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Original Research Article

Strategic Innovation and Performance of Hydrogen Fuel Consumption in Kenya

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Abstract: The utilization of hydrogen fuel represents a global shift towards sustainable energy sources, yielding significant reductions in carbon dioxide and greenhouse gas emissions. Despite the abundance of renewable energy options, widespread adoption has been slow, with persistent reliance on fossil fuels. The purpose of this study was to establish the effect of strategic innovation on the performance of hydrogen fuel consumption in Kenya. The proposed objectives of this study were: to determine the effect of product innovation on the performance of hydrogen fuel consumption in Kenya, and to assess the influence of process innovation on the performance of hydrogen fuel consumption in Kenya. Employing a desktop research methodology, the study emphasizes the pivotal role of strategic innovations in fostering sustainability, product and process innovation in hydrogen fuel consumption and the renewable energy sector. This study concludes that strategic innovations, including product innovation and process innovation have a positive effect on the performance of hydrogen fuel consumption in Kenya. Further, robust policy frameworks are essential to incentivize and facilitate innovation in hydrogen fuel production. The study recommends that the Kenyan government prioritize policy formulation to stimulate hydrogen generation and utilization, integrating incentives for research and development, tax exemptions, and financial support to encourage private investment and domestic industry growth, thus reducing reliance on imports and fostering economic diversification.

Keywords: Strategic innovation, product innovation, process innovation, hydrogen fuel, fuel consumption.

Introduction and Background of the Study

Farias *et al*., (2022) trace hydrogen discovery to Henry Cavendish in 1766 and credits Antoine Lavoisier for the significance of hydrogen. Hydrogen, being the most prevalent element on Earth (Jain, 2009), shows potential as an eco-friendly energy source due to its superior energy output in comparison to fossil fuels and its lightweight composition. Nevertheless, the process of extracting it via electrolysis from water highlights its limited availability (Nath & Das, 2003), which is consistent with the resource-based view theory that emphasizes the importance of scarcity and efficient exploitation for gaining a competitive edge. According to Müller *et al.,* (2023), hydrogen is utilized in diverse industrial applications, such as the manufacturing of important compounds like ammonia fertilizer methanol and in the steel process.

Strategic innovation refers to a range of methods that aim to transform a company's competitive advantage and future direction. Lüdeke-Freund (2020) explains that strategic innovation includes making improvements to products, processes, business models, marketing, organizations, and sustainability. Strategic innovation plays a pivotal role in facilitating breakthroughs and promoting the adoption of hydrogen fuel consumption within the given environment (Yue *et al*., 2021). The enhancement of efficiency and dependability in hydrogen fuel cell technologies is facilitated by product innovation, while the streamlining of production and distribution is achieved through process innovation, hence increasing the accessibility of hydrogen. Business model innovation entails re-evaluating tactics to encourage the usage of hydrogen fuel, contributing to a more environmentally friendly future and addressing the concerns related to the environment. Marketing innovation aims to inform and

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captivate consumers Lüdeke-Freund (2020) regarding the advantages of hydrogen fuel, while organizational innovation promotes cooperation and adaptability among enterprises engaged in the production and distribution of hydrogen fuel. Ultimately, the implementation of sustainable innovation guarantees that the manufacturing and consumption of hydrogen fuel are in accordance with environmentally favourable methods, thereby fostering enduring environmental sustainability.

Vijayakumar *et al*., (2022) credit the global momentum of strategic innovation in hydrogen fuel consumption has been driven by countries such as Japan, South Korea, and Germany. Similarly, Behling *et al*., (2015) argue that innovation in fuel cell technologies and infrastructure is propelled by initiatives such as Japan's hydrogen society concept and South Korea's Hydrogen Economy Roadmap. Furthermore, the European Union's Hydrogen Strategy in Europe aims to establish a cutting-edge hydrogen market by making strategic investments and implementing regulatory frameworks (Behling *et al*., 2015). Hydrogen research funded by the United States and Canada in North America, with California taking the lead in developing the necessary infrastructure has given impetus to hydrogen fuel consumption (Ogden & Yang, 2009). Sunny and Shu (2019) argue that strategic innovation has regional variations, influenced by factors such as resource availability, regulatory backing, and market dynamics with the predominant objective being to shift towards a future powered by hydrogen.

Kenya, like numerous countries, confronts significant climate change repercussions due to human activities modifying the composition of the biosphere, leading to global warming and uneven temperature rises that affect phenomena such as El Niño and La Niña. Situated on the equator, Kenya's tropical environment renders it susceptible to climate fluctuations, especially considering its reliance on agriculture and the limited ability of the impoverished and marginalized population to adapt (Liru, 2020). The increased attention from governmental bodies and stakeholders highlights the pressing need to mitigate and tackle the causes and consequences of climate change. The economic stability of developing countries is at risk due to their significant dependence on climate and natural resources. Adenuga *et al*., (2021) project that Sub-Saharan Africa will experience a 10% decline in its GDP by 2050 because of climatic changes. The prioritization of environmentally sustainable development is of utmost importance to protect economies, hence requiring a shift towards the adoption of sustainable energy alternatives such as the utilization of hydrogen fuel. Kenya has successfully enacted climate change policies that prioritize both mitigation and adaptation techniques. These policies include the National Climate Change Action Plan and the Climate Change Act of 2016. The act of investing in hydrogen fuel is in accordance with Kenya's commitment to sustainable development, as it provides opportunities for economic expansion and energy stability, while simultaneously decreasing carbon emissions and addressing climate-related hazards. The adoption of hydrogen fuel has the potential to further global endeavours aimed at achieving a more sustainable and resilient future.

The utilization of hydrogen as a sustainable fuel in both residential and industrial contexts is progressively acknowledged as a substantial catalyst for decarbonization, serving as a replacement for fossil fuels that are notorious for their substantial carbon dioxide emissions and greenhouse gas potential (Schöne *et al*., 2023). Employing sustainable energy sources such as wind, hydropower, and solar electricity in the process of electrolysis provides an ecologically conscious alternative for the generation of green hydrogen (Sharma *et al*., 2021). The combustion of hydrogen fuel results in the release of water without the contribution of carbon or greenhouse gas emissions (Züttel *et al*., 2010). This underscores the potential of hydrogen fuel in tackling environmental issues and promoting the development of sustainable energy sources. The promotion of clean energy sources, such as renewable energy and hydrogen, is driven by global environmental difficulties, which are worsened by carbon dioxide emissions mostly from industries like the automobile sector (Farias *et al*., 2022; Nath & Das, 2003). According to Schöne *et al*., (2023), hydrogen fuel exhibits potential as a supplementary energy resource for off-grid stations and transportation because of its lightweight, compressible characteristics and substantial energy output. When used in conjunction with LPG, hydrogen fuel can efficiently satisfy Kenya's energy requirements, reducing emissions and promoting economic growth.

Statement of the Problem

Hydrogen fuel's use as a sustainable energy source on a global scale has resulted in substantial decreases in carbon dioxide and greenhouse gas emissions, thus aiding in the fight against global warming (Webster, 2023). Nevertheless, Kenya's utilization of hydrogen fuel is not commensurate, as the nation predominantly depends on charcoal (24%), LPG (15%), kerosene (11%), and fuel wood (86%) by the year 2020. Similarly, Kenya's transport industry in 2010 contributed 20% of carbon dioxide emissions a figure expected to have risen accelerating global warming challenges (Mbandi *et al*., 2023). These fuel sources are significant contributors to carbon emissions (Schöne *et al*., 2023). Kenya's reliance on fossil fuels, despite the presence of ample renewable energy sources such as wind, hydro, and solar power, is a significant obstacle to achieving decarbonization and environmental sustainability (Chemengich & Masara, 2022). The slow uptake of hydrogen fuel in Kenya poses a significant challenge, considering the nation's capacity to utilize renewable energy sources for the purpose of generating clean energy and mitigating carbon emissions (Müller *et al*., 2023).

Hydrogen fuel, derived from renewable sources such as wind, hydro power, and solar energy via electrolysis, holds the potential to provide a reliable and environmentally sustainable source of energy. Although renewable energy sources have the potential to contribute to hydrogen fuel production in the USA, they only account for 1% of the total. The majority of hydrogen fuel production still depends on fossil fuels and coal, making it unsuitable for relying on renewable energy (Wilson, 2023). However, nations are actively promoting the adoption of hydrogen fuel, with the European Union aiming to achieve a consumption target of 20 million tons, with half of this amount being obtained from imported renewable energy sources (Majkut *et al*., 2022). Amidst the energy crisis caused by the Ukraine-Russia conflict, there has been a significant increase in interest in hydrogen fuel, emphasizing its economic worth and promise as an environmentally friendly energy option.

Kenya is well positioned to utilize its substantial renewable energy resources to facilitate the production of environmentally friendly energy. Nevertheless, the widespread adoption of hydrogen fuel in Kenya is impeded by various challenges, including high production costs, inadequate infrastructure, and policy gaps (Schöne *et al*., 2023). These obstacles restrict the potential of hydrogen fuel to effectively address respiratory illnesses, emissions, and imports, thereby affecting the trade balance and hindering industrial development (Müller *et al*., 2023).

Purpose of the Study

To establish the effect of strategic innovation on the performance of hydrogen fuel consumption in Kenya.

Objective of the Study

i. To determine the effect of product innovation on the performance of hydrogen fuel consumption in Kenya.
ii. To assess the influence of process innovation on the performance of hydrogen fuel consumption in Kenya.

SIGNIFCANCE OF THE STUDY

The government of Kenya in 2023 developed Roadmap (European Commission, 2023) geared toward green hydrogen economy production starting with policy and regulation development and projecting maturity in 2032. Notably, Kenya is wealthy in clean renewable Energy resources such as of hydro, wind, geothermal and solar power. Kenya is also rich in water resources especially from different waterbodies including various lakes and rivers and Indian Ocean. Therefore, achieving green energy through chemical electrolysis to give rise to hydrogen, which is used as fuel, or undergo further processing to produce methanol and ammonia fertilizer. This empirical study will help the Government and Industrial stakeholders to strategically position themselves for green hydrogen economy revolution, which contribute positive to climate change dynamic and mitigate global warming and ozone layer depletion. Consequently, there will be reduction in fossil fuel importation, job creation, and growth in agriculture in Kenya as the fertilizer price would drop as the supply and distribution chains are shortened.

THEORETICAL FRAMEWORK

Jevons' Paradox Theory

In 1865, Williams Stanely Javons formulated Jevons' Paradox Theory, which is centred on the utilization of coal. Jevons observed that enhancing the efficiency of resource utilization results in a higher utilization of that resource, rather than a decrease. This theory is not just applicable to fossil fuel usage but also extends to other domains such as food production (Alcott *et al*., 2012). The rise in technological progress leads to an increase in resource consumption due to the cost reductions associated with technology, which in turn increases demand. The economic expansion of a nation is driven by high consumption resulting from greater energy use (Züttel *et al*., 2010).

According to Jevons' Paradox Theory, the implementation of strategic innovations in the research may result in heightened consumption of commodities, as opposed to a decrease in consumption (Lange *et al*., 2021). This study examines the possible impact of strategic innovations on energy consumption efficiency, which may lead to an increased demand for hydrogen fuel. For instance, if the advancements result in decreased costs or enhanced accessibility of hydrogen fuel, it could potentially stimulate heightened utilization of this energy resource, notwithstanding its primary objective of mitigating carbon emissions. Hence, although these strategic innovations have the potential to alleviate environmental issues, they may also unintentionally lead to heightened consumption of goods, underscoring the complex relationship between efficiency enhancements and resource allocation. However, it is important to acknowledge that efficiency enhancements may inadvertently result in a higher need for hydrogen fuel, which goes against sustainability goals. To fill this gap, this study utilized empirical studies that investigate strategic innovations, highlighting product and technological innovations.

Resource-Based View (RBV) Theory

Rugman and Verbeke (2002) state that RBV theory, initially introduced by Edith Penrose in 1959 and later expanded upon by Jay B. Barney in the 1980s and 1990s, centres around the notion that a company's capacity to sustain a competitive advantage over time is contingent upon its possession of unique and valuable resources. The resources mentioned encompass a diverse array of assets, encompassing tangible elements like as physical infrastructure and human capital, as well as intangible assets like organizational culture, knowledge, and patents (Burvill *et al*., 2018). For a resource to confer a competitive advantage, it must meet specific criteria.

The criteria encompassed in this study are scarcity, value, difficulty of imitation, and non-substitutability (Burvill *et al*., 2018). However, an important limitation of this theory is the challenge of identifying and evaluating intangible resources. Additionally, it tends to overlook external factors and the dynamics of the industry (Priem & Butler, 2001). Furthermore, RBV may not consistently offer a thorough study of the influence of institutional factors on firm success (Barney & Arikan, 2005).

Within the framework of the research pertaining to strategic innovations and the consumption of commodities, it is plausible to perceive these inventions as valuable assets that contribute to a firm's competitive advantage. This theory emphasizes the significance of resources satisfying distinct criteria such as scarcity, value, and difficulty of imitation, which can be utilized to assess the efficacy of strategic innovations (Miller, 2019). Nevertheless, it is subject to several constraints, such as its challenge in precisely defining and assessing intangible resources, as well as its inclination to disregard external influences and industrial dynamics. Furthermore, it may not comprehensively account for the impact of institutional elements on the achievement of a firm. To overfill these knowledge gaps, this study investigated the influence of strategic innovations on consumption behaviours within a particular market setting. Through examination of empirical studies on the effect of strategic innovations on hydrogen fuel consumption performance, it considered both tangible and intangible resources, while also taking into consideration external influences and institutional components.

Conceptual Framework

The relationship between the independent and dependent variables is shown in Figure 1. The strategic innovations: product innovation and process innovation were the independent variables while the performance was the dependent variable. Product innovation through water electrolysis result to water broken down to hydrogen and oxygen. Hydrogen is used as fuel, or manufacturing of methanol and ammonia fertilizer. This leads to growth of hydrogen industry and at the same time becomes substitute for fossil fuel leading to decarbonisation. Similarly, process innovation affects efficiency, reduces the environmental effect, and facilitates the integration of hydrogen fuel consumption into existing infrastructure and systems, so enhancing its performance and the end by product in hydrogen fuel combustion is water not carbon dioxide which is the lead cause of global warming.

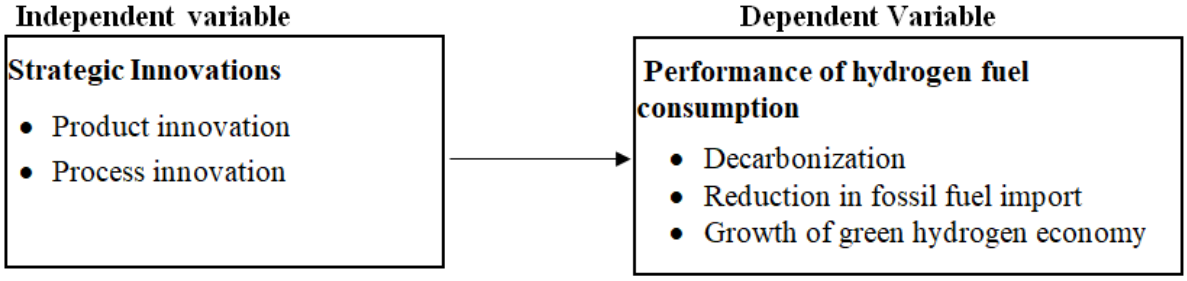

Figure 1: Conceptual Framework
Source: Authors (2024)

METHODOLOGY

This research adopted desktop research design. Desktop research entails the collection and examination of pre-existing data, literature, and pertinent material pertaining to the research subject, without the direct acquisition of raw data from primary sources (Kevin, 2023). According to Demberere *et al*., (2023), desktop research provides numerous benefits, such as cost and time effectiveness, extensive scope, and the capacity to retrieve a broad collection of information from various sources. This tool enables researchers to integrate pre-existing knowledge, ascertain significant patterns, theories, and optimal methodologies, and situate the study within the wider body of literature and knowledge foundation. Moreover, Huang (2019) argues that the utilization of desktop research is considered highly appropriate for this investigation owing to the logistical complexities and limited resources inherent in carrying out primary research. This study sought to establish the effect of strategic innovation on the performance of hydrogen fuel consumption in Kenya by incorporating information from various online sources including past research in journals and other published works on the specific constructs under study. The publications considered were for this study covered the period from 2018 to 2023. The resulting data was analysed systematically on the data obtained on the desktop research with the aim of uncovering patterns, themes, and significant insights. The purpose of the systematic analysis is to address the research objectives and the knowledge gaps identified. Other scholars that have used this design include Kevin (2023), and Demberere *et al*., (2023).

EMPIRICAL LITERATURE

Product Innovation and Performance

Yllemo (2023) emphasizes the USA's deliberate transition towards renewable energy as a means of

safeguarding national security. The emissions of carbon dioxide and greenhouse gases are widely recognized for their role in causing respiratory disorders, which in turn affects the eligibility of individuals for military recruiting. The USA's focus on renewable energy is aimed at reducing dependence on fossil fuels and foreign gasses, particularly in response to competitive challenges from nations such as China, given that air pollution is responsible for over 20,000 early deaths annually. The nation's dedication to resolving environmental and health concerns is evident through initiatives such as granting California the authority to establish air pollution standards and offering subsidies and carbon credits for green energy, including hydrogen fuel and electric cars (Yllemo, 2023).

According to Wilson (2023), the utilization of hydrogen fuel will result in a complete absence of carbon emissions, if the hydrogen is produced from sources that do not release carbon dioxide or other greenhouse gases. He contends that the primary constraint on the widespread adoption of hydrogen will be its cost in comparison to alternative energy sources used to power vehicles, such as electric cars and fossil fuel or hybrid systems. Research conducted in California by Basma and Rodríguez (2023) assessed the projected energy costs of different sources for a 400-mile journey by a tractor truck by the year 2030. The price of hydrogen fuel was set at USD 1112, while the hybrid of hydrogen and fossil cell was priced at USD 960. Diesel fuel was priced at USD 764, and battery electric vehicles were priced at USD 760.As subsidies and acceptance increase and manufacturing efficiency improves, the cost of hydrogen is anticipated to decrease and become competitive with other energy sources. The study observed that over time, the overall cost of owning hydrogen fuel will be the most economical, which will be advantageous for the reduction of carbon emissions and the eradication of greenhouse gases.

Moreover, Alsulaiman (2024) argue that the aviation industry is a significant contributor to pollution due to its emissions of carbon dioxide and greenhouse gases. The aviation sector is expected to become capital intensive, and it is predicted that by 2050, it will have achieved a level of development where it can utilize hydrogen fuel as a sustainable alternative to traditional aviation fuels. Aviation accounts for 2% of carbon dioxide emissions, with industrialized countries responsible for 50% of international flight emissions and 60% of domestic emissions. The aviation business is a complex network of interconnected stakeholders that generate demand for goods and services. As the population continues to grow, this industry is poised to thrive and expand. Employment opportunities are generated, and diverse sectors emerge. The realization of hydrogen fuel may be achieved as early as 2035. Due to the stringent safety regulations in the aviation industry, the implementation process may be time-consuming. The Airbus corporation has committed to developing airplanes that prioritize zero carbon emissions by utilizing hydrogen fuel for jet engines. The lack of capital investments and inadequate infrastructural development pose significant obstacles to the success of this venture. The researcher should have examined the alternative of inquiring with the suppliers of jet fuel regarding their inclination to utilize, embrace, and conform to the anticipated transition from fossil fuel to hydrogen fuel.

Ahmed *et al*., (2016) conducted an empirical review that specifically examined the implementation of hydrogen fuel in the Malaysian transportation system with the aim of attaining sustainability and environmental objectives. Malaysia's interest in new energy technologies stems from the necessity to comply with energy security criteria and decrease greenhouse gas emissions. The government has actively promoted renewable energy and energy efficiency, further fueling this desire. These efforts were designed to tackle difficulties related to environmental goals, specifically in the energy industry. In Malaysia, many initiatives were undertaken to promote the use of hydrogen fuel in the transportation sector. These efforts were driven by the goals of ensuring a reliable energy supply in the future and fostering a sustainable environment. The article provides a thorough analysis of the Malaysian government's climate road map and emission reduction plan, using a paradigm that focuses on environmental sustainability. This study examined the macroeconomic concerns of a country and explores many viable choices for achieving a sustainable environmental future. Although there were clear advantages to giving priority to a modern, emission-free transportation system, the process of discussing and putting such policy alternatives into action sometimes leads to disagreements within the national economy. Whereas this study was done in Malaysia with different macroeconomic characteristics, this study was adopted in the desktop research on the effect of strategic innovations on the performance of hydrogen fuel consumption in Kenya. The relevance of this study is to provide guidance to national policymakers in incorporating sustainability and environmental considerations while implementing an efficient hydrogen fuel economy in the contemporary transportation system.

Agustia *et al*., (2022) in Indonesia established a strong positive link between product innovation and company performance, with a significant p-value (0.000) and coefficient (18.434), indicating a beneficial impact on return on assets. However, technological capability showed no statistically significant direct relationship with business performance (p-value: 0.135, coefficient: 0.057), acting only as a moderator that reduced the influence of product innovation. Their study, based on 261 annual reports from 2015 to 2020, used moderation regression analysis, while this research will employ desktop methods, focusing solely on product innovation and not hydrogen fuel consumption, limiting generalizability. This study used firms registered in the

Indonesian Stock Exchange offering a multi-sectoral perspective and cannot be generalized to hydrogen fuel consumption.

Shin *et al*., (2022) analyzed product and service innovation's performance and efficiency, measuring innovation efficiency as the ratio of outputs to inputs, comparing three types: combined, product-only, and service-only innovation. Using data from the 2020 Korean Innovation Survey, they studied a subset of firms 902 out of 951 and found that firms engaged in both product and service innovation showed superior performance but lower efficiency. While their study focused on Korea and included both product and service innovation, this study concentrates solely on product innovation, limiting generalizability across different macroeconomic contexts.

Process Innovation and Performance

In their study, Dincer and Acar (2017) introduced a comprehensive framework for analyzing innovation in hydrogen production, known as the "18S concept." This concept encompasses multiple dimensions including source, system, service, scope, staff, scale-up, safety, scheme, sector, solution, stakeholder, standardization, subsidy, stimulation, structure, strategy, support, and sustainability. The participants engaged in a conversation regarding the functions of these abstract entities and underscored their significance. In addition, the study evaluated novel techniques for hydrogen production using a ranking methodology for the aim of comparison and evaluation. The findings demonstrated that renewable sources, specifically hydro, geothermal, and solar, possess distinct capacity to facilitate creative hydrogen generation methods. Comparisons among different hydrogen production systems have shown that systems that incorporate heat recovery (thermal) and photonic-based solutions perform better in terms of emissions, cost, and efficiency. Moreover, hydrogen production innovation is crucially imperative for addressing energy and environmental concerns in a clean, efficient, effective, dependable, and economical manner, while also meeting the essential implementation requirements. The innovative solutions are anticipated to enhance various aspects, including efficiency, resource use, affordability, environmental protection, energy security, and system design and performance analysis. Whereas the study looked at the comprehensive framework for hydrogen production in Malaysia, this study seeks to determine the effect of product innovation on the performance of hydrogen fuel consumption.

According to Miller-Wang (2023), a study has found that the towns of Zhangjiakou, Datong, and Chengdu in China have implemented the usage of hydrogen in their transportation systems as a means of reducing carbon emissions. The study observed that the utilization of renewable energy for hydrogen fuel production is the most promising option. However, in Datong city, they also rely on coal for fuel generation, which means it does not achieve complete carbon dioxide emission neutrality. Datong has established a goal to reduce carbon dioxide emissions and greenhouse gas emissions between 2015 and 2020, as well as by 2025. To enhance the commercial feasibility of hydrogen, its application has been expanded beyond large trucks to include light cars as well. This diversification aimed to utilize hydrogen in the manufacturing of Ammonia, a crucial commodity in agricultural farming. This success was attributed to the implementation of a hydrogen strategy, the establishment of a goal plan, the development of infrastructure, and the provision of financial support and subsidies for the deployment of hydrogen buses. The city of Chengdu possessed a total of 370 hydrogen-powered buses and trucks in the year 2020. The production focus in Datong city aims to achieve a production volume of one million tons of hydrogen, valued at USD 5.8 million, within the timeframe of 2026-2030.This study should have considered other towns that have not yet embraced hydrogen as a fuel and investigated the underlying causes for the delay. Whereas this study looked at the usage of hydrogen in the transportation systems in China, this study is desktop research that seeks to determine the performance of hydrogen fuel consumption in Kenya.

In a study conducted by Frost *et al*., (2023), it was projected that by 2050, over 50% of truck buses in the United Kingdom would be powered by hydrogen fuel. This prediction was based on modelling conducted by Innovate, which considered anticipated developments in technology and reductions in the cost of green energy generation. Local authorities were mandated to make strategic policy decisions to promote the construction of infrastructure for hydrogen fuel and electric vehicles to accomplish decarbonization and reduce greenhouse gas emissions. The coach drivers expressed a favorable stance towards the use of cleaner energy, urging for its prompt adoption and the complete eradication of diesel usage on the highways. Frost *et al*., observe that hydrogen fuel trucks possess a competitive edge over electric trucks in terms of their capacity for abundant storage and ability to drive greater distances without frequent interruptions. This contrasts with electric vehicles, which necessitate charging pauses after completing specific distances, resulting in delays. Several designers have proposed the placement of the hydrogen fuel tank on the roof of vehicles to optimize storage capacity at the base and improve stability, taking into consideration the relatively low density of hydrogen fuel. In addition, Frost *et al*., contended that China received acclaim for its implementation of hydrogen coaches. These findings indicate an upward trajectory in the consumption of hydrogen fuel as more and more industry players in the transport sector adopts hydrogen transport vessels. Whereas Frost *et al*., provide evidence for the changes in the transport sector brought about by hydrogen production, focused on hydrogen fuel usage in the transport sector, this study focuses on the hydrogen

fuel consumption in the whole country as opposed to individual sectors.

Kowo *et al*., (2018) investigated the impact of process innovation on organizational performance in Nigeria, finding a significant correlation between service process innovation and organizational performance ($r = 0.485$, $p = 0.000 < 0.01$). as well as service modification and sales volume ($r = 0.408$, $p = 0.000 < 0.01$). Their study involved administering 114 questionnaires to employees of major telecommunication operators in Lagos State, Nigeria. However, the specific focus on the telecommunications sector in Nigeria limits the generalizability of their findings to the study of process innovation's effect on hydrogen fuel consumption performance in Kenya. Additionally, while Kowo *et al*., utilized survey methodology and regression analysis, this study employs desktop research, offering a different analytical approach.

Mooi *et al*., (2020) explored the correlation between process innovation and organizational performance, analyzing divergence in process innovation's impact across different environmental contexts. The study analyzed survey and archival data from 5,594 enterprises in 15 countries, including Australia, Austria, Brazil, Brazil, Finland, Germany, Greece, Hong Kong (SAR), Hungary, Ireland, Mainland China, the Netherlands, New Zealand, Slovenia, the United Kingdom, and the United States. While their findings revealed varied correlations based on environmental uncertainty and competitive intensity, they also highlighted a positive correlation between anticipated process innovation and overall performance improvement. However, the study's limitation lies in its focus on developed countries, making the findings less applicable to emerging economies like Kenya, and its lack of direct relevance to hydrogen consumption, the focus of this study.

In Kenya, Mutisya *et al*., (2022) investigated process innovation's impact on Tier 2 Commercial Banks' performance, using regression and correlation analysis on data from senior management staff, collected via questionnaires and secondary sources. The study employed regression and correlation analysis techniques to investigate the associations between variables. The collection of data involved the utilization of both primary and secondary sources. They found a significant positive correlation ($r = 0.623$, $p = 0.000 < 0.01$), indicating that process innovation, including mobile and internet banking, enhanced operational effectiveness. However, the sample's size and focus limit generalizability, and while Mutisya *et al*., used an explanatory approach, this study adopts desktop research.

STUDY FINDINGS

The present investigation employed a desktop research design to examine the impact of strategic innovation on the performance of hydrogen fuel consumption in Kenya. The dependent variable in this study was performance with decarbonization, reduction in fossil fuel use, growth of green hydrogen economy as indicators while strategic innovations including product innovation and process innovation were considered as the independent variables.

Product Innovation Findings

Product innovation plays a crucial role in influencing the way hydrogen fuel is used in Kenya. Basma and Rodríguez (2023) conducted a study on anticipated energy expenses in California. Their findings indicate that as subsidies and manufacturing efficiency improve, the costs associated with hydrogen fuel are likely to decline, hence enhancing its economic feasibility. In addition, Alsulaiman (2024) emphasizes the aviation industry's potential utilization of hydrogen fuel, despite the obstacles posed by safety laws and infrastructure development. These findings highlight the importance of product innovation and regulatory assistance in promoting the use and effectiveness of hydrogen fuel. This has implications for Kenya's energy sector development and efforts to achieve environmental sustainability goals including decarbonization and reduction of fossil fuel imports. Product innovation in the renewable energy industry in Kenya has significant potential to promote the development of hydrogen fuel technology, providing personalized solutions that meet the specific needs of the local market. Innovative firms may expedite the adoption of clean energy solutions, diminish carbon emissions, and move Kenya towards a more sustainable future by improving the efficiency, cost-effectiveness, and environmental friendliness of hydrogen fuel systems.

Moreover, the positive correlation between product innovation, organizational success, and performance has been substantiated by studies conducted by Tamunomiebi and Okorie (2019) and Agustia *et al*., (2022). Product innovation plays a key role in the renewable energy sector of Kenya, as it facilitates progress in hydrogen fuel technology. This, in turn, empowers enterprises to provide inventive fuel cell solutions, storage systems, and distribution networks. Companies can expedite the acceptance of clean energy solutions, diminish carbon emissions, and aid Kenya's shift towards a more environmentally friendly and sustainable future by consistently enhancing the quality, dependability, and cost-effectiveness of hydrogen fuel products.

These results emphasize the immediate requirement for Kenya to establish a thorough policy structure for hydrogen fuel, considering its capacity to promote the use of renewable energy and improve environmental sustainability. Kenya's failure to implement a specific strategy may result in the country lagging in utilizing the advantages of hydrogen fuel technology. This might also hinder Kenya's progress in meeting its energy sector development objectives and

environmental targets. An effective policy should give top priority to encouraging and promoting product innovation in the renewable energy sector. It should also help with research and development efforts and promote cooperation between the government, industry, and research institutions. Furthermore, policy interventions should aim to overcome obstacles to entering the market, such as high initial costs and limited infrastructure, to facilitate the widespread adoption of hydrogen fuel technology. Kenya can foster innovation, attract investment, and expedite the shift towards a cleaner and more sustainable energy future by establishing a strong policy framework.

Process innovation Findings

The study conducted by Dincer and Acar (2017) highlights the significant impact of process innovation on the performance of hydrogen fuel consumption in Kenya. Their all-encompassing framework, known as the "18S concept," offers a complete method for examining innovation in hydrogen generation. It considers multiple aspects, including source, system, service, and sustainability. The study emphasizes the importance of renewable sources, specifically hydro, geothermal, and solar, in enabling creative methods for generating hydrogen. Furthermore, when comparing various hydrogen production systems, it is evident that those that utilize heat recovery and photonic-based solutions provide superior performance in terms of emissions, cost, and efficiency. The findings highlight the significance of process innovation in tackling energy and environmental issues. They imply that innovative solutions have the potential to improve efficiency, resource utilization, affordability, and environmental protection in Kenya's hydrogen fuel industry. Insights from Miller-Wang (2023) and Frost *et al.*, (2023) offer valuable context on global trends in hydrogen fuel adoption and its implications for transportation and energy sectors. On the other hand, Kowo *et al*., (2018) and Mooi *et al.*, (2020) emphasize the strong relationship between process innovation and organizational performance in many settings. In their study, Mutisya *et al*., (2022) demonstrate the favorable effects of process innovation techniques, namely in the domains of mobile and online banking. These insights provide additional perspectives for policymakers and industry stakeholders in Kenya to consider when developing strategies to improve the performance of hydrogen fuel consumption in the country through process innovation.

The findings emphasize the vital significance of process innovation in improving the performance of hydrogen fuel consumption in Kenya, specifically highlighting its favorable effects on efficiency, resource usage, and consumer satisfaction. Considering Kenya's absence of a hydrogen policy, it is crucial for policymakers to give priority to the creation of a thorough plan that encourages advancements in the hydrogen fuel industry through process innovation. This approach may entail providing incentives for research and development endeavors aimed at investigating novel manufacturing techniques, including those that make use of sustainable energy sources such as hydro, geothermal, and solar power. In addition, it is crucial to build legislative frameworks that will facilitate the implementation of cutting-edge technologies like heat recovery and photonic-based solutions, which have proven to be more effective in producing hydrogen. Moreover, it is crucial to engage in infrastructure and capacity-building projects to enable the smooth incorporation of process innovation into the hydrogen fuel supply chain, guaranteeing its ability to be expanded and maintained over time. To effectively address these policy gaps and create a favorable environment for process innovation, policymakers can strategically position Kenya to take advantage of hydrogen fuel. This will not only help advance the country's energy transformation agenda, but also promote economic growth and ensure environmental sustainability.

Theoretical Evidence

The empirical evidence overwhelmingly corroborates Jevons' Paradox Theory, as demonstrated in the investigations conducted by Tamunomiebi and Okorie (2019), Agustia *et al*., (2022), and Shin *et al*., (2022). According to their research, investing in innovation unintentionally results in increased utilization of resources, such as hydrogen fuel. This relationship between innovation and resource use is consistent with Jevons' Paradox. Moreover, the hypothesis is further supported by the research conducted by Dincer and Acar (2017) and Basma and Rodríguez (2023). Given the progress in hydrogen fuel technology and good market conditions, it is probable that Kenya will experience a rise in fuel consumption. In the absence of adequate regulatory measures, this unintended outcome has the potential to impede progress towards achieving energy sustainability and environmental objectives.

Yllemo (2023) and Alsulaiman (2024) have conducted empirical research that provides good support for the RBV Theory. Yllemo demonstrates the strategic utilization of renewable resources, such as hydrogen fuel, by governments to bolster security and tackle environmental issues. This approach aligns with RBV's emphasis on leveraging valuable resources to gain a competitive edge. Alsulaiman's research on hydrogen fuel in aviation highlights the significance of utilizing novel resources to reduce environmental effect, hence strengthening the principles of RBV. Furthermore, empirical studies on strategic innovation and organizational success provide additional support for the RBV, indicating that companies that embrace innovative practices and environmental strategies achieve superior performance. This highlights the importance of RBV in comprehending how resources contribute to gaining a competitive advantage in rapidly changing business contexts.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

This study concludes that product innovation is crucial in determining how Kenya uses hydrogen fuel, as it provides potential to reduce costs, improve feasibility, and make improvements in the energy sector. These developments are in line with Kenya's objectives for developing the energy industry and contribute to the goal of environmental sustainability. In order to properly exploit these prospects, Kenya must build a strong policy framework that encourages and facilitates product innovation in the hydrogen fuel market. This framework aims to promote collaboration among stakeholders, assist research and development projects, and tackle obstacles to entering the market. Through the implementation of these measures, Kenya can expedite the acceptance of cutting-edge hydrogen fuel technology and enhance its standing in the worldwide energy shift.

This study also concludes that process innovation plays a vital role in improving the efficiency of hydrogen fuel usage in Kenya. Understanding of effective hydrogen generating techniques and superior production systems highlights the importance of focusing on process innovation. Kenya ought to formulate policies that give priority to process innovation in the hydrogen fuel industry, encourage the adoption of sustainable manufacturing methods, and allocate resources towards infrastructure development and capacity enhancement. Kenya can stimulate innovation, enhance energy efficiency, and encourage environmental sustainability by creating a favorable policy climate.

Ultimately, the empirical data significantly corroborates both Jevons' Paradox Theory and the Resource-Based View (RBV) Theory when examining the relationship between hydrogen fuel usage and strategic innovation. Jevons' Paradox Theory emphasizes the necessity of implementing efficient regulations to counteract unforeseen rises in resource consumption caused by investments in innovation, such as the widespread adoption of hydrogen fuel. The RBV Theory highlights the need of using resources such as hydrogen fuel strategically to gain a competitive edge. It emphasizes the connection between strategic innovation and organizational performance. Kenya can strategically harness its plentiful renewable energy sources to produce hydrogen fuel, hence decreasing reliance on fossil fuels. Kenya can improve energy security, reduce greenhouse gas emissions, and promote sustainable economic growth by implementing policies that support the development of renewable energy and the investment in hydrogen fuel production infrastructure. The reallocation of financial resources, which are saved due to reduced imports, into sectors like healthcare and security, serves to reinforce Kenya's socio-economic development objectives. To summarize, policy-oriented measures can assist Kenya in utilizing hydrogen fuel innovation to facilitate positive transformation and accomplish sustainable development goals.

RECOMMENDATIONS

From the study findings the following recommendations were made:

i. Kenya's government should give high priority to the formulation of policies that promote the growth of hydrogen generation and utilization. These policies should incorporate incentives to encourage research and development in hydrogen technology, along with laws that facilitate the widespread adoption of hydrogen fuel across many industries.
ii. In order to encourage private enterprises to invest in the hydrogen industry, the government of Kenya should offer incentives such as tax exemptions and financial support for initiatives connected to hydrogen. This will incentivize enterprises to allocate resources towards the development and implementation of cutting-edge hydrogen technologies and infrastructure.
iii. Kenyan Government should formulate policies to promote the growth of companies that can decrease dependence on imports of hydrogen-related products, such as ammonia fertilizer and methanol manufacturing, through industry diversification. Kenya may enhance its economy and decrease its reliance on imported commodities by fostering the growth of certain businesses within its own borders.
iv. Kenya should execute its green hydrogen strategy, as delineated by the Ministry of Energy and Petroleum. The primary purpose of this strategy is to formulate and implement policies and regulations that will facilitate the growth of the hydrogen economy. This will be achieved by addressing key areas such as enhancing the balance of payments, ensuring food security through the production of fertilizers, generating employment opportunities, mitigating climate change, and attracting investment.
v. To fully harness its economic potential of hydrogen fuel, Kenya should strive to replace imported items with locally created ones in order to promote hydrogen use. This encompasses the local production of fertilizer, the generation of hydrogen for use as shipping fuel, and the exportation of any surplus hydrogen to other countries.

Limitation of the Study

This study was constrained due to the early stage of hydrogen fuel research and development in Kenya. Nevertheless, the Ministry of Energy and Petroleum has provided a framework to build laws and legislation to assist the hydrogen economy starting with the 2023 roadmap for a green hydrogen strategy where

the first commercial production is expected to be in 2028 and highest peak in 2032 (European commission, 2023).

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