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Organizational Management in the VUCA Hydrogen Era: Towards a Hybrid Model of Adaptive Theories

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ABSTRACT

In a world defined by volatility, uncertainty, complexity, and ambiguity (VUCA), energy organizations must rapidly adapt to the transition towards clean and sustainable sources, such as green hydrogen and other renewable energies. This manuscript explores the transformation of organizational management within this context, emphasizing the importance of integrating classical theories with emerging paradigms to address the challenges of the contemporary energy sector. The analysis reveals that, while traditional management theories provide a solid framework for understanding organizational dynamics, their capacity to respond to the speed of technological change and the fluctuations of the energy market is limited. In this regard, organizations must adopt a more flexible and adaptive approach that fosters innovation and collaboration among diverse actors such as academia, industry, and government. A hybrid model of adaptive management is proposed, combining the stability of classical organizational structures with the agility and collective intelligence demanded by VUCA environments in hydrogen era. This approach seeks not only to optimize operational efficiency but also to promote a culture of continuous learning and experimentation, essential for facing the uncertainty inherent in the adoption of new energy technologies. The manuscript concludes that the integration of classical management theories with digital and agile approaches enables a more comprehensive understanding of organizational phenomena in the energy sector. This theoretical synthesis is crucial for developing effective strategies that not only address the specific challenges of hydrogen and other renewable energies but also facilitate the transition towards a more sustainable and resilient global energy future.

Keywords: Theories, VUCA, green environments, electric transition/, integration, hydrogen industry.

INTRODUCTION

Have the classical theories of business sciences lost their relevance in the face of the dizzying digital transformation and the growing complexity of the contemporary world? This question invites reflection on the nature and scope of the theoretical frameworks that highlight the study and practice of organisational management in complex areas such as mining and energy, respectively. Far from being obsolete, classical theories constitute the epistemological foundation that enables us to understand the structures, dynamics, and contingencies inherent in organisations. However, the new energy industries demand a paradigm shift and a closer alignment with emerging organisational trends. Modern organisations continue to establish certain key principles such as (i) efficiency, (ii) productivity, (iii) hierarchical organisational structures, and (iv) specialisation, among others. Their value lies in offering universal principles and rigorous analytical tools that remain essential for interpreting and guiding strategic decision-making in complex scenarios, where the study of data as a primary source of information enhances value and performance. Today, the analysis of historical data using machine learning algorithms and computational intelligence is being applied to study changes and degradation in solar systems such as CSP thermal storage plants, photovoltaic solar facilities, and hydrogen systems, which are being integrated as pilot projects in many parts of the world [1]. Chile has positioned itself as a strategic actor in the global green hydrogen landscape due to its exceptional renewable energy potential, particularly in solar and wind resources. However, the development of the green hydrogen industry faces several structural challenges. These include high initial investment requirements for production, storage, and transport infrastructure; regulatory uncertainty regarding certification, safety standards, and long-term incentives; technological challenges related to electrolyser efficiency and system integration; limited domestic demand in early stages; and the complexity of coordinating supply chains involving multiple public and private actors. These challenges create a highly VUCA environment that directly affects organizational decision-making and management structures within the energy sector.

The relationship between the VUCA model (Volatility, Uncertainty, Complexity, and Ambiguity) and the study of energy, particularly green hydrogen, is highly fruitful from a strategic, educational, and technological management perspective, especially considering Chile's goal of achieving carbon neutrality by 2050 [2]. The VUCA model and its connection with energy studies, such as green hydrogen, are increasingly relevant in the current context. Today, we live in an era defined by a global energy transition aimed at decarbonising the world. The pursuit of clean and sustainable sources, such as green hydrogen, is taking place within a VUCA environment, where technological, regulatory, and geopolitical changes are accelerating and challenging traditional planning models. The volatility resulting from the energy transition reflects the speed and magnitude of these changes. In the field of green hydrogen and other energy carriers such as lithium for batteries, energy prices and electrolysis costs fluctuate significantly, particularly when storage is not considered thereby increasing CAPEX, while public policies and fiscal incentives vary according to political and economic contexts [3]. The empirical object of this study is defined as energy-sector organizations involved in the development, deployment, or strategic planning of green hydrogen technologies operating under VUCA conditions. The analysis focuses on organizational management models within emerging hydrogen-related initiatives, with contextual reference to Chile as a case of interest due to its national green hydrogen strategy and ongoing energy transition. Although the research adopts a theoretical–analytical approach, it is anchored in observable organizational practices and sectoral dynamics reported in existing energy organizations and industry cases. This manuscript presents a highly novel perspective by linking VUCA aspects with renewable energy in emerging energy organisations.

VUCA and Renewable Energy

Technological advances in the efficiency of electrolysers or energy storage systems become obsolete in a short time, which exacerbates the uncertainty surrounding these technologies. Building energy resilience requires flexibility in investments, public–private partnerships, and diversification of sources and companies willing to invest venture capital in technologies that remain unpredictable within the energy market (*uncertainty*).

The green hydrogen industry does not yet exist within a mature global market. Although hydrogen itself is not an unfamiliar gas to the industry, the pace at which countries will adopt this technology remains uncertain. Competition among renewable energy sources such as solar, wind, and nuclear, among others creates shifting scenarios that amplify uncertainty in the sector, leading to the development of scenario models and adaptive energy policies. *Complexity* is reflected in the multiplicity of factors involved in the development of green hydrogen, such as:

(i) interconnection between electrical, transport, and storage systems;
(ii) international regulations, origin certification, and sustainability standards;
(iii) the need for collaboration among academia, industry, government, and civil society;

(iv) the application of collaborative governance, artificial intelligence systems in the energy sector, and interdisciplinary models of complex analysis to determine CAPEX and OPEX, while ensuring that key variables such as degradation and corrosion of major technological components are not overlooked.

On the other hand, *ambiguity* arises when information is insufficient or contradictory; however, there is also a great deal of information that has not been properly disseminated. There are ongoing debates regarding its real profitability compared with other energy alternatives, although all of these, to varying degrees, contribute to pollution.

Storage technologies still present significant challenges and compel the system to foster a culture of continuous learning and ethical vision, grounded in scientific evidence and environmental impact assessment.

A VUCA perspective for sustainable energy should not be viewed as a threat, but rather as a framework for strategic management and regulation aimed at driving energy innovation. Green hydrogen, developing within an uncertain and volatile environment, requires transformational leadership, systemic thinking, and collaboration with both national and international actors. Education, research, and public management must align with this vision to promote a sustainable, resilient, and ethical energy future [4].

Nevertheless, these theories today face an ontological paradox. On the one hand, they are essential for understanding the structural and functional nature of organisations; on the other, their formulation and scope present limitations when it comes to addressing the dizzying pace and global interconnectedness that characterise the digital era in relation to renewable energy. The exponential acceleration of technological change within industries and the constant emergence of disruptive innovations challenge the rigidity implicit in some classical models that have been implemented and functioning for years, models conceived in less volatile and interrelated contexts. In this sense, classical theories require rethinking and expansion towards new paradigms that incorporate flexibility, agility, and adaptive capacity as fundamental attributes of the twenty-first century.

The integration of digital and emerging theories should not be understood as a replacement, but rather as a dialectical synthesis that enriches and strengthens the theoretical corpus by broadening knowledge. The incorporation of concepts such as collective intelligence, connectivism, and agile management makes it possible to address organisational phenomena in VUCA environments with an approach that transcends mere predictability, allowing uncertainty, ambiguity, and heightened complexity to assume a fundamental role.

Classical theories remain the indispensable foundation for understanding and analysing organisations in emerging industries; however, their relevance and effectiveness today depend on their ability to engage in dialogue with new currents that capture the dynamic and disruptive essence of the present. Only through such integration can a theoretical praxis emerge that responds with depth and creativity to contemporary challenges, contributing to strategic thinking that is both rigorous and adaptable, universal and contextualised to a VUCA environment applied to the energy sector, where the boundaries between companies, approaches, and nations are not limitations, but rather opportunities for improvement [5].

This systematic exploration is justified by the need to understand how traditional theoretical frameworks, which have been fundamental for the structural analysis of established organisations, can be complemented by more recent approaches capable of responding to the volatility, uncertainty, complexity, and ambiguity of the current environment. Far from being mutually exclusive, both approaches offer valuable perspectives which, when integrated, enable the development of a broader and more flexible understanding of contemporary organisational phenomena [6].

Based on the theoretical framework and sectoral context described above, this study advances the following research hypotheses:

H1: High initial investment requirements constitute a primary barrier to the organizational adoption of green hydrogen projects in emerging energy markets.

H2: Regulatory uncertainty significantly increases managerial complexity and risk perception in organizations operating within the green hydrogen sector.

H3: The integration of digital and agile management paradigms enhances organizational adaptability under VUCA conditions in the hydrogen industry.

H4: Hybrid management models that combine classical organizational structures with adaptive digital approaches are better suited to address volatility and uncertainty in the energy transition.

These hypotheses are explored and theoretically substantiated through the analytical integration of classical management theories, digital paradigms, and documented organizational practices in the renewable energy sector

Regarding the theoretical structure, three thematic axes are addressed. The first outlines the foundations and relevance of classical theories in organisational management, presenting their epistemological and practical value within the business sciences. The second axis refers to the challenges of the VUCA environment and the emergence of digital paradigms, describing the demands this place on organisational management. Finally, the third axis

involves a conceptual dialogue leading to a dialectical integration towards a hybrid model of adaptive management. This section argues for the necessity and advantages of integrating classical and digital theories into a theoretical synthesis that enables a more holistic and flexible understanding of organisations.

Foundations and relevance of classical theories in organisational management

A VUCA environment oriented towards renewable energy is a concept that describes the conditions of instability and constant change that organisations face today when operating in intermittent contexts such as solar and wind energy. Although recent literature has explored various aspects of business management in VUCA contexts such as effective leadership, strategic foresight, and the transition towards new paradigms like the BANI environment few studies have addressed the energy issue from a theoretical synthesis perspective, which gives this manuscript significant novelty [7,8].

In this scenario, classical management paradigms, focused on hierarchical control and rigid planning, are becoming obsolete, as they no longer respond effectively to changing contexts. In their place, digital paradigms and agile approaches have emerged, promoting adaptability, collective intelligence, and continuous innovation, providing rapid responses for a world in constant transformation. Connectivism, proposed by Siemens (2005), suggests that knowledge and learning are processes distributed across networks of connected nodes, supported by digital technologies that facilitate collaboration and real-time information transfer [9]. This perspective redefines organisational knowledge management, transforming it into a dynamic and relational practice. However, collective intelligence is more than the sum of individual knowledge; it is an emergent phenomenon resulting from social and technological interaction, which enhances the capacity to solve complex problems. This notion is crucial in a VUCA environment, where challenges exceed the capacity of individuals acting in isolation.

Agile methods applied to solar or wind farms, with their iterative cycles, constant feedback, and self-organising teams enable rapid responses to changes imposed by the climate, thereby increasing operational uncertainty due to technological unpredictability. These digital paradigms and agile approaches represent not merely a methodological shift but an epistemological transformation that redefines managerial practice, enabling organisations to thrive in volatile and uncertain environments [10].

VUCA and the emergence of digital paradigms in energy

The contemporary organisational environment oriented towards renewable energies—and particularly the industrialisation of hydrogen, is characterised by unprecedented complexity and dynamism, which highlights the disruptive and ever-changing nature of markets and the external conditions faced by companies under the social and political pressure for the world to become carbon neutral by 2050. The emergence of digital paradigms in processes such as hydrogen production is a direct response to the challenges imposed by the VUCA environment. Complexity requires critical and systemic thinking that recognises the multidimensional nature of organisational phenomena, moving beyond simplistic cause-and-effect relationships. Given the limitations of classical theories in addressing VUCA dynamics, digital paradigms have emerged that enable more adaptive and collaborative management, which will help to strengthen the hydrogen industry. Connectivism redefines knowledge as a distributed network of nodes, facilitating continuous learning and networked decision-making through digital technologies. This perspective enhances collective intelligence as an "emergent capacity of groups and communities to create and share knowledge through social and technological interaction," a fundamental element in complex contexts, which can also be described as soft infrastructure. From this perspective, understanding the nature of the VUCA environment and the emergence of digital paradigms applicable to energy is crucial for developing organisational capabilities that enable effective navigation of uncertainty [7,11].

Dialectical integration: towards a hybrid model of adaptive management

In the current context, business management faces the urgent need to integrate its theoretical and practical frameworks to respond to the challenges of a rapidly changing, technology-driven environment. The dialectical integration between classical and digital theories emerges not only as a strategy but also as an epistemological imperative for building a hybrid model of adaptive management that transcends the limitations of each paradigm in isolation.

On the one hand, classical management theories—rooted in rationality and hierarchical control—constitute the fundamental basis for organisational structure and efficiency. Therefore, the effective integration of both approaches requires a dialectical understanding, conceived as a process of tension and synthesis. This maintains a continuous dialogue between business management and energy technology [12].

This synthesis does not negate previous paradigms but rather elevates them, articulating stability and change, control and autonomy, rigidity and flexibility. The hybrid model recognises the need for solid formal structures to maintain order, alongside fluid spaces that foster creativity and adaptability. Amazon is a clear example of this structural duality, combining rigorous logistical processes with a culture that encourages experimentation and agility [13]. From an epistemological perspective, the hybrid model of adaptive management conceives organisational knowledge as a dynamic and relational phenomenon, in which the ongoing dialogue between theory and practice becomes central. Furthermore, this adaptive management approach is grounded in the development of capacities for anticipation and experimentation. It seeks to develop "antifragile" organisations—those that not only withstand uncertainty but grow stronger because of it. To achieve this, dialectical integration requires transformational and distributed leadership capable of managing the tension between traditional hierarchy and collaborative governance. Such leadership must promote a culture open to continuous learning, recognising collective intelligence as a strategic resource (soft infrastructure).

FINDINGS

The findings presented in this section address the proposed research hypotheses by examining how classical and emerging management theories explain organizational responses to investment constraints, regulatory uncertainty, technological change, and systemic complexity in the green hydrogen sector. Rather than testing hypotheses through econometric methods, the study provides a conceptual and analytical substantiation grounded in documented sectoral evidence and organizational behavior patterns observed in VUCA environments.

The findings constitute a fundamental element in the process of generating new knowledge, where the rigorous analysis of conceptual frameworks not only makes it possible to identify epistemological trends but also to propose pathways for critical articulation between consolidated theories and emerging paradigms, which are increasingly common in the emerging hydrogen industry. In this case, the results provide a deeper understanding of how classical and digital theories can be integrated to effectively address the challenges of the VUCA environment, thus framing a theoretical contribution of significance for contemporary organisational management [14].

Traditional models continue to offer solid principles of structure, control, and efficiency that remain relevant in certain contexts; however, the review demonstrated that these tools can also be applied to the development of business organisations dedicated to hydrogen and renewable energies, which must be updated and complemented with adaptive approaches that prioritise flexibility, decentralisation, and continuous learning—central aspects of digital frameworks applied to the energy sector.

On the other hand, the findings concerning emerging and digital theories—such as connectivism, collective intelligence, and agile management—show that these offer particularly powerful tools for addressing the dynamism, interdependence, and ambiguity inherent in VUCA environments in uncertain business settings, such as the hydrogen industry. In particular, the connectivism 0model stands out for its focus on decentralising knowledge, promoting collaborative networked work, and encouraging iterative and distributed decision-making. These characteristics make digital theories not merely predictive or proactive in the face of uncertainty, but transformative in organisational practice.

Finally, the analysis reveals that the renewable energy sector, especially the emerging hydrogen industry, has generated a second-order integrative theoretical proposal. In other words, it represents an interpretative model that does not reject the contributions of the past but reinterprets them in light of present-day demands, proposing a holistic, complex, and adaptive vision of management. This new understanding enables an organisational praxis that transcends structural determinism without falling into the relativism of constant change, thereby offering a powerful conceptual framework for addressing management in the twenty-first century from a critical, flexible, and resilient perspective in an electrified world.

Key Points

- **Relevance of Classical Theories:** Classical management theories remain fundamental for understanding organisational structure and functioning. However, their effectiveness in the current context is limited by the rapid pace of change in the energy environment.
- **Need for Adaptation:** Organisations must evolve towards hybrid management models that integrate traditional principles with agile and digital approaches. This will enable them to be more flexible and respond effectively to the volatility and complexity of the energy market.
- **Interdisciplinary Collaboration:** The transition towards sustainable energies, such as green hydrogen, requires effective collaboration between different sectors, including academia, industry, and government. This synergy is crucial for driving innovation and the development of energy technologies.

- **Culture of Continuous Learning:** Fostering an organisational culture that values continuous learning, and experimentation is essential to face uncertainty and the challenges of the VUCA environment. Organisations must be willing to adapt and evolve according to new market realities.
- **Sustainability and Resilience:** An integrated approach combining classical and emerging theories not only facilitates the management of uncertainty but also contributes to the development of a more sustainable and resilient energy sector. This theoretical framework enables organisations not merely to survive but to thrive in a constantly changing environment.
- **Global Perspective:** The proposed hybrid model of adaptive management has implications beyond the hydrogen sector, being applicable to other industries seeking transformation within a global context of sustainability and environmental responsibility. This comprehensive approach can serve as a guide for organisational management in the twenty-first century.

CONCLUSIONS

In the hydrogen era, marked by volatility, uncertainty, complexity, and ambiguity, the energy sector faces unprecedented challenges that demand a profound transformation in organisational management. The transition towards clean and sustainable energy sources, such as green hydrogen, poses not only technical and economic challenges but also requires a rethinking of the management theories and practices that have guided organisations for decades. Classical management theories, which have long served as the foundation of organisational studies, still offer valuable tools for understanding structural and functional dynamics. However, in an environment as dynamic as the present one, their applicability is limited. Organisations operating in the energy sector must be capable of rapid adaptation to change, which necessitates the integration of more flexible and agile approaches. The creation of a hybrid management model that combines the robustness of traditional theories with the agility of digital paradigms has therefore become an imperative. This hybrid model not only provides a foundation for organisational stability but also promotes a culture of continuous learning and collaboration. The interconnection between different actors within the energy ecosystem including governments, universities, and companies, is essential for fostering innovation. Such collaboration can lead to the development of more efficient and sustainable technologies that respond to the demands of a world striving for decarbonisation.

Moreover, the ability of organisations to thrive in a VUCA environment is intrinsically linked to their willingness to experiment and learn from uncertainty. Fostering an organisational culture that values adaptability and continuous learning will enable companies not only to navigate current challenges but also to capitalise on the opportunities that emerge along the way. Sustainability and resilience are key concepts that must guide organisations on their path towards the future. An approach that integrates classical and emerging theories not only helps to manage uncertainty but also contributes to building a more responsible and sustainable energy sector. This emerging theoretical model is not confined to the hydrogen field but can be applied to a range of industries seeking to adapt to a global context increasingly concerned with sustainability.

In conclusion, the transformation of the energy sector in the VUCA era requires a comprehensive approach that combines tradition with innovation. Organisations must be willing to evolve, to learn, and to collaborate to face the challenges of the present and the future. Only in this way can they contribute to a more sustainable, resilient, and ethical world one in which clean energy is not merely an aspiration, but an achievable reality.

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