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RESEARCH ARTICLE

Transitioning to a Hydrogen Future: Analyzing Demand and Supply Dynamics in New Zealand's Transportation Sector

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Abstract: This study conducts a comprehensive literature review, analyzing academic articles, government documents, and reports from international organizations to discern trends in hydrogen fuel deployment for heavy transportation in New Zealand (NZ). It specifically assesses the current state-of-the-art technology, economic policies, and the impact of hydrogen fuel and fuel cell vehicles on decarbonization efforts and economic growth, acknowledging the influence of consumer preferences, diesel prices, and technological advancements on market demand. While recognizing the cost-competitiveness challenges these vehicles face, the research highlights the necessity of significant investments in infrastructure development. Methodologically, the study integrates economies of scale and technological learning rates to evaluate hydrogen fuel investment returns. Furthermore, this paper employs the Castalia-MBIE model for scenario analysis, revealing two key insights. First, it underscores the criticality of maintaining a favorable equilibrium between domestic and international production costs alongside hydrogen fuel consumption to bolster NZ's competitiveness on the global stage. Second, it highlights the pronounced vulnerability of fuel cell electric vehicles to supply-side influences as compared to demand-related variables. These insights contribute scientifically to understanding the economic dynamics of hydrogen fuel adoption and its implications for NZ's transport sector.

Keywords: hydrogen, heavy transport, fuel cell electric vehicles, scenario analysis, energy transition

1. Introduction

In the evolving discourse of sustainable energy transitions, New Zealand (NZ) stands as a proactive participant and it is evident in the country's endorsement of the Paris Agreement in 2016, which stipulates ambitious targets: a 30% reduction from 2005 greenhouse gas (GHG) emission levels by 2030, culminating in a vision of carbon neutrality by 2050 [1]. The path to these commitments is being diligently presented. At the heart of this strategy is NZ's Emissions Reduction Plan [1], an integrated approach which amalgamates efforts from key governmental agencies, including the Ministry of Transport, Ministry for Environment, and the Ministry of Business, Innovation and Employment (MBIE). Within this framework, hydrogen fuel emerges as a crucial element in the strategic plan to decarbonize the transport sector, marking a shift from theoretical considerations to actionable strategies. Despite the recognized potential of hydrogen as a sustainable energy vector, its widespread adoption faces multifaceted challenges. This research aims to thoroughly analyze these challenges, particularly in the transport sector, and explore the factors influencing the increasing demand for hydrogen compared to traditional fuels like diesel. It also seeks to identify and navigate infrastructural, technological, and economic barriers to hydrogen's mass production and deployment. Specifically, this research intends to address the subsequent pivotal research questions:

1) What factors contribute to the rising demand for hydrogen in transportation, and how does it compare with established alternatives such as diesel? An in-depth analysis of associated technologies, like electrolyzers, is essential.
2) While hydrogen's potential is evident, are there inherent infrastructural, technological, or economic impediments hindering its mass production and deployment? Identification and strategic navigation of these challenges are crucial.

Recognizing that a universal solution may not be effective, this study, fortified by an extensive literature review, seeks to delineate solutions tailored to NZ's distinct socio-economic and infrastructural context. By leveraging the Castalia-MBIE model, this study constructs potential scenarios, shedding light on the complex interplay between supply and demand in NZ's hydrogen landscape. The research contributes significantly by providing an empirically grounded and comprehensive framework to inform policymaking, guide stakeholders, and stimulate industry transformation. It plays a pivotal role in reinforcing NZ's trajectory toward a sustainable energy future, positioning hydrogen as a key driver in this energy transitioning journey.

The remainder of the study is organized as follows. Section 2 discusses hydrogen's demand dynamics, emphasizing its competition with diesel, its suitability for the heavy freight industry compared to battery electric vehicles (BEVs), and electrolyzer selection. This section also delves into various methodologies for measuring demand, referencing both academic research and models from global entities like the International Energy Agency (IEA). Section 3 investigates

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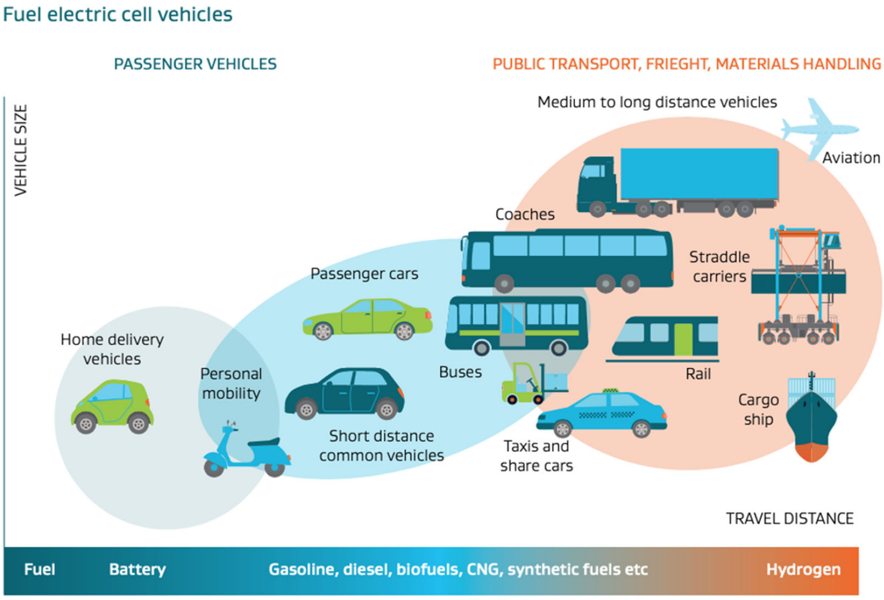
Figure 1
Vehicles that can be powered by hydrogen



hydrogen fuel production and its primary cost barrier. It emphasizes how the total cost of hydrogen in the heavy vehicle sector is affected by transport, storage, and delivery. Section 4 elaborates on the initial deployment and development of hydrogen infrastructure and vehicles. Section 5 presents scenarios for supply and demand in the NZ context, based on the Castalia-MBIE model, comparing these results with existing literature. The concluding section summarizes the findings and suggests directions for future research.

2. Demand for Hydrogen Fuel

To date, no standard method exists for estimating hydrogen fuel demand for heavy vehicles on a global scale, and NZ's exact hydrogen fuel needs remain uncertain. The nascent state of this energy source underscores the value of reviewing different methodologies. Perez et al. [2] estimated the hydrogen demand for very heavy vehicles (VHVs) at 71 million kg. In contrast, the Castalia-MBIE green hydrogen model projects a demand ranging from 195 million kg to 605 million kg. These discrepancies highlight the significant variations based on methodological approaches. Nevertheless, the increasing global trend underscores the growing demand for hydrogen fuel as a means of decarbonization. Most countries have ratified the Paris Agreement in 2016, indicating governmental support [3]. Furthermore, importing hydrogen could enhance European hydrogen production, supporting the rapid development of the European hydrogen economy [4].

Perez [5] evaluated the hydrogen fuel demand, factoring in hydrogen production technology readiness, which is contingent upon cost, efficiency, and electrolyzer commercial viability. The Ministry of Business, Innovation and Employment [6] focused on the energy consumption value across economic sectors, resulting in an "observed consumer energy demand". Another critical factor is the investment distribution between BEVs and hydrogen fuel cell vehicles (FCVs) for heavy vehicle fleet decarbonization. Currently, most of NZ's heavy vehicles use diesel; for hydrogen to dominate, it must be economically competitive.

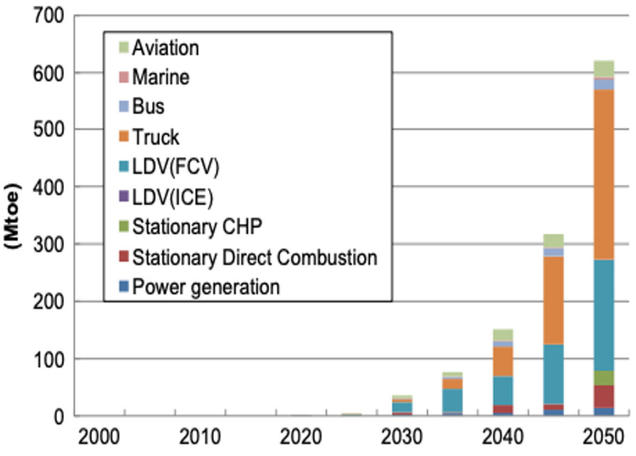
2.1. BEVs and FCEVs for heavy vehicle fleet

Figure 1 [7] shows that NZ's strategy to achieve net-zero emissions in the transport sector has a general direction to adopt hydrogen fuel for the heavy vehicle fleet [7]. BEVs face challenges for heavy vehicle fleets. Hydrogen fuel's higher energy density offers more favorable powertrain cost and weight attributes compared to BEVs [8]. This advantage is pivotal for heavy load-bearing vehicles with extended ranges. Fuel cell electric vehicles (FCEVs) also surpass BEVs in travel distance between refuels and have shorter refueling times. The weight and charging restrictions of BEVs curtail their freight capabilities [9]. Furthermore, FCEVs' refueling infrastructure mirrors that of conventional fuel systems [5], offering familiarity and ease. Despite the initial high costs, the practical benefits of FCEVs suggest a promising return on investment. NZ's strategy leans toward FCEVs for heavy-duty trucks and BEVs for light-duty vehicles, potentially suitable for public transport and freight. Additionally, the Hydrogen Council [10] suggests that while all land vehicles could utilize hydrogen, medium to heavy vehicles would benefit the most due to extended ranges and reduced refueling times. Current projections [11] indicate that by 2025, large battery and fuel cell technologies would not be as cost-effective as battery tech for medium to heavy trucks. The adoption rate for BEVs in long-range heavy fleets hinges on potential limitations, which could become moot with battery tech advancements. Both tech types have similar developmental trajectories, with their prevalence contingent on technological breakthroughs and cost-reduction rates [12].

2.2. Diesel and hydrogen fuel for heavy vehicle fleet and international demand

In 2019, diesel cost $1.22 NZD/liter in NZ, while hydrogen was about NZD $11.2/kg [9]. With hydrogen costing an estimated $0.48 more per km and heavy trucks covering three billion km annually,

Figure 2
World hydrogen demand structure



hydrogen trucks would incur an extra $1.44 billion in yearly fuel costs. These figures do not account for market fluctuations or potential subsidies. Refueling times for both hydrogen and diesel trucks are roughly 7 min, with hydrogen trucks having a range of 400 km per 30 kg tank without significantly affecting weight [5].

The global green hydrogen demand is growing. Countries like Japan are searching for cheaper hydrogen sources due to high domestic production costs. NZ, rich in natural resources, is emerging as a significant supplier, with projections of exporting 70 million tons annually, expected to rise further by 2030 [7]. Cuda et al. [13] predict a global demand of 621 million tons by 2050, mainly in transportation. Major economies, including the USA, China, and India, will dominate consumption. By 2050, green hydrogen could save up to 296 billion NZD annually. As countries diversify energy sources, metrics like the Herfindahl–Hirschman Index will capture these shifts.

2.3. Demand for hydrogen fuel and its application in buses and heavy fleets

The growing interest in hydrogen fuel's application in the transportation sector promises significant economic and environmental dividends. Research underscores the potential of hydrogen propulsion in substantially curbing carbon emissions. For instance, the Canadian study by Cuda et al. [13] evaluated the impact of hydrogen utilization across various transportation types. Their results demonstrated that even with a modest market share for hydrogen-powered vehicles, significant emissions reductions could be achieved. Specifically, vehicles under 4,500kg registered a notable drop in emissions. In scenarios where hydrogen vehicles secured just 15% of the market share, carbon emissions fell by an impressive 10%.

These findings suggest a positive trajectory for hydrogen's adoption. Projected hydrogen demand showcased an upward trend, with consumption for vehicles under 4,500 kg anticipated to jump from 19 kilo tons in 2009 to a staggering 240,000 tons by 2020. In essence, a relatively small increase in hydrogen market share could lead to meaningful emissions reductions, negating the need for a vast portion of the production mix to come from low-carbon methods. Closer to home, a NZ study by Perez [5] zeroed in on hydrogen demand for VHVs, those weighing over 30 tons. Using data from MBIE reports, the study projected an annual green hydrogen demand of 71 million kg for VHVs. This projection was based on the logic that hydrogen production would equate to diesel fuel consumption in these vehicles. To arrive at this, the study considered the diesel demand of VHVs and an established fuel consumption rate of 43 litres per 100 km, as identified by Collier et al. [14].

$$\textit{Travel distance} = \textit{Diesel demand}\ (\textit{in litres}) \times \frac{100\ km}{43\ litres}\ (km)$$

The study estimated the green hydrogen demand from the calculated travel distance and an assumed constant consumption rate for hydrogen-powered VHVs:

$$\textit{Net hydrogen demand} = \textit{Travel distance} \times \frac{8\ kg}{100\ km}\ (kg)$$

Furthermore, using the Quantum Geographic Information System, the research identified Auckland as the region with the most pronounced demand for green hydrogen, as illustrated in Figure 4.

Liu et al. [15] analyzed hydrogen demand for FCVs in Ontario, focusing on three hydrogen FCVs market penetration scenarios as Figure 5 [15] shows. Using data from the GM Equinox hydrogen FCV pilot of 100 vehicles, they projected the FCV count based on Ontario's annual new vehicle sales, adjusted for predicted hydrogen FCV market shares. By 2025, scenarios suggested 4% to 15% market shares, and by 2050, over 90%. These scenarios represent conservative, moderate, and optimistic outlooks for 2015, 2025, and 2050.

Figure 3
(a) World stock and (b) energy consumption of trucks

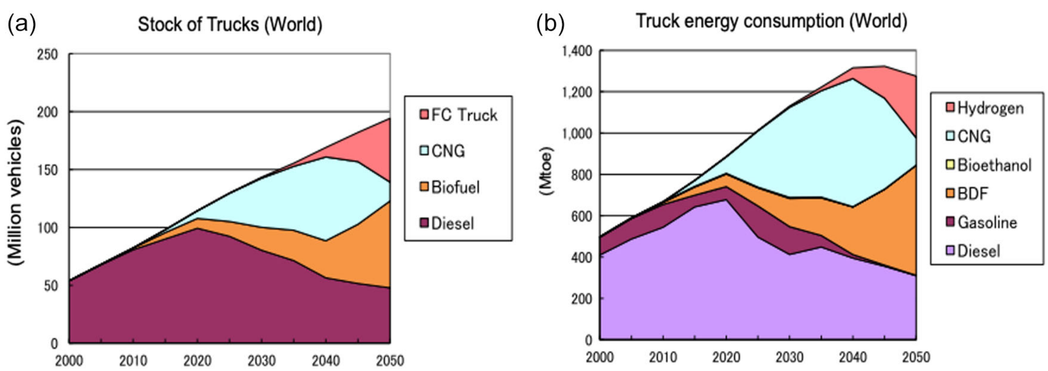
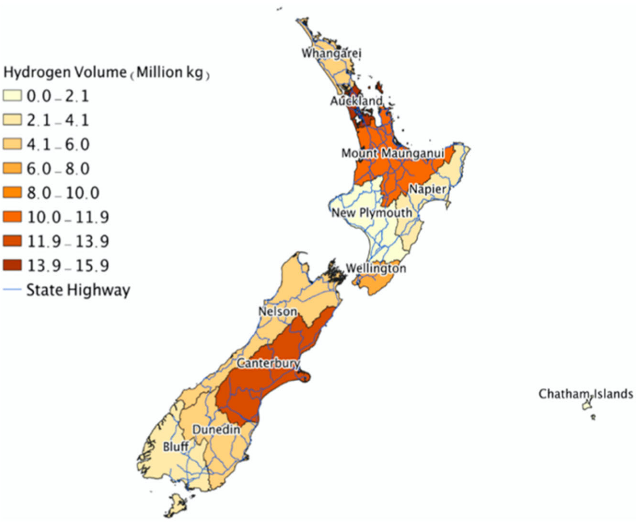


Figure 4
Regional demand for hydrogen fuel

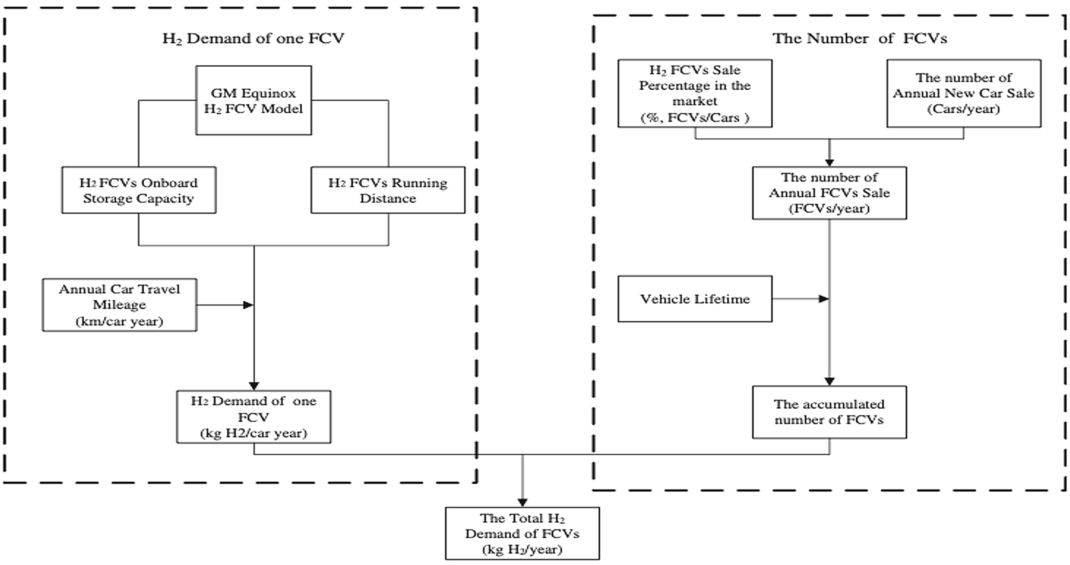


3. Supply

3.1. Economics of hydrogen fuel production

NZ is working to boost green hydrogen supply, essential for decarbonizing its heavy freight industry. However, producing green hydrogen, derived from water electrolysis, is costlier than using fossil fuels. The production cost hinges on renewable energy prices, plant efficiency, and the chosen electrolyzer type. Scaling up green hydrogen production could strain NZ's electricity network due to increased demand [17]. To manage this, there is a need to balance current electricity supply-demand and explore investments in renewables like wind energy. Optimizing green hydrogen plant designs and electrolyzer operations can also help reduce expenses. NZ's green hydrogen sector is still emerging. The country's inaugural green hydrogen plant, a collaboration between Tuaropaki Trust and Obayashi Corporation, began in 2021 in Taupo.[1] Powered by the neighboring Mokai geothermal plant, it showcases NZ's potential to leverage its rich renewable resources for hydrogen fuel production in transport.

Figure 5
Flow chart of hydrogen demand estimation model



According to this calculation, the hydrogen demand of FCVs and the number of FCVs both followed the same trend, i.e., they did not diverge. Therefore, the overall demand was projected to remain very low in scenario 1 and quickly rose during scenario 2 and reached the highest level in scenario 3 (see Figure 6 [15]).

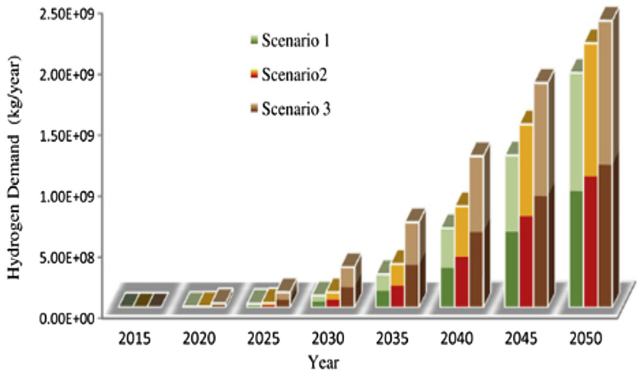
Liu et al. [15] and Perez [5] differ in their approach to hydrogen demand. Perez evaluates the potential of hydrogen as an alternative to diesel, whereas Liu assesses the shift to hydrogen FCVs based on yearly new vehicle sales. The IEM's world energy model, as referenced by International Energy Agency [16], gauges demand using factors like income and regional attributes. Ultimately, the method chosen depends on the research objective and country-specific contexts.

3.1.1. Hydrogen production methods

The IEA reports that most hydrogen fuel is derived from fossil fuels, leading to notable CO_2 emissions. Clean hydrogen emerges from renewable sources, nuclear, or fossil fuels using carbon capture (CCUS). While hydrogen primarily serves refining and chemical sectors, it represents 6% of global natural gas and 2% of coal use. Yukesh Kannah et al. [18] state that 96% of hydrogen originates from non-renewables, with only 4% from water electrolysis. Economically, steam reforming of natural gas stands out as cost-effective and efficient for hydrogen

[1] Scoop. *New Zealand's first green hydrogen plant begins production*. https://www.scoop.co.nz/stories/BU2112/S00257/nzs-first-green-hydrogen-plant-begins-production.htm

Figure 6
The projection of hydrogen demand from on-road FCVs in Ontario



production, even though it relies on non-renewable inputs like methanol and emits substantial CO_2.

The choice of electrolyzer technology affects cost, efficiency, and demand. Current advancements in electrolyzers make demand predictions challenging, contingent on various assumptions. Alkaline electrolyzers, due to their market maturity, dominate commercial applications, despite potential safety issues. Polymer electrolyte membrane (PEM) electrolyzers, which address these issues, are anticipated to grow in prominence [19]. Both the type of electrolyzer and renewable electricity sources influence the energy needed for hydrogen production [5]. Water electrolysis, which divides water into hydrogen and oxygen using electricity, yields no carbon emissions. Yukesh Kannah et al. [18] confirm this technique's commercial maturity in some countries. Traditional grid electrolysis emits GHGs, so the shift is toward renewable-sourced electricity, like wind. Pairing wind energy with PEM electrolyzers could enhance hydrogen production efficiency by 4.5 times. Costs for PEM-based electrolysis are cited at $11.76/kg of hydrogen [20]. Alkaline water electrolysis, another mature method in Europe, costs approximately $6.12/kg in Germany, with slightly higher costs in Austria and Spain due to elevated electricity prices [18].

3.1.2. Hydrogen fuel production cost components

Green hydrogen, seen as a leading low-carbon solution, is predicted to become cost-competitive against conventional alternatives. However, this cost parity is influenced by regional energy prices, infrastructure readiness, and policy frameworks [11]. The alkaline electrolyzer is fully commercialized, while PEM electrolysis is mostly used for applications under 300 kW [21]. While most cost components for different electrolyzers are similar, utilization rates can vary. Production costs for water electrolysis are split between CAPEX (e.g., plant and electrolyzer) and OPEX (e.g., electricity). Factors like production technology, system design, and energy resources affect these costs [2]. Research emphasizes that the capital cost of electrolyzers and operational electricity costs are the major influencers of production costs [2]. Further details on transport-related production costs will also be explored.

3.1.3. Capital and operational expenditures

CAPEX for hydrogen production primarily involves investments in the electrolyzer and production plant [22]. Policies focus for promoting hydrogen fuel cells in heavy vehicles will be on CAPEX, especially during initial rollouts [23]. With economies of scale, water electrolysis capital costs are expected to decline rapidly over the next 10–20 years [2]. By 2020, the capital cost gap between PEMEC and other electrolyzers had already narrowed significantly due to PEMEC's operational flexibility and technological advancements [24].

The utilization rate, which represents the ratio between estimated and maximum electrolyzer capacity, affects capital expenditure and overall hydrogen cost. Dedicated renewable energy sources like wind typically have low utilization rates due to energy fluctuations [9]. Yukesh Kannah et al. [18] found that an electrolyzer utilization of 3000–6000 h minimizes production costs. Cost and performance improvements for PEMEC are projected to come from standardization and production scale-up [24]. The US Department of Energy's Energy Earthshot initiative, launched in 2021, aims to cut clean hydrogen costs by 80% to $1/kg in a decade, primarily through electrolysis that, when coupled with renewable electricity, emits no GHGs.

While many nations currently use non-renewable electricity for hydrogen production, this method is not ideal due to its GHG emissions and inefficiency. The production costs of using renewable (e.g., wind, solar) and nuclear energy for hydrogen need to decrease to compete with established carbon-based methods like natural gas reforming. Several studies [2, 25] have explored wind-based electricity for hydrogen production, suggesting areas where electricity is not fully utilized could benefit from wind-powered refueling stations or hydrogen production. The size of the electrolysis system is determined by CAPEX, while its full-load hours, maintenance, and operation costs contribute to OPEX. Research over the last decade confirms that electricity cost will significantly influence green hydrogen production costs [2]. The US Department of Energy's recommendations for enhancing hydrogen production, applicable to NZ as well, includes:

1) Better understanding electrolyzer systems' performance, cost, and durability using carbon-free electricity.
2) Reducing electrolyzer unit capital costs and improving system efficiency.
3) Enhancing the efficiency of electricity-to-hydrogen conversion across diverse operating conditions.

3.1.4. Wind energy for electrolysis

Song et al. [26] conducted a techno-economic analysis on the feasibility of supplying Japan with green hydrogen produced from offshore wind in Chinese coastal provinces. The study optimized investment and hourly operations against the unpredictability of offshore wind. It concluded that China could meet Japan's projected hydrogen needs both in volume and cost. Meanwhile, Siyal et al. [27] found that Sweden's wind energy, specifically from V-112 turbines and PEM electrolyzers, could generate 25.6 million tons of hydrogen annually. Using just a fifth of this amount could halve gasoline and carbon emissions. Northern Sweden, with its expansive land and fewer restrictions, could produce more wind-generated hydrogen than the south, although transporting this hydrogen southward requires significant infrastructure. While in NZ, underutilized renewable energy resources exist. By examining the hydrogen supply chain models from China to Japan and the wind-powered hydrogen technologies in China and Sweden, NZ could harness its renewable potential. China's offshore wind, concentrated in its special economic zones with shallow waters under 60 m, offers cost savings and can generate roughly 12 petawatt hours of electricity yearly, four times its projected 2050 demand. This suggests significant potential for green hydrogen production.

3.2. Economics of hydrogen fuel transportation, storage, and delivery

Transportation costs can significantly influence the overall price of hydrogen fuel. Centralized electrolysis plants can reduce hydrogen production costs due to economies of scale, but they also increase transportation expenses [22]. The US-based Argonne National Laboratory's Hydrogen Delivery Scenario Analysis Model tool showed that hydrogen transport costs were $7.18/kg for a 100km pipeline, $4.88/kg for 293 km by compressed gas truck, and $4.81/kg for 283 km by liquefied hydrogen truck [28]. Ajanovic and Haas [29] determined that the most cost-effective large-scale delivery method is via pipelines at $2.73/kg, which also happens to be the most environmentally friendly option. The levelized transport cost of hydrogen depends on capacity, distance, and associated costs such as compression, storage, and transportation. Lahnaoui et al. [30] demonstrated that this cost diminishes with increased capacity and rises with greater distance, peaking around 350 km due to labor expenses.

For the transportation sector, the cost dynamics change based on storage requirements. Hydrogen costs can vary considerably depending on whether it is stored in a moving vehicle or at refueling stations. Rath et al. [22] detailed that with a 35 megapascal pressure, vehicles could store 7.3 kg of hydrogen, 2.5 times more than a conventional tank at the same pressure. Additionally, tanks can rapidly recharge to 80% in 5 min, and at temperatures as low as −30 °C, they can effectively supply hydrogen. Such technological progress could shift the economic landscape of hydrogen use in heavy vehicles.

3.3. Economics of hydrogen fuel application in road transport: Heavy truck fleets

Hydrogen trucks, while environmentally promising, currently lag in cost-competitiveness compared to traditional trucks, mainly due to high upfront costs and risks linked to the nascent hydrogen fuel cell technology. Despite these challenges, NZ has started embracing hydrogen vehicles. Hyundai NZ introduced its first hydrogen-powered truck in November 2021, and Auckland Transport piloted a hydrogen fuel cell bus in March 2021. Hydrogen FCVs face pricing challenges against diesel, compressed natural gas, and hybrid vehicles. As Concept Consulting [9] noted, while a heavy diesel truck costs around $175,000, a fuel cell counterpart reaches $500,000. Li and Kimura [23] found that even with increased hydrogen production from renewables, FCEVs struggle to compete with conventional gasoline or diesel vehicles, primarily due to high per-km fuel costs. Their study, however, was hopeful that if capital and hydrogen production costs halve, FCEVs' total cost of ownership could compete with traditional vehicles.

Perez [5] highlighted successful hydrogen vehicle initiatives in NZ, such as Toyota's heavy-duty vehicle with a 321 km range and commercial hydrogen trucks by ESORO and Hyundai. Comprehensive data on this subject are detailed in Table 1. A potential avenue to improve hydrogen vehicle economics is customization for specific needs. As Kast et al. [31] observed, many medium and heavy-duty vehicles can accommodate hydrogen storage without compromising on space or weight, making them suitable for longer ranges.

Table 1
Technical specifications of the hydrogen trucks from ERSORO and Hyundai Motors NZ

Parameters	Hyundai fuel cell truck	ESORO fuel cell truck
Gross vehicle weight	34 t	34 t
Driving range	approx. 400 km	375–400 km
Hydrogen consumption	8.2 kg/100 km	7.5–8.0 kg/100 km
Tank capacity	32.86 kg H2	34.5 kg H2
Tank pressure	350 bar	350 bar

4. Initial Deployment and Development of Hydrogen Infrastructure and Vehicles

The expansion of hydrogen FCVs hinges on the availability of refueling infrastructure, particularly for heavy trucks. Conversely, the development of this infrastructure is contingent on the broad adoption of hydrogen vehicles, encapsulating the "chicken or egg" dilemma [32]. Current literature, based on both qualitative and quantitative research, advocates for a greater investment in infrastructure, including production plants and refueling stations. Köhler et al. [33] emphasized this, stating that at least 500 stations, costing 200 million euros in urban areas, are essential for hydrogen vehicles to gain traction in Europe. Their study revealed that although hydrogen vehicles initially cost 20% more than conventional vehicles, their price decreases as demand escalates.

MBIE's green paper underscores the economic significance of infrastructure, highlighting opportunities to synergize hydrogen generation and refueling points across heavy industries. NZ is making strides in this arena, with plans for eight refueling stations spanning both North and South Islands, promising coverage for 95% and 82% of heavy-duty routes, respectively. Notably, Hiringa, a NZ energy firm, is integrating these stations with renewable energy sources [34]. The success of hydrogen infrastructure in nations like the USA, Japan, and South Korea offers guidance for NZ's advancements [35]. Comprehensive road transport infrastructure can catalyze hydrogen's replacement of diesel in sectors like maritime and rail, due to the advantage of quick refueling and greater energy density [36] (see Figure 2).

Liu et al. [37] examined fuel cell electric trucks (FCETs), determining their market viability by comparing incremental vehicle costs to FCET technology targets. Their study found that for 10% FCET market penetration, 79% of stations along major interstates are necessary. A key insight was the inverse relationship between station costs and shipment demand.

In the EU, an assessment spanning 15 years explored the commercial viability of hydrogen refueling stations [38]. Profitability was tethered to return on investment, with positive net present values emerging in the latter half of the program. Similarly, NZ is launching a 15-year emissions reduction scheme. Switzerland's case demonstrated that increasing refueling stations and daily refueling opportunities could potentially result in a 100% switch to FCEVs.

The "chicken or egg" situation in hydrogen transport deployment demands robust refueling infrastructure, which can influence the broader energy sector [36]. The IEA's world energy model, comprising two sub-models, gauges this situation, quantifying the advantages of expanding infrastructure for hydrogen fuel distribution. As hydrogen's share in energy consumption rises, costs for FCVs and distribution diminish. An upsurge in FCVs also optimizes the refueling network, making it more cost-effective. This cyclical relationship suggests that either starting point—infrastructure or vehicle adoption—does not substantially impact the eventual benefits.

5. NZ's Quantitative Model

This section conducts a scenario analysis based on the Castalia-MBIE model to examine the influencing factors that impact hydrogen technology adoption. Commissioned by the NZ government, the Castalia-MBIE model was crafted by Castalia[2], a globally recognized consultancy serving corporations, utilities, governmental bodies, international agencies, and infrastructure investors, to inform the NZ Hydrogen Roadmap. This model investigates the various factors influencing the uptake of hydrogen technology. It integrates parameters and assumptions based on a detailed presentation by Castalia for the Green Hydrogen Program NZ [39], with energy price references drawn from Ministry of Business, Innovation and Employment data [35]. More information on the Castalia-MBIE model is available in Appendix B.

Castalia-MBIE model consists of three sections: assumptions and variables for NZ hydrogen production, heavy vehicle demand assumptions and variables, and international exporter in hydrogen production assumptions and variables. This model has a base case with default levels for all parameters in each of the three sections; this base case and the benchmark price figures are underpinned by empirical data on capital and operating costs from existing commercial projects, current literature, and authoritative sources [39].

5.1. Scenario analysis of the Castalia-MBIE hydrogen supply and demand model

A scenario analysis using the dashboard for this model remains insightful regarding the relationships between various factors discussed in this literature review so far.

The base case presented in the dashboard serves as a neat introduction to this model and its underlying assumptions. The base case is retrievable by clicking on the "reset to base case" in the dashboard. The variables for domestic and international hydrogen production both assume an average electricity cost of $61 per MWh, electricity price change of −0.25%, and electrolyzer utilization factor of 41.5% for NZ in 2020. Domestic consumption of green hydrogen in the heavy vehicle fleet is projected to increase significantly from 2046, reaching approximately 60 tons a year later and remaining at this level until 2050, which is the end of the timeline in this model. However, it should be noted that the demand assumptions and variables also influence consumption, although this is assumed to be a consequence of a shift in the demand curve. NZ is likely to produce hydrogen for domestic use only rather than becoming an importer or exporter. In 2020, NZ's levelized cost of green hydrogen is competitive against the benchmark of international exporter and Australia, where the international exporter's levelized cost of green hydrogen is approximately $0.74 per kg more expensive than NZ's levelized costs. By 2050, NZ, Australia, and Canada are projected to reach a similar levelized cost which is $0.74 per kg lower than that of the international exporter. As a result, the rise of export of hydrogen from NZ would arguably require a higher price margin than $0.75 per kg.

On the demand side, the model calculates using changes in truck and bus capital cost per annum as well as changes in diesel prices. The base case uses the assumptions of 5% decrease in capital cost per annum for hydrogen fuel cell and −2.5% for battery electric, and 3% increase for diesel price change. The total number of hydrogen heavy vehicles is modeled to increase significantly by 2032, reaching approximately 190 thousand by the end of 2050.

[2]https://castalia-advisors.com/about/

Four scenarios:

1) NZ will have high supply and high demand of hydrogen fuel domestically.
2) NZ will have high supply and low demand of hydrogen fuel domestically.
3) NZ will have low supply and low demand of hydrogen fuel domestically.
4) NZ will have low supply and high demand of hydrogen fuel domestically.

All scenarios are further compared to two cases if NZ is more/less competitive against other international exporters. In particular, if an "international exporter" can produce green hydrogen at a lower cost, then NZ is likely to be an importer or producing green hydrogen for domestic use only, and vice versa.

5.1.1. NZ's domestic conditions in high and low supply

In the model, a major cost is the cost of electricity used to produce and supply green hydrogen. Currently, grid powered is the most available source of electricity for hydrogen production. The model also assumes largely grid power and reflects the scarce source of renewable electricity; hence, the base case assumes $61 per MWh. With this assumption and using wind energy as the renewable source of electricity and MBIE's EDG, the low and high levels will be set according to the commercial standards. A low case for hydrogen production should range between $70 and $80 per MWh, which is the long run marginal cost of wind energy as provided by the NZ wind energy association. MBIE's scenario analysis of electricity in 2019 also similarly notes $75 per MWh as the long run marginal cost for its base scenario. However, the model's base case assumed $61. To stay true to the scenario analysis for a low supply case, $55 per MWh will be used. An appropriate estimation of a high supply of hydrogen production could be the average cost for industrial electricity in NZ for 2021, which is $159 per MWh, with a 16.4% increase from 2020 [40]. In total, $150 will be used for the case of high supply as that is the maximum price available on the dashboard.

Fifty percent utilization rate is chosen for the low supply scenario. This is based on the average load factor of new wind in NZ[3]. The high supply will adopt a utilization rate of 85%. Eight-five percent utilization rate was used as an assumption by Concept Consulting [9] and in a GRAPE model by Ishimoto et al. [41] (see Figure 3). This indicates that 85% is possible in the best-case scenario of technological advancements.

5.1.2. NZ's domestic conditions in high and low demand

As shown in the base case, hydrogen will be in higher demand if the capital cost per annum of electricity or diesel price increases at a faster rate. As discussed above, it is well established that battery electric technology is unlikely to be adopted for the heavy vehicle fleet or the heavy freight industry. The capital cost annum of battery electric can be appropriate at a decreasing rate of −2.5%. The presentation of the model stated the key assumption was diesel prices rise at 3% annually for the base case, 5% at the high case (high demand) case, and 0% at the low case (low demand). To keep true to all assumptions of the existing dashboard and model, 5% and 0% will be adopted for the cases of high demand and low demand, respectively.

The hydrogen fuel cell truck and bus capital costs are set to decrease at a rate of 5% per annum. The specific methodology for the demand size in this model is unique and has not been adopted widely in the literature. Therefore, it would be inappropriate to

[3]New Zealand Wind Energy Association. *Wind generation in New Zealand*. https://www.windenergy.org.nz/generation#:~:text=On%20an%20annual%20basis%2C%20New,the%20highest%20in%20the%20world

Table 2
Hydrogen fuel cell truck and bus capital cost change per annum

Hydrogen fuel cell truck and bus capital cost change per annum	Consumption of green hydrogen in NZ	Composition of NZ heavy vehicle fleet
−7%	The consumption level increases from 2030 to 2050 and the amount of hydrogen consumed in 2050 is 390,000 tons	The number of hydrogen vehicles increases from 2031 to 2050 and in 2050, there are 80,000 FC vehicles
−5%	The consumption level increases from 2034 to 2050 and the amount of hydrogen consumed in 2050 is 200,000 tons	The number of hydrogen vehicles increases from 2033 to 2050 and in 2050, there are 35,000 FC vehicles
−3%	The consumption level increases from 2036 to 2050 and the amount of hydrogen consumed in 2050 is 170,000 tons	The number of hydrogen vehicles increases from 2036 to 2050 and in 2050, there are 10,000 FC vehicles

use external literature in justify the changes of this parameter for the high and low demand in this scenario analysis. Table 2 is a test of the dashboard with a 2% change increase and decrease from 5% to inform how sensitive the overall demand is specifically to the parameter of hydrogen fuel cell truck and bus capital cost. The results show demand is very sensitive to the capital cost of hydrogen FC trucks and buses. A 2% change increase per year for 20 years will bring 190,000 more tons of consumption of green hydrogen in heavy vehicles and 45,000 more FC vehicles. Note the Gas Pipeline blending assumptions and variables are kept the same as the base case in all four scenarios.

5.1.3. International conditions for supply

If Australia, Canada, the USA, or the "international exporter" can produce hydrogen at a lower cost, then NZ is likely to be an importer or produces hydrogen solely for domestic use, and vice versa. In the case NZ is exporting, this scenario is referred to as the "competitive case," while situations where NZ is importing or producing exclusively for domestic use will be referred to as the "less competitive case". The international export/import question has the same production assumption and variables as NZ's domestic production in this model. In the competitive case, the utilization factor and electricity cost will adopt values from NZ's domestic conditions for a low supply of hydrogen fuel. The less competitive case will adopt the values from NZ's domestic conditions for a high supply of hydrogen fuel.

5.2. Results and discussions

Section 5.1 systematically executed various scenarios through a dashboard analysis, comparing NZ's competitiveness in the green hydrogen market against international exporters. The scenarios are classified into two categories based on NZ's market competitiveness: scenarios where NZ is more competitive (Scenarios 1 and 2) and those where it is less so (Scenarios 3 and 4). Findings from Scenarios 1 and 2, characterized by high hydrogen supply, suggest that NZ is poised to become an exporter of green hydrogen due to favorable domestic conditions compared to international markets. Interestingly, demand fluctuations appeared to have a minimal impact on this trend. Conversely, in Scenarios 3 and 4, marked by lower hydrogen supply, NZ may lean toward importing green hydrogen, as domestic conditions are less favorable for competitive export. This inference is corroborated by the dashboard's levelized cost analysis, indicating that NZ's export potential hinges on maintaining lower production costs than its international counterparts.

The research further reveals that in Scenario 1, where NZ's levelized cost of green hydrogen is competitively low, the country is predicted to export, especially when international market conditions are not favorable for exportation. Scenario 1 also shows the highest consumption of green hydrogen fuel, particularly in heavy vehicles and natural gas blending, reaching nearly 450 tons. However, in Scenario 2, a decrease in demand precipitates a notable reduction in hydrogen fuel consumption for heavy vehicles. Scenario 3, characterized by low supply and demand, sees major consumption in heavy vehicles, while Scenario 4, marked by low supply but high demand, indicates negligible consumption of green hydrogen.

These outcomes underscore the necessity for strategic investments and policy interventions, particularly to address the technological and economic challenges inherent in transitioning to a hydrogen economy. Empirically, the study concludes that NZ's competitiveness in the green hydrogen market is contingent on maintaining a substantial margin between domestic and international production costs. Furthermore, the consumption patterns of hydrogen fuel and FCEVs demonstrate greater sensitivity to supply-side variables compared to demand-side factors. Supporting data, including tables and figures from the scenario analysis and dashboards, are detailed in the Appendix. The study also notes that the levelized cost of hydrogen production is significantly influenced by the cost of electricity, as noted by Perez et al. [2] as well as Li and Kimura [23]. In NZ, where renewable sources contribute to 80% of the electricity mix, the price of electricity is closely tied to seasonal rainfall patterns due to its reliance on hydroelectric systems [42, 43]. Shirizadeh et al. [44] also discovered that the optimal power mix is highly sensitive to the selected weather-year data. de Guibert et al. [45] introduced a variable time-step optimization model designed to meet the need for fine temporal resolution while handling long periods of weather data in an energy system heavily reliant on renewable energy sources. The current Castalia-MBIE model does not account for these weather and seasonal variations, which presents a limitation in its predictive accuracy. Consequently, future research should focus on validating the simulations and scenario analyses of the Castalia-MBIE model. This process should consider weather conditions and incorporate alternative modeling frameworks, such as the energy system optimization model developed by Shirizadeh and Quirion [46], to ensure a comprehensive validation that enhances the robustness of the findings.

6. Conclusion

Hydrogen fuel cell technology presents a transformative potential for NZ's transport sector, particularly in heavy-duty vehicles. This study provides a comprehensive economic analysis of hydrogen's path, comparing fuel cell technologies with BEVs and conventional diesel. While FCEVs currently bear higher costs, technological advancements, such as lightweight batteries, could alter the economic landscape. Although diesel remains cost-effective, its long-term viability is threatened by forecasted price increases. Globally, regions including the USA, China, Western Europe, and India are leading in hydrogen fuel demand, driven not only by environmental benefits but also by economic incentives like job creation. The economic feasibility of green hydrogen production hinges on the capital costs of electrolyzers and the variable prices of renewable electricity. NZ, with its substantial wind energy resources, is strategically positioned to mitigate these costs through energy efficiency improvements and a robust strategy for hydrogen transportation, storage, and distribution.

Our study highlights a critical roadway for NZ, pinpointing the integration of hydrogen energy into the transport sector as a catalyst for economic and environmental transformation. With projections indicating a decline in hydrogen-related costs, contingent on renewable electricity pricing and technological advancements, NZ faces a decision on infrastructure development. Our recommendation advocates for a balanced focus on both refueling stations and vehicle deployment to maximize benefits. The results from our scenario analyses suggest that NZ, leveraging its distinctive domestic resources, could become a notable player in the international hydrogen market, fostering broader economic expansion. This research underscores the opportunity for NZ to lead in creating a hydrogen-centric economy, pivoting on its abundant renewable energy resources. To actualize this vision, a cohesive national strategy involving public–private partnerships, hydrogen research incentives, and infrastructure investment is imperative, setting the stage for a sustainable and economically vibrant hydrogen future.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The data that support the findings of this study are openly available in New Zealand Wind Energy Association at https://www.windenergy.org.nz/generation#:~:text=On%20an%20annual%20basis%2C%20New,the%20highest%20in%20the%20world.

Author Contribution Statement

Mingyue Selena Sheng: Conceptualization, Formal analysis, Investigation, Data curation, Writing – review & editing, Supervision, Funding acquisition. **Le Wen:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Beryl Tan:** Methodology, Software, Validation, Formal analysis, Investigation, Writing – original draft, Visualization. **Stephen Poletti:** Conceptualization, Writing – review & editing.

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Appendix A

Table A1
A summary of selected studies

References	Case study/countries	Model, key considerations, and limitations
Shirizadeh and Quirion [46]	France	The EOLES_elec_H2 model is part of the EOLES (energy optimization for low-emission systems) series, focusing on energy solutions with low emissions. It is designed to find the most cost-effective mix of energy production and storage options to meet hourly electricity demand over a year, under the condition of achieving net-zero CO_2 emissions. It is applicable for exploring questions related to energy policy but operates based on linear optimization techniques
Shirizadeh et al. [4]	Europe	An energy system optimization model and a hydrogen import model are employed to examine the impact of methane leakage on the role of natural gas in the European energy transition. Findings suggest that hydrogen plays a key role in the shift from fossil fuels under the European net-zero target and importing hydrogen can complement European hydrogen production and sustain the ambitious development of the European hydrogen economy. One limitation of this study is that the cost of methane abatement was not endogenously incorporated into the model. As a result, this omission may lead to an unaccounted-for increase in the price of natural gas in the Best Available Technologies (BAT) scenario when compared to the current emissions (CEF) scenario
Shirizadeh et al. [44]	France	The EOLES_elec_H2 model is used to optimize investment and dispatch of renewable energy and storage technologies subject to meet hourly demand. It suggests that the optimal mix is sensitive to the specific weather year selected and the assumptions made about costs
Shirizadeh and Quirion [3]	France	The EOLES_elec_H2 model considers only the power sector. It is used to investigate the role of different emission technologies. Hydrogen options were excluded due to the computation time of the model
de Guibert et al. [45]	France and Germany	The study introduces a variable time-step model designed to meet the need for fine temporal resolution while handling long periods of weather data in an energy system heavily reliant on renewable energy sources. In the case studies, hydrogen is treated as a form of long-term storage. The results demonstrate a significant reduction in optimization time, approximately by a factor of 60. This study suggests that the variable time-step model is a valuable tool for future research due to its accuracy and efficiency in model execution
Ajanovic and Haas [29]	EU	Literature review
Li and Kimura [23]	ASEAN countries	Well-to-wheel model to capture energy supply and consumption process, costs, and emissions; total cost of ownership model to access cost of owning and driving a vehicle
Perez et al. [2]	NZ	Assessment of green hydrogen fuel for the very heavy vehicle fleet by establishing demand, size of renewable energy sources available, and determining the price
Song et al. [26]	China	Optimization model for least-cost hydrogen delivery for delivering hydrogen between China and Japan; linear regression model used
Chapman et al. [47]	Global (Japan as case study)	Dynamic New Earth to consider energy system at the global level, studies stakeholder engagement using Japan as a case study
Lahnaoui et al. [30]	France and Germany	Mathematical model: find the optimum combination of CGT at different pressure levels to transport hydrogen at the minimum cost for different trip distances and different hydrogen flow demand
Liu et al. [37]	USA	Hydrogen Delivery Scenario Analysis Model (HDSAM) and Heavy-Duty Refueling Station Analysis Model (HDRSAM); feasibility of fuel cell trucks based on infrastructure deployment
Ajanovic and Haas [48]	Not applicable	Dynamic assessment of hydrogen production by electrolysis using surplus electricity from RES investigates production costs and learning effects of fuel cell vehicles
Kast et al. [31]	USA	Novel model to calculate the mass of stored hydrogen and storage tanks using vehicle simulation models to estimate fuel economy
Papadopoulos et al. [49]	Global	Global linear optimization model; Dynamic New Earth (optimization model) uses a 15 MW PV park to combine wind power and battery storage
Ishimoto et al. [41]	Japan	Global and long-term intertemporal optimization energy model (GRAPE) applied to analyze the significance of green hydrogen in terms of global energy system costs and observes effects on a localized region such as Japan
Iordache et al. [38]	Europe Union	Uses a tool distributed by Fuel Cell Joint Undertaking which displays key business case outputs of roll-out for hydrogen refueling stations
Schmidt et al. [24]	Global	Expert elicitation
Siyal et al. [25]	Sweden	Hybrid Optimization Model for Electric Renewable (HOMER) to analyze standalone wind-powered hydrogen refueling stations at three selected sites in Sweden

(*Continued*)

Table A1
(*Continued***)**

References	Case study/countries	Model, key considerations, and limitations
Siyal et al. [25]	Sweden	Geographic Information System; meso-scale higher-order numerical model (MIUU-model) to assess wind generated hydrogen production
Liu et al. [15]	Canada	Hydrogen demand estimation model based on scenario analysis of various demand levels to estimate hydrogen FCVs market penetration; scenario analysis of fuel cell vehicle deployment
Cuda et al. [13]	Canada	Scenario analysis of hydrogen demand
Köhler et al. [33]		An integrated transport policy assessment (ASTRA) model; economic policy analysis of co-evolution or interdependent development of fuel infrastructure build-up and vehicle adoption

Appendix B

As requested by the New Zealand government, the Castalia-MBIE model was developed to prepare the New Zealand Hydrogen Roadmap by Castalia (https://castalia-advisors.com/about/), a trusted advisor of corporations, utilities, governments, international agencies, and infrastructure investors around the world. The model examines the influencing factors that impact the adoption of hydrogen technology. The parameters and assumptions for this analysis are supplemented by a presentation given by Castalia for the Green Hydrogen Programme NZ [39]. Energy prices are referenced from Ministry of Business, Innovation and Employment [35].

There are four scenarios:

5. NZ will have high supply and high demand of hydrogen fuel domestically.
6. NZ will have high supply and low demand of hydrogen fuel domestically.
7. NZ will have low supply and low demand of hydrogen fuel domestically.
8. NZ will have low supply and high demand of hydrogen fuel domestically.

All scenarios are further compared to two cases: one where NZ is more/less competitive against other international exporters. Specifically, if an "international exporter" can produce green hydrogen at a lower cost, then NZ is likely to be an importer or producing green hydrogen for domestic use only, and vice versa. The model includes a base case with default levels for all parameters; this base case and the benchmark price figures are based on actual capital and operating cost evidence from commercial projects, current literature, and other authority [39]. Parameters for scenarios 1–4 are presented in Tables B1–B4, respectively. Using the Castalia-MBIE model online dashboard tool, accessible via the link https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-strategies-for-new-zealand/hydrogen-in-new-zealand/hydrogen-modelling-tool/, inputting parameters for each scenarios, Figures B1–B12 can be produced. Users can modify the major assumptions to forecast future states of hydrogen demand and supply.

Legal disclaimer

The dashboard is for information use only and provides limited functionality of the underlying model. It has been provided in downloadable format to allow users flexibility with generating scenarios for their own information. The dashboard and model remain the intellectual property of MBIE and Castalia and may not be used for any commercial purpose. MBIE and Castalia accept no responsibility for the any loss suffered from the use of the model and make no representation as to the accuracy of the data, formulae, or outputs. The model is not intended for commercial decision-making or as a forecasting tool. The model may not be provided to any third party, nor may it be incorporated in any product or service which is provided to third parties.

Table B1
Inputs for scenario 1 – High supply and high demand

		High supply and high demand		Base case
Assumptions and variables for NZ hydrogen production	Electricity cost for NZ 2020 average	$55 NZD/MWh		$61 NZD/MWh
	Electricity price change for NZ	0.25% decrease in price per annum		0.25% decrease in price per annum
	Electrolyzer utilization factor NZ	85%		41.5%
International exporter hydrogen production assumptions and variables	*NZ compared to international exporter, Australia, Canada, and USA*	NZ is competitive: NZ is likely to export green hydrogen	NZ is less competitive: NZ is likely to produce hydrogen for domestic use only	Result: NZ is likely to produce hydrogen for domestic use only
	Electricity cost as an international exporter 2020 average	$150 NZD/MWh	$55 NZD/MWh	$61 NZD/MWh
	Electricity price change for international export	0.25% decrease in price per annum	0.25% decrease in price per annum	0.25% decrease in price per annum
	Electrolysis utilization factor for international export	50%	85%	41.5%
Heavy vehicle demand assumptions and variables – Truck and bus capital cost change per annum	Hydrogen fuel cell truck and bus	7% decrease in capital cost per annum		5% decrease in capital cost per annum
	Battery electric truck and bus	3% decrease in capital cost per annum		3% decrease in capital cost per annum
	Diesel price change	5% increase in price per annum		3% increase in price per annum

Table B2
Inputs for scenario 2- High supply and low demand

		High supply and low demand		Base case
Assumptions and variables for NZ hydrogen production	Electricity cost for NZ 2020 average	$55 NZD/MWh		$61 NZD/MWh
	Electricity price change for NZ	0.25% decrease in price per annum		0.25% decrease in price per annum
	Electrolyzer utilization factor NZ	85%		41.5%
International exporter hydrogen production assumptions and variables	*NZ compared to international exporter, Australia, Canada, and USA*	NZ is competitive: NZ is likely to export green hydrogen	NZ is less competitive: NZ is likely to produce hydrogen for domestic use only	Result: NZ is likely to produce hydrogen for domestic use only
	Electricity cost as an international exporter 2020 average	$150 NZD/MWh	$55 NZD/MWh	$61 NZD/MWh
	Electricity price change for international export	0.25% decrease in price per annum	0.25% decrease in price per annum	0.25% decrease in price per annum
	Electrolysis utilization factor for international export	50%	85%	41.5%
Heavy vehicle demand assumptions and variables – Truck and bus capital cost change per annum	Hydrogen fuel cell truck and bus	2% decrease in capital cost per annum		5% decrease in capital cost per annum
	Battery electric truck and bus	3% decrease in capital cost per annum		3% decrease in capital cost per annum
	Diesel price change	0% increase in price per annum		3% increase in price per annum

Table B3
Inputs for scenario 3 – Low supply and high demand

		Low supply and high demand		Base case
Assumptions and variables for NZ hydrogen production	Electricity cost for NZ 2020 average	$150 NZD/MWh		$61 NZD/MWh
	Electricity price change for NZ	0.25% decrease in price per annum		0.25% decrease in price per annum
	Electrolyzer utilization factor NZ	50%		41.5%
International exporter hydrogen production assumptions and variables	*NZ compared to international exporter, Australia, Canada, and USA*	NZ is competitive: NZ is likely to import green hydrogen	NZ is less competitive: NZ is likely to import green hydrogen	Result: NZ produces hydrogen for domestic use only
	Electricity cost as an international exporter 2020 average	$150 NZD/MWh	$55 NZD/MWh	$61 NZD/MWh
	Electricity price change for international export	0.25% decrease in price per annum	0.25% decrease in price per annum	0.25% decrease in price per annum
	Electrolysis utilization factor for international export	50%	85%	41.5%
Heavy vehicle demand assumptions and variables – Truck and bus capital cost change per annum	Hydrogen fuel cell truck and bus	7% decrease in capital cost per annum		5% decrease in capital cost per annum
	Battery electric truck and bus	3% decrease in capital cost per annum		3% decrease in capital cost per annum
	Diesel price change	5% increase in price per annum		3% increase in price per annum

Table B4
Inputs for scenario 4 – Low supply and low demand

		Low supply and low demand		Base case
Assumptions and variables for NZ hydrogen production	Electricity cost for NZ 2020 average	$150 NZD/MWh		$61 NZD/MWh
	Electricity price change for NZ	0.25% decrease in price per annum		0.25% decrease in price per annum
	Electrolyzer utilization factor NZ	50%		41.5%
International exporter hydrogen production assumptions and variables	*NZ compared to international exporter, Australia, Canada, and USA*	NZ is competitive: NZ is likely to import green hydrogen	NZ is less competitive: NZ is likely to import green hydrogen	Result: NZ produces hydrogen for domestic use only
	Electricity cost as an international exporter 2020 average	$150 NZD/MWh	$55 NZD/MWh	$61 NZD/MWh
	Electricity price change for international export	0.25% decrease in price per annum	0.25% decrease in price per annum	0.25% decrease in price per annum
	Electrolysis utilization factor for international export	50%	85%	41.5%
Heavy vehicle demand assumptions and variables – Truck and bus capital cost change per annum	Hydrogen fuel cell truck and bus	2% decrease in capital cost per annum		5% decrease in capital cost per annum
	Battery electric truck and bus	3% decrease in capital cost per annum		3% decrease in capital cost per annum
	Diesel price change	0% increase in price per annum		3% increase in price per annum

Figure B1

Dashboard for scenario 1 – The international exporter section adopts base case inputs

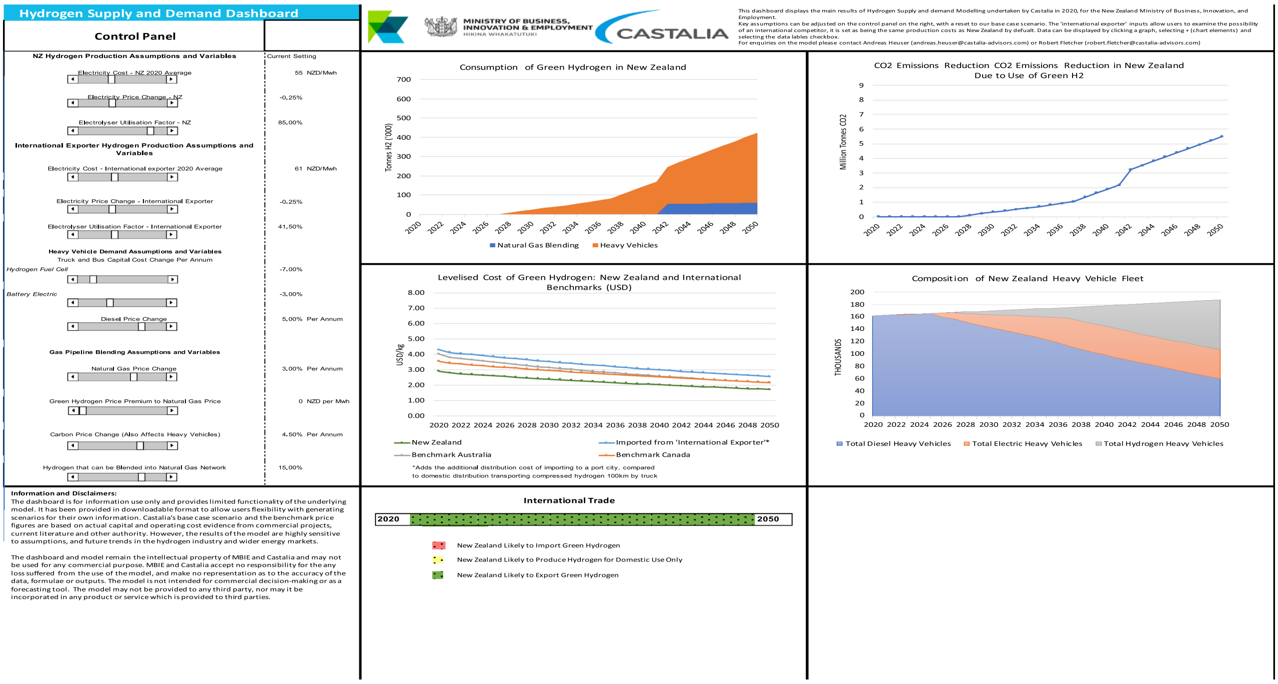

Figure B2

Dashboard for scenario 1 – The international exporter with less competitive inputs than New Zealand

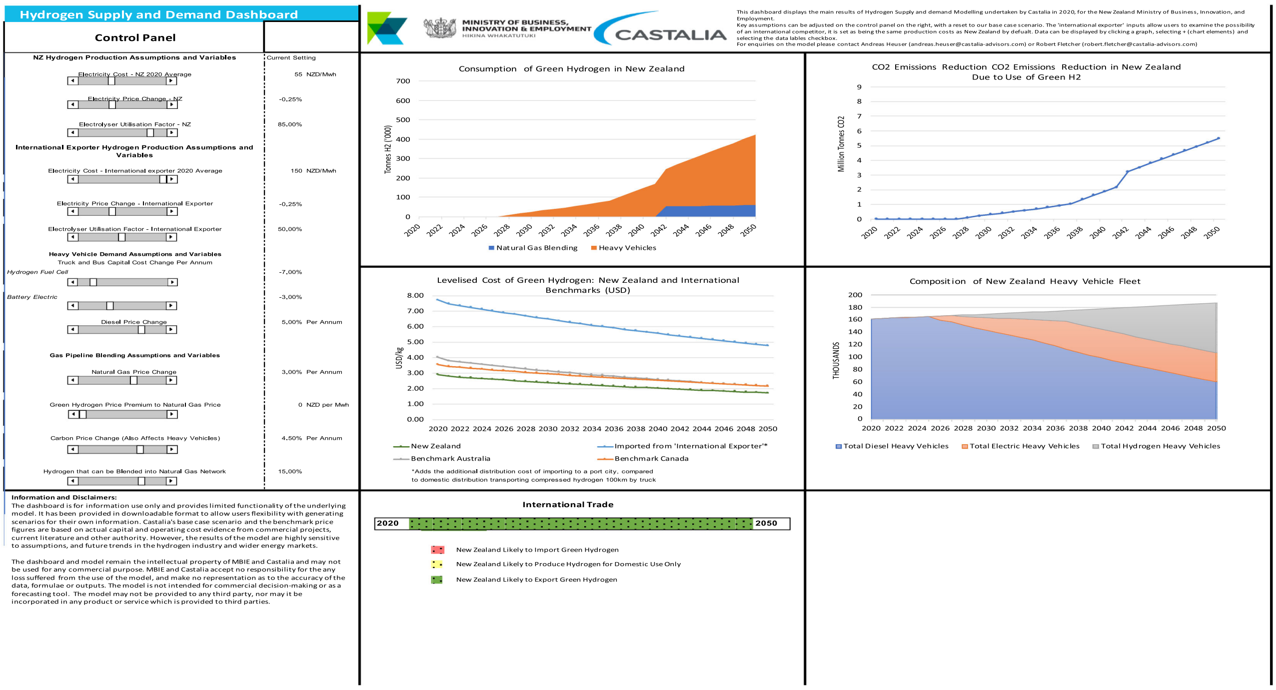

Figure B3

Dashboard for scenario 1 – The international exporter with more competitive inputs than NZ

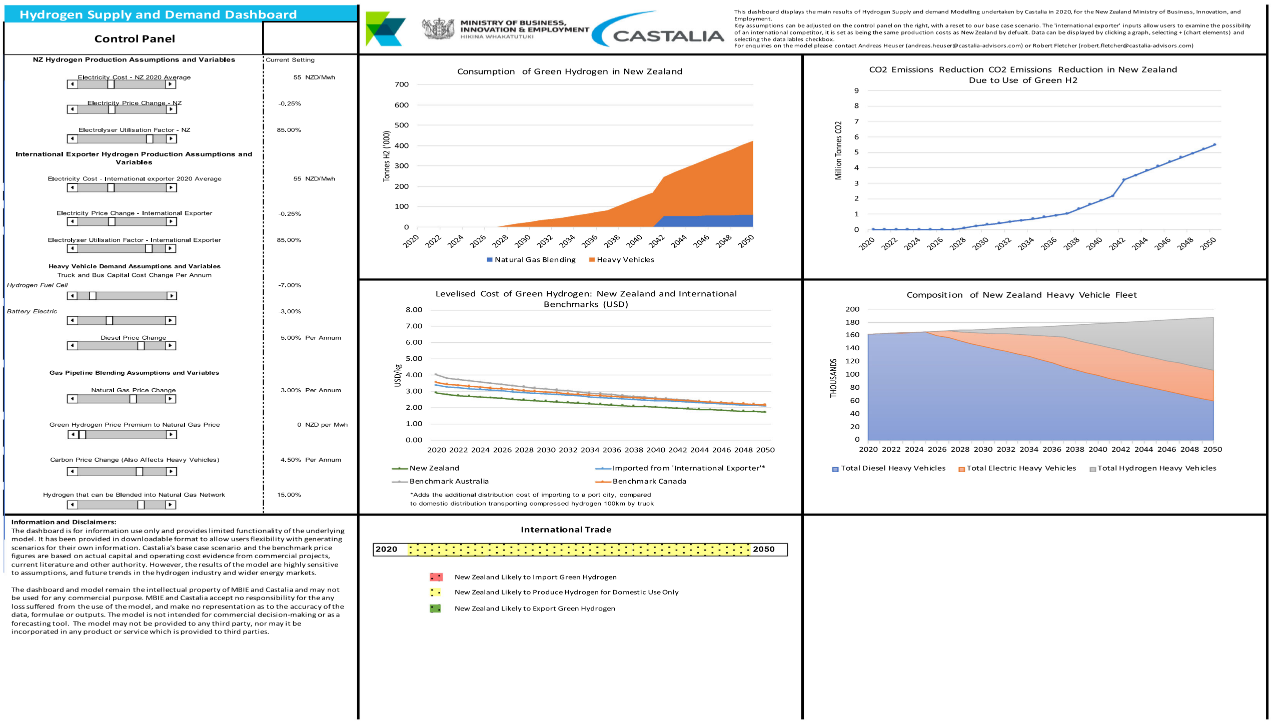

Figure B4

Dashboard for scenario 2 – The international exporter section adopts base case inputs

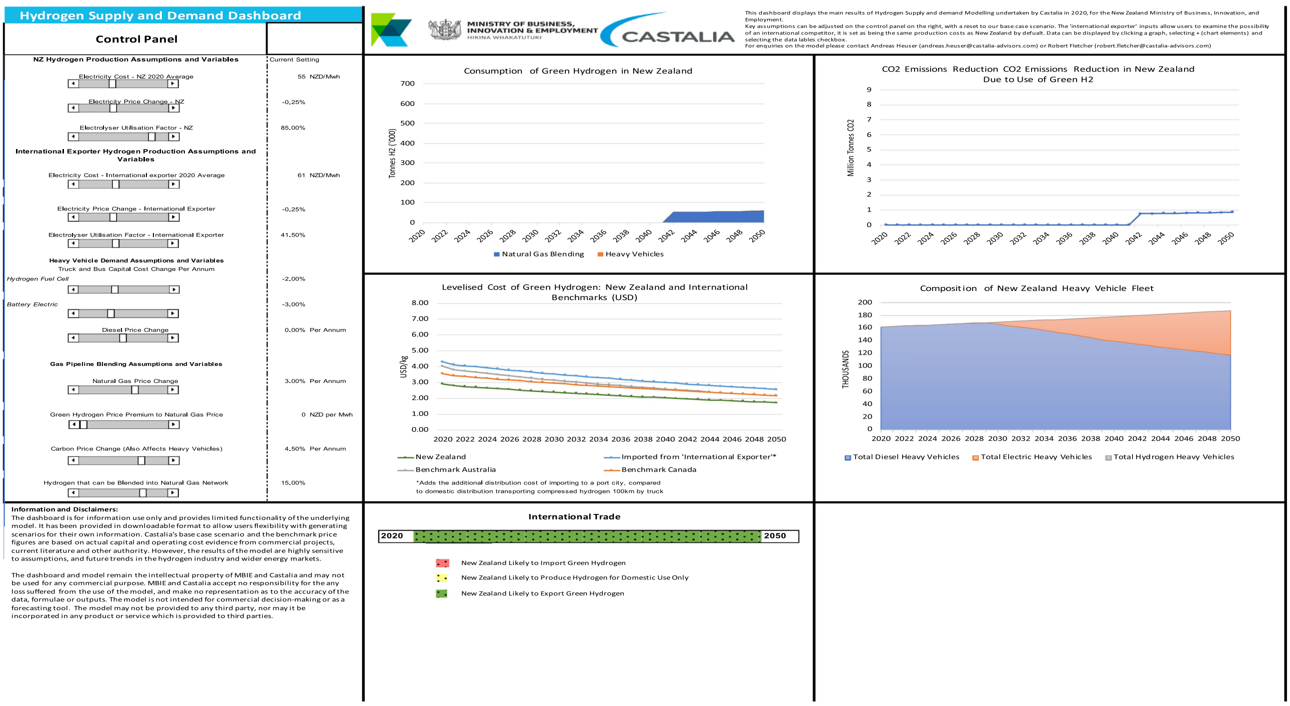

Figure B5

Dashboard for scenario 2 – The international exporter with less competitive inputs than NZ

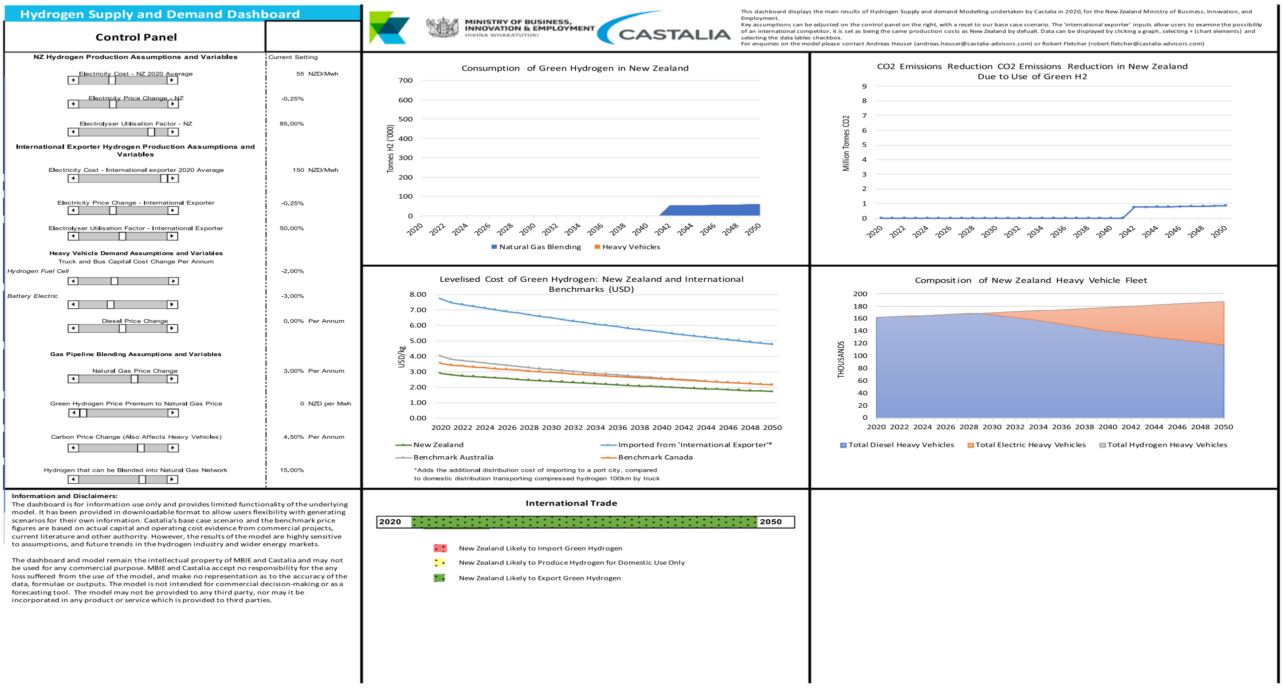

Figure B6

Dashboard for scenario 2 – The international exporter with more competitive inputs than NZ

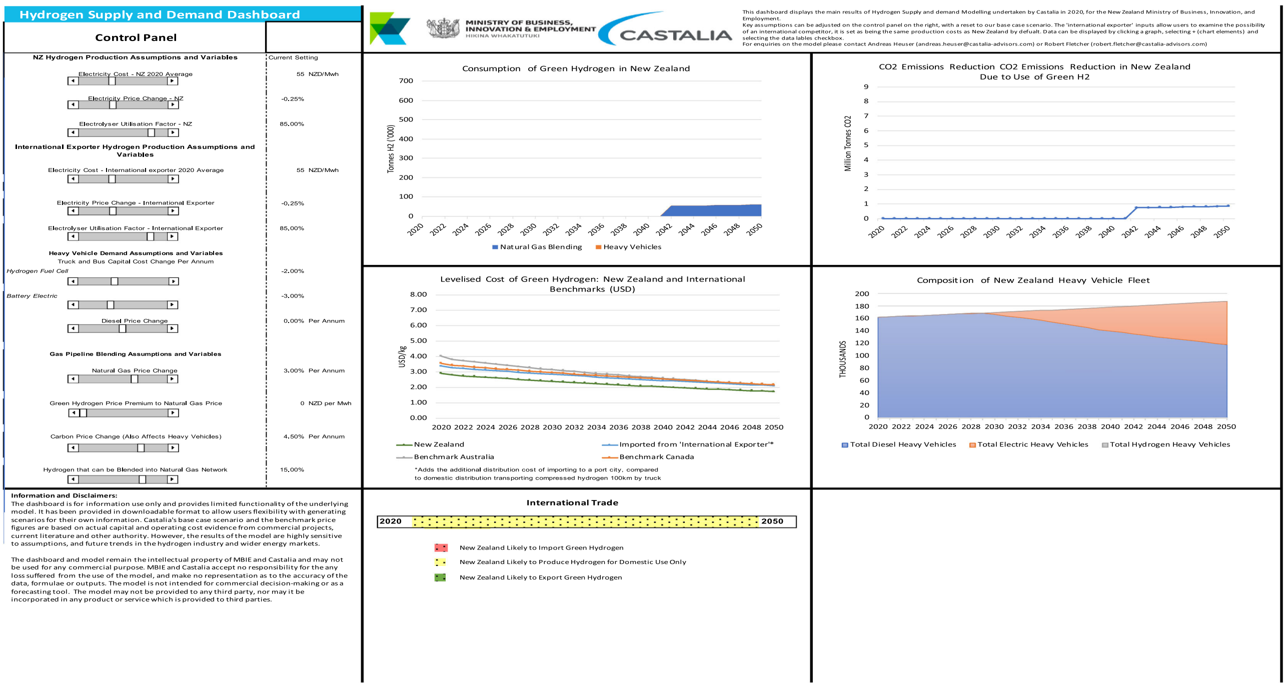

Figure B7

Dashboard for scenario 3 – The international exporter section adopts base case inputs

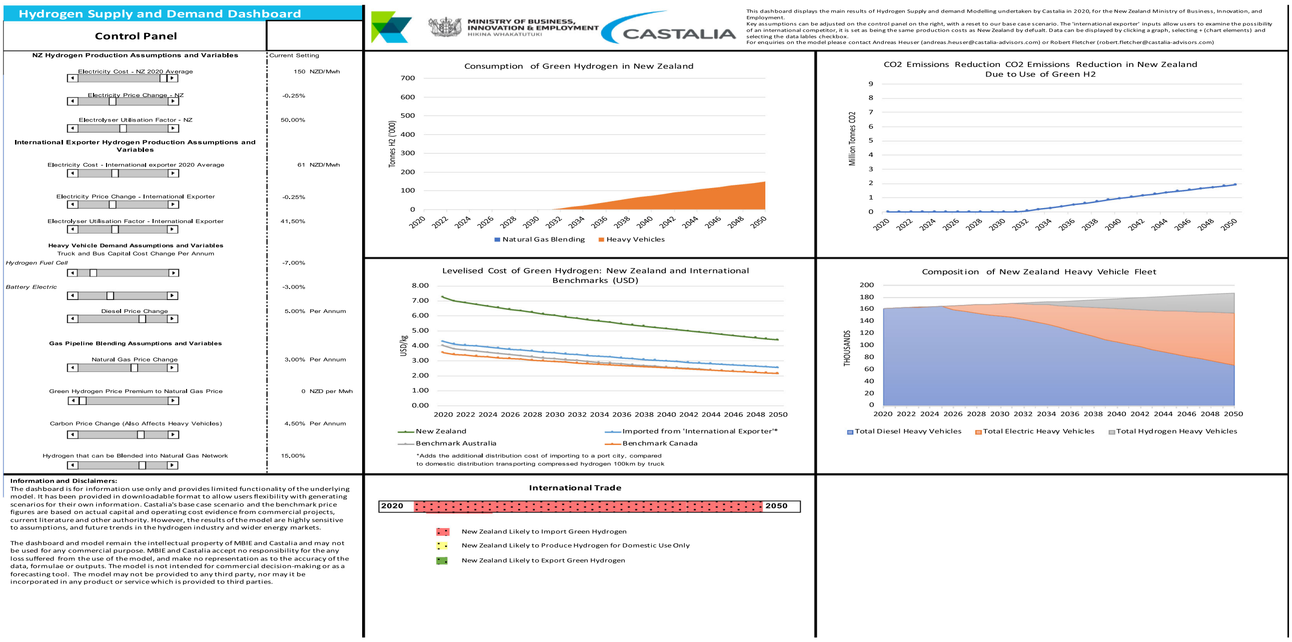

Figure B8

Dashboard for scenario 3 – The international exporter with less competitive inputs than NZ

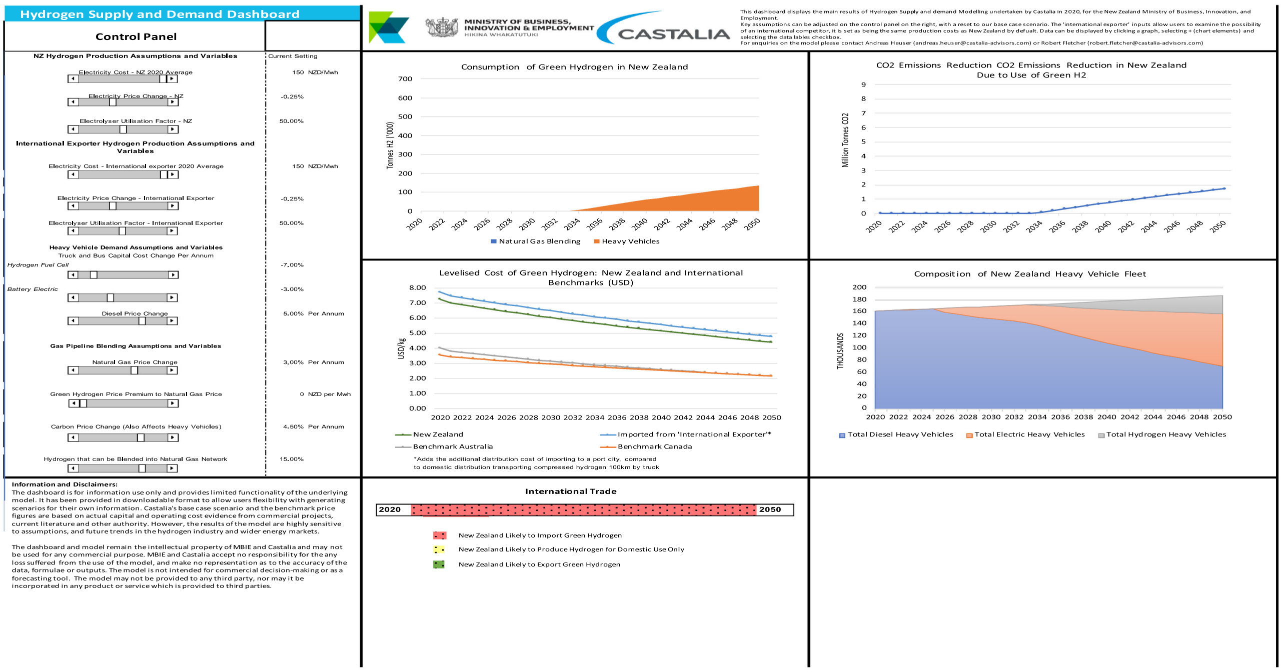

Figure B9
Dashboard for scenario 3 – The international exporter with more competitive inputs than NZ

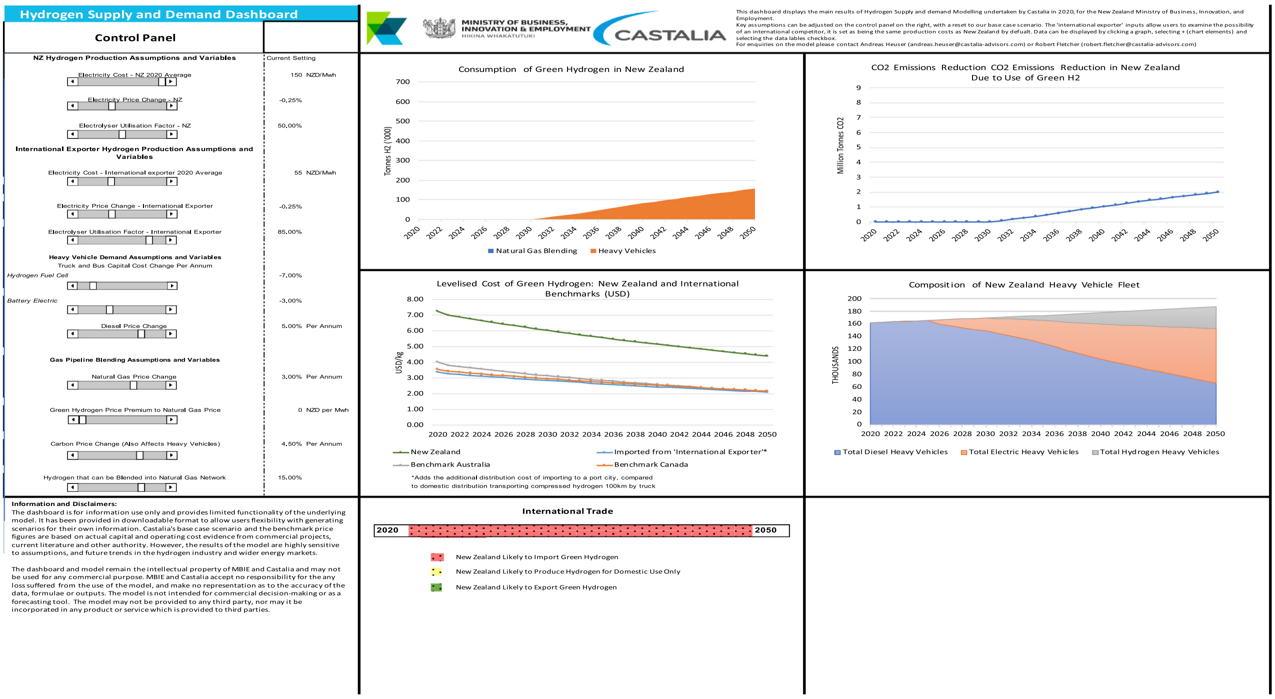

Figure B10
Dashboard for scenario 4 – The international exporter section adopts base case inputs

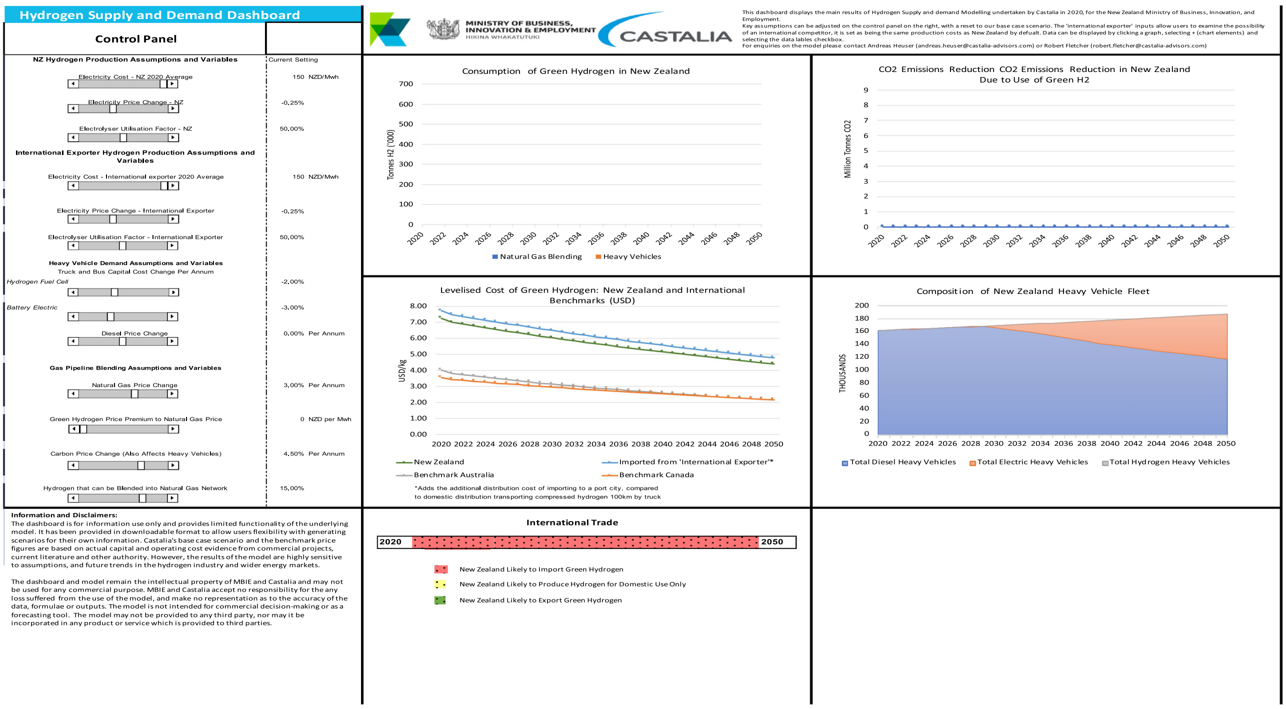

Figure B11

Dashboard for scenario 4 – The international exporter with less competitive inputs than NZ

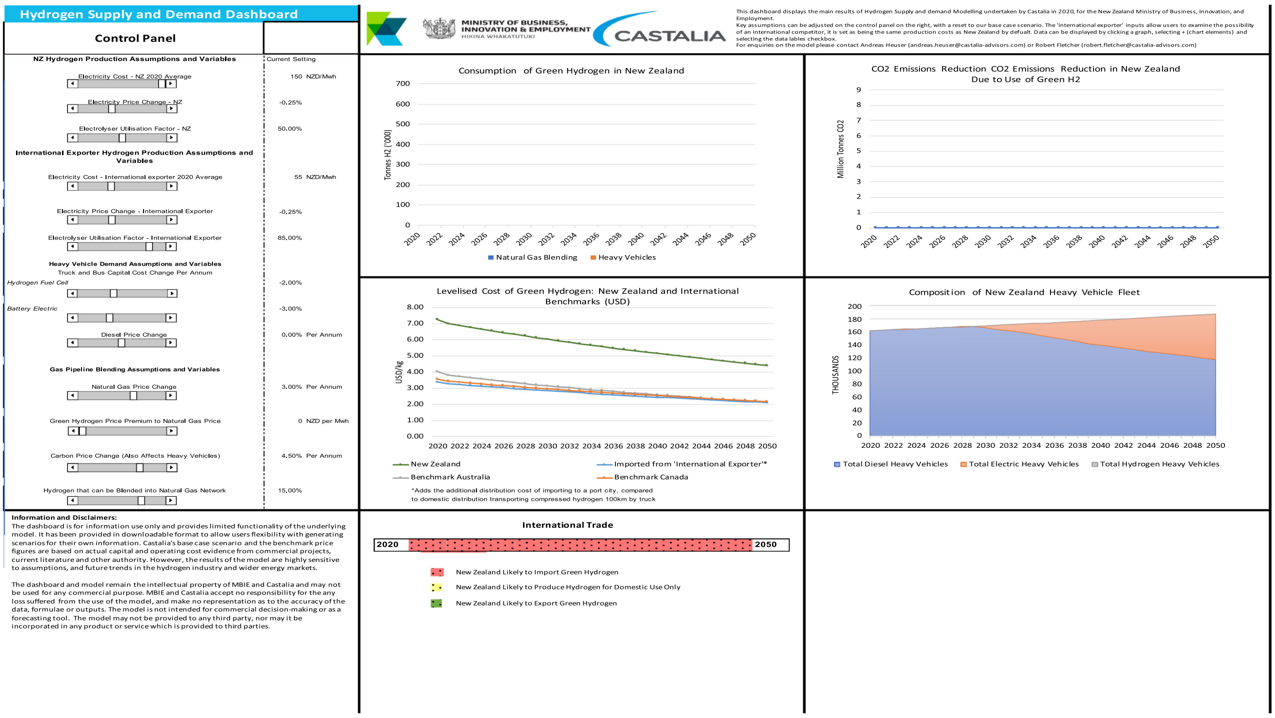

Figure B12

Dashboard for scenario 4 – The international exporter with more competitive inputs than NZ