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Developing a Progressive Regulatory Framework to Enable Innovation in Neom's Green Hydrogen Ecosystem

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Abstract

In this paper, a novel regulatory framework tailored to Neom's green hydrogen ecosystem is proposed, stemming from an in-depth analysis of globally recognized policies in the green hydrogen sector. Policies originating from the European Union, Australia, and Japan, carefully selected due to their pioneering work in green hydrogen, are dissected, and salient features are identified. Utilizing a novel methodological approach, the key facets of these policies are integrated into a tailor-made regulatory framework to bolster the innovation and sustainability of Neom's green hydrogen ecosystem. While the proposed framework offers significant potential to drive innovation and sustainability, it is recognized that the implementation could encounter challenges. These might emerge from Neom's unique socio-cultural context, the nascent state of the global green hydrogen industry, and the need for inter-jurisdictional coordination and harmonization. Recommendations for mitigating these challenges, including proactive engagement with ethical and social issues surrounding data-driven policy making, are incorporated into the proposed framework. This study serves to broaden our understanding of policy-making in the green hydrogen sector. By drawing upon international best practices and contextualizing them to Neom's unique circumstances, valuable insights are contributed to both academic discourse and the practical implementation of green hydrogen initiatives. The paper concludes with recommendations for future research in this nascent yet critical field, underscoring the dynamic and evolving nature of green hydrogen policy-making.

Keywords: *Green Hydrogen, Regulatory Framework, Sustainable Innovation, Policy Analysis, Neom City.*

I. Introduction

Imagine a beacon of sustainable energy and innovation rising from the Saudi Arabian landscape: Neom, a city conceptualized to be entirely powered by clean energy, particularly green hydrogen. Green hydrogen, a clean energy carrier produced via electrolysis of water using renewable energy sources, represents a promising step towards

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decarbonization and climate change mitigation. Despite this potential, the absence of a robust regulatory framework, especially pertinent given the green hydrogen's nascent status and Neom's unique sociocultural and economic environment, presents a formidable hurdle towards achieving Neom's ambitious vision. This conundrum forms the central research question guiding this academic exploration: "What legal policy framework can effectively drive and sustain innovation in Neom's green hydrogen vision?"

The purpose of this paper is to propose a comprehensive, progressive regulatory framework tailored to Neom's unique vision and green hydrogen innovation requirements. This involves meeting a set of specific objectives, including a review of globally recognized policies related to green hydrogen production, analysis of the policy-innovation-green hydrogen production nexus, and development of policy recommendations cognizant of Neom's distinctive characteristics.

This paper is structured to maintain a logical flow that aligns with the established objectives. It begins with a with a literature review on global green hydrogen policies landscape and their instrumental role in spurring innovation. This exploration facilitates the subsequent unveiling of the theoretical framework based on the International Renewable Energy Agency (IRENA) guide, Cognitive City Framework and Policy Innovation Cycle, paving the way for a comprehensive exploration of Neom's ambitious vision for a green hydrogen ecosystem.

Drawing valuable insights from this comprehensive policy review and understanding Neom's unique context, an analysis of universally recognized policies will be performed, aimed at extracting key lessons for Neom. This analysis provides the foundation for the development of a customized regulatory framework specifically tailored to Neom's needs. The implications of this proposed framework on green hydrogen innovation within Neom will be explored, shedding light on potential advancements and hurdles alike. In conclusion, the paper will synthesize the central findings and will highlight possible avenues for future research.

II. Literature Review

A. Green Hydrogen Production: Key Policies and Regulatory Frameworks Globally

Green hydrogen, a clean energy carrier produced through the electrolysis of water using renewable energy sources, is regarded as a promising solution for global decarbonization and climate change mitigation (IRENA, 2019; Schmidt et al., 2017). Realizing this potential requires sound policies and regulatory frameworks that stimulate its production and use. Various approaches to integrate green hydrogen into the energy sector have been adopted worldwide, with their effectiveness and applicability largely depending on regional contexts (Endres et al., 2019).

This section critically reviews the key global policies and regulatory frameworks related to green hydrogen production, focusing on the European Union, Japan, and Australia, selected due to their diverse approaches and commitment levels. The following subsections offer a comparative analysis of these policies in terms of their scope, objectives, strategies, and outcomes, evaluating their implications for Neom's green hydrogen ecosystem.

B. The EU's Hydrogen Strategy

The EU's Hydrogen Strategy, part of the European Green Deal aiming at climate neutrality by 2050, presents an ambitious roadmap to upscale green hydrogen production by 2030 (European Commission, 2020). It focuses on significant investments in electrolyzer capacity, innovation promotion in green hydrogen technologies, and fostering a conducive market for hydrogen-based products. The strategy underscores the

significance of public-private partnerships in accelerating the transition (Menner and Reichert, 2020).

However, the EU's strategy faces certain limitations. Critics argue that its focus on technology neutrality could lead to investments being diverted away from green hydrogen to other forms of low-carbon hydrogen still reliant on fossil fuels (Kopp et al., 2020). The absence of harmonized regulations and standards across member states may also obstruct the development of a single market for hydrogen (Hydrogen Europe, 2020). These challenges suggest that Neom's regulatory framework needs to prioritize green hydrogen and ensure regional coherence.

C. Japan’s Basic Hydrogen Strategy

Japan's Basic Hydrogen Strategy, released in 2017, has been integral in steering the nation's hydrogen-based endeavors (Ministry of Economy, Trade and Industry, 2017). The strategy's main emphasis lies in achieving cost parity with competitive fuels, thereby making hydrogen an economically viable energy source. However, the strategy has been critiqued for its heavy reliance on foreign hydrogen supplies, triggering worries about market dynamics and geopolitical uncertainties (Kucharski, 2019).

Japan's reliance on overseas hydrogen supplies exposes the nation to geopolitical risks and uncertainties, making it susceptible to fluctuations in international energy markets. Besides, dependence on foreign supplies could lead to supply disruptions due to diplomatic tensions or logistical issues (Nagashima, 2018). This aspect of Japan's strategy serves as a reminder that over-reliance on external hydrogen supplies can result in unpredictability and volatility, potentially obstructing steady progress towards green hydrogen-based goals.

Recognizing this, Neom's framework could substantially benefit from an emphasis on self-reliance in hydrogen production. By prioritizing domestic production and the establishment of a robust local supply chain, Neom can ensure consistent progress in the green hydrogen sector, circumventing the risk of supply disruptions and reducing susceptibility to external market forces (Huang, 2023). However, this approach should not discount potential challenges such as technological advancement and capacity building for domestic production. Therefore, a balanced, pragmatic strategy is crucial - one that not only focuses on self-reliance but also acknowledges potential barriers and implements strategies to mitigate them (House, 2021). This could be instrumental in shaping Neom's successful transition to a green hydrogen-powered future

D. Australia’s National Hydrogen Strategy

Australia's National Hydrogen Strategy, unveiled in 2019, marked a significant step towards developing a sturdy hydrogen industry. The strategy, however, has faced substantial criticism for not detailing specific actions and targets, making the monitoring of its effectiveness and progress challenging (COAG Energy Council, 2019; Macfarlane, 2019).

While the strategy ambitiously outlines aspirations for industry growth, a critique has emerged concerning its lack of specificity (Longden, 2020). For instance, the strategy's objectives, though commendable, lack accompanying timelines or quantifiable milestones, resulting in an overall perception of the plan as being more aspirational than operationally feasible (Kar et al, 2023). Moreover, an absence of defined resources necessary to actualize these goals has raised doubts about its feasibility and raised questions about optimal resource allocation.

For Neom to evade such pitfalls, it is essential that its regulatory framework encompasses not only a visionary outlook but also precise, actionable goals. By incorporating clear targets and timelines into its policy framework, Neom can foster greater transparency, ensuring that progress is measurable and accountable. The challenges should not be

overlooked either; potential barriers such as technical, financial, or social hurdles may arise and should be acknowledged and addressed. Providing this balance and realism in the approach will not only inspire confidence in stakeholders but also propel the development and innovation within Neom's green hydrogen sector.

The subsequent section extends this discussion to examine the relationship between policy, innovation, and green hydrogen production, setting the groundwork for a regulatory framework that would foster green hydrogen innovation in Neom.

B. Relationship between Policy, Innovation, and Green Hydrogen Production: An Overview

Green hydrogen, understood as a form of renewable energy, is derived from the process of electrolysis - the separation of water molecules into hydrogen and oxygen, facilitated by electricity generated from renewable energy sources such as solar or wind power (IEA, 2019). Green hydrogen holds potential for decarbonizing various sectors of the economy including transport, industry, and power generation, acting as a replacement for fossil fuels and reducing greenhouse gas emissions (Bilgili et al., 2020). Nevertheless, the production of green hydrogen is impeded by technical, economic, and regulatory challenges (Schmidt et al., 2017).

The interplay between policy, innovation, and green hydrogen production is complex yet integral for achieving a decarbonized global economy (Geels, 2014). Schumpeter’s Theory of Innovation (Schumpeter, 1942) offers a lens to understand this system, suggesting that policy adjustments may shape and in turn, be shaped by technological advances. These policy initiatives must address prevalent market failures, such as positive externalities and public goods associated with green hydrogen innovation (Aghion et al., 2019).

Empirical data gathered from multiple studies underscore the effect of policy on green hydrogen innovation (IEA, 2020). This data depicts a marked rise in patents, publications, projects, and investments in green hydrogen technologies, resulting from policy incentives. Moreover, regression models demonstrate the relationship between policy variables, such as carbon taxes and renewable energy targets, and innovation outcomes (Aghion et al., 2019).

Case studies, for instance, the European Union’s Renewable Energy Directive II (RED II) and Germany's National Hydrogen Strategy, showcase the potential of well-structured policy frameworks in stimulating green hydrogen technology innovation (Kuittinen and Velt 2018). However, Christensen's Disruptive Innovation Theory (Christensen et al, 2013) suggests that innovation can manifest even in the absence of policy support.

Striking a balance between technological innovation and socio-economic considerations, such as accessibility and affordability, along with the potential employment impact is imperative (Borenstein, 2012). Without the backing of apt market mechanisms or social policies, green hydrogen production could incur substantial costs to consumers or taxpayers (Helm, 2020).

Contending with potential resistance from vested interests or public opinion, as well as managing limited resources for effective policy implementation for green hydrogen production are significant challenges policymakers must navigate (Lockwood, 2022).Addressing these challenges may entail enhanced stakeholder engagement, elevated public awareness, and international cooperation (Wüstenhagen et al., 2007). Efforts to educate the public on the advantages and challenges of green hydrogen production could be instrumental in overcoming social barriers. Collaborative endeavors with other nations engaged in green hydrogen production could foster a common vision and facilitate knowledge exchange (Hassan et al, 2023).

The symbiotic relationship between policy, innovation, and green hydrogen production is evident. Policies need to be designed to stimulate innovation while possessing the flexibility to accommodate technological advancements. The roadmap to a sustainable, green future necessitates strategic planning, concerted efforts, and consistent adaptation (IRENA, 2020).

C. Green Hydrogen Vision in Cognitive Cities: A Review

With the dawn of the Fourth Industrial Revolution, urban development and innovation have accelerated at an unprecedented pace. Notably, the concept of cognitive or smart cities has gained momentum, offering a vision of an urban environment where information technology, data analysis, and artificial intelligence (AI) blend seamlessly with urban planning and management (Bibri et al, 2023). This section delves into the integral role green hydrogen plays in shaping the vision of cognitive cities, exploring the facilitating elements and hurdles involved in integrating green hydrogen systems into such cityscapes.

Green Hydrogen Vision in Cognitive Cities: An Integrated Review

Cognitive cities refer to urban spaces that smartly employ data and AI to optimize urban services, refine decision-making processes, and cultivate a sustainable living environment. A cognitive city gathers and examines data from diverse sources, such as IoT devices, sensors, social media, and more(Bibri et al, 2023). This information is then harnessed to manage and regulate urban systems, including energy, transportation, waste management, and public services, in a more efficient and sustainable manner (Batty et al., 2012).

Green hydrogen, embodying the qualities of versatility, sustainability, and cleanliness as an energy carrier, holds enormous potential to revolutionize the energy landscape of cognitive cities as follows:

Energy System Decarbonization: Green hydrogen can play a pivotal role in decarbonizing urban energy systems. It can be utilized to store surplus renewable energy, deliver heating and cooling, fuel hydrogen-powered vehicles, and substitute fossil fuels in industrial processes. This multi-faceted usage results in a reduction in greenhouse gas emissions and improves air quality (IRENA, 2020).

Grid Flexibility and Energy Storage: As the proportion of variable renewable energy sources like wind and solar increases in the energy mix, green hydrogen can offer the much-needed grid flexibility. It can store surplus renewable energy during periods of peak production and dispense it when the demand is high or production is low, thereby maintaining grid balance and ensuring a consistent power supply (Klok et al., 2020).

Sector Coupling: Green hydrogen can facilitate sector coupling by integrating the energy, transport, industry, and building sectors. It enables the utilization of renewable energy across these sectors, thereby enhancing overall energy efficiency and reducing reliance on fossil fuels (Schiebahn et al., 2015).

Enabling and Hindering Factors for Green Hydrogen in Cognitive Cities

The integration of green hydrogen into cognitive cities is a complex and multifaceted process that involves various enablers and barriers. This section discusses the main factors that can facilitate or hinder the adoption of green hydrogen as a clean and sustainable energy source for cognitive cities.

One of the key enablers for green hydrogen is policy support. Government policies that champion the use of renewable energy, establish emission reduction targets, and provide incentives for green hydrogen production and use can significantly propel its integration into cognitive cities (Van Der Burg et al., 2020). Policy support can create a favorable environment for green hydrogen by stimulating demand, reducing risks, and encouraging

investments. However, policy support alone is not sufficient to ensure the success of green hydrogen. It needs to be complemented by technological innovations that can enhance the efficiency, affordability, and accessibility of green hydrogen. Technological innovations are another crucial enabler for green hydrogen. Advances in technologies related to hydrogen production, storage, transportation, and end-use can render green hydrogen more competitive and attractive for cognitive cities (IEA, 2019). For instance, innovations in electrolysis can lower the cost and increase the reliability of green hydrogen production from renewable electricity. Innovations in storage and transportation can improve the safety and convenience of green hydrogen delivery. Innovations in end-use can expand the range and performance of green hydrogen applications in various sectors, such as mobility, industry, and buildings. The third enabler for green hydrogen is public acceptance. Raising awareness and acceptance of the benefits of green hydrogen can expedite its adoption. This necessitates the implementation of transparent communication, educational initiatives, and community engagement strategies (Linzenich et al., 2020). Public acceptance can foster trust and confidence in green hydrogen among various stakeholders, such as consumers, businesses, and policymakers. Public acceptance can also influence the social norms and values that shape the preferences and behaviors of cognitive city residents.

While there are several enablers for green hydrogen, there are also significant barriers that need to be overcome. One of the major barriers is economic cost. The high costs associated with green hydrogen production, storage, and distribution systems can be a significant deterrent. In addition, the relatively low efficiency of hydrogen energy systems, when compared to direct electricity usage, can pose a challenge (Schmidt et al., 2017). Economic cost can affect the profitability and viability of green hydrogen projects, as well as the affordability and attractiveness of green hydrogen products and services for cognitive city residents. Another barrier for green hydrogen is infrastructure requirements. The absence of robust hydrogen infrastructure – including production facilities, pipelines, and fueling stations which can hinder the integration of green hydrogen into cognitive cities (Eichman et al., 2020). Infrastructure requirements can entail high capital expenditures, long lead times, and complex coordination among multiple actors. Infrastructure requirements can also pose technical and logistical challenges for integrating green hydrogen into existing energy systems and networks. The final barrier for green hydrogen is regulatory hurdles. Existing regulations and standards may not be well-suited for green hydrogen applications, thereby necessitating revisions or further development (Smith et al., 2022). Regulatory hurdles can create uncertainty and inconsistency for green hydrogen producers and users, as well as potential legal and safety issues. Regulatory hurdles can also limit the interoperability and compatibility of green hydrogen systems across different regions and markets.

Overall, it is important to acknowledge that the integration of green hydrogen into cognitive cities is influenced by a number of factors that can enable or hinder its development and deployment. These factors include policy support, technological innovations, public acceptance, economic cost, infrastructure requirements, and regulatory hurdles. By understanding these factors, we can identify the opportunities and challenges for achieving a renewable hydrogen economy in cognitive cities.

D. Gaps in Existing Literature

A comprehensive review of the existing literature uncovers discernible gaps. This study endeavors to bridge these, thereby enriching our comprehension of green hydrogen's role within cognitive cities, specifically within Neom’s framework. These gaps are as follows:

- Context-Specific Understanding: Green hydrogen, a sustainable energy source, holds the potential to reduce greenhouse gas emissions and bolster energy security. However, existing literature often generalizes its production and deployment, largely neglecting the unique circumstances, resources, and demands of individual regions or

cities. Studies such as those by IRENA (2020a) and Batty et al. (2012) offer broad insights but overlook context-specific challenges and prospects. Despite growing interest in localized research, exemplified by Das et al. (2023), Li et al. (2023), and Buonomano et al. (2023), these investigations remain limited in scope. Recognizing this gap, our paper aims to conduct an in-depth, context-specific analysis of green hydrogen, highlighting the unique opportunities and challenges posed by different regions and cities, thus facilitating more effective integration of this promising technology.

- Interdisciplinary Approach: Prevailing literature predominantly handles green hydrogen, cognitive cities, and policymaking as discrete domains. Few studies adopt an interdisciplinary perspective encompassing the interaction and amalgamation between these sectors. For instance, the IEA (2019) report provides an exhaustive analysis of green hydrogen technologies but overlooks the potential support from cognitive city data and AI systems or policy measures. Similarly, Litvinenko et al. (2020) offer an in-depth assessment of regulatory barriers for green hydrogen, yet fail to explore overcoming these through cognitive city innovations or policy shifts.

- Evaluation of Policy Innovation Cycle: Despite acknowledging policy's crucial role in advancing green hydrogen, literature fails to thoroughly assess green hydrogen policies via the Policy Innovation Cycle lens. This dynamic model elucidates policy innovation through five stages: agenda setting, policy formulation, decision-making, implementation, and evaluation (Dincer and Acar, 2009). Such a framework can aid systematic study and improvement of green hydrogen policies in different contexts and stages.

- Cognitive Cities and Green Hydrogen Integration: Limited research explicitly investigates the integration of green hydrogen systems within cognitive city infrastructure and the associated opportunities and challenges (Bibri & Krogstie, 2017; Yigitcanlar, 2016). This integration necessitates addressing technical, economic, social, and environmental aspects of green hydrogen production, storage, transport, and usage within cognitive city systems and services.

Overall, by bridging these gaps, this study not only enhances the existing knowledge pool on green hydrogen, cognitive cities, and policymaking, but also provides practical insights to steer the implementation of green hydrogen systems in cognitive cities, such as Neom.

III. Theoretical Framework

The examination of green hydrogen's integration within cognitive cities calls for a theoretical framework that can grasp and reflect the multiple dimensions involved. The foundational pillars of our theoretical framework are rooted in three main constructs:

1. International Renewable Energy Agency (IRENA) Guide
2. Cognitive City Framework
3. Policy Innovation Cycle

These frameworks, while disparate in focus, coalesce to form a multi-pronged approach addressing distinct dimensions of the overarching research question. These framework will be discussed next.

A. The International Renewable Energy Agency (IRENA) Guide

The International Renewable Energy Agency (IRENA), a pivotal institution in the advancement of renewable energy, routinely produces detailed guides to aid nations in harnessing renewable energy technologies (IRENA, 2020). One seminal guide issued in 2020 by IRENA is titled "Green hydrogen: A guide to policy making." This document

serves as an elaborate blueprint for the inception and proliferation of green hydrogen(IRENA, 2020). In the context of Neom, a city that aspires to pioneer in renewable energy technologies, the guide could be an instrumental resource for the establishment and execution of green hydrogen policies (Balabel et al, 2023).

The guide proffers an exhaustive, structured methodology for delineating the potential of green hydrogen as a renewable energy source, as well as the challenges that might impede its development (IRENA, 2020). Commencing with an in-depth elaboration of the definition and salient characteristics of green hydrogen, including its production modalities, the guide goes on to sketch a global overview of the current status and trends of green hydrogen's evolution and deployment (Ceylan et al, 2023). Further, it evaluates the propelling factors and hindrances that influence the adoption of green hydrogen across varying sectors and regions, encompassing aspects such as costs, infrastructural considerations, regulatory practices, market structure, societal acceptance, and environmental ramifications (IRENA, 2020).

An inventory of policy tools and measures designed to catalyze and expedite the deployment of green hydrogen is also included in the guide. These encompass the setting of strategic objectives, formulation of standards, creation of incentive structures, provision of subsidies, imposition of taxes, regulation of the sector, and promotion of research, development, innovation, and international collaboration (IRENA, 2020).

Moreover, the guide presents a rich trove of successful practices and gleaned insights from extant green hydrogen policies and projects deployed worldwide. This evidence-based compendium offers a plethora of insights and pragmatic steps that could significantly influence the trajectory of green hydrogen in Neom. A distinctive feature of the guide is the introduction of policy toolboxes, designed to enable policymakers to customize their green hydrogen strategies in accordance with their specific contexts and objectives. For instance, the policy framework toolbox delineates the critical components of a green hydrogen policy framework, comprising vision, goals, targets, indicators, governance, stakeholder engagement, and monitoring (ibid).

The guide, underpinned by thorough research and data analysis, presents authoritative and dependable information on the development and deployment of green hydrogen. The guide's comprehensive, systematic, practical, and actionable methodology offers a lucid framework for policy examination and design. Nonetheless, the guide acknowledges its limitations(ibid). It eschews a monolithic approach and acknowledges that individual nations or regions possess unique contexts, requirements, and objectives for the development of green hydrogen. The guide also recognizes that the green hydrogen sector is replete with uncertainties and challenges such as data availability, technology maturity, cost reduction, market development, regulation, public awareness, and international cooperation (ibid).

This paper will complement the IRENA guide with the other two constructs of the theoretical framework: the Cognitive City Framework and the Policy Innovation Cycle. These constructs will provide additional perspectives and methods to understand and design a progressive regulatory framework for Neom’s green hydrogen ecosystem. The next sections will explain how these constructs can be integrated with the IRENA guide.

B. Cognitive City Framework

At the intersection of urban planning, information technology, and human cognition lies a novel conceptualization of cities: the Cognitive City (Batty et al., 2012). This term expands on the smart city concept by adding a cognitive dimension, suggesting not just a physical space enhanced by information and communication technologies (ICT), but also a city that constantly learns from and interacts with its citizens (Angelidou, 2014). This continuous dialogue, mediated by advanced ICT infrastructure, enables the city to evolve in efficiency, sustainability, and resilience (Bibri & Krogstie, 2017).

The Cognitive City Framework, as conceptualized by Batty et al. (2012), serves as a theoretical blueprint for such cities. The framework outlines the four integral layers of a cognitive city: physical, digital, social, and cognitive. These layers are interrelated, each contributing uniquely to the city's operations (Chamoso et al., 2018). The physical layer comprises tangible assets, such as buildings, roads, and basic infrastructure, which facilitate the city's functions (Neirotti et al., 2014). The digital layer includes the ICT infrastructure and applications that allow for the collection, processing, and exchange of data. This layer forms the backbone of a cognitive city, acting as the nexus for integration and communication (Finger, 2016). The social layer comprises the city's inhabitants, their interactions, and the cultural, normative, and behavioral framework they create (Batty et al., 2012). This layer forms the basis for community engagement and knowledge sharing, enabling the development of co-created solutions. Finally, the cognitive layer represents the knowledge and intelligence of the city, generated from the combination of data, information, and human cognition (Bibri & Krogstie, 2017).

The framework also outlines five key capabilities that distinguish cognitive cities: sensing, processing, learning, acting, and adapting. Sensing involves capturing data from various sources, and processing refers to transforming this data into information. Learning, the third capability, involves extracting insights from the processed information. Acting refers to decision-making based on these insights, while adapting involves implementing these decisions using feedback mechanisms(Batty et al., 2012).

Applied to the city of Neom and its green hydrogen vision, the Cognitive City Framework offers a systemic and holistic perspective. It provides a roadmap for leveraging the city's layers and capabilities to support the green hydrogen vision (Finger, 2016). The Framework poses pertinent questions for each layer. For the physical layer, these questions concern the infrastructure needed for green hydrogen production and how to ensure the safety and sustainability of these systems (Batty et al., 2012). For the digital layer, the questions revolve around the necessary ICT infrastructure and applications for monitoring and optimizing green hydrogen production. The social layer questions concern the human actors needed for a collaborative green hydrogen ecosystem and how to engage and empower these stakeholders. Finally, for the cognitive layer, questions concern the knowledge and intelligence required to guide green hydrogen policy-making and implementation (Chamoso et al., 2018).

The five key capabilities, as identified by the Framework, also invite critical questions about Neom's path toward its green hydrogen vision. These involve considerations about the type of data sources required, the methods for data transformation and analysis, the decision-making processes, and the means to implement and monitor these decisions. The Framework's multi-disciplinary approach, which integrates concepts from systems theory, complexity science, design thinking, urban planning, and social sciences, offers a rich perspective on the urban challenges associated with the green hydrogen sector (Neirotti et al., 2014). The model's flexibility and adaptability make it applicable to different scales, promoting stakeholder engagement and fostering innovation. However, the Cognitive City Framework is a descriptive, not prescriptive model. Its application poses logistical challenges due to its complexity and the sophistication required for data collection, analysis, synthesis, and communication. Furthermore, its dynamic nature necessitates continuous monitoring, evaluation, and feedback (Angelidou, 2014).

To mitigate these limitations, the paper integrates two other constructs with the Cognitive City Framework: the IRENA Guide and the Policy Innovation Cycle. These provide additional guidance to develop and implement a progressive regulatory framework for Neom's green hydrogen ecosystem. The constructs also offer innovative methods to facilitate the development of Neom's urban systems that are smart, sustainable, and resilient. The integration of the the Policy Innovation Cycle construct will be addressed in the next section.

C. The Policy Innovation Cycle

The Policy Innovation Cycle (PIC) represents an innovative methodology for generating, testing, and executing groundbreaking policy solutions aimed at tackling intricate, dynamic public sector issues (Howlett et al., 2015). It is founded on the belief that policymaking transcends linear or sequential procedures and instead encompasses an iterative, experimental journey that necessitates constant learning and adaptability to evolving contexts (Howlett, 2019). The PIC employs a diverse array of tools, techniques, and approaches from fields such as design thinking, behavioural insights, agile development, and prototyping (Bason, 2018).

This cycle is composed of four primary phases: discovery, design, delivery, and evaluation (McGann et al., 2018). The discovery phase signifies the stage at which the problem or opportunity is recognized and outlined, with contextual and stakeholder analysis taking place, evidence and data gathered and synthesized, and insights and opportunities generated (Howlett, 2019). The design phase involves ideating and prioritizing potential solutions, identifying and testing assumptions and risks, refining prototypes, and assimilating feedback (Lewis et al., 2018). The delivery phase encompasses the actual implementation and scaling of solutions, the coordination and mobilization of resources and partnerships, and planning and execution of communication and engagement strategies, while also monitoring and measuring outcomes and impacts (Bason, 2018). Lastly, the evaluation phase involves assessment and review of solutions, capturing and sharing of results and learnings, making necessary adjustments, and taking decisions on whether to continue, adapt, or cease the solution (Howlett et al., 2015).

Utilizing the PIC, Neom can devise, test, and implement innovative policy solutions for its green hydrogen ecosystem (McGann et al., 2018). This practical, flexible approach to policymaking is well-suited to manage the uncertainties and complexities associated with such an ambitious venture (Howlett, 2019). By addressing critical questions at every phase of the cycle, Neom can uncover the problems and opportunities associated with developing a progressive regulatory framework for its green hydrogen sector (Lewis et al., 2018). The process includes methodologies and sources for problem identification and definition, stakeholder and context analysis, understanding current scenarios and future trends through evidence and data, and generation of insights and opportunities for sector improvements(ibid).

At the design phase, Neom can strategize and develop solutions for its green hydrogen sector. Methods and tools for ideation and prioritization of solutions, identification and testing of assumptions and risks, development and refinement of prototypes, and collection and incorporation of stakeholder feedback can all be utilized (Howlett et al., 2015). During the delivery phase, strategies for the implementation and scale-up of chosen solutions, mobilization and coordination of partnerships and resources, planning of communication and engagement strategies, and monitoring and measurement of outcomes and impacts can be put into place (Howlett, 2019). The evaluation phase can assess and review the implemented solutions, capture and share results and learnings, make improvements and adjustments, and decide on the continuance, adaptation, or termination of implemented solutions (ibid).

By employing the PIC for the development of Neom’s green hydrogen ecosystem, the paper can leverage the advantages of this approach, such as its user-centric, problem-oriented approach that emphasizes understanding and meeting stakeholder needs. The iterative, experimental nature of the PIC promotes agile, adaptive policymaking that allows testing of various ideas and prototypes and adjusting to changing circumstances and feedback. It also fosters a more inclusive, innovative policymaking process due to its collaborative and co-creative approach, leveraging the collective intelligence and diversity of the green hydrogen sector.

Despite these advantages, the PIC's application in Neom's green hydrogen ecosystem also poses some limitations. Firstly, it does not guarantee the success or effectiveness of the policy solutions (Bason, 2018). While it increases the likelihood of better policy solutions, it does not eliminate the potential for failure or unintended consequences. Secondly, the PIC demands significant time, resources, and skills for implementation and requires strong trust, communication, and coordination among stakeholders (Howlett et al., 2015). Lastly, it is not a one-size-fits-all methodology and needs customization and adaptation to specific problems, contexts, and objectives of the policymaking process.

D. Integrating the Constructs of the Theoretical Framework

This paper strategically integrates three foundational constructs: the International Renewable Energy Agency (IRENA) Guide, the Cognitive City Framework, and the Policy Innovation Cycle. Each is adaptively employed for the formulation of an encompassing policy blueprint for the advancement of Neom's green hydrogen development as follows:

IRENA Guide: This guide serves as the primary navigational instrument for policy formulation, providing a systematic and in-depth framework to understand and address the drivers and barriers of green hydrogen uptake across multiple sectors and regions. The paper draws upon the case studies within the guide as heuristic models, but avoids a mere replication of these strategies. Instead, the focus is on the careful adaptation of these models to suit Neom's unique sociopolitical and cultural context.

Cognitive City Framework: As a heuristic tool for understanding and designing sustainable and resilient urban systems, this framework is employed to provide a multi-layered analysis of Neom. The objective is to extend beyond technocentric viewpoints to holistically integrate the city's cultural, social, and political dynamics into the green hydrogen policy. Therefore, the measure of Neom's progression as a cognitive city incorporates not just technological advancements, but also sociocultural realities and region-specific factors.

Policy Innovation Cycle: The Policy Innovation Cycle serves as a methodological guide for policy formulation and implementation. This approach provides an iterative, adaptable process for policymaking, drawing on varied techniques from fields such as design thinking, behavioural insights, agile development, and prototyping. However, its application is sensitive to Neom's unique legal, regulatory, and ethical context to ensure the viability and relevance of the resulting policies.

The paper strives for an integrative approach that allows for flexibility and adaptability. Policy creation is recognised as a dynamic process, with stages from opportunity identification to policy implementation potentially requiring iterative revisions. The paper constructs a regulatory framework that strikes a balance between innovation and practicality, rooted firmly within the realities of Neom's green hydrogen sector. The proposed approach allows for comprehensive integration of the IRENA Guide, Cognitive City Framework, and Policy Innovation Cycle while remaining agile enough to accommodate the evolving nature of policy-making.

IV. Neom's Green Hydrogen Vision

Neom, a high-tech, futuristic city in Saudi Arabia, ambitiously envisions to be powered 100% by renewable energy and become a globally recognized hub for innovation and sustainability. As part of this plan, Neom is dedicated to becoming a leader in green hydrogen production. This ambition is more than mere rhetoric, with several critical partnerships and initiatives already underway.

A. Neom’s Vision and Plan for Green Hydrogen Production

Central to Neom's strategy is a unique partnership with ACWA Power and Air Products, forming the Neom Green Hydrogen Company (NGHC). This equal joint venture aims to construct the world’s largest green hydrogen plant. The plant, set to be operational by 2026, aims to produce green ammonia at scale, contributing significantly to Neom's renewable energy matrix (Al-Maamary et al., 2017).

The planned NGHC plant represents a new wave of renewable energy innovation. Powered by up to 4GW of solar and wind energy, it aims to produce 600 tonnes of carbon-free hydrogen per day. This prodigious output equates to an annual saving of 5 million tonnes of CO2 emissions (Neom Company, 2021). Financial backing for this initiative is robust, with a total investment value of USD 8.4 billion, including USD 6.1 billion in non-recourse financing from 23 regional, international banks, and financial institutions. Further bolstering the project's economic viability is an exclusive 30-year off-take agreement with Air Products for all the green ammonia produced at the facility (Balabel et al, 2023).

Beyond the economic and environmental aspects, Neom's vision for green hydrogen will significantly impact the global hydrogen market and Saudi Arabia's energy export dynamics (Borett, 2023). The project, when fully realized, will redefine Saudi Arabia's energy landscape, transforming it from a global petroleum leader to a pioneer in green energy, and contribute to global carbon emission reduction goals.

B. Analyzing the Current Scenario and Challenges in the Absence of Green Hydrogen Policies

Despite the immense potential, the development and widespread adoption of green hydrogen face several challenges, primarily due to the absence of robust green hydrogen policies (Borett, 2023). Green hydrogen, as an energy source, finds applications in numerous sectors, including transportation, power plants, and various manufacturing industries like steel, cement, and fertilizer production (Nayak-Luke et al., 2020). It plays a pivotal role in enabling the circular carbon economy, a concept aiming to reduce, reuse, recycle, and remove carbon emissions (Mohamed et al., 2022).

However, several hurdles need to be addressed for the successful deployment and adoption of green hydrogen are as follows:

- High costs: Electrolysis, the process of splitting water into hydrogen and oxygen using electricity from renewable sources, remains an expensive operation. The high costs currently associated with green hydrogen production are a major deterrent to its widespread adoption (Sarkar & Banerjee, 2019).

- Infrastructure: Currently, there is a lack of dedicated pipelines, storage facilities, and refueling stations for transporting and distributing hydrogen across regions and markets (Welder et al., 2021).

- Regulation: The absence of clear and consistent policies, standards, and incentives poses a significant challenge for the development and deployment of green hydrogen projects and technologies (IRENA, 2020).

- Public awareness: There is a relatively low public awareness and acceptance of hydrogen as a clean and safe energy source, especially compared to other alternatives such as batteries and biofuels (Upham et al., 2022).

C. Opportunities for Policy Development in Neom

Neom is uniquely positioned to overcome these challenges and become a leader in green hydrogen production and utilization(AbdelMeguid et al., 2023). Its ambition does not stop there; it also aims to be a catalyst for policy development in the region and beyond.

There are several opportunities for policy development that Neom can explore (Boretti et al , 2022):

- Natural Resources: Neom's abundant solar and wind energy can be harnessed to produce green hydrogen at competitive costs and scale.
- Infrastructure: Neom can create dedicated infrastructure for green hydrogen, including pipelines, storage facilities, and refueling stations. This infrastructure can facilitate hydrogen distribution within Neom and export to other markets such as Japan and Europe.
- Policies and Incentives: Neom has the opportunity to establish policies, standards, and incentives supporting the growth and innovation of green hydrogen projects and technologies. These policies can also attract investments and partnerships from local and international stakeholders.
- Use Cases and Public Engagement: Neom can showcase green hydrogen's practical applications in various sectors such as transportation, industry, power generation, and agriculture. This can not only validate the effectiveness of green hydrogen but also educate and engage the public about the benefits and safety of hydrogen energy.

Through these initiatives, Neom's vision for green hydrogen not only serves its own developmental interests but also can provide a blueprint for other regions and countries to follow in their green hydrogen journey. By addressing the challenges and seizing the opportunities for green hydrogen production and use, Neom can become both a role model and a catalyst for green hydrogen development globally.

D. Cultural and Economic Influences on Policy Formulation in Neom

As Neom positions itself as a green hydrogen hub, it must consider the cultural and economic factors influencing the formation and execution of its green hydrogen policies (Aldusari, 2023):

- Cultural Influences: Green hydrogen, being a relatively new concept, may find varying degrees of acceptance, especially in regions where fossil fuels are predominant. The social and cultural acceptance of green hydrogen as a new energy medium is pivotal for its successful integration (Farag, 2019). Understanding and acknowledging the cultural dynamics are crucial as they may significantly influence the public's perception and acceptance of green hydrogen technologies. Factors such as the potential impacts on local communities and stakeholders, the aesthetics of the facilities, and the alignment with cultural and religious values are just a few examples of how cultural influences may play a vital role in the broader acceptance and success of green hydrogen projects (Gordon et al, 2022).
- Economic Influences: The economic landscape is equally critical in the context of green hydrogen. Currently, the cost dynamics of green hydrogen, attributed to the high costs of renewable electricity, electrolyzers, and infrastructure, pose a challenge when compared to conventional hydrogen or fossil fuels (Cader et al, 2021). The economic feasibility, viability, and competitiveness of green hydrogen production are essential considerations for its market development and expansion. Additionally, the economic influences extend to the value proposition of green hydrogen, encompassing aspects such as job creation, value addition opportunities, and alignment with broader national and regional development goals and strategies. The economic narrative around green hydrogen can significantly impact the perceptions and decisions of potential investors, developers, and end-users (Scita, 2020).

Overall, Green hydrogen holds the potential to aid in the global energy transition. Yet, it is not without challenges that need coordinated policy interventions. As nations devise strategies to promote green hydrogen, Neom can learn from these practices and adapt

them to its specific needs and aspirations. However, Neom must also account for the cultural and economic factors that may affect the implementation of its green hydrogen policies. By doing so, Neom can create a comprehensive and robust green hydrogen strategy, reinforcing its potential as a global green hydrogen production and export hub.

V. Recommendations for a Progressive Regulatory Framework in Neom

A. Recommendations based on the Theoretical framework

Grounded in the theoretical framework discussed earlier, we propose a series of recommendations for establishing a progressive regulatory framework in Neom. The following recommendations leverage the intersectionality of the International Renewable Energy Agency (IRENA) Guide, the Cognitive City Framework, and the Policy Innovation Cycle, underpinning a cohesive, ambitious, and viable green hydrogen strategy.

- Adoption of an IRENA-Inspired Policy Guide: Neom should design its regulatory framework influenced by IRENA's holistic approach, integrating economic, technical, and policy dimensions. A shift towards green hydrogen necessitates a blend of market incentives, regulatory measures, and technical standards that collectively foster the establishment and operation of green hydrogen facilities (IRENA, 2020). Policymakers must implement strategic tax incentives, subsidies, and grants to stimulate green hydrogen production and consumption. Simultaneously, the formulation of stringent environmental and safety standards is vital to ensure responsible and sustainable green hydrogen practices.

While the IRENA framework provides a comprehensive guide for establishing green hydrogen initiatives, it is essential to acknowledge potential challenges. Neom will need to harmonize its policies with international norms, standards, and best practices, considering the global nature of environmental concerns and the green hydrogen market. This calls for active participation in international discussions and forums concerning green hydrogen policy and regulation. Additionally, Neom should proactively seek partnerships and alliances with other countries and regions to ensure alignment and compatibility of its green hydrogen policies, especially concerning trade, investment, and environmental standards.

- Leveraging the Cognitive City Framework for Data-Driven Policy: In keeping with the Cognitive City Framework, Neom should leverage its cutting-edge technology and data-driven approach in policy formulation and implementation. Policies must be data-informed, utilizing advanced analytics to guide decisions on green hydrogen integration (Kumar and Jaiswal, 2022). Establishing a real-time monitoring system, for instance, can enable ongoing evaluation of green hydrogen initiatives and policies, facilitating adjustments as necessary. Moreover, AI could be leveraged to predict the impact of green hydrogen integration on Neom's energy matrix, informing policies on infrastructure development, capacity building, and public engagement (Stübinger and Schneider, 2020).

As Neom leverages data for informed policymaking, it must address ethical and social issues, including data privacy, security, and ownership. This means implementing robust data governance measures that guarantee transparency, accountability, and respect for citizens' rights and interests. There should be clear policies on data collection, storage, sharing, and usage, with stringent safeguards to prevent unauthorized access or misuse. Citizens should also be involved in decision-making processes related to data policy, ensuring their concerns and perspectives are adequately taken into account.

- Policy Innovation Cycle for Continuous Improvement: The Policy Innovation Cycle can guide Neom in crafting and iterating its regulatory framework. Policymaking

should not be static; it must be receptive to feedback and able to evolve in response to new evidence, technology, and stakeholder input (Dincer and Acar, 2017). Neom must establish a mechanism for consistent policy evaluation, innovation, and refinement, thus facilitating the creation of a dynamic regulatory environment that keeps pace with the rapidly evolving green hydrogen sector.

While the Policy Innovation Cycle emphasizes the need for constant evolution and adaptation, it is crucial to recognize the associated costs and risks. Policy uncertainty can deter investment and disrupt long-term planning, hindering the development of the green hydrogen sector (Correia et al, 2021). To balance innovation and stability, Neom should establish a predictable policy pathway that outlines the long-term vision, strategic priorities, and milestones for green hydrogen development. Policy adjustments and refinements should be evidence-based, consultative, and communicated in a timely manner to all stakeholders. This approach will provide a stable and reliable environment for green hydrogen initiatives while allowing for necessary adaptations and improvements.

B. Recommendations Based on the Global Best Practices

In the endeavor to construct a progressive regulatory framework in Neom, it is invaluable to reflect upon and learn from global best practices. Due to the nascent yet transformative nature of the green hydrogen economy, gleaning insights from the experiences and strategies of leading nations in this sector is instrumental. We will dissect the distinctive yet successful strategies employed by the European Union (EU), Australia, and Japan in bolstering their green hydrogen economies, and how Neom can adapt these strategies to suit its unique scenario. We will also address potential challenges or risks that might arise.

- Adopting the Collaborative Approach of the EU’s Green Hydrogen Strategy: The EU, through its robust emphasis on collaboration among varied stakeholders, has successfully shaped its green hydrogen policy (Koneczna and Cader, 2021). Neom can operationalize this approach by instituting mechanisms like regular stakeholder consultations, public hearings, and online platforms for open feedback. Ensuring that the voices of marginalized or underrepresented groups are heard is crucial; this can be achieved by setting up dedicated representation quotas or channels for these groups in policy-making, and by creating local advisory groups at the community level (Kakoulaki et al, 2021).

- Leveraging the Strategic Focus of Australia's National Hydrogen Strategy: Australia's national hydrogen strategy is an example of a roadmap that strategically expands the hydrogen economy, focusing on both domestic use and export potential (Wood, 2019). Neom can balance its domestic consumption and export-oriented goals by adopting a phased approach - initially focusing on domestic demands and gradually scaling up for exports. Regarding geopolitical implications, diplomacy and international partnerships are key (Rowell et al, 2022). For environmental implications, it is essential to carry out stringent environmental impact assessments for each hydrogen project and ensure compliance with international environmental standards (Hartley, 2022).

- Incorporating the Regulatory Harmonization Principle from Japan's Basic Hydrogen Strategy: Japan's hydrogen strategy emphasizes aligning its hydrogen regulations with international norms, thereby facilitating trade and technology exchange (Nagashima, 2018). While striving for such alignment, Neom must also maintain its sovereignty and autonomy. 'Selective harmonization', where global standards are adhered to when beneficial and viable, could help manage this delicate balance. To deal with potential uncertainties in the global green hydrogen landscape, a dedicated regulatory body could monitor global trends and suggest necessary amendments to the national regulatory framework (Cheng and Lee, 2022).

The extraction of insights from these global best practices can offer valuable guidance for Neom as it seeks to develop a progressive regulatory framework for its green hydrogen economy. It's paramount to remember that these strategies must be custom-fitted to Neom's unique context and goals. The process of adaption and innovation will underpin Neom's success in this burgeoning frontier of sustainable energy.

C. Recommendations Considering Neom’s Unique Cultural and Economic Context

In crafting a progressive regulatory framework for the green hydrogen economy in Neom, it is essential not only to learn from international best practices but also to take into account the region's unique cultural and economic context. Only with a comprehensive understanding of this context can we propose a framework that aligns with Neom's societal values, economic aspirations, and developmental trajectory. In the following sections, several recommendations tailored to Neom's unique context will be presented.

- Promoting Cultural Acceptance of New Technologies: Historically, the introduction of new technologies can be met with resistance or apprehension, particularly when they might disrupt established ways of life (Häubermann et al, 2023). Hence, ensuring cultural acceptance of green hydrogen technologies in Neom is paramount. This could be achieved through targeted education and awareness campaigns that emphasize the societal and environmental benefits of green hydrogen. Additionally, integrating traditional cultural elements with new technology, such as designing hydrogen fuel stations that reflect local architectural styles which can help cultivate acceptance(Galich and Marz, 2012).

- Harnessing the Youth Demographic: Saudi Arabia has a youthful population, with over half under the age of 25 (Cheng, 2022). This represents a considerable asset that Neom can harness to drive its green hydrogen economy. Tailoring educational curricula to include subjects on sustainable energy technologies can inspire interest and pave the way for future green hydrogen professionals. Moreover, policy initiatives can be introduced to incentivize startups and entrepreneurship in the green hydrogen sector, empowering the young population to become pioneers of this new economy.

- Building on Existing Economic Strengths: Saudi Arabia is globally recognized for its petroleum industry. Transferring skills and knowledge from this sector to the green hydrogen economy can be beneficial (ILO, 2021). Training programs can be established to re-skill and up-skill existing energy sector workers, enabling them to transition to green hydrogen jobs. Meanwhile, taking advantage of the existing infrastructure, logistical capabilities, and export relations developed through the petroleum sector can help boost the green hydrogen economy.

- Capitalizing on the Geographical Advantage: Neom's location along the Red Sea provides an excellent opportunity for developing maritime transport powered by green hydrogen (Smith et al., 2020). Regulatory incentives can be put in place to encourage the development and adoption of hydrogen-fueled shipping. Furthermore, given its ample solar resources, policies can be drafted to support the use of solar power for hydrogen production.

- Balancing Progress with Environmental Preservation: Neom is envisaged as a city co-existing with nature. The regulatory framework should include stringent environmental protection and biodiversity conservation measures. Regular environmental impact assessments and strict compliance with these assessments should be mandated for all hydrogen projects (Razi and Dincer, 2022). Overall, the regulatory framework for Neom's green hydrogen economy should be intricately woven with the cultural and economic fabric of the region. The framework should not only guide the development of the hydrogen economy but also be reflective of Neom's unique characteristics and aspirations.

VI. Impact of the Proposed Regulatory Framework on Green Hydrogen Innovation in Neom

The proposed regulatory framework for green hydrogen in Neom seeks to foster innovation and sustainability in the green hydrogen economy. This section will address the anticipated impact of the framework on three key aspects: green hydrogen production, innovation within the green hydrogen ecosystem, and Neom's sustainability objectives.

- Facilitating Scale-Up: The regulatory approach that builds upon international best practices is anticipated to foster an environment conducive to the scale-up of green hydrogen production (Odenweller at al,2022). By modeling the EU's collaborative approach, the policy structure could stimulate collective action, accelerating production (Derks at al, 2022). Nevertheless, implementation might face challenges such as coordination complexities and stakeholder consensus-building.

- Capitalizing on Solar Potential: Neom's abundant solar resources provide a unique advantage for green hydrogen production. Policies encouraging solar utilization could significantly augment production, yet ensuring constant supply given solar power's intermittent nature poses a potential challenge (Alkeaid., 2018).

- Encouraging Technological Advancements: The regulatory framework is expected to stimulate research and development, resulting in new technological solutions within the ecosystem (Kovač et al, 2021). A policy innovation cycle, as proposed, could promote a culture of continuous improvement. However, this must be weighed against potential costs, including policy instability and financial risks.

- Fostering Entrepreneurial Activity: The proposed framework also aims to encourage startups and entrepreneurship in the green hydrogen sector. This incentive could lead to innovative business models and solutions, although the high-risk nature of startup ventures could necessitate robust support systems and risk mitigation strategies (Fernández-González et al, 2022).

- Promotion of Clean Energy: A regulatory focus on green hydrogen could contribute significantly to Neom's vision of sustainability. As Neom aims for carbon neutrality, the transition to a hydrogen-based energy system could align with global sustainability standards (Balabel et al, 2023). Nevertheless, the transition needs to be carefully managed to ensure energy security during the transition period.

- Balancing Development and Conservation: Emphasizing environmental impact assessments and conservation in the proposed framework ensures that progress does not compromise Neom's natural environment. This would help meet sustainability goals while maintaining ecological balance. However, rigorous assessments may slow down development, necessitating a careful balance between preservation and progression (Alkeaid, 2018).

Overall, the proposed regulatory framework, though promising, is not without potential hurdles. It can indeed catalyze the green hydrogen economy in Neom and make Neom a global leader in green hydrogen production and innovation, yet the challenges along the path should not be overlooked. Future research might further explore strategies to overcome these potential barriers to fully reap the benefits of this regulatory framework.

VII. Conclusions

This research critically analyses the role of regulatory policies in the green hydrogen sector, with a particular focus on the implications for Neom - a visionary city that aims to redefine the intersection of technology, ecology, and urban design. The analysis has generated a set of key recommendations, informed by international best practices and judiciously adapted to accommodate Neom's distinctive cultural, economic, and

geographical characteristics. These include the adoption of an IRENA-inspired policy guide, the application of the Cognitive City Framework for data-driven policy development, and the establishment of a Policy Innovation Cycle that fosters continuous learning and improvement.

This scholarly endeavor has significant implications, both theoretically and practically, as it contributes to the academic literature on regulatory practices in green hydrogen and provides actionable insights for policy makers and practitioners in Neom. With the proposed regulatory framework, Neom could potentially spearhead the green hydrogen revolution, resulting in enhanced hydrogen production, an innovation boom in the sector, and substantial progress towards the ambitious sustainability goals. However, the paper also recognizes the challenges that lie ahead. The practical execution of the proposed regulatory framework will require careful consideration of various stakeholder interests, ethical issues surrounding data usage, and a delicate trade-off between policy stability and evolution.

This analysis opens up new avenues for future research. Potential areas of inquiry could include empirical evaluations of the theoretical framework, comparative analyses of Neom's experiences vis-a-vis other cities venturing into green hydrogen, socio-cultural studies arising from the application of our framework, and a commitment to ongoing assessment and refinement of the enacted policies. In conclusion, this paper provides a roadmap for Neom's green hydrogen revolution. The proposed progressive regulatory framework, grounded in an examination of global best practices and attuned to local realities, promises to bridge this gap. The paper aims not only to enrich the academic discourse on regulatory practices in green hydrogen but also to influence the tangible policies that will shape a sustainable future. It is evident that the pathway to harnessing the full potential of green hydrogen is marked by continuous learning, adaptation, and thoughtful policy creation - a journey towards a greener and cleaner future.

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