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Blockchain Based Hydrogen Market: A Paradigm-Shifting Innovative Solution for Climate-Friendly and Sustainable Structural Change

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***Abstract*—**Regional and global strategies focusing on hydrogen (H2) and blockchain technologies are fueling remarkable advancements. These strategies underpin the revolutionary 'Blockchain Based Hydrogen Market (BBH2)' project, with the primary objective of creating a Blockchain Minimum Viable Product (B-MVP) tailored to the hydrogen market. The B-MVP harnesses blockchain's capabilities, establishing a unified platform for secure, automated transactions via smart contracts. This innovation promises to reshape hydrogen logistics, trade, and transactions. The B-MVP carries transformative potential across diverse sectors, benefiting renewable energy producers, surplus energy-based hydrogen manufacturers, grid operators, and consumers. By implementing standardized, automated, tamper-proof processes, it bolsters cost-efficiency and enables transparent, traceable transactions. Its core mission is to verify the integrity of 'green' hydrogen, tracing its journey from renewable producers to end-users. This emphasis on transparency fosters economic, ecological, and social sustainability within a secure, transparent market. A standout feature of the B-MVP is its cross-border adaptability, obviating the need for nation-specific data storage, and broadening its global reach. This adaptability also spurs long-term job creation by establishing a dedicated blockchain operating firm. By attracting skilled labor and offering training, the B-MVP fortifies the hydrogen sector's workforce. Furthermore, it catalyzes innovative business models, luring more companies and startups, contributing to sustained job growth. For example, data analysis can tailor tariffs to offer demand-centric network capacities to producers and operators, providing tamper-proof pricing options to redistributors and end-customers. Beyond technological and economic progress, the B-MVP amplifies the prominence of national and international standards efforts. The region implementing the B-MVP becomes recognized as a pioneer in climate-friendly, sustainable, and forward-thinking practices, generating interest and attention beyond its geographic boundaries. Additionally, it fosters knowledge transfer between academia and industry, promoting scientific advancements, aligning with innovation management, and nurturing an innovation culture in the hydrogen sector. Through blockchain-hydrogen integration, the B-MVP champions comprehensive innovation, contributing to a sustainable future in the hydrogen industry. Implementation involves evaluating blockchain tech, developing smart contracts, and ensuring interoperability with existing systems. Scalability testing and data format development further validate the B-MVP's potential. BBH2 secures funding under the 'Technology Offensive Hydrogen,' a part of the Federal Ministry of Economics and Climate Protection's 7th Energy Research Program.

***Keywords*—**Hydrogen, blockchain, sustainability, structural change.

I. Introduction

IN the context of regional, national, and international hydrogen (H2) and blockchain strategies, the convergence of these initiatives is poised to facilitate a groundbreaking transformation. These strategies span governance levels, encompassing state, federal, European, and global domains. They collectively lay the crucial political and societal groundwork for the innovative 'Blockchain Based Hydrogen Market (BBH2)' project [3], [4], [8], [13], [14]. The BBH2 project, distinguished by its visionary concept, secures funding through the 'Technology Offensive Hydrogen,' a vital component of research funding administered by the Federal Ministry of Economics and Climate Protection. It occupies a prominent position within the 7th Energy Research Program of the Federal Government. At its core, the BBH2 project is committed to the realization of a fully operational B-MVP. This entails the deployment of a purpose-built blockchain, complete with a shared database and platform. The integration of self-executing Smart Contracts further accentuates the project's ambition. Together, these innovations underpin the entire supply chain within the 'green' hydrogen sphere, marking a momentous paradigm shift. The adoption of this blockchain-driven solution signifies a pivotal stride toward climate-friendly and sustainable structural transformation. It introduces a multitude of unique selling propositions, ushering in a range of benefits across economic, ecological, and social dimensions of sustainability. A comprehensive exposition of these dimensions is meticulously detailed in Chapter III.

II. State of the Art in Science and Technology

Blockchain technology enables companies and public authorities to share data in a decentralized, fast, (forgery)-secure, transparent, traceable, automated and significantly cost-saving manner [12]. Due to these advantages, various use cases of this technology have already been identified [17], [15], [1], [5], [6] and partially implemented [1], [5], [10], [11] in the medical, logistics, financial, real estate, identity management, administration, and energy sectors. In the energy sector, for example, there are various regional power models based on blockchain technology. Blockchain trading places for locally generated green electricity are offered, for example, by Stadtwerke Wuppertal with Tal.Markt [18], in the district of Biberach with BiberEnergie [2], and by enviaM in cooperation

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with Elblox [9]. In addition, the German government recommends the development & implementation of blockchain-based proof of origin processes for (eco)electricity and (bio)gas [6], which will be implemented in the next years in the context of the showcase program "Secure Digital Identities" [11]. Today, it is difficult for electricity and gas consumers to trace the actual origin of the energy. Proof is only provided in retrospect via fuzzy certificates. In addition, a central body has been created for (eco)electricity and (bio)gas in Germany (the Federal Environment Agency for green electricity [16] and the Deutsche Energie-Agentur GmbH for biogas [7]), which is laboriously involved in the partially manual process. The potential use of blockchain technology for proof of issuance, trading, tracking, and collection of electricity or gas will then allow end-to-end certification for the first time and thus "plant-specific" proof. Once a facility is registered, an energy purchase agreement is made with a consumer. After entering the trade deal on a blockchain, the quantities generated and consumed are transferred to a smart contract by the responsible meter operators. In this way, origin tokens are generated for the generated units on the registered system and subsequently transmitted to the consumer. The benefits that blockchain brings to this exemplary proof-of-origin process are equally applicable to hydrogen. For instance, it can seamlessly provide automatic, foolproof, tamper-resistant proof of the authenticity of 'green' hydrogen, as opposed to 'grey' hydrogen (without considering the suboptimal proof records that currently exist). Moreover, it introduces unique advantages to the supply chain of the ('green') hydrogen market and the broader context of sustainable structural transformation (as elaborated in the following chapter). Hence, its development through the BBH2 project becomes imperative.

III. Benefit from BBH_2

The key benefits of BBH_2 are as follows: First, the B-MVP shown in Fig. 1 improves for the first time the logistics, trading and transaction processes within the entire hydrogen market actor process chain (renewable energy producers, the hydrogen producers using surplus energy, hydrogen transport and distribution grid operators and the hydrogen consumers) in such a way that they now grant common protected access, are more cost-efficient and can be processed transparently & traceably, flexibly standardized & automated, stored audit- & tamper-proof, shared and evaluated. Thus, the focus of the Blockchain is the flawless tamper-proof verification of climate-friendly "green" instead of e.g., climate-damaging "grey" hydrogen and the thus possible tracking of the origin from the renewable energy producer to the end user, so that the entire supply chain of "green" hydrogen is represented in terms of economic, ecological and social sustainability and mapped in a secure and transparent market. Second, the B-MVP could be valid across countries and thus does not require country-specific data management. Third, the B-MVP creates jobs in the long term via an associated possible establishment of a blockchain operating company and serves to attract skilled workers as well as qualification and training. Fourth, the B-MVP allows new viable business models to emerge, which are the basis for further company settlements or start-ups and in turn goes hand in hand with additional long-term job creation. For example, producers and transport network operators can develop individual tariffs by evaluating data and provide demand-oriented network capacities. Redistributors and end customers would benefit from demand-based tariffs and tamper-proof proofs. Fifth, the B-MVP contributes to an increase in value creation through technological and economically usable advances and to an associated improved, national and international standard-setting visibility in the sense of a climate-friendly, sustainable, future-oriented and pioneering showcase region that will manifest itself as a trailblazer with supraregional appeal. Sixthly, the above-mentioned points create additional incentives for research and development and contribute to the improvement & bundling of the knowledge transfer of universities and companies, to the increase of scientific performance and thus to a correspondence of the understanding of strategic innovation management and innovation culture, because two future-oriented technologies are bundled in the innovative mantle of sector coupling in a superordinate manner.

IV. Implementation Method

The method of implementation is as follows:

a) Evaluation & mapping of a suitable blockchain technology and architecture: This includes the requirements assessment, the evaluative requirements management, development of survey and research methods, evaluation of the German & European market with regard to regulation, determination of the procedural mapping possibilities of the German and the European market for the B-MVP, evaluation of conformity with the Basic Data Protection Regulation, creation of a data protection concept, creation of market conformity/market standards/ acceptance research, conceptualization of the collection and evaluation of the collected data, creation of a UX/UI concept, creation of the system architecture including the existing systems, analysis of interconnected systems, their data management and process integration, determination of the technical parameters for the blockchain and the necessary infrastructure, as well as the creation of a hosting and security concept.
b) Development & implementation of the blockchain, the smart contracts and the deposit of proofs of origin: This includes the inclusion of concrete processes for the mapping of smart contracts, concretization and selection of the smart contracts to be implemented, their functional, content-related, process-related design and concrete technical description, definition of the trigger points for actions in the context of the physical delivery process, legal verification and legitimation, development of smart contracts, testing of AI applications for automated decision-making, the requirements for the technical design of the guarantees of origin, their conceptual design for technical implementation and the definition of the trigger points for the transfer of these, linking with external trading points (exchanges/OTC markets), developing digital

proofs of origin, analyzing, defining and setting up a suitable blockchain, setting up a real demo environment, connecting the recorded systems and the analyzed and standardized data, implementation of the smart contracts on the blockchain, implementation of the proofs of origin within the B-MVP, the front-end and back-end development, implementation of secure identification by means of self-sovereign identities, linking of the smart contracts with the smart contract register and the security check of the B-MVP.

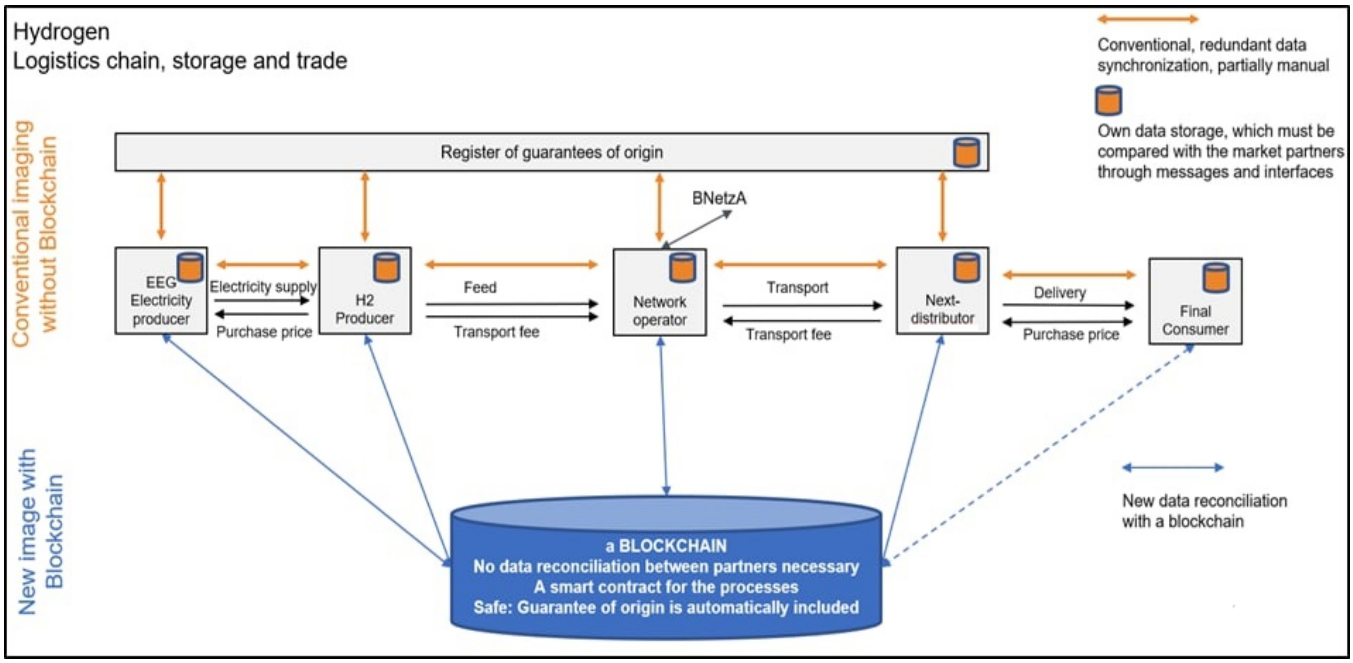

Fig. 1 B-MVP design & benefits for the hydrogen market

c) Development of suitable interfaces to existing systems of the users: This includes the requirements analysis for the interface analysis in the hydrogen process, definition of required data interfaces, the interface architecture for the nomination, portfolio management, trading and settlement systems and the interface development depending on the B-MVP development.
d) Development of suitable data formats for the exchange of process-relevant data: This includes the requirements for process-relevant data and data formats, their description and harmonization, mapping of technical relevant processes, comparison with the workflow to be described and technical description of the automation steps as preparation for the B-MVP development.
e) Carrying out field studies to test the B-MVP and examine the scaling of the B-MVP in other markets and user groups: This includes the selection of suitable test users, preparation of the test implementation concept, formulation and creation of the test cases, testing of the B-MVP in the market, a review of the test results within the field study, an iterative test setting, evaluation of the results, preparation for market launch, adaptations and documentation and the communication of the results with politics, the economy and the population.

V. Conclusion

The BBH2 project represents a paradigm-shifting solution for achieving climate-friendly and sustainable structural changes. It introduces unparalleled unique selling propositions, advantages, and added values, detailed in Chapter III, all within the framework of economic, ecological, and social sustainability. Its active implementation, which is supported within the framework of the funding call "Technology Offensive Hydrogen" within the research funding of the Federal Ministry of Economics and Climate Protection in the 7th Energy Research Program of the Federal Government, is not only in the special interest of the numerous partners from industry involved in the project, but is also supported by political partners, so that BBH_2 receives supraregional attention and an exposed national and international position and will thus manifest itself in the sense of a sustainable and pioneering frontrunner solution with supraregional appeal.

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