-of-Source mining, Proof-of-Control mining, the Srcful Foundation, and founders and investors.

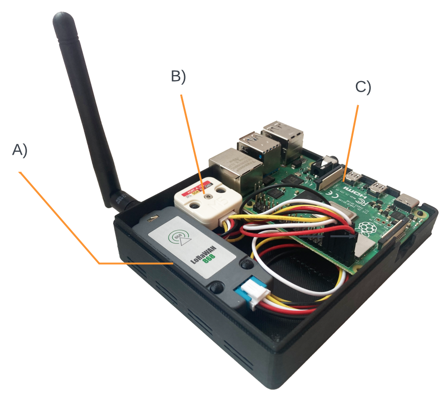

Fig. 3. Srcful Energy Gateway (eGW) - inside the case. A) LoRaWAN module, B) Crypto Authentication Unit (ATECC608B), C) Raspberry Pi 4

D. Srcful Incentives: Proof-of-Source and Proof-of-Control

The Srcful eGW incorporates a cryptographic chip which is crucial to all transactions relayed from the device to the validator. This chip fundamentally authenticates the identity of all transactions, thus providing an indisputable data source for all energy generation or storage operations.

For such purposes, we are using the ATECC608B Crypto Authentication Unit, which provides hardware-based cryptographic key storage, enhancing data security in the process of validation for green energy production, often referred to as Proof-of-Source. Concurrently, in the operational framework of Proof-of-Control, the Crypto Authentication Unit ensures that the control assigned to Srcful is both secure and verifiable. The added layer of security furnished by the Unit aids in upholding the equitable distribution of SRC-tokens and prevents potential duplication.

E. Srcful Data Platform

The Srcful Data Platform backend is implemented in the C# programming language and .NET framework. Srcful Data Platform integrates Elasticsearch [18] as a robust, open-source search and analytics engine that supports full-text search capabilities. This integration enables the platform to store, search, and analyze extensive datasets with near real-time efficiency. We employ a stateless, typed API that leverages GraphQL [19] to provide precise data structures and streamline data retrieval. To secure communications, the platform adopts a blockchain-based message signing protocol. Initial authentication occurs through message signing with a cryptographic chip, which links a designated wallet to a gateway. For all following interactions, message signing through a Solana wallet is mandatory, ensuring the authenticity and integrity of the messages. The incorporation of Elasticsearch, combined with a stateless API architecture, guarantees the system's ability to handle and process significant data volumes while maintaining optimal performance.

F. Data monitoring with Srcful Explorer

The Srcful Explorer is an instrument that compiles data from all participating entities. Its design seeks to enhance network transparency by enabling the visualization of each participant's individual contributions. The tool operates in real-time, connecting directly with the Solana blockchain, which is integral to upholding data integrity and building trust within the system. The srcful Explorer is shown in Figure 4.

The Srcful Explorer tool is publicly available for further inspection at [20].

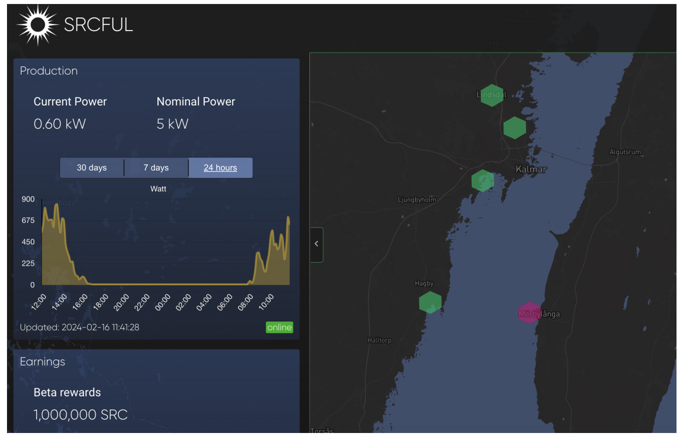

Fig. 4. Srcful Explorer: showing energy production of one of the Srcful nodes.

III. Impact on Energy Systems

The possibilities of this innovative technology extend far beyond the current energy market, and the Srcful platform can be used in various ways. The power and potential of the Srcful platform to drive the transition towards renewable energy and a more sustainable future can be described with two potential use cases, i.e., flexibility services and guarantee of origin With these potential use cases, utilities and grid operators, policymakers and regulators, energy producers or consumers, and prosumers can benefit. With the provision of incentives or compensation, individuals with solar PV systems and/or batteries are encouraged to align their energy generation and consumption with real-time grid status. The guarantee of origin enables individuals to validate the source of their electricity and ensure that it meets their sustainability and ethical standards.

A. Reward to individuals (incentives)

Srcful incentive model is based on Burn Mint Equibilibrium (BME) [21], [22]. The model operates on the principle of burning and minting tokens to regulate the supply and demand dynamics, thereby maintaining equilibrium. Burning tokens refers to permanently removing them from circulation. The equilibrium is maintained by adjusting the rate of token burning and minting based on the supply and demand dynamics.

B. Energy companies

As the global shift toward renewable energy accelerates, governments and organizations have introduced diverse incentives to prompt individuals and businesses to adopt sustainable energy sources. These incentives come in various forms such as tax credits, grants, and rebates, with variations depending on the country and region. The Srcful platform is a powerful tool to complement these incentives and encourage individuals to invest in renewable energy sources. The vision of Srcful extends beyond Kalmar city in Sweden. Srcful is at the forefront of a transformative movement, leveraging blockchain technology to build the world's first community-driven power plant.

C. Sustainability

Srcful is driven by a deep commitment to building a more sustainable future for all. The decentralized energy system is designed to help create a more sustainable, equitable, and efficient energy system. Srcful is committed to achieving the United Nations' Sustainable Development

Goal 7 (SD7), i.e., affordable and clean energy [23]. SD7 aims to ensure access to affordable, reliable, sustainable, and modern energy for all. Srcfuls decentralized energy system can play a crucial role in achieving this goal.

While there are a few of companies like Arkreen Networks in China and Rowan Energy in the United Kingdom that are also leveraging blockchain technology in the energy sector, Srcful distinguishes itself in a number of ways. Arkreen Networks focuses on building a decentralized digital infrastructure by incentivizing renewable energy prosumers [24]. Rowan Energy, on the other hand, operates its own blockchain platform and employs a proof of generation consensus mechanism [25]. Contrary to these approaches, Srcful implements a unique dual-incentive blockchain mechanism that integrates both the "Proof-of-Source" and "Proof-of-Control" strategies. By integrating a global network of IoT devices based on open source hardware, Srcful further strengthens its distinction by fostering a community-centric energy ecosystem that pushes it further ahead in the decentralized energy sector.

IV. Conclusion and future work

Srcful presents a transformative vision for the future of energy management and distribution. By embracing the principles of decentralization, sustainability, and transparency, Srcful incentivizes the production of green energy through SRC-tokens and it also empowers individuals to become active participants in an evolving energy marketplace. The integration of blockchain technology ensures secure and transparent transactions, fostering trust among members. The current focus of Srcful is on validating and rewarding green energy production rather than facilitating peer-to-peer energy trading. However, its infrastructure provides the foundation for potential expansion into that domain in the future. Furthermore, Srcful has plans to connect various high-energy consumption devices, such as electric cars, heaters, and air-conditioning units. As a virtual power plant (VPP), Srcful aims beyond merely offering optimization for individual homes and extending its benefits on a larger scale. Integrating connected batteries will pave the way for energy trading opportunities, facilitating an arbitrage trade system. Moreover, the utility of the Srcful Explorer could be expanded to benefit additional stakeholders in the energy market beyond the participants within the network. The aggregation and display of data from the Solana blockchain, which is compiled across various sites, holds the promise of offering valuable insights for grid owners, energy companies, and other market players. These stakeholders can greatly benefit from the rich insights available in the validated energy data, which, when made public, could enhance transparency in the market. Public access to verified data can facilitate better decision-making and enable more effective management of resources. This could lead to improved strategies for energy distribution, more accurate demand forecasting, and the development of more resilient energy infrastructures. The future integration of Srcful Explorer with these external entities will aim to capitalize on the implications of making validated energy data publicly accessible, thereby supporting the overall advancement of the energy sector.

Srcful is moving forward with its plan to transform the energy sector while several research questions and scientific directions emerge for future investigation. Researchers might explore the optimization of the platform using advanced machine learning algorithms for real-time energy management and the application of game theory to refine incentive mechanisms. Moreover, addressing cybersecurity within DePINs, assessing the platform's role in energy equity, and the effective integration of energy storage solutions remain critical areas for further study. Regulatory challenges and the environmental impact of blockchain's energy consumption also present vital research avenues. Potential pitfalls such as regulatory compliance, technology adoption resistance, scalability, data privacy, and interoperability challenges must be navigated with foresight and strategic planning. These explorations and precautions will contribute to the academic discourse and foster the development of a robust, equitable, and sustainable energy future.

References

[1] K. Dong, Q. Jiang, Y. Liu, Z. Shen, and M. Vardanyan, "Is energy aid allocated fairly? a global energy vulnerability perspective," *World Development*, vol. 173, p. 106409, 2024.

[2] M. Choobineh, A. Arabnya, B. Sohrabi, A. Khodaei, and A. Paaso, "Blockchain technology in energy systems: A state-of-the-art review," *IET Blockchain*, vol. 3, no. 1, pp. 35–59, 2023.

[3] M. Ourahou, W. Ayrir, B. E. Hassouni, and A. Haddi, "Review on smart grid control and reliability in presence of renewable energies: Challenges and prospects," *Mathematics and computers in simulation*, vol. 167, pp. 19–31, 2020.

[4] T. B. Nadeem, M. Siddiqui, M. Khalid, and M. Asif, "Distributed energy systems: A review of classification, technologies, applications, and policies: Current policy, targets and their achievements in different countries (continued)," *Energy Strategy Reviews*, vol. 48, p. 101096, 2023.

[5] Y. Sun, P. Gao, and A. Razzaq, "How does fiscal decentralization lead to renewable energy transition and a sustainable environment? evidence from highly decentralized economies," *Renewable Energy*, vol. 206, pp. 1064–1074, 2023.

[6] N. Maleki, X. Xie, A. Musaddiq, T. Olsson, D. Mozart, and F. Ahlgren, "Unraveling energy consumption patterns: Insights through data analysis and predictive modeling," in *15th International Conference on Applied Energy*, Doha, Qatar, December 3-7 2023.

[7] J. Wu and N. K. Tran, "Application of blockchain technology in sustainable energy systems: An overview," *Sustainability*, vol. 10, no. 9, p. 3067, 2018.

[8] X. Fan and L. Xu, "Towards a rollup-centric scalable architecture for decentralized physical infrastructure networks: A position paper," in *Proceedings of the Fifth ACM International Workshop on Blockchain-enabled Networked Sensor Systems*, 2023, pp. 9–12.

[9] M. C. Ballandies, H. Wang, A. C. C. Law, J. C. Yang, C. Gösken, and M. Andrew, "A taxonomy for blockchain-based decentralized physical infrastructure networks (depin)," *arXiv preprint arXiv:2309.16707*, 2023.

[10] Srcful (Accessed on 07/02/2024). [Online]. Available: https://docs.srcful.io/whitepaper/

[11] A. Haleem, A. Allen, A. Thompson, M. Nijdam, and R. Garg, "A decentralized wireless network," *Helium Netw*, pp. 3–7, 2018.

[12] A. Musaddiq, N. Maleki, F. Palma, D. Mozart, T. Olsson, M. Omareen, and F. Ahlgren, “Internet of things for wetland conservation using helium network: Experience and analysis,” in *Proceedings of the 12th International Conference on the Internet of Things*, 2022, pp. 143–146.

[13] A. Yakovenko, “Solana: A new architecture for a high performance blockchain v0. 8.13,” *Whitepaper*, 2018.

[14] “Srcful Energy Gateway Documentation,” https://docs.srcful.io/energy-gateway/, 2024, accessed: 2024-02-13.

[15] “Srcful eGW Firmware,” https://github.com/srcfl/egw-diy/, 2024, accessed: 2024-02-13.

[16] “SRC-Token,” https://solscan.io/token/SRCo2rhGpy9DBpAfroR97UYPSDzY7iv5578MWF5JBqB, 2024, accessed: 2024-02-13.

[17] “Solana Token Program,” https://spl.solana.com/token-2022, 2024, accessed: 2024-02-13.

[18] Elastic, “Elasticsearch: The official distributed search analytics engine,” 2024, accessed: 2024-02-08. [Online]. Available: https://www.elastic.co/

[19] “GraphQL: A query language for your API,” https://graphql.org/, 2024, accessed: 2024-02-08.

[20] “Srcful Explorer,” https://explorer.srcful.io/, 2024, accessed: 2024-02-13.

[21] “Burn and Mint Equilibrium,” https://messari.io/report/burn-and-mint-equilibrium, 2024, accessed: 2024-02-13.

[22] U. Kalabic, M. C. Ballandies, K. Paruch, H. Nax, and T. Nigg, “Burn-and-mint tokenomics: Deflation and strategic incentives,” in *Int. Workshop Decentralized Physical Infrastructure Networks, page submitted for publication*, 2023.

[23] G. Timilsina and K. U. Shah, “Energy technologies for sustainable development goal 7,” *Science, Technology, and Innovation for Sustainable Development Goals: Insights from Agriculture, Health, Environment, and Energy*, p. 36, 2020.

[24] “Arkreen Networks,” https://arkreen.com/, 2024, accessed: 2024-02-13.

[25] “Rowan Energy,” https://rowanblockchain.com/, 2024, accessed: 2024-02-13.