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Decarbonizing the Built Environment via Green Hydrogen Technologies: A New Zealand Study

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Abstract: **Decarbonizing the building sector is critical for countries like New Zealand seeking to meet ambitious climate goals and transition towards sustainable energy systems. Green hydrogen presents a compelling yet under-explored opportunity as a versatile energy carrier that can provide emissions-free heat, power and storage to displace fossil fuel usage in buildings. This study addresses key knowledge gaps by investigating the potential of green hydrogen technologies to enable low-carbon built environments in the New Zealand context. Expert interviews and literature synthesis develop technical, economic and policy considerations for deployment across residential, commercial and public buildings. The research aims to guide safe, strategic implementation of hydrogen systems by providing evidence-based insights for government, industry and research communities. The authors contend that with appropriate planning and stakeholder engagement, green hydrogen may help pave the pathway to net-zero buildings and a sustainable New Zealand.**

Keywords: Decarbonization, Built Environment, Green and Low-Carbon Hydrogen, Hydrogen Technologies.

1. INTRODUCTION

With the building sector accounting for over 20% of New Zealand's greenhouse gas emissions, decarbonizing buildings is pivotal for meeting the country's net zero carbon target by 2050 [1], [2], [3], [29]. Globally too, the need to transition buildings away from fossil fuel reliance towards sustainable energy alternatives aligns with ambitious climate goals like the Paris Agreement [4], [5].

Renewable electricity faces significant challenges. Intermittency and grid capacity constraints principle amongst these. Electrification of heat using resistance heating has high operational costs [22], [23]. Green hydrogen presents a promising but under-explored opportunity as a versatile energy carrier that can provide emissions-free heat, power and energy storage [6]. Produced via electrolysis from renewable electricity, green hydrogen can displace natural gas usage in buildings for thermal needs and generate electricity through fuel cells [7].

However, research focused specifically on green hydrogen systems for built environment decarbonization in the New Zealand context remains limited. This knowledge gap needs to be addressed to uncover pathways for successful deployment across residential, commercial and public buildings.

This study aims to guide strategic implementation by examining technical, economic and policy considerations through an interdisciplinary lens. The insights generated can shape safety regulations, incentives, infrastructure and practices to leverage hydrogen's potential, contributing to sustainable low-carbon built environments.

1.1 Background

New Zealand has set a target for 100% renewable electricity by 2035 alongside economy-wide carbon neutrality by 2050 [1]. Hydrogen adoption has focused predominantly on the transportation and industrial sectors thus far. However, the building sector consumes over 50% of the country's energy and contributes significantly to emissions from fossil fuel usage [2]. To meet climate goals, greater emphasis on sustainable energy solutions for low-carbon buildings is imperative.

New Zealand's substantial renewable resources provide an opportunity to produce green hydrogen via electrolysis and displace natural gas usage [7]. However, research has not yet explored nuances specific to hydrogen deployment across residential, commercial and public buildings. This study aims to address this critical knowledge gap.

The subsequent sections present the study's objectives, significance, limitations and projected timeline. The literature review will establish the theoretical foundations while subsequent chapters will discuss primary data collection and analysis. By investigating green hydrogen's potential to enable building decarbonization in the New Zealand context, this research ultimately seeks to uncover pragmatic pathways towards net-zero built environments.

2. LITERATURE REVIEW

This paper seeks to present a comprehensive literature review, aiming to explore the critical themes of energy, population growth, and sustainability, with a specific emphasis on the context of New Zealand. The review establishes a strong interdependence between population growth, escalating energy demand, and the subsequent environmental impacts, largely driven by increased reliance on fossil fuels. It underscores the urgent need to transition towards renewable energy sources, particularly green hydrogen, to meet the increasing energy demand while mitigating emissions. The literature review also highlights the lack of a regulatory framework in New Zealand as a critical challenge in the transition towards sustainable energy solutions.

2.1 Green Hydrogen Technologies for Building Applications

Green hydrogen, a versatile energy carrier, can be produced at both low and high temperatures [8]. Notably, when produced at high temperatures, the waste heat energy released by the electrolyser can be harnessed for heating applications, making it an efficient dual-energy provider, offering both electricity and heat. This capability has significant implications, particularly in the context of buildings during cold seasons. Hydrogen applied for heating purposes has the potential to alleviate the electrical burden on infrastructure during wintertime, effectively becoming a winter energy vector [9].

Knosala's research extends to the analysis of hydrogen technologies for self-sufficient homes, where hybrid systems play a pivotal role. These systems have the potential to achieve energy autonomy and high energy efficiency by simultaneously supplying electricity and heat, as opposed to relying solely on electricity from centralized grids. According to Knosala's estimations, such hybrid systems could reduce the total annual energy cost by up to 80%, aligning with one of the New Zealand Government's core objectives, namely, energy affordability [9].

However, it is crucial to note that research in this area is still in its infancy, primarily due to the limited production of hydrogen in large quantities. More comprehensive investigations are required to understand and optimize the performance of hydrogen technologies for building applications [10]. This underscores the importance of addressing this knowledge gap to unlock the full potential of green hydrogen in decarbonizing the built environment.

2.2 The Need for a Strategic Framework

Hydrogen's implication in the built environment is in its early stages, and scepticism may prevail regarding the commercial viability of hydrogen technologies compared to conventional solutions [24], [25], [26]. However, climate goals necessitate rapid decarbonization across all sectors including buildings [27], [28], [30], [31]. To truly accelerate the transition to the Hydrogen Era, there is a critical need to establish a strategic framework and adopt a holistic systems approach [11]. Such an overarching framework would provide the necessary guidance and structure to systematically address the technical, economic, social, and policy dimensions required to enable the successful integration of hydrogen technologies into the built environment, ultimately contributing to sustainable, low-carbon building practices [32], [33]. Strategic priorities include optimizing renewable hydrogen production pathways, facilitating robust demonstration projects in real-world buildings, devising appropriate safety protocols and training programs, shaping financing mechanisms and policy incentives to improve economic competitiveness, and fostering public awareness and social acceptance [34], [35], [36], [37], [38], [39], [40].

Adopting such a comprehensive framework can ultimately provide the foundation to accelerate the transition and realize hydrogen's extensive potential to contribute to sustainable, low-carbon, resilient building practices and communities across residential, commercial, and industrial spaces.

2.3 Population Growth and Energy Demand

Population growth is a significant contributing factor to residential energy consumption, and this steady trend suggests that energy demand will increase in proportion to the population's growth [12]. Projections based on New Zealand's population dynamics, correlated with electricity consumption, imply a linear energy consumption model for long-term energy demand forecasts [13]. This perpetual population growth leads to increased energy consumption, creating environmental challenges [14]. The interdependence between population, energy, and economic growth unfortunately results in environmental degradation, an upsurge in fossil fuel consumption, and elevated carbon dioxide emissions [15]. Notably, emissions from the energy sector have surged from 23.9 million tonnes in 1990 to 31.5 million tonnes of carbon dioxide equivalent in 2020 [3]. This trend illustrates the cyclical pattern of environmental degradation stemming from population and economic growth, augmented energy consumption, fossil fuel reliance, and CO2 emissions.

Khan highlights the necessity of controlling the ecological footprint, especially since controlling population growth is a complex challenge. Effective government policies, a transition to renewable energy sources, and an emphasis on energy efficiency in the short term can curtail this ecological footprint. This, in turn, can enhance the environment and improve the overall quality of life in the long term [16].

In contrast, Yunez-Cano suggests that a transition to renewable energy, particularly hydrogen, can contribute significantly to reducing fossil fuel dependency and pollution emissions, offering a potential reversal of the ongoing upward trajectory. The interdependence between population, energy, and economic growth may continue to rise, but a transition to renewable energy sources can mitigate fossil fuel consumption and pollution emissions [17].

It is estimated that if the growing population continues to rely on fossil fuels to meet energy demands, it will contribute to a continuous increase in global temperatures. However, the replacement of fossil fuels with green hydrogen could potentially stabilize this upward trend, offering hope for a more sustainable future [18]. This highlights the critical role that hydrogen technologies can play in reshaping the trajectory of environmental impact associated with population and energy growth.

2.4 Green Hydrogen in the New Zealand Context

The literature review emphasizes the potential for green hydrogen in New Zealand, highlighting its role as an ideal energy carrier capable of providing sustainable heat, power, and storage to decarbonize the energy sector. While cost, safety concerns, and the lack of practical demonstrations pose barriers, the development of strategic roadmaps, regulatory frameworks, and tailored systems can facilitate the adoption of green hydrogen across residential, commercial, and public buildings. Knosala and Ghenai & Bettayeb underscore the necessity for tailored systems designed specifically for the New Zealand context to reveal their viability and environmental benefits, which can shape supportive policies [9], [19].

2.5 Energy Affordability and Fuel Poverty

The literature review also addresses broader considerations, such as energy affordability and fuel poverty in New Zealand, underscoring the need for energy solutions that enhance access to secure, sustainable, and affordable energy services [41]. The discussion highlights New Zealand's pursuit of energy efficiency while ensuring energy security, affordability, and sustainability [42]. In the late 20th century, the country enjoyed relatively low gas and electricity tariffs. However, electricity costs have increased significantly, particularly impacting households during cold winters. The COVID-19 pandemic heightened residential energy consumption, affecting financially strained individuals. "Fuel poverty" affected 25% of households in 2012 due to inadequate heating and insulation. This issue results in higher mortality rates during the cold season [43], [44]. Families spending over 10% of their income on electricity are considered in "fuel poverty" [41]. The government's Aotearoa New Zealand Energy Strategy strives to balance energy security, affordability, and sustainability. The versatility of hydrogen can address these challenges while catalysing the transition to low carbon built environments.

2.6 Significance of the Research

In summary, this comprehensive literature review provides a robust foundation for understanding the interconnectedness between population growth, escalating energy demand, and environmental impacts, particularly within the context of New Zealand. It highlights the urgency of transitioning towards renewable energy sources, with green hydrogen emerging as a promising solution. Importantly, the review identifies the lack of a regulatory framework in New Zealand as a critical challenge in the transition towards sustainable energy solutions.

This research carries significant implications for policymakers, industry stakeholders, and researchers. By recognizing the potential of green hydrogen technologies in decarbonizing the built environment, this research can inform the development of regulatory frameworks tailored to New Zealand's unique energy landscape. Furthermore, this work can contribute to the creation of policies, incentives, and infrastructure that will facilitate the widespread adoption of green hydrogen. The transition to sustainable, low carbon built environments can enhance energy affordability, address fuel poverty, create economic opportunities, reduce emissions, and catalyse the achievement of environmental sustainability.

3. PHILOSOPHY OF THIS RESEARCH

This research is grounded in a post-positivist philosophy, recognizing that many of the challenges society faces today, such as climate change and environmental degradation, stem from human activities and technological advancements. This philosophy of technology intersects with environmental philosophy, highlighting the role of human values and interests in shaping technologies [21].

As Poel suggests, technologies are products of human choices and can lead to either techno-pessimistic or techno-optimistic impacts on society. This aligns with a constructivist approach, where humans play a central role in shaping new technologies to address environmental concerns.

Consumerism and human actions have contributed to environmental degradation, pollution, and climate change. To mitigate these issues and achieve decarbonization and sustainability goals, aligning technological innovations with revised values and environmental ethics is essential [21].

Introduction of new technologies can create new realities and moral challenges, necessitating a review of existing moral values, obligations, and standards. In essence, the cause-and-effect relationships in this research are closely linked to environmental philosophy and ethics. For example:

- Population growth (cause) leads to increased energy demand (effect).
- Increased energy demand (cause) results in higher fossil fuel consumption (effect) and fuel poverty (effect).
- Fuel poverty (cause) leads to health deterioration and reduced productivity (effect).
- Increased fossil fuel consumption (cause) contributes to environmental degradation (effect).

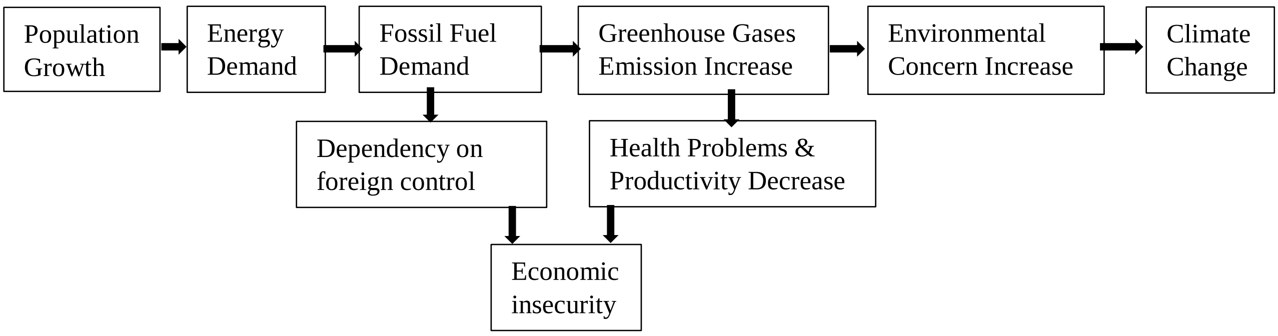

Figure 1: Relationships of variables based on the analysis of the current situation

To address these issues, the research proposes a set of hypotheses suggesting that a shift towards sustainable energy sources like green hydrogen and hydrogen technologies can lead to a decrease in environmental concern.

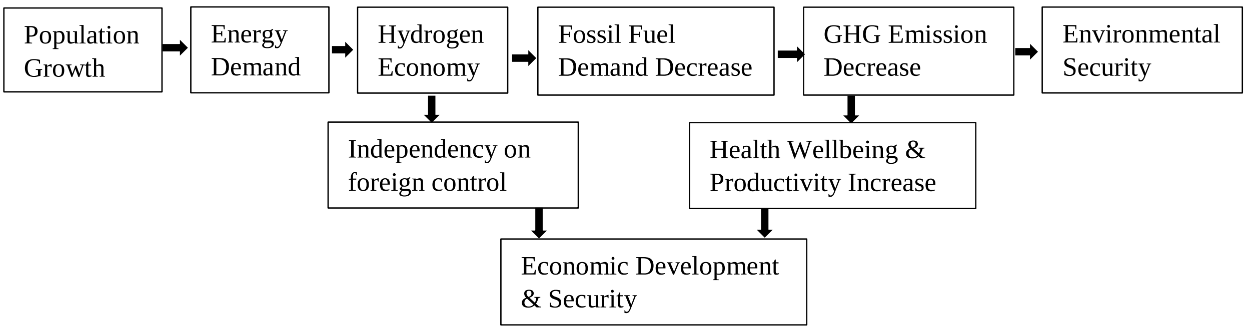

Figure 2: Relationships of variables based on the proposed hypotheses

The intricate relationship between population growth, energy consumption, and their impact on the environment is central to this research. High fertility rates and improved health contribute to population growth, which can be seen as an investment in human capital. However, the environmental consequences of increased energy production and consumption can have a negative effect on natural resources and the environment.

Environmental degradation caused by climate change, in turn, has implications for health, socio-economic situations, and political dynamics. The question of controlling population growth is complex, raising moral and ethical dilemmas. Environmental ethics emphasizes human obligations to protect and preserve the environment, underscoring the interconnectedness of human actions and the natural world.

In this study, environmental ethics focuses on human responsibilities and moral duties towards nature, challenging anthropocentric views. Nonanthropocentrists criticize consumerism as ecologically destructive and advocate reconnecting with nature for sustainability. Environmental philosophy, a discipline within this field, emphasizes human obligations to treat the environment as they treat themselves, aligning with Māori values for nature protection. Māori's strong connection with the land reflects their concern for the environment, emphasizing the parallel between a healthy environment and human spiritual welfare [65], [66], [67], [68].

In conclusion, the philosophical underpinnings of this research emphasize the imperative of integrating environmental ethics and philosophical considerations into the study of green hydrogen and its potential to address environmental challenges.

This philosophical framework provides a solid foundation for the subsequent exploration of findings and the analysis of the complex interplay between population growth, energy demand, and their environmental consequences.

3.1 Methodology and Theoretical Framework

This research adopts a multi-method approach, blending elements of exploratory and explanatory research within a triangulation and mixed method framework [45], [46], [47]. This approach enables a comprehensive exploration of the complex problems faced by societies today. To address these issues effectively, the research combines subjectivity and objectivity, qualitative and quantitative methods, and multiple philosophical viewpoints, allowing a more holistic understanding of the research problem.

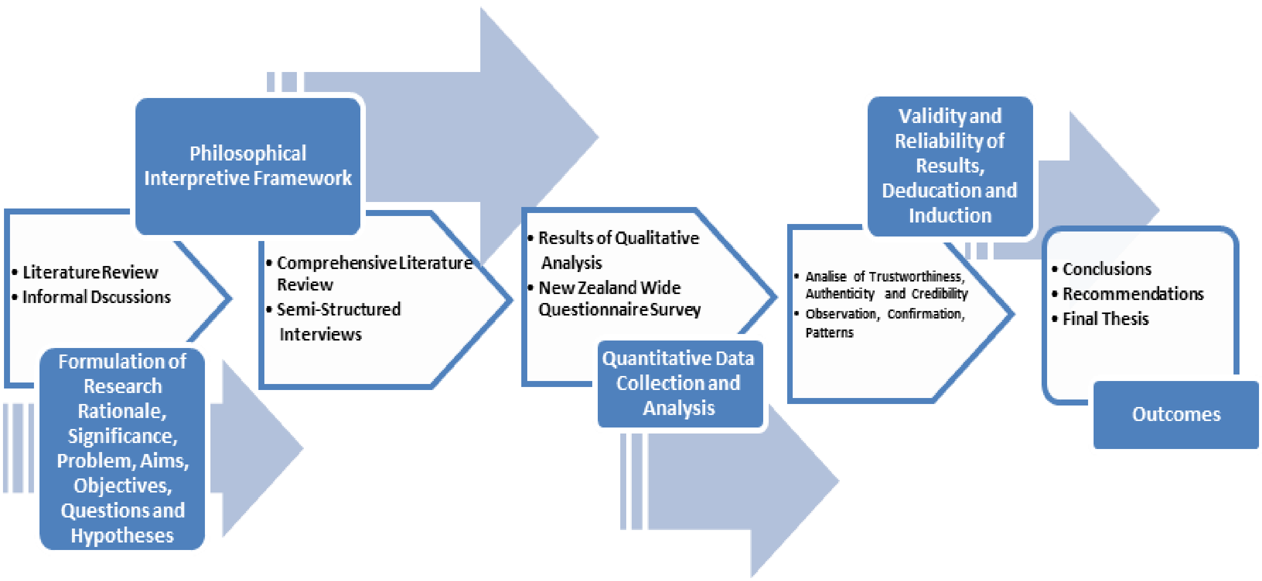

Figure 3: Research Methodology

The main features of various research techniques have been applied in this study due to their distinct purposes, methods, applications, characteristics, and the questions they aim to answer. The decision to combine different research types is driven by the novelty of the research topic - exploring the introduction of green hydrogen technologies in the NZ market. As green hydrogen is a new energy vector, the study seeks answers to exploratory (how?), applied (how to solve?), and fundamental (what?) questions [56], [57].

Research Types	Fundamental	Applied	Descriptive	Analytical	Explanatory	Exploratory
Purpose	Formulation a theory, generalisation, create new or expand current knowledge	Find a solution for an immediate problem society or an organisation facing, policies formulation	Description of the state of affairs as it exists at present, report data, conduct comparison, get the participants' understanding and opinions about a phenomenon	Analyse facts and available information, critical evaluation of the materials, discover and examine cause and effect	Define and explain causes and effects relationship of a certain problem or phenomenon; solve a problem	Explore and investigate a problem which has not been previously studied and/or clearly defined
Methods	Internal Validity, Generalizability, examination, verifications, induction	External validity, deduction	Surveys, data collection and analysis via different techniques	Data	Secondary resources analysis to gather the data, in-depth interviews, literature review, focus group interviews	Data collection through questionnaire and survey, observations
Application	Human Behaviour, Mathematics	Social, economic and political science	Social science, demographic questionnaire, companies' questionnaire, consumers' research	Social science	Case studies	Pilot Projects
Main Characteristics	self-initiated,	set by a sponsor	no control over the variables	quantitative, variables are uninfluenced and uncontrolled	structured, relationship based, successor of exploratory research	non-structured, discovery based, predecessor of explanatory research
Questions	What?	How to solve?	What's happening?	What and why happening?	Why?	How?

Table 1: Main research types and techniques applied in this study. Adapted from Kothari, 2004 [56] and Yin, 2003 [57]

This study adopts positivism, utilizing the hypothetico-deductive method to identify causal relationships, such as population growth impacting energy demand. Additionally, a multi-paradigm approach, particularly emphasizing pragmatism, will be employed. This allows flexibility in methods and data analysis to achieve optimal research outcomes, connecting theory and practice. Participants' values and beliefs will be considered, reflecting characteristics of both positivism and post-positivism briefly and concisely [20], [46], [47], [59], [60], [61], [62].

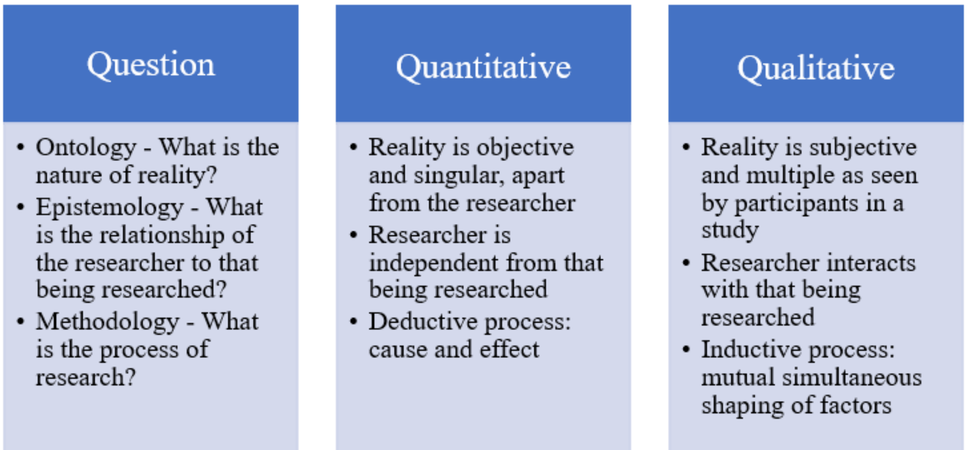

Figure 4: Philosophical Assumptions. Adapted from Creswell, 2014 [47]; Groat &Wang, 2013 [58]; Hudson & Ozanne, 1988 [59]

This study adopts a multi-paradigm strategy, utilizing deduction to test hypotheses and induction to observe patterns and form generalizations, contributing to the overall research methodology [64].

Deduction > theory > hypothesis > observation > confirmation

Induction > observation > pattern > hypothesis > theory

The theoretical framework for this study encompasses both positivist and constructivist traditions. Positivism is applied for objective measurement of multiple variables, reflecting practical reality. Concurrently, constructivism manifests in subjective epistemology, with researchers and participants collaboratively generating understanding and knowledge for practical problem-solving [58].

Objective ←---→ Subjective

	Positivism/Post-Positivism		**Intersubjective**	**Constructivism**	
Epistemology	Knowledge distinct from object of inquiry	Knowing through distance from object	Knowledge framed by understanding sociocultural engagement	Knowledge co-constructed with participants	Knowledge perpetually provisional
Ontology	Assumes objective reality	External reality revealed probabilistically	Diverse realities situated in sociocultural context	Multiple constructed realities	Infinite realities

Figure 5: Continuum of research paradigms. Adapted from Mugerauer, 1995; Guba and Lincoln, 1998; Teddlie and Tashakorri, 2009; and Mertens, 2010 (Groat &Wang, 2013) [58]

3.2 Literature Review and Data Collection

The research process commences with a comprehensive literature review aimed at identifying gaps, refining the research topic, pinpointing the research problem, and underlining its significance [48]. Mixed methods are employed for this review, incorporating both qualitative and quantitative data gathered through university online library catalogues, databases, and Google Scholar [47], [49]. The search uses a variety of keywords pertinent to the research topic, such as "green hydrogen", "production of green hydrogen", and "hydrogen fuel cells". Grey literature, including government reports, conference articles, statistical reports, and working papers, is also explored through government and organization websites [50], [51].

Data obtained is critically evaluated for relevance, and the selected information is organized and annotated, ensuring its future usability. This literature review aligns with the theoretical framework, research aims, objectives, and hypotheses [47], [48].

3.3 Interviews

In the second phase, a series of interviews, both in-person and online, are conducted with key informants, including experts in green hydrogen and hydrogen technologies, as well as those involved in government strategies for reducing carbon emissions. Contacts are established through professional platforms like LinkedIn. Ethics approval was sought and granted through standard university procedures.

Key informants are selected through snowball sampling, and the interviews are semi-structured to allow flexibility and adaptability as the research progresses. The snowball sampling method was chosen to identify participants with valuable knowledge. This method, also known as chain-referral sampling, involves recruiting initial contacts (seeds) who contribute insights and recommend further participants [52]. The process continues in waves until a sufficient number of participants are gathered. The selection of participants was guided by a deliberate sampling approach, deliberately choosing individuals with specific characteristics relevant to the research [63]. This non-probabilistic method requires careful consideration to avoid bias. Initial interviews begin with more general questions, which are refined based on qualitative data gathered in the first round. This iterative process ensures comprehensive data collection and understanding [53]. The interview sample size may vary depending on the achievement of "thematic saturation,", a point at which no new concepts emerge from subsequent interviews [54], [55].

3.4 Survey

In the third phase, data from qualitative interviews inform the development of questionnaires for a survey. These surveys contain a combination of open-ended, dichotomous (yes/no), and closed questions with multiple-choice or Likert scale responses. The questions are meticulously crafted to ensure clarity, fairness, and ease of understanding. The survey is administered through online survey software, Qualtrics.

3.5 Data Analysis and Validation

Data from qualitative interviews and quantitative surveys are processed and analysed, enabling the research to address its objectives and research questions. Qualitative data is coded using NVivo software, while quantitative data is analysed using SPSS. The research employs both descriptive and analytical methods to assess the data collected.

3.6 Final Data Validation

In the fourth phase, a final data validation is carried out. Qualitative and quantitative data are synthesized and analysed together, enhancing the overall understanding of the research problem. This validation ensures the applicability of findings and their potential for future use.

The methodology is guided by ethical principles, ensuring participant confidentiality and respect. Feedback from participants is encouraged to refine the research process. Ultimately, the research combines various data sources and analytical techniques to answer research questions, meet objectives, and verify the formulated hypotheses.

This multimethodological approach aligns with the problem-focused nature of the research and is better suited to addressing the complexity of the issues at hand compared to a traditional, generic research design [20].

4. RESULTS

This research embarked on the next phase by conducting semi-structured interviews with experts in the field of green hydrogen technologies, with a focus on decarbonizing the built environment. A combination of comprehensive literature review and these interviews played a pivotal role in unravelling the multifaceted landscape of green hydrogen and its potential applications. The insights gathered during this phase were invaluable in gaining a deeper understanding of the challenges, opportunities, and key factors that influence the successful implementation and advancement of hydrogen technologies, specifically within the built environment.

4.1 Interviews with Industry Professionals

A total of 16 diverse participants, hailing from different countries, were strategically selected to provide a broad spectrum of global perspectives on hydrogen-related matters. These professionals included key stakeholders, industry experts, and decision-makers from various sectors such as government, industry, research institutions, and non-governmental organizations. Their wealth of knowledge and experience enriched the study, shedding light on different aspects of hydrogen technology adoption.

4.2 Data Collection and Analysis

Data Collection: The primary data collection method was semi-structured interviews, which allowed for in-depth exploration of the research landscape. The interview questions were meticulously designed to cover a wide array of topics, ranging from hydrogen technologies, applications in the built environment, decarbonization, safety considerations, regulatory frameworks, to public perceptions and skills required for the emerging hydrogen industry. The interviews provided a platform for experts to share their first-hand knowledge and perspectives.

Data Analysis: The qualitative data harvested from these interviews underwent a systematic analytical process. NVivo, a robust qualitative data analysis software, was employed for data management, coding, and categorization. An iterative approach was used to scrutinize the data, enabling the identification of recurring themes, patterns, and subtle variations across the participants' perspectives. Thematic analysis was the framework of choice, which facilitated the systematic exploration of the underlying structures within the data.

Emergence of Themes: Thematic analysis unveiled a rich tapestry of participant responses. Consensus on certain issues emerged, reflecting the convergence of viewpoints among participants. At the same time, intriguing divergences emerged, encapsulating the diversity of perspectives resulting from the participants' different geographic and professional backgrounds.

Research Rigor: The research's rigor was maintained through several strategies. The diversity of participants from various countries enriched the depth and breadth of insights. The open-ended interview questions allowed for a comprehensive exploration of the research landscape. Triangulation was employed, cross-referencing participant responses against existing literature and knowledge to ensure data validity and credibility.

4.3 Key Themes and Insights

In the preceding chapters, the focus has been on presenting the primary and additional research questions established during the semi-structured interviews, along with the corresponding responses and the overarching themes that have emerged from these extensive discussions. The valuable insights and perspectives offered by the interviewees have been meticulously transcribed and later interpreted, providing a comprehensive understanding of the research area.

Furthermore, in the post-interview phase, an extensive exploration of the topic was undertaken by sourcing additional knowledge and insights from various literature sources. This exploratory approach was designed to ensure a well-rounded grasp of the research area, enabling an effective address of the research questions, fulfilment of the research objectives, and assessment of the validity of the hypotheses presented.

During this process, four main themes have come to light through the interviews, serving as the guiding principles in addressing our research questions:

Question 1: Hydrogen Safety Requirements and Regulations in New Zealand

The interviewees' perspectives have underscored the critical importance of establishing comprehensive safety regulations and standards that align with global best practices:

> *"I'm seeing more of a focus on creating the standards that can then be referred to in the regulations" (KQ).*

Key points that have emerged include the necessity of adhering to stringent safety protocols and regulations, addressing public concerns due to historical incidents like the Hindenburg, and the need for tailored safety regulations for new applications in buildings:

> *"People still go on about the Hindenburg and safety and stuff, but it's largely a misrepresentation because fossil fuels are much more risky and more poisonous" (JH).*

> *"Sometimes they could be a little bit reluctant because the only thing that they have heard is the Hindenburg" (RGJA).*

> *"Most people think that hydrogen is very dangerous. Toshima event and the Hindenburg it's that kind of stuff a bit association. I think we have to let people know that it is not so dangerous" (JAGR).*

> *"We're still a few years away from completing all of those things for public will trust hydrogen as a fuel and they'll accept it in their houses because Hindenburg is a very big story and everybody loves psych, talking about Hindenburg and then there's lessons from that as well. If we get this wrong, it only takes one incident to ruin it for everybody" (TW).*

> *"All these images like the Hindenburg are tough to get out of people's head like that. That's something that sticks" (VG).*

Moreover, international standards have been recommended for hydrogen technologies and products, although the adaptation of these standards to the New Zealand context is essential:

> "*New Zealand's really lagging on. Some guidelines and standards are really needed. But it's a waste of time reinventing the wheel. We should be using as much from overseas as possible, and I don't really see what's different about New Zealand compared to the rest of the world. Standards and regulations are currently lacking. I don't think the standards are there" (JH).*

Crucial focus areas encompass leakage monitoring, infrastructure compatibility, personnel training, and the development of codes that align with global best practices while catering to New Zealand's unique context. These insights collectively highlight the significance of robust safety protocols in introducing hydrogen technologies across various applications in New Zealand.

Question 2: Hydrogen Technologies and Decarbonization of the Built Environment

In addressing the second question, expert perspectives have converged on several key elements concerning the role of hydrogen technologies in mitigating carbon emissions within the built environment:

> *"Hydrogen is very possibly one of the key enabling technology of the future" (JH).*

Notably, experts concur on the potential of hydrogen to replace natural gas and fossil fuels in heating, cooking, and power generation in buildings. This shift is seen as instrumental in reducing carbon emissions:

> *"I believe that if we find a way of generating hydrogen using relatively cheap renewable energy. And then we have a solution to decarbonize not only the built environment, but everything that uses energy basically" (DA).*

Hydrogen technologies, particularly hydrogen fuel cells, have been identified as promising solutions for clean power generation and heating:

> *"Hydrogen can generate heat and electricity with the only emissions being water" (EEF).*

> *"The only way of decarbonizing the built environment is through a fuel cells. So that's the only way that's left for carrier for countries like Korea, Japan and Taiwan where the land is quite restricted" (DA).*

> *"Japan is a world champion in terms of residential and commercial building fuel cells. I can't recall the statistics now, but they've got significant number of fuel cells that are applied specifically in residential buildings and commercial buildings and I see great potential" (DA).*

Renewable energy sources, particularly green hydrogen production through electrolysis, are considered a critical factor in ensuring environmental friendliness and sustainability:

> *"I think it's the magic of hydrogen. The magic of creating a fuel from water" (JAGR).*

> *"When we produce hydrogen, then we do also use activity then if that is from grid then it is, but it's not 100% green. But when it is produced from renewable, then it is 100% green" (TN).*

Measuring the impact of carbon emissions reduction involves comparing hydrogen systems with conventional fossil fuel-based systems they displace:

> *"We take the equivalent consumption of whatever fuel we are substituting; there's a carbon content based on the norms, and then from there we quantify in a certain period of time how much CO2 emissions we are reducing" (EEF).*

> *"Displace that exist exact carbon content of the fuel that you're using. So compared to LPG, you can drop by however many carbon atoms are in there or methane or diesel or any of those other fossil fuel sources" (TW).*

There is a consensus that the benefits of hydrogen technologies are more pronounced when there is a collective shift toward a hydrogen-based economy:

> *"We can migrate from being fossil fuel providers to be hydrogen providers" (JAGR).*

> *"We can migrate from being fossil fuel providers to be hydrogen providers" (JAGR).*

> *"When we see the world that we understand clearly that fossil fuel area has to stop. And if we want to stop. And if you want to stop, let's say it is the threat of global warming, then only we have to make a threat to something. Fuel. And then we understood very well that there is an infrastructure in need. And there's a lot of things which also has to come. But the most crucial part to do this kind of change stopping fossil fuel industry is to produce hydrogen in the most efficient and the most cheapest way" (SJS).*

The participants also emphasized recycling and reusing materials in hydrogen technologies, aligning with principles of the Circular Economy. These insights collectively underline the significant potential of hydrogen technologies in decarbonizing the built environment.

Question 3: Accelerating Public Acceptance of Hydrogen Technologies

In addressing the question of public acceptance, experts have articulated strategies to expedite the endorsement of hydrogen technologies in New Zealand. These strategies include comprehensive education campaigns to increase awareness and address safety misconceptions, government leadership through policy initiatives, subsidies, and incentives, and emphasizing local benefits like energy independence and economic growth.

> *"We should do something to let people to understand that hydrogen is safe" (TN).*

Collaboration with Māori communities and financial incentives are also identified as crucial for promoting adoption. These strategies collectively aim to empower the public and build confidence in hydrogen technologies by transparently communicating their benefits, aligning with values such as sustainability, energy security, clean air, and economic resilience:

> *"When you can quantify the amount of employees, you can create full time employment.*
>
> *When you can quantify how much you will save for the public health service by avoiding illness from the respiratory system" (JAGR).*

Question 4: Influencing Government Confidence and Support for Hydrogen Technologies

Lastly, the experts' insights reveal key factors that can influence government confidence and decisions regarding the acceleration of new energy vectors like hydrogen. These factors include highlighting energy security and diversification, quantifying the potential for decarbonization and emissions reduction, demonstrating economic viability and cost competitiveness, showcasing job creation and economic benefits, and emphasizing the successes of pilot projects and local demonstrations. The reduction of bureaucratic hurdles and streamlining the adoption of renewable energy technologies is also crucial. Government support in the form of policies, subsidies, and streamlined regulations is deemed essential. These insights collectively provide a roadmap for building government confidence and fostering strategic policy support for the integration of hydrogen technologies:

> *"I think they [the government] need to develop this road map and I think that's really important that they actually do the thinking..." (JH).*
>
> *"I don't see much road map or initiative from the government toward hydrogen. Not only subsidies, but I don't see the leadership there at all. So that is critically missing here. Then when I look at, say not only Japan but Australia or US, they have clearer picture of where a country is heading. So that's what has been missing here in New Zealand" (TN).*

While these main themes have guided our understanding, it is important to note that, within these themes, experts have expressed varying perspectives and opinions. These differences highlight the nuanced nature of the transition to hydrogen technologies and the necessity for a tailored approach to address the unique challenges and opportunities in New Zealand's context.

In the next phase of our research, an expansion of data collection efforts will be conducted through comprehensive surveys involving a broader spectrum of stakeholders connected to New Zealand's building and construction ecosystem. This primary data collection will offer a more extensive and varied dataset, allowing the validation and expansion of the themes and perspectives derived from the interviews. The goal is to capture a holistic view of New Zealand's readiness to adopt hydrogen technologies in the built environment and identify the steps needed to overcome barriers and enhance acceptance.

4.4 Contribution to Research and Future Directions

The findings from this qualitative phase have laid a pivotal foundation for addressing the research's overarching questions, objectives, and aims. These insights will be instrumental in shaping the survey questions for the subsequent quantitative phase, bridging the gap between qualitative and quantitative research paradigms. By drawing upon the expertise and perspectives of industry professionals, this research is poised to offer valuable insights for policymakers, industry practitioners, researchers, and stakeholders interested in the development and advancement of hydrogen technologies.

4.5 Conclusion

This report delved into the intricacies of the research's methodological underpinnings, explaining the rationale, design, and execution of the qualitative phase. The rich diversity of participants, in conjunction with the thematic analysis approach, has resulted in a comprehensive panorama of perspectives on green hydrogen and hydrogen technologies within the built environment. This foundational phase sets the stage for the forthcoming quantitative phase, strengthening the research's holistic exploration of hydrogen's multifaceted facets.

In summary, this research phase has successfully uncovered a wide range of perspectives and insights from industry professionals, further enhancing the depth and breadth of knowledge surrounding green hydrogen technologies and their role in decarbonizing the built environment.

This comprehensive understanding forms the basis for the subsequent quantitative phase, which will provide a more data-driven exploration of these critical topics. Through this multi-methodological approach, the study aims to provide valuable contributions to the field of green hydrogen technologies and their application in decarbonizing the built environment.

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