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Turning the Water–Energy–Food Perfect Storm into Business Opportunities: A Blockchain Framework for South Africa

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Abstract

This study examines the "perfect storm" of simultaneous water, energy, and food (WEF) resource challenges in South Africa from a business and entrepreneurial perspective, leveraging blockchain technology. The study aims to analyze the state of the WEF perfect storm in the Republic of South Africa and develop a blockchain-enabled business framework to identify and exploit new entrepreneurial opportunities. The research is grounded in Dynamic Capabilities Theory, emphasizing how firms can adapt, innovate, and reconfigure resources in complex environments. A Systematic Literature Review (SLR) was employed as a qualitative research method. Findings indicate a moderate intensity of the WEF perfect storm in South Africa and support the development of a six-component integrated blockchain business framework for resource optimization. The framework comprises: (1) Market Gap Analysis, (2) Product Configuration and Differentiation, (3) Business Case Justification, (4) Digitalization of Administration, (5) Smart Contracts, and (6) Digital Sustainability. The study concludes that the resource crises represented by the perfect storm can be transformed into business and innovation opportunities. It recommends the establishment of a Living Lab within South African WEF agencies to facilitate experimentation, collaboration, and entrepreneurial value creation.

Keywords: Perfect storm, Blockchain, Entrepreneurship, Innovation, Water–Energy–Food

INTRODUCTION

Water, energy, and food (WEF) resources constitute a transformative economic resource system that underpins sustainability, economic stability, and the competitive advantage of businesses and nations. According to David et al. (2022), these three resources are developmental assets that shape enterprise performance, national development trajectories, and import–export dynamics within the global market. However, the three resources operate as "Siamese twins," in that activities affecting one resource inevitably influence the others. Seeliger et al. (2018) argue that these interdependencies explain why the three resources are conceptualized as a nexus, capturing the multiple cross-sectoral linkages that span disciplines and involve both state and non-state actors in governance and management. Esan, Nwulu, and Adepoju (2024) further

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posit that the interconnectedness of the WEF nexus necessitates a systems-based perspective that recognizes intricate interlinkages, while uncovering and managing sectoral synergies and trade-offs. Similarly, David et al. (2022) observe that competition among water, energy, and food resources reinforces the need for coordinated management strategies to mitigate conflicts and optimize value creation across sectors.

Despite the growing demand for WEF resources, increasing population growth, unsustainable extraction mechanisms, rapid urbanization, and migration trends have intensified multidimensional resource pressures. Meadows et al. (1972) warned that persistent population growth, industrialization, pollution, food production, and resource depletion would ultimately push the planet toward its limits. In their words, "If the present growth trends in the world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years." Consequently, Sir John Beddington described the simultaneous crisis affecting water, energy, and food systems as a "Perfect Storm" (Beddington, 2009; Fermeglia et al., 2020). Poppy et al. (2014) define the perfect storm as the "simultaneous shortage and instability of water, energy, and food resources within a geographical domain." This framing highlights not merely scarcity, but systemic instability and interlinked vulnerabilities across critical resource sectors.

In the Republic of South Africa, evidence suggests that elements of this perfect storm are already emerging. Ololade, Esterhuyse, and Levine (2017) affirm the growing pressure on water, energy, and food resources, noting increasing stress on groundwater resources amid rising demand and climate change impacts. They further highlight a widening gap between electricity generation capacity and energy demand, while recurrent drought conditions continue to undermine agricultural productivity. These dynamics indicate systemic stress across the WEF nexus in South Africa. Also, Seeliger et al. (2018) demonstrate, through a South African case study, how the WEF nexus framework can identify pathways for improving farm profitability. Caixeta et al. (2023) evaluate business excellence models integrated with the WEF nexus to assess sustainability maturity among agri-food companies in Brazil and Kenya. Bigolin et al. (2025) further argue that the WEF nexus can be embedded within corporate sustainability strategies. These studies collectively suggest that the so-called "Perfect Storm" can be reframed from a crisis narrative into a business and innovation opportunity.

In this regard, Esan et al. (2024) contend that blockchain technology represents a pivotal digital innovation for WEF management, enabling decentralized record-keeping of resource transactions, automated processes, and peer-to-peer trading. David et al. (2024a) assert that blockchain enhances process optimization across water, energy, and food systems. Furthermore, David et al. (2024b) highlights that blockchain applications can determine transaction multipliers, facilitate stakeholder-oriented smart contracts, and enable the creation of WEF-specific digital tokens and wallets for trading. However, despite these technological insights, a notable gap persists in the

literature: the absence of a structured blockchain-based business framework specifically designed to address the Perfect Storm arising from simultaneous insecurity in water, energy, and food systems. Existing studies focus on technological capabilities or sustainability integration, but limited attention has been given to entrepreneurial value creation, business model innovation, and competitive advantage within the WEF nexus. Also, the research on the perfect storm has shown that there is no research on the nature of the perfect storm from a national perspective, as most research has focused on the problem of individual resources, hence, this paper explores the perfect storm in South Africa, an emerging economy within developing economies, given its publication output on WEF Nexus among developing economies. Therefore, this study seeks to address this critical research gap.

The cardinal objective is to turn the Water–Energy–Food Perfect Storm into a business opportunity by developing a blockchain-enabled business framework for South Africa. The specific objectives are:

a. To examine the state of the Perfect Storm in South Africa.
b. To develop a blockchain-based business framework for addressing the Perfect Storm in South Africa.

The findings of this study contribute to research on optimizing business management and on the economic opportunities arising from managing synergies and trade-offs within the WEF nexus. Additionally, the study provides systematic, innovation-oriented guidelines for enterprises seeking to leverage blockchain technology to create competitive advantage and sustainable business success in resource-constrained environments.

THEORETICAL PERSPECTIVE

This study is grounded in the Dynamic Capabilities Theory introduced by Teece and Pisano (1994), which explains how organizations adapt, reconfigure internal and external competencies, and integrate new capabilities in response to rapidly changing environments (Nayernia, 2026). The theory addresses volatility, uncertainty, complexity, and rapid technological change within both global and domestic markets. It emphasizes that sustained competitive advantage does not arise merely from possessing valuable resources, but from the firm's ability to continuously sense opportunities and threats, seize emerging opportunities, and transform its resource base accordingly. This perspective underpins the present study because the competitive and interdependent nature of water, energy, and food (WEF) resources, manifested in the so-called Perfect Storm, represents a condition of systemic uncertainty that directly affects business operations, evidenced in fluctuations in resource availability, pricing instability, regulatory shifts, and climate-related disruptions, creating an environment in which firms must continuously adapt. Addressing such uncertainty requires organizations to embrace technological change, particularly innovations associated with the Fourth Industrial Revolution, such as blockchain technology.

David et al. (2022) describe blockchain technology as a decentralized digital environment in which transactions are recorded in an immutable ledger that cannot be altered unilaterally. This decentralized and trust-enabled architecture enhances transparency, traceability, and transactional security across complex networks. In volatile business environments, such as those shaped by WEF resource instability, blockchain provides structural stability to transactional systems. For example, fluctuations in raw material pricing within the agri-food system may reflect environmental or market shifts; however, blockchain-based records ensure that transactions cannot be retroactively manipulated in ways that undermine business trust or operational continuity. In line with Shiferaw and Amentie Kero (2024), the integration of blockchain within WEF-related enterprises strengthens dynamic capabilities by enabling firms to optimize their existing resource base while developing new digital competences for sustained and superior performance. Furthermore, Wang and Liu (2023) affirm that Dynamic Capabilities Theory supports enterprise coordination, heterogeneous resource sharing, resource integration, continuous organizational evolution, and organizational learning. These attributes align closely with blockchain-enabled business frameworks, which facilitate decentralized coordination, smart contracts, secure data exchange, and ecosystem-based collaboration.

Therefore, the Dynamic Capabilities lens provides a robust theoretical foundation for this study. It explains how blockchain adoption can enhance firms' abilities to sense emerging WEF-related risks, seize entrepreneurial opportunities arising from the Perfect Storm, and transform their operational and business models to achieve resilience, innovation, and competitive advantage.

RESEARCH METHODOLOGY

This study adopted a qualitative research methodology to investigate the state of the Water–Energy–Food (WEF) Perfect Storm in South Africa and to develop a blockchain-enabled business framework aimed at transforming the crisis into entrepreneurial opportunities. Qualitative research is appropriate for examining complex, multidimensional phenomena and generating context-specific insights (Makateng & Ntsoaki, 2025). It enables an in-depth understanding of systemic challenges and supports the development of conceptual and strategic frameworks grounded in existing knowledge. Therefore, to enhance methodological rigor, the study employed a Systematic Literature Review (SLR) approach. The SLR method allows for structured identification, appraisal, and synthesis of relevant literature to answer clearly defined research questions and achieve stated objectives (Snyder, 2019). Through this approach, the study systematically reviewed scholarly publications addressing the WEF nexus, the Perfect Storm concept, blockchain technology, and business innovation. This facilitated the identification of dominant research paradigms relevant to the South African context, thereby informing the development of the integrated blockchain business framework.

To ensure transparency and reproducibility, the SLR was guided by the PICO protocol: Population (Problem), Intervention, Comparison, and

Outcome as articulated by Smela et al., (2023) and exemplified in David et al. (2023). In this study, the Population/Problem refers to the Perfect Storm characterized by simultaneous shortages and instability in water, energy, and food systems. The Intervention is the adoption of blockchain technology through a business-oriented framework. The Comparison relates to traditional centralized mechanisms for managing WEF challenges. The Outcome focuses on creating business opportunities, optimizing operations, and developing structured blockchain guidelines for innovation and implementation. Moreover, in alignment with methodological rigor standards, the review process also incorporated the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, as emphasized by Smela et al. (2023). These guidelines supported structured screening, documentation, and reporting, including clearly defined inclusion and exclusion criteria.

The inclusion criteria comprised publications addressing the Water–Energy–Food nexus, blockchain technology, the Perfect Storm concept, and business or entrepreneurial dimensions. Studies published in English with geographical relevance to South Africa were prioritized. Eligible sources included peer-reviewed journal articles, conference proceedings, book chapters, and scholarly books. Additionally, selected policy briefs and credible news publications were included to address the first research objective, which concerns the current state of the Perfect Storm in South Africa. The exclusion criteria encompassed non-peer-reviewed reports (unless institutionally authoritative and directly relevant especially for objective one of this study), publications in languages other than English, errata publications, and studies lacking clear methodological grounding. Therefore, following the PICO protocol and PRISMA guidelines, the Scopus database was utilized as the primary source of literature coverage (David et al., 2022). The structured search and screening process yielded 43 relevant publications, which served as the analytical foundation for this study.

RESULT AND DISCUSSION

Perfect Storm Scenario in South Africa

The perfect storm is a state of resource crisis characterized by imbalances, unavailability, instability, and scarcity of water, energy, and food resources for a growing population. According to Schlor et al. (2018), the perfect storm is an impending threat to the global economy, as reflected in various statistics on predicted and calculated resource challenges to humanity, particularly in terms of water, energy, and food, as stated earlier. These challenges are associated with threats that make the perfect storm even more deadly, including climate change, drought, ocean acidification, rising global temperatures, war and armed conflicts, illness & diseases, extreme weather conditions such as fluctuating precipitation, and economic inequality (Schlor et al., 2018). Beddington (2009) summarized the concept of the perfect storm with these questions: Can 9 billion people be fed equitably, healthily & sustainably? Can we cope with the future demands for water? Can we provide enough

energy to support the growing population emerging from poverty? Can we do all this whilst mitigating and adapting to climate change? These show the intrinsic and interrelationship nature of the challenges that make the perfect storm, which must be tackled simultaneously.

However, this objective is to micro-view the perfect storm of challenges faced within the food, energy, and water spaces, and their associated challenges in South Africa. According to Statistics South Africa, 14% of South Africa's population suffers from severe food insecurity, 23.6% suffers from moderate food insecurity, and about a thousand children in the Republic are experiencing malnutrition (Ellis, 2022). Moreover, according to the World Wildlife Fund, South Africa will need to produce 50% more food by 2050 to avert food crises affecting the estimated 73 million people (Von Bormann, 2019). Also, South Africa is a water-stressed country, where it is predicted that water demand will outstrip supply by 2025, and the country will experience a 17% water deficit by 2030 (Smith, Strugnell, and Swanepoel, 2022). According to the authors, this is due to pollution, unsustainable water use, misappropriation of funds, a lack of skilled human capital, and dysfunctional municipal sewage systems within the built environment. Moreover, on the energy resources front, South Africa has high access to electricity. Still, it suffers from the effects of non–renewable energy sources and deteriorating electricity infrastructure, leading to load shedding and brownouts (Winkler, 2022). The country will continue to face the consequences of climate change in the next 50 years due to unsustainable activities in the country, which will affect weather patterns, food security, biodiversity, water availability, extreme temperature events, reduced agricultural production, decreased freshwater availability, severe storms, intense tropical cyclones, heat waves, intense thunderstorms, long term drought, infrastructural damage, premature extinction of species, increasing evaporation and decreasing rainfall (Center for environmental rights, 2021).

Furthermore, the study used the Global Hunger Index (GHI) to assess the broader picture beyond local statistics. According to Grebmer et al., (2023), GHI is measured through four component of undernourishment (share of the population that has insufficient caloric intake), child wasting (under five children with low weight for their height, reflecting acute undernourishment), child mortality (children who die before their fifth birthday due to unhealthy environment and inadequate nutrition), and child stunting (under five children with a low height for their age, reflecting chronic undernutrition). The GHI is scored on a 100–point scale, with a zero score indicating no hunger and a 100 score representing the worst hunger. The severity of the Hunger scale is as follows: Low (GHI ≤ 9.9), Moderate (GHI 10.0 – 19.9), Serious (GHI 20.0 – 34.9), Alarming (GHI 35.0-49.9), and extremely alarming (GHI ≥ 50.0). According to the Global Hunger Index (GHI) for 2023, South Africa is ranked 58 out of 125 countries, with an index score of 13.0, indicating moderate severity.

Also, in providing a comprehensive overview of the perfect storm, the study evaluated the Global Food Security Index (GFSI), the latest report of which is 2022 by Economist Impact. The Global Food Security Index

(GFSI) evaluates the Global food environment measured on four (4) pillars: affordability, availability, quality and safety, and sustainability and adaptation (Economist Impact, 2022a). The indicators of the four pillars are as follows: Affordability (changes in average food costs, proportion of population under global poverty line, inequality of adjusted income index, agricultural trade, and food safety net programs); Availability (access to agricultural inputs, agricultural research & development, farm infrastructure, supply chain infrastructure, sufficiency of supply, political and social barriers to access, and food security and access policy commitments); Quality and Safety (Dietary diversity, nutritional standards, micronutrient availability, protein quality, and food safety); and Sustainability and adaptation (environmental exposure, water quality & quantity, land use, oceans, rivers & lakes, political commitment to adaptation, and disaster risk management). According to Economist Impact (2022b), South Africa ranks 59th out of 113 countries in the 2022 Global Food Security Index, with a score of 61.7. The measures of the pillars are as follows: Affordability (63.4), Availability (60.1), Quality & Safety (66.1), and Sustainability and Adaptation (56.9). This score depicts moderate food security standards, as Economist Impact (2022b) highlights areas for improvement: sufficiency of supply (due to dependence on chronic food aid and inadequacy in food supply), inequality–adjusted income index (due to lack of policy action towards income disparity), and nutritional standards (due to lack of nutritional labeling and deteriorating nutrition surveillance and monitoring).

The water security index of South Africa was assessed using the Water Security Index components outlined in MacAlister et al. (2023) based on the UN-Water security definitions. The ten (10) components are drinking water, sanitation, good health, water quality, availability, water value, governance, human safety, economic safety, and water resource stability. According to the authors, the level of water security is ranked as follows: Secure (> = 75), Moderately secure (65-74), Insecure (41 – 64), and critically insecure (< = 40). According to the ranking, South Africa has a water security index score of 56, which classifies it as a water-insecure country. The score components are as follows: Drinking water (5), Sanitation (4), Good health (2), Water Quality (7), Water Availability (4), Water Value (5), Water Governance (8), Human Safety (9), Economic Safety (7), and Water Resource Stability (5).

Furthermore, the study evaluated the World Energy Trilemma Index prepared by the World Energy Council. According to the World Energy Council (2022), the World Energy Trilemma Index is measured via three components: Energy security (measuring the capacity of a nation to reliably meet current and future energy demands, withstand system shocks and bounce back swiftly with minimal disruption to supplies), Energy equity (the ability of a country to provide universal access to fairly priced, affordable, and abundant energy for commercial and domestic purposes); and Environmental sustainability (the transition prowess of a nation energy system, which ensures mitigation of climate change and avoidance of environmental harm). The Energy Trilemma is measured based on Grade, Rank, and Score. The Grade is for performance in the three components, where A is the best and

D is the worst, in AAAa, where the first three letters represent the grade for the first three letters, while the last letter represents the country category: Grade A (top 25% countries), Grade B (between 25% and 50%), Grade C (between 50% and 75%) and Grade D (between 75% and 100%). Therefore, according to the World Energy Council (2022), South Africa has a Grade of CCDb, ranking 58% globally and as a Grade B country. This shows that the country has average performance in energy security and energy equity, but poor performance in environmental sustainability.

However, multidimensional poverty was evaluated to get a robust overview of the effects of the aforementioned water, energy, and food indices. The study assessed the 2023 multidimensional poverty index, capturing three deprivation dimensions: health, education, and living standards (UNDP, 2023). According to the report, the health dimension measures nutrition and child mortality, the education dimension comprises years of schooling and school attendance, while the standard of living entails cooking fuel, sanitation, drinking water, electricity, housing, and assets). According to the report, 0.9% of South Africans are experiencing severe multidimensional poverty, while 12.2% are vulnerable to multidimensional poverty, and 55.5% are within the poverty line. In assessing the contribution of deprivation across the three dimensions, there are 39.5% to health, 13.1% to Education, and 47.4% to the the standard of living.

These perfect storm facts and statistics for South Africa reveal a moderate one, with underlying economic issues, as illustrated by Beddington. This paper argues that a massive economic commitment from the South African government and relevant sectors of the economy to energy, food, and water resources will help mitigate the impact of the perfect storm.

A Blockchain-Based Business Framework for Addressing the Perfect Storm in South Africa

The Perfect Storm in the Republic of South Africa reflects a moderate but economically driven crisis, suggesting that a stronger, more business-oriented transformation approach can help reverse the persistent challenges. This study therefore posits that blockchain technology provides the necessary leverage for transforming business dynamics within the water, energy, and food (WEF) resource space.

The research of Chethan (2024) asserted that blockchain technology is reshaping the business landscape and operations by enhancing transparency, security, and data integrity, reducing costs through the elimination of intermediaries, and improving operational efficiency. Similarly, Dlamini, Ndaba, and Mbatha (2024) posited that blockchain positively impacts entrepreneurship by strengthening trust and efficiency, thereby enabling market penetration, fundraising opportunities, automation of business operations, smart contract management, and improved collaboration. Chao and Goli (2024) further affirmed that blockchain technology enhances business performance by improving innovation capacity, increasing sales volume, strengthening data transparency, and boosting efficiency capabilities. In addition, Mercuri, della Corte and Ricci (2021) established that blockchain

enables sustainable business models through the non-manipulability of information, enhanced security, and traceability. The research of David et al. (2024c) also confirmed that blockchain technology can be applied to the business dynamics of water, energy, and food management. In line with this body of scholarly evidence on the transformative potential of blockchain technology, six integrative and sequential steps are proposed to constitute the Blockchain-Enabled Framework. These include: (1) Market Gap Analysis, (2) Product Configuration and Differentiation, (3) Business Case Justification, (4) Digitalization of Administration, (5) Smart Contracts, and (6) Digital Sustainability.

Market Gap Analysis

Market Gap Analysis serves as a foundational prerequisite in examining the dynamics of the Perfect Storm in South Africa and identifying viable business opportunities within the water, energy, and food (WEF) nexus. The deliberate use of the term "market" rather than "business idea" reflects the reality that South Africa is not short of innovative ideas in water provision, renewable energy, and agro-food systems. Rather, the major challenge lies in the transition from innovation to scalable, market-driven implementation. In the South African context, characterized by water scarcity, electricity instability, rising food prices, infrastructure backlogs, and socio-economic inequality, identifying market gaps is critical to aligning entrepreneurial solutions with real societal needs. Sukiennik, Kowal, and Bąk (2021) argue that identifying market gaps in resource sectors supports entrepreneurial activity and strengthens businesses. Therefore, market gap analysis within the WEF nexus should be grounded in a thorough needs assessment of each of the three resources, particularly within urban municipalities, rural communities, informal settlements, and agricultural zones. This analysis should investigate what has gone wrong within the WEF market structure in South Africa and how those failures can be optimized into business opportunities that enhance both profitability and resource security. It should be conducted separately for water, energy, and food, while recognizing their interdependence. Key areas of analysis should include prevailing distribution structures, impact assessment on actual and potential consumers, opportunities for digitalization, demand–supply gaps, pricing distortions, resource consumption patterns, inefficiencies, business risks, cross-sectoral entrepreneurial opportunities, and both local and international market barriers. Furthermore, the process should be detailed, systematic, and evidence-based, incorporating strategic tools such as Porter's Five Forces (Pangarkar & Prabhudesai, 2024), SWOT Analysis (Ayub et al., 2013), PESTLE Analysis (Dunaievskyi, 2022), and the Osterwalder Business Model framework (Verrue, 2014). Such rigorous analysis ensures that identified gaps are economically viable and institutionally feasible within South Africa's regulatory and developmental environment.

Product Configuration and Differentiation

The outcomes of the market gap analysis, whether business ideas, innovation gaps, or structural inefficiencies, should culminate in the development of a product or service offering that is genuinely appealing and accessible

to consumers. In the South African WEF context, this could include decentralized water services, renewable energy solutions, agro-processing innovations, or integrated resource platforms along product configuration and differentiation. Product configuration involves structuring the product in terms of its evolution within a product family, supplier selection, and cost structure to ensure affordability and maximum customer satisfaction (Zou, Li & He, 2023). Zhang (2014) further explains that product configuration emphasizes customization, improved management of product variety, enhanced quality, order fulfillment, and alignment between product features and functional requirements. Applied to South Africa's WEF nexus, this implies experimenting with different features, production mechanisms, accessibility innovations, quality improvements, sustainability considerations, and packaging models suited to diverse income groups and geographic regions. Blockchain technology can enhance this process by enabling digital billing systems, tokenized blockchain wallets, peer-to-peer knowledge sharing and energy trading, traceability of production mechanisms, and the reduction or elimination of intermediaries in transactions and supply chains. In addition, agro-food products are deeply interconnected with water and energy inputs, often have complementary and substitute products. Thus, Product differentiation becomes essential, as it provides customers with enhanced value propositions and potentially more affordable options (Hikmah, Ratnawati & Darmanto, 2021).

Consequently, product configuration and differentiation must be approached from both entrepreneurial and customer-centered perspectives. In South Africa, water, energy, and food services are often treated primarily as mostly government responsibilities. However, for sustainable transformation and investment mobilization, these resources must also be packaged, produced, and marketed with clear customer value propositions. Therefore, viewing WEF resources through a market-oriented lens can unlock private sector participation, attract investment, and strengthen long-term resource security.

Business Case Justification

This phase follows the preceding two steps, which focus on internal innovation justification from both a product perspective and a customer-centered lens. The Business Case Justification stage shifts attention to attracting the investment needed to fund WEF resource products within the South African context. Historically, water, energy, and food resources in South Africa have largely been treated as public utilities, heavily dependent on government patronage, subsidies, and grants. This overreliance has made these sectors vulnerable to fiscal constraints and budgetary allocations, a challenge that has contributed to the current Perfect Storm in the Republic of South Africa. Therefore, Business Case Justification must prioritize the development of comprehensive business plans for each of the three resources as standalone products, as well as for their integration as a nexus product (David et al., 2024c). The business case should clearly justify investment by detailing projected Return on Investment (ROI), Net Present Value (NPV),

and cost of production, while considering both domestic and international investors. In doing so, it should reposition WEF resources not merely as social goods but as structured investment opportunities with measurable financial performance indicators.

Moreover, this phase should leverage the financial probity, transparency, and fundraising capabilities of blockchain technology to attract capital into the sectors and their associated products. dos Santos et al. (2022) posited that blockchain-powered decentralized finance (DeFi) can mobilize financial resources within trusted systems, creating opportunities in liquidity provision, arbitrage advantages, liquidation mechanisms, and digital asset holdings. Similarly, Chen, He, and Wang (2023) affirmed that blockchain can enhance organizational investment efficiency and reduce systemic risks. However, the propensity for blockchain-enabled investment must be supported by comprehensive and credible business plans that incorporate the outputs of the two preceding steps.

Digitalization of Administration

Administrative inefficiencies across the water, energy, and food sectors, particularly within government-owned entities have contributed to limited business innovation, constrained entrepreneurial opportunities, and weakened investor confidence. Manual processes, bureaucratic red tape, and traditional administrative systems remain prevalent despite the global shift toward the Fourth Industrial Revolution. There is therefore a pressing need to digitalize operational mechanisms across these sectors. This includes automating billing systems and transactions, integrating real-time monitoring systems, implementing cross-border payment platforms, digitizing administrative tasks, reducing paper-based processes, developing dedicated application platforms and service portals, and incorporating analytics to support data-driven decision-making. Such a digital transformation would redefine the perception and management of water, energy, and food enterprises in South Africa, positioning them as modern, accountable, and investment-ready sectors. This, in turn, can attract both financial and knowledge-based investment, generating broader macroeconomic spillover effects. Digital Technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), cloud computing, and blockchain can support the digitalization of administrative systems and broader business operations (Iriyadi et al., 2023; Khan et al., 2023).

Smart Contracts

The water, energy, and food sectors in South Africa are characterized by a multiplicity of stakeholders, including government agencies, private firms, municipalities, farmers, energy producers, financiers, and consumers. These actors often operate with differing or competing interests, which has historically contributed to fragmented coordination and silo-based operations (David et al., 2024d). Such fragmentation has weakened sectoral collaboration and reduced the efficiency of the WEF nexus. Consequently,

Smart contracts provide a mechanism for formally capturing, assessing, and assuring these varying interests within a tamper-resistant digital framework. Through blockchain-based smart contracts, agreements, including service-level agreements, can be structured so that no single entity or stakeholder can unilaterally alter or compromise the terms (David et al., 2025; Tan et al., 2022). This is particularly relevant in South Africa, where governance challenges and contractual disputes have affected infrastructure delivery and service reliability. Beyond contract negotiation and enforcement, smart contracts enable automatic compliance with regulatory obligations. They provide real-time monitoring capabilities for tracking adherence to contractual and statutory requirements, thereby strengthening accountability and transparency across the WEF sectors (Ladleif & Weske, 2019).

Digital Sustainability

Water, energy, and food resources, individually and collectively within the nexus serve as foundational inputs for sustainable development across environmental, social, and economic dimensions (Hamidov & Helming, 2020). In the South African context, where resource scarcity, inequality, and environmental pressures intersect, maintaining the sustainability value of these resources is essential for long-term national development. However, the integration of blockchain technology into the WEF sector must not undermine the sustainability benefits of these resources. If poorly implemented, digital transformation could introduce new risks that compromise resource availability or long-term regenerative capacity, thereby threatening their future contribution to economic and nexus-based value generation (David et al., 2025). Therefore, Digital sustainability therefore becomes paramount when blockchain technology is incorporated into the management of the three resources. It ensures that business, entrepreneurial, economic, and resource value are preserved while meeting the needs of both present and future generations. Digital sustainability, according to Dapp (2013), is the sustainable management of digital resources to maximize their societal utility, ensuring that the digital needs of contemporary and future generations are equally met. According to the author, digital needs are optimally fulfilled when resources are widely accessible and reusable with minimal restrictions. Digital resources include knowledge and cultural artifacts represented in digital form, such as text, images, audio, video, or software. Accordingly, the incorporation of blockchain technology within South Africa's WEF nexus should be pursued in a manner that preserves and does not compromise the regenerative capacity and long-term sustainability of the three resources.

CONCLUSION

The Perfect Storm confronting South Africa's water, energy, and food (WEF) nexus is not an irreversible phenomenon. While its impacts are significant, they can be mitigated through deliberate transformation of structural challenges into viable business opportunities. Blockchain technology provides a strategic enabler in this regard, offering tools for transparency, efficiency,

accountability, investment mobilization, and coordinated governance across the three resource sectors. When properly integrated into market structures, product development, investment frameworks, administrative systems, contractual governance, and sustainability safeguards, blockchain can help reposition the WEF nexus from a crisis-prone system to a resilient and innovation-driven ecosystem.

However, technological enablement alone is insufficient. The successful implementation of a blockchain-enabled framework requires coordinated cooperation among national and provincial government entities, municipalities, private sector actors, entrepreneurs, researchers, financiers, regulators, and local communities. It also demands careful, phased, and context-sensitive operationalization that takes into account South Africa's socio-economic inequalities, infrastructural disparities, regulatory environment, and varying provincial realities. Accordingly, this study recommends establishing a Living Lab across the three (3) sectors in the Republic of South Africa. Such a Living Lab would function as an innovation-driven and business-oriented ecosystem that brings together diverse stakeholders to pilot, test, refine, and operationalize the proposed blockchain framework in real-world settings. It would enable experimentation, stakeholder co-creation, iterative learning, and contextual adaptation across diverse geographical and economic contexts, including urban municipalities, rural agricultural zones, and energy-constrained regions. Therefore, through this collaborative and adaptive approach, the Living Lab can facilitate the practical translation of the framework into scalable solutions, ensuring that the transformation of the Perfect Storm into sustainable economic opportunity is both inclusive and enduring.

REFERENCES

Ayub, A., Rassaq, A., Salman Aslam, M., and Iftekhar, H., (2013). A Conceptual Framework on Evaluating SWOT analysis as the Mediator in Strategic Marketing Planning throuhg Marketing Intelligence. European Journal of Business and Social Sciences, 2(1), pp. 91–98.

Beddington, J. (2009) 'Food, Energy, Water and the Climate: A Perfect Storm of Global Events?' World Development 1–9.

Bigolin, E., Rossetto, R., Corsini, F., & Frey, M. (2025). The Integration of the Water-Energy-Food Nexus Framework Into Corporate Sustainability Strategies: A Systematic Literature Review. Corporate Social Responsibility and Environmental Management, 32(6), 7490–7509. https://doi.org/10.1002/csr.70090

Caixeta, F., Saraiva, P., Freire, F., & Shitandi, A. (2023). Water-energy-food nexus and business excellence models for a sustainability maturity evaluation of ten agri-food companies from Brazil and Kenya. Journal of Cleaner Production, 420, 138429. https://doi.org/10.1016/j.jclepro.2023.138429

Centre for Environmental Rights (2021). If we don't take climate action now, this is what life in South Africa will look like. CER. Retrieved from: https://cer.org.za/news/if-we-dont-act-now-on-climate-change-this-is-what-life-in-south-africa-will-look-like

Chao, Y., & Goli, A. (2024). Integrating Blockchain Technology in Business Models for Sustainable Innovation. Sustainability, 16(16), 7217. https://doi.org/10.3390/su16167217

Chen W, He K, and Wang L (2023), "Blockchain technology, macroeconomic uncertainty and investment efficiency". International Journal of Emerging Markets, Vol. 18 No. 7 pp. 1493–1514, doi: https://doi.org/10.1108/IJOEM-10-2020-1250

Chethan, V.K., (2024). The Role of Blockchain Technology in Transforming Business Management Systems. International Journal of Creative Research Thoughts, 12(10). https://www.ijcrt.org/papers/IJCRT2410315.pdf

Dapp M., (2013). Open government data and free software—cornerstones of a digital sustainability Agenda. In: The 2013 open reader—stories and articles inspired by OKCon 2013: open data, broad, deep, connected. http://books.buchundnetz.com/the2013openreader

David LO, Nwulu NI, Aigbavboa CO, Adepoju OO (2025), "Resource sustainability in the water, energy and food nexus: Role of technological innovation". Journal of Engineering, Design and Technology, Vol. 23 No. 3 pp. 725–743, doi: https://doi.org/10.1108/JEDT-05-2023-0200

David, L. O., Nwulu, N. I., Aigbavboa, C. O., & Adepoju, O. O. (2022). Integrating fourth industrial revolution (4IR) technologies into the water, energy & food nexus for sustainable security: A bibliometric analysis. Journal of Cleaner Production, 363, 132522. https://doi.org/10.1016/j.jclepro.2022.132522

David, L. O., Nwulu, N., Aigbavboa, C., & Adepoju, O. (2023). Towards global water security: The role of cleaner production. Cleaner Engineering and Technology, 17, 100695. https://doi.org/10.1016/j.clet.2023.100695

David, L., Kgomo, M., & Aigbavboa, C. (2025). Smart contract in construction procurement: Insights and recommendations from South Africa. Frontiers in Built Environment, 11, 1620790. https://doi.org/10.3389/fbuil.2025.1620790

David, L., Kgomo, M., & Aigbavboa, C. (2025). Smart contract in construction procurement: Insights and recommendations from South Africa. Frontiers in Built Environment, 11, 1620790. https://doi.org/10.3389/fbuil.2025.1620790

David, L.O., Aigbavboa, C., Nwulu, N., Adepoju, O.O. (2024a). Role of Fourth Industrial Revolution (4IR) Technologies in Water, Energy, and Food (WEF) Resources. In: Sustainable Synergy: A Digital Framework for the Water-Energy-Food Nexus Project Delivery in Developing Economies. Green Energy and Technology. Springer, Cham. https://doi.org/10.1007/978-3-031-72833-4_8

David, L.O., Aigbavboa, C., Nwulu, N., Adepoju, O.O. (2024b). Application of Digital Technologies of the Fourth Industrial Revolution (4IR) in Water, Energy, and Food (WEF) Nexus. In: Sustainable Synergy: A Digital Framework for the Water-Energy-Food Nexus Project Delivery in Developing Economies. Green Energy and Technology. Springer, Cham. https://doi.org/10.1007/978-3-031-72833-4_9

David, L.O., Aigbavboa, C., Nwulu, N., Adepoju, O.O. (2024c). Synergistic Frameworks for Water-Energy-Food (WEF) Nexus. In: Sustainable Synergy: A Digital Framework for the Water-Energy-Food Nexus Project Delivery in Developing Economies. Green Energy and Technology. Springer, Cham. https://doi.org/10.1007/978-3-031-72833-4_12

David, L.O., Aigbavboa, C., Nwulu, N., Adepoju, O.O. (2024d). General Introduction. In: Sustainable Synergy: A Digital Framework for the Water-Energy-Food Nexus Project Delivery in Developing Economies. Green Energy and Technology. Springer, Cham. https://doi.org/10.1007/978-3-031-72833-4_1

Dlamini, A., Ndaba, T., and Mbatha, Z., (2024). Blockchain Technology and its impact on Entrepreneurship and Supply Chains. Journal of Entrepreneurship & Organization Management, 13(5). https://www.hilarispublisher.com/open-access/blockchain-technology-and-its-impact-on-entrepreneurship-and-supply-chains.pdf

dos Santos, S., Singh, J., Thulasiram, R.K., Kamali, S., Sirico, L., and Loud, L., (2022). A New Era of Blockchain - Powered Decentralized Finance (DeFi) - A Review. 2022 IEEE 46th Annual Computers, Software, and Applications Conference (COMPSAC). https://doi.org/10.1109/COMPSAC54236.2022.00203

Dunaievskyi, S.S., (2022). PESTLE Analysis: An Important Business Analysis Tool. Youth Research on Europe Integration. Collection of Abstracts, International Scientific and Practical Conference of Young Researchers and Students. pp 58–59. Retrieved from https://sci.ldubgd.edu.ua/jspui/bitstream/123456789/10820/1/%D0%97%D0%B1%D1%96%D1%80%D0%BD%D0%B8%D0%BA%20%2B%2B%2B.pdf#page=57

Economist Impact (2022a). Global Food Security Index 2022. Retrieved from: https://impact.economist.com/sustainability/project/food-security-index/reports/Economist_Impact_GFSI_2022_Global_Report_Sep_2022.pdf

Economist Impact (2022b). Country Report: South Africa. Global Food Security Index 2022. Retrieved: https://impact.economist.com/sustainability/project/food-security-index/reports/Economist_Impact_GFSI_2022_South_Africa_country_report_Sep_2022.pdf

Ellis, E., (2022). Food paste to the rescue: Plain rice the only meal a day for malnourished kids in Eastern Cape. Daily Maverick; Retrieved on: https://www.dailymaverick.co.za/article/2022-04-04-food-paste-to-the-rescue-plain-rice-the-only-meal-a-day-for-malnourished-kids-in-eastern-cape/#:~:text=Stats%20SA%20noted%20that%20almost,acute%20malnutrition%20stalks%20the%20land.

Esan, O., Nwulu, N., & Adepoju, O. O. (2024). A bibliometric analysis assessing the water-energy-food nexus in South Africa. Heliyon, 10(18), e37651. https://doi.org/10.1016/j.heliyon.2024.e37651

Fermeglia, M., Lughi, V., and Pavan, A. M., (2020). How to avoid the perfect storm: The role of energy and photovoltaics. MRS Energy & Sustainability - A Review Journal, 7(1). http://dx.doi.org/10.1557/mre.2020.36

Grebmer, K., Bernstein, J., Wiemers, M., Reiner, L., Bachmeier, M., Hanano, A., Cheileachair, R., Foley, C., Sheehan, T., Gitter, S., Larocque, G., and Fritschel, H., (2023). Global Hunder Index. The power of Youth in shaping food systems. https://www.globalhungerindex.org/pdf/en/2023.pdf

Hamidov, A., & Helming, K. (2020). Sustainability Considerations in Water–Energy–Food Nexus Research in Irrigated Agriculture. Sustainability, 12(15), 6274. https://doi.org/10.3390/su12156274

Hikmah, H., Ratnawati, A.T., and Darmanto, S., (2021). The Role of product Differentiation and Word of Mouth on Purchase Decision of Creative Industrial Products. Advances in Social Science, Education and Humanities Research, Volume 641. https://doi.org/10.2991/assehr.k.220202.014

Khan, A.A., Laghari, A.A., Li, P., Dootio, M.A., and Karim, S., (2023). The collaborative role of blockchain, artificial intelligence, and industrial internet of things in digitalization of small and medium-size enterprises. Sci Rep 13, 1656 (2023). https://doi.org/10.1038/s41598-023-28707-9

Ladleif, J., Weske, M. (2019). A Unifying Model of Legal Smart Contracts. In: Laender, A., Pernici, B., Lim, EP., de Oliveira, J. (eds) Conceptual Modeling. ER 2019. Lecture Notes in Computer Science(), vol 11788. Springer, Cham. https://doi.org/10.1007/978-3-030-33223-5_27

MacAlister, C, Baggio, G, Perera, D, Qadir, M, Taing, L, Smakhtin, V. (2023). Global Water Security 2023 Assessment. United Nations, University Institute for Water, Environment and Health, Hamilton, Canada. https://collections.unu.edu/eserv/UNU:9107/n23-116_UNU_Water_Security_WEB_Final_updated.pdf

Makateng, D., and Ntsoaki T.M., (2025). "Understanding Qualitative Research Methodology: A Systematic Review," E-Journal of Humanities, Arts and Social Sciences 6, no. 3 (2025): 327–335. https://doi.org/10.38159/ehass.2025637

Mercuri, F., della Corte, G., & Ricci, F. (2021). Blockchain Technology and Sustainable Business Models: A Case Study of Devoleum. Sustainability, 13(10), 5619. https://doi.org/10.3390/su13105619

Nayernia, H., (2026). Dynamic Capabilities Theory : A review. In S. Papagiannidis (Ed), TheoryHub Book. Available at https://open.ncl.ac.uk / ISBN: 9781739604400. https://open.ncl.ac.uk/theories/19/dynamic-capabilities-theory/

Ololade, O. O., Esterhuyse, S., & Levine, A. D. (2017). The Water-Energy-Food Nexus from a South African Perspective. 127–140. https://doi.org/10.1002/9781119243175.ch12

Pangarkar, N., & Prabhudesai, R. (2024). Using Porter's Five Forces analysis to drive strategy. Global Business and Organizational Excellence, 43(5), 24–34. https://doi.org/10.1002/joe.22250

Poppy G. M., Chiotha S., Eigenbrod F., Harvey C. A., Honzák M., Hudson M. D., Jarvis A., Madise N. J., Schreckenberg K., Shackleton C. M., Villa F. and Dawson T. P. (2014). Food security in a perfect storm: Using the ecosystem services framework to increase understanding. Philosophical Transactions of the Royal Society B, 369(1639). http://doi.org/10.1098/rstb.2012.0288

Schlör, H., Venghaus, S., Fischer, W., Märker, C., & Hake, J. F. (2018). Deliberations about a perfect storm – the meaning of justice for food energy water-nexus (FEW-nexus). Journal of Environmental Management, 220, 16–29.

Seeliger, L., de Clercq, W. P., Hoffman, W., Cullis, J. D., Horn, A. M., & de Witt, M. (2018). Applying the water-energy-food nexus to farm profitability in the Middle Breede Catchment, South Africa. South African Journal of Science, 114(11/12). https://doi.org/10.17159/sajs.2018/5062

Shiferaw, R. M., & Amentie Kero, C. (2024). Dynamic capabilities view practices of business firms: A systematic literature review. Cogent Business & Management, 11(1). https://doi.org/10.1080/23311975.2024.2336309

Smela, B., Toumi, M., Świerk, K., Gawlik, K., Clay, E., & Boyer, L. (2023). Systematic literature reviews over the years. Journal of Market Access & Health Policy, 11(1). https://doi.org/10.1080/20016689.2023.2244305

Smith, A., Strugnell, D., and Swanepoel, D., (2022). SA has experienced rain increases and most dams are full, yet a national water crisis persists. Daily Maverick. Retrieved from: https://www.dailymaverick.co.za/article/2022-04-06-sa-has-experienced-rain-increases-and-most-dams-are-full-yet-a-national-water-crisis-persists/

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. Journal of Business Research, 104, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Sukiennik, M., Kowal, B., & Bąk, P. (2021). Identification of Market Gap as a Chance for Enterprise Development—Example of Polish Raw Materials Industry. Energies, 14(15), 4678. https://doi.org/10.3390/en14154678

Tan, W., Zhu, H., Tan, J., Zhao, Y., Xu, L. D., & Guo, K. (2022). A novel service level agreement model using blockchain and smart contract for cloud manufacturing in industry 4.0. Enterprise Information Systems, 16(12). https://doi.org/10.1080/17517575.2021.1939426

Teece, D.J., Pisano, G. and Shuen, A. (1997) Dynamic Capabilities and Strategic Management. Strategic Management Journal, 18, 509–533. https://josephmahoney.web.illinois.edu/BA545_Fall%202022/Teece,%20Pisano%20and%20Shuen%20(1997).pdf

UNDP (United Nations Development Programme). 2023. 2023 Global Multidimensional Poverty Index (MPI): Unstacking global poverty: Data for high impact action. New York. https://hdr.undp.org/system/files/documents/hdp-document/2023mpireportenpdf.pdf

Verrue, J. (2014). A critical investigation of the Osterwalder business model canvas: An in-depth case study. Belgian Entrepreneurship Research Day, Proceedings. Presented at the Belgian Entrepreneurship Research Day, Ghent, Belgium. https://biblio.ugent.be/publication/5712151

Von Bormann, T., (2019). Agri-food systems: Facts and futures: How South Africa can produce 50% more by 2050 (WWF South Africa Report). WWF South Africa. Retrieved from: https://wwfafrica.awsassets.panda.org/downloads/wwf_food_report_facts_and_futures_2019.pdf?27341/agri-food-systems-facts-and-futures

Wang, W., & Liu, C. (2023). Dynamic Capability Theory Based Study on Performance of Intelligent Manufacturing Enterprise under RFID Influence. Electronics, 12(6), 1374. https://doi.org/10.3390/electronics12061374

Winkler, H., (2022). South Africa's efforts to tackle its energy crisis lack urgency and coherence. The Conversion. Retrieved from: https://theconversation.com/south-africas-efforts-to-tackle-its-energy-crisis-lack-urgency-and-coherence-176993

World Energy Council (2022). World Energy Trilemma Index 2022. Retrieved from: https://www.worldenergy.org/assets/downloads/World_Energy_Trilemma_Index_2022.pdf?v=1669842216

Zhang, L. L. (2014). Product configuration: A review of the state-of-the-art and future research. International Journal of Production Research, 52(21), 6381–6398. https://doi.org/10.1080/00207543.2014.942012

Zou, G., Li, Z., & He, C. (2023). A New Product Configuration Model for Low Product Cost and Carbon-Neutral Expenditure. Sustainability, 15(13), 10358. https://doi.org/10.3390/su151310358