Hydrogen Economy and Its Production Impact on Automobile Industry Forecasting in Ecuador Using Principal Component Analysis

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Abstract. Hydrogen vehicles are operating in many parts of the world. However, in South America these cars are not on the streets. Even there are merchant hydrogen plants in the continent, hydrogen stations are not available yet. Doing a PCA analysis with H_2 Vehicle Simulator Framework, Principal component 1 is related with amount of storage of hydrogen. Second principal component is related with autonomy and the last principal component with raw distance. Nowadays hydrogen price is around 12 USD per kilo in Europe and it is expensive for South America. The goal is to achieve a price of 2.15 USD in future with different renewable energies like: nuclear energy, hydro electrical, biomass and photo voltaic. Other goal is to reduce the vehicle price because the cost of a hydrogen car is 2.62 more expensive on average than a combustion car in Ecuador. One alternative to incentive the introduction of hydrogen vehicles is with hydrogen taxis vehicles like Paris is doing. Photo voltaic energy available in Tungurahua province is enough to produce hydrogen for all the taxis of Ambato city.

Keywords: PCA · Hydrogen · Vehicle · Simulation · Cost

1 Introduction

Hydrogen (H_2) is the first element in the Periodic Table and the main constituent of matter in the Universe with approximately 75%. On Earth, H_2 is also found in abundance, but adhered to organic components such as methane or oxygen, forming water [1]. Currently, H_2 is considered an Energetic Vector like cells, batteries and all fossil fuels because it is a substance that stores energy that

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can be released in a controlled way later [2]. H_2 as an energy vector serves as "fuel" and it must be manufactured through the separation of the other elements because it is not found in its pure state on the planet. Because the emission result is water and electricity, H_2 is considered the clean fuel of the present and future [3]. To replace fossil fuels due to the pollution to the environment that their use generates, we have chosen to use renewable energy to boost our means of transport. Such is the case that today you have electric or battery-powered motorcycles, cars, trucks, trains, boats and even aeroplanes. However, these means of transport are not found in abundance or on par with H_2 as an energy source. Although H_2 is commonly recognized as the fuel of the future, it does not burn like gasoline, LPG, or diesel. In fact, H_2 generates energy to move an electric motor and thus obtain the movement of the vehicle. So, talk about an hydrogen vehicle is talk about an electric vehicle, whose difference from commonly known electric vehicles is in how electricity is generated. While an H_2 vehicle uses this gas to generate electricity through a fuel cell integrated with it and thus drive the engine, an electric vehicle receives the electrical charge generated in a Power Plant (solar, wind, hydro or combustion) to insert it into a battery and finally propel the vehicle. There are some processes to manufacture H_2 at an industrial level like: grey hydrogen, blue hydrogen and green hydrogen. Gray hydrogen consists of obtaining H_2 through natural gas, oil or coal, generating carbon dioxide (CO_2) and carbon monoxide (CO). Steam Methane Reforming (SMR) is a pressure swing adsorption purification technology. An example of grey hydrogen is compressing methane with steam and heat, thus obtaining H_2. Blue hydrogen is generated by electrolysis, which consists of separating hydrogen from oxygen in water by applying electrical energy. If in the electrolysis process the electricity comes from renewable energies such as solar, wind, water; then it is called green hydrogen. The electrolysis process loses efficiency between 20 to 30% of the energy. A feasible technology to implement in Ecuador is through residual biomass suitable for the production of bio-ethanol and thus obtain hydrogen and acetaldehyde [4]. Another potential source of hydrogen production is hydroelectricity. Just as a study has been developed on the production of H_2 for an economy in Colombia, it can be developed for Ecuador since it has 27 hydroelectric plants and where an approximate waste of 50% is assumed [5,6]. According to the Hydrogen Tools organization, in 2021 10068 Hydrogen Fueled Vehicles are operating in the US. The vehicles are subjected to the cycle mentioned during their operation. However, in South America, that kind of vehicles are not on the streets. Just a few projects or demo hydrogen cars are available in few cities. To apply hydrogen economy in the country, Ecuador has to overcome the following barriers: low and disperse investigation activity; low academic formation needed to operate and innovate on hydrogen technologies; lack of legal framework and regulations that incentive SESH penetration and incipient formation of collaborative networks in research and promotion [7]. Principal component analysis (PCA) is a technique of dimensional reduction. It means turn high dimensional data in a lower dimensional form using sophisticated underlying mathematical principles. Possible correlated variables are into smaller variables called principal components. PCA can be applied for all topics like health: analysis of Munich

Functional Developmental Diagnosis to Industry and technology: relationship between important properties of bio diesel and its chemical composition, reduction of different features of products and customers or to describe the correlation and necessity of dependent and independent variables on a research work and mathematical model [8–11]. The aim of this paper is to present hydrogen economy and its production for hydrogen operating vehicles in Ecuador.

- We show the merchant and captive hydrogen plants available in south America and their production capacity.
- We mention three alternatives to produce hydrogen in Ecuador based on energies: nuclear, hydro, biomass and photo voltaic.
- We run H_2 Vehicle Simulation Framework with 700 bar compressed gas system as a hydrogen storage system for four different standard drive cycles.
- We apply Principal Component Analysis (PCA) to the results of H_2 Vehicle Simulation Framework.
- We show a comparative of best-selling commercial hydrogen vehicles in USA and best-selling commercial combustion vehicles in Ecuador according to three main principal component analysis: storage of H_2, autonomy and raw distance.
- We present an alternative to introduce hydrogen vehicles and overcome the egg hydrogen dilemma with a demand of 2055 hydrogen taxis operating in Ambato city thanks photo voltaic hydrogen production of the province.

The remainder of this paper is organized as follows: Sect. 2 mentions the materials; Sect. 3 describes methods applied; Sect. 4 presents the results and discussion, while Sect. 5 contains the conclusions.

2 Materials

2.1 Literature

Academic articles, international organisms web pages, Ecuadorian government web pages, reviews, reports and news mentioned on references were used. Free data source excel sheets were downloaded from Hydrogen Tools organization. https://h2tools.org/. Excel sheets used are: "Asia merchant hydrogen plants Jan 2016.xlsx"; "Worldwide refinery hydrogen production capacities by country Jan 2017.xlsx"; "Worldwide refinery hydrogen production capacities by country Jan 2017.xlsx" and "US Hydrogen-Fueled Vehicles - FY21Q2.xlsx"

2.2 H_2 Vehicle Simulation Framework Configured at 700 Bar Storage System

H_2 Vehicle Simulation Framework is a Matlab tool that simulates a light commercial vehicle with a fuel hydrogen cell (PEM) and its hydrogen storage system. Test cases are played on the vehicle simulation framework related to the storage system. Driving conditions are associated with standard drive cycles on a

specific test case. Fist case is the Ambient drive cycle or Fuel economy test. Cycles involved in it are UDDS which means low speeds in stop-and-go urban traffic and HWFET or Free-flow traffic at highway speeds. The second case is Aggressive drive using the cycle US06 for higher speeds; harder acceleration and breaking. The third case is Cold drive with FTP-45 cycle at colder ambient temperature (−20 °C). Finally, Hot drive cycle related to SC03 standard is used for hot ambient (35 °C) conditions [12]. A 700 bar compressed gas system is used as a hydrogen storage system. Because hydrogen is very light, at atmosphere pressure, transport 1 Kg of H_2 would need an 11 000 Lt tank for more than 100 Km. That's a problem. The solution, compress H_2 at 700 bar to transport 4–5 Kg of it given 500 Km of autonomy.

2.3 Information Management Software: Microsoft Excel and Minitab 18

Microsoft excel is used to organizing numbers and data with functions and formulas. Info organized is represented on histograms as figures of this paper. Minitab 18 is a software used in high education and industry because his statistics analysis, graphics capacity, quality evaluation and experiment designer.

3 Methods

One of the most important tools on industry to represent qualitative data or quantitative data of a discrete type of variable are histograms [13]. Variables are on X axis while frequency values are on Y axis. The graphic with a surface bar is proportional to the frequency of the values presented. Figure 1 to Fig. 3 are histograms built with free data source excel sheets from Hydrogen Tools organization once information was leaked and organized with Microsoft excel software. H_2 Vehicle Simulation Framework was downloaded from the Hydrogen Materials Advanced Research Consortium organization (HyMARC) and run on Matlab R2014a [12]. A compressed 700 bar was selected on Storage System. The fuel economy test was chosen for the first test case. The second case was an aggressive cycle. The third case was the cold cycle and finally, the hot cycle. All the tests were input with 0.7 auxiliary loads and the run. Each drive cycle has his standard and configuration. Variables result of each simulation at the end are: H_2 delivered [kg], H_2 used [kg], Usable H_2 [kg], Storage system mass [kg], Storage system volume [L], Gravimetric capacity [%], Volumetric capacity [g/L], Temperature [°C], Pressure [bar], Raw distance [miles], On-board efficiency [%], Calculated fuel economy [mpgge] and Calculated range [miles]. Storage system mass, Store system volume and On-board efficiency were excluded for PCA. PCA is the first step to analyses large data sets. This technique uses a transform vector to reduce dimensional and project the data in the directions of large variance [14]. PCA plays an important role in efficiently reducing dimensional of data, but preserving the variation present in the data set. It can be represented and applied like:

$$1st\ principal\ axis = argmax_{||a||=1} Var\left[a^T X\right] \tag{1}$$

$$Var\left[a^T X\right] = \frac{1}{n}\sum_{i=1}^{n}\left\{a^T\left(X_i - \frac{1}{n}\sum_{j=1}^{n}X_j\right)\right\}^2 = a^T V_{XX} a \tag{2}$$

$$V_{XX} = \frac{1}{n}\sum_{i=1}^{n}\left(X_i - \frac{1}{n}\sum_{j=1}^{n}X_j\right)\left(X_i - \frac{1}{n}\sum_{j=1}^{n}X_j\right)^T \tag{3}$$

4 Results

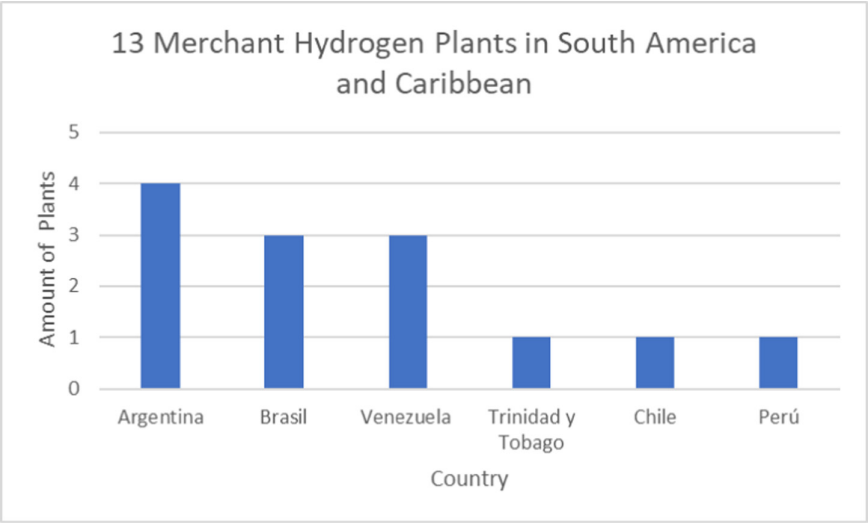


Fig. 1. Merchant hydrogen plants in South America and the Caribbean (2016) [15]

In 2016 Argentina had 4 commercial H_2 production plants, three of these run by Air Liquide and one by Galileo. Two Air Liquide production companies have as their source of H_2 gas production, while the other plant of the company does it for SMR. In Brazil, Air Liquide owns two Plants, one of which is for SMR. The other Plant in that country corresponds to Air Products, producing H and CO. In Venezuela, two plants correspond to Hyundai-Wison, while the other is owned by Linde (BOC) by SMR. The production plant in Trinidad and Tobago is Air Liquide, in Chile, it is Linde (BOC) and in Peru, it corresponds to Praxair, all the latter by SMR.

According to Fig. 1, Argentina, Brazil and Venezuela cover 76.92% of the number of commercial H_2 production plants in South America and the Caribbean. Ecuador does not appear on the list due to the following barriers: scant and scattered research activity; minimum training offer of the human talent necessary for the operation and innovation in H_2 technologies; lack of a legal

and regulatory framework that encourages the penetration of the SESH and the incipient formation of collaborative networks in research and promotion [7].

To achieve an H_2 economy in Ecuador, it is important to produce it in a massive, clean, safe and efficient way. An alternative is implementing a Nuclear Hydrogen Production Plant. VHTR, a Very High-Temperature Reactor, is a helium gas-cooled graphite-moderated thermal neutron spectrum reactor that can provide electricity and process heat for a wide range of applications, including hydrogen production [16]. The characteristics of said Plant and the approximate costs to it are shown in Table 1 [17]. The cost of production of 1 kg of H_2 would be approximately $2.15 in the Nuclear Hydrogen Production Plant [17].

Table 1. (a) Specification for nuclear hydrogen production plant [17], (b) Summary of costs for nuclear hydrogen plant (USD M/year) [17]

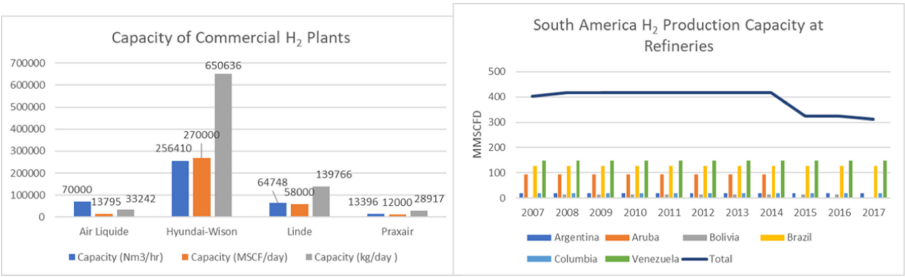
Design Parameters	**Specifications**
Reactor Plant	VHTR
Hydrogen Plant	SI-Based Plant
Thermal Output	4 x 600 MWth
Operating Life	60 years
Plant Availability	90%
Capacity Factor	90%
Fuel Cycle	Open

(a)

Account Description	**Amount ($M/year)**
Reactor Plant Capital Cost	115.7
Reactor Plant O&M Cost	73.4
Nuclear Fuel Cost	81.8
Decommissioning Cost	1.1
Total Annual Cost	272.0
SI Plant Capital Cost	85.1
SI Plant O&M Cost	34.8
Energy Cost	222.8
Total Annual Cost	342.7

(b)

The Fig. 2(a) shows the different producers and their capacity for: the volume of non-condensate H_2 at 1 atm pressure and 0 °C or Normal cubic meter per hour (Nm^3/hr), thousand standard cubic feet per day (MSCF/day) and kilograms per day (Kg/day). Hyundai-Wison located in Venezuela is the Company that has the most capacity in all the exposed aspects. In the second place, regarding the capacity of Normal cubic meter per hour, there is Air Liquide, then there is Linde and finally Praxair. In second place in terms of capacity in standard cubic feet per day is Linde, followed by Air Liquide and finally Praxair. Finally, the second place regarding capacity in Kg per day is for Linde, then there is Air Liquide and finally Praxair. It should be noted that Air Liquide opened in 2002, Hyundai-Wison opened in 2014, Linde in 1996 and Praxair in 2016.



(a) **(b)**

Fig. 2. (a) Capacity of commercial H_2 Plants in South America and Caribbean (2016) [15], (b) South America H_2 production capacity at refineries (2017) [18]

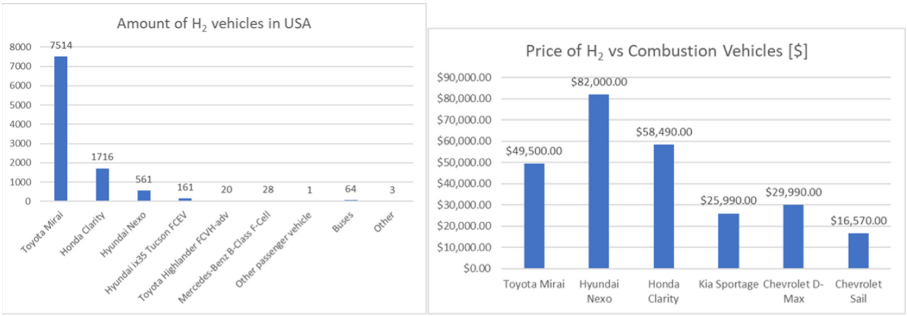
Table 2. South America captive H_2 production capacity at refineries [18]

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Argentina	19	19	19	19	19	19	19	19	19	19	19
Aruba	93	93	93	93	93	93	93	93	–	–	–
Bolivia	0	14	14	14	14	14	14	14	14	14	–
Brazil	126	126	126	126	126	126	126	126	126	126	126
Columbia	18	18	18	18	18	18	18	18	18	18	18
Venezuela	148	148	148	148	148	148	148	148	148	148	148
Total	**404**	**418**	**418**	**418**	**418**	**418**	**418**	**418**	**325**	**325**	**311**

The South American capacity for captive hydrogen production in refineries is shown in Fig. 2(b) and Table 2. Captive hydrogen is the amount of H_2 that the Plant produces for its consumption in million standard cubic feet per day. As with commercial H_2, Venezuela ranks first in terms of captive H_2 production until 2017. In second place is Brazil and in third place until 2014 Aruba. As of 2015, third place is occupied by Argentina.

H_2 vehicles operating or planned to operate in the United States with an updated date of March 31, 2021, are shown in Fig. 3(a) [19]. The Toyota Mirai and Honda Clarity account for more than 80% of hydrogen-powered vehicles in the United States according to Fig. 3(a).

Even though there are hydrogen-producing plants in South America, observe these cars on streets is not frequent. Today, different automotive companies already have a commercial hydrogen product such as Toyota with its Mirai sedan, Hyundai with the Nexo jeep or Honda with the Clarity sedan, but these are not currently available in the South American continent. The 9 existing units are demos or projects [20]. The base cost of Toyota Mirai is $49500 in California [21], Hyundai Nexo is $72850 or $82000 more or less [22] and Honda Clarity $58490 [23]. In Ecuador, the best-selling vehicles in 2017 and which remain until 2020 are the Kia Sportage R jeep, the Chevrolet D-Max pick-up and the Chevrolet Sail



(a) **(b)**

Fig. 3. (a) Amount of H_2 vehicles operating in USA (2021) [19]. (b) Price of H_2 vehicles vs Combustion [$] (2020–2021)

sedan [24,25]. The price for these cars is around $25,990, $ 29,990 and $16,570 respectively [26,28].

Table 3. Detail of price of H_2 and combustion vehicle

Vehicle	Price USD	Energetic vector	Avarage Price USD
Toyota Mirai	49,500.00	Hydrogen	63,330.00
Hyundai Nexo	82,000.00	Hydrogen	
Honda Clarity	58,490.00	Hydrogen	
Kia Sportage	25,990.00	Gasoline	24,183.33
Chevrolet D-Max	29,990.00	Diesel	
Chevrolet Sail	16,570.00	Gasoline	
		Relation	**2.62**

According to Fig. 3(b) and Table 3, commercial hydrogen cars not yet available in Ecuador are priced 2.62 times higher than the average price of the best-selling vehicles in the country in 2020. Comparing the autonomy and the price of filling the tank of the Hyundai Nexo and the Kia Sportage R, the following results are obtained: Both, the Hyundai Nexo and the Kia Sportage are 5-passenger Jeep-type vehicles. On the one hand, taking into account the information from the manufacturer of Nexo of 1 Kg of H_2 per 100 Km and the price of the Kilo of H_2 at $ 12, the Price/Autonomy ratio is 0.12 $/Km [29]. Taking advantage of the Green Hydrogen Catapult (GHC) project, the price of 1 Kg of H_2 would be $ 2 by 2026 and with it, the ratio drops to 0.02 $/Km in the Hyundai Nexo [30,31]. On the other hand, as of April 17, 2021, and with data from the manufacturer, the Kia Sportage R, with an extra gasoline price of $ 1.91 per gallon, requires $ 27.79 to cover the range of 552 km, obtaining a

Table 4. Relation price autonomy

Vehicle	Autonomy [Km]	Price fuel tank [$]	Relation Price/ Autonomy [$/Km]	Energetic vector
Hyundai Nexo	666	79.92	0.12	Hydrogen
Kia Sportage R	552	27.79	0.05	Gas
Hyundai Nexo con GHC	666	13.32	0.02	Hydrogen

Table 5. Gasoline vs. H_2 taxi economy

Vehicle	Range [Km]	Amount energetic vector	Price energetic vector	Cost energetic vector [USD]	Incomes [USD]	Utility [USD]
Gasoline Taxi (gal)	300	12	1.91	22.92	45	22.08
H2 GHC Taxi (Kg)	300	3	2.15	6.45	45	38.55

ratio of 0.05 $/Km [26,32]. Paris in 2015 already had 5 hydrogen taxis. In 2019 the number of taxis amounted to 100, while by 2020 600 units were expected [33,34]. In 2018 the number of taxis registered in Ambato was 2055 units [35]. A taxi travels up to 300 km a day in 20 races consuming 10 to 12 gallons of extra gasoline. In this way, the driver of the unit has an income of $ 40 to $ 45 [36]. A taxi driver in Ambato if he used a hydrogen unit with GHC would obtain a daily profit of approximately $ 38.55 versus $ 22.08 that he obtains for using a gasoline vehicle. Amount of hydrogen required for the circulation of 2055 taxis during a year: 300 km $\frac{1\,\text{Kg}}{100\,\text{Km}}$ * 365 days * 2055 taxis = 2.2502 * 10^6 Kg (Tables 4, 5).

Tungurahua has a potential for hydrogen production from Solar Photo voltaic Energy, which in one year would be capable of producing 3.29 * 10^6 Kg, which is enough to cover the demand of the 2055 taxis [37]. H_2 vehicles need a safe "hydro generation" and continuous supply as infrastructure for refuelling this energy vector. A viable deployment of such a refuelling infrastructure requires an initial market for vehicles, such as city taxis. Using the city's fleet of taxis as consumers, the hydrogen chicken and egg dilemma can be overcome: "What comes first: Assemble the infrastructure to lower the price and promote consumption or Consumption to accelerate the implementation of the infrastructure". In addition to meeting the objectives of ensuring the supply of hydrogen, having a city refuel the energy vector and promote the use of H_2 [38] (Tables 6, 7 and 8).

The first principal component represents 75.8% of the total variation. The variables that are more correlated with Principal Component 1 (PC1) are: H_2 delivered (0.362), H_2 used (0.362), Usable H_2 (0.362), Pressure (−0.362), Gravimetric capacity [%] (0.360) and Volumetric capacity [g/L] (0.360). PC1 has a positive correlation with the first three variables and the last two. However, it

Table 6. Summary simulation storage system 700 bar

N°	Detail	H_2 delivered [kg]	H_2 used [kg]	Usable H_2 [kg]	Gravimetric cap.[%]	Volumetric cap.[g/L]	Temperature[°C]	Pressure[bar]	Raw distance[miles]	Calculated fuel economy[mpgge]	Calculated range[miles]
1	Fuel Economy test (UDDS+HWY, 24C)	5.67	5.67	5.67	4.8	25.3	7.5	5	464	55	311
2	Aggressive cycle (US06, 24C)	5.66	5.66	5.66	4.8	25.3	−6.4	6	328	58	328
3	Cold cycle (FTP-75, −20C)	5.4	5.4	5.4	4.5	24.1	−29.1	25	403	75	403
4	Hot Cycle (SC03, 35C)	5.66	5.66	5.66	4.8	25.3	19.3	6	409	72	409

Table 7. Eigenanalysis of the correlation matrix

Principal component (PC)	1	2	3	4	5	6	7	8	9	10
Eigenvalue	7.5763	1.3769	1.0467	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Proportion	0.7580	0.1380	0.1050	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Cumulative	0.7580	0.8950	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

has a negative correlation with Pressure. So, increase the values of H_2 delivered, H_2 used, Usable H_2, Gravimetric capacity and Volumetric capacity will increase the value of the first principal component. But, increase the value of Pressure will decrease the value of PC1. The first three components have an Eigenvalue of more than 1. According to Kaiser criterion, components with a value of more than 1 are used as Principal Components. The first three principal components explain 100% of the variation of the data. So, PC1, PC2, PC3 are used. Also, the Scee plot shows that Eigenvalues form a straight line after the third principal component.Results show that principal component 1 has a positive association with H_2 delivered, H_2 used, Usable H_2, Gravimetric capacity and Volumetric capacity, but a negative association with Pressure. Five positive PC1 are the amount of H_2 before, while and after a hydrogen vehicle function. The second principal component is associated with Calculated fuel economy and calculated range. So, this component measures the autonomy of the vehicle. Finally, the third principal component is Raw distance. The loading plot shows the variables that are heavier on each component. Influences approaching −1 or 1 indicate that the variable significantly affects the component. Influences close to 0 means

Table 8. Eigenvectors

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
H_2 delivered [kg]	0,362	0,064	−0,062	0,398	0,172	−0,333	0,707	0,236	−0,081	0,009
H_2 used [kg]	0,362	0,064	−0,062	0,398	0,172	−0,333	−0,707	0,236	−0,081	0,009
Usable H_2 [kg]	0,362	0,064	−0,062	0,398	0,172	0,667	0,000	−0,471	−0,081	0,009
Gravimetric capacity [%]	0,360	0,073	−0,095	−0,476	0,187	0,408	0,000	0,577	−0,226	−0,208
Volumetric capacity [g/L]	0,360	0,073	−0,095	−0,476	0,187	−0,408	0,000	−0,577	−0,226	−0,208
Temperature [C]	0,302	0,466	0,091	−0,079	−0,700	0,000	0,000	0,000	−0,181	0,392
Pressure [bar]	−0,362	−0,061	0,050	0,165	−0,008	0,000	0,000	0,000	−0,912	−0,064
Raw distance [miles]	0,015	0,272	0,925	−0,000	0,224	0,000	0,000	0,000	0,034	−0,135
Calculated fuel economy [mpgge]	−0,272	0,536	−0,202	−0,113	0,533	0,000	0,000	0,000	−0,002	0,549
Calculated range [miles]	−0,227	0,629	−0,250	0,160	−0,129	0,000	0,000	0,000	0,111	−0,660

that the variable has a low influence on the component. In Fig. 4(b), Volumetric capacity, H_2 used, Usable H_2, Gravimetric capacity and H_2 delivered have a positive influence on component one. Pressure has a negative influence on PC 1. Calculated fuel economy and Calculated range have a strong positive influence on principal component 2. It means autonomy of the vehicle, an important factor now to decide which car to buy.

Table 9. Eigenvectors for PC

Variable	PC1	PC2	PC3
H_2 delivered [kg]	0.362	0.064	−0.062
H_2 used [kg]	0.362	0.064	−0.062
Usable H_2 [kg]	0.362	0.064	−0.062
Gravimetric capacity [%]	0.360	0.073	−0.095
Volumetric capacity [g/L]	0.360	0.073	−0.095
Temperature [$^{\circ}C$]	0.302	0.466	0.091
Pressure [bar]	−0.362	−0.061	0.050
Raw distance [miles]	0.015	0.272	0.925
Calculated fuel economy [mpgge]	−0.272	0.536	−0.202
Calculated range [miles]	−0.227	0.629	−0.250

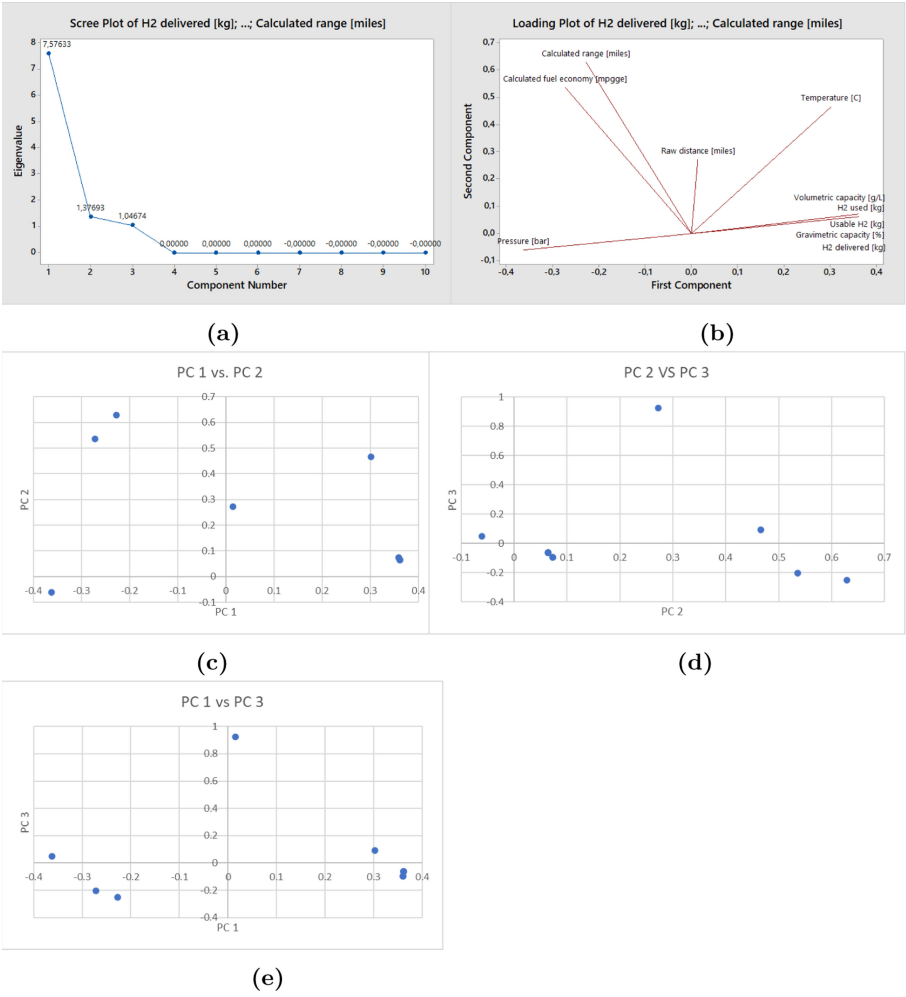


Fig. 4. (a)Scree plot, (b)Loading plot, (c) PC 1 vs PC 2, (d) PC 2 vs PC 3, (e) PC 1 vs PC

Information from Table 9. can be used with other methodology such as Factor Analysis to improve knowledge. Principal Components become the new axes that provide the best angle for viewing and evaluating the data, so that the differences between the observations are more visible. Figure 4(c), (d), and (e) represent a contrast the three principal components to each other. Values close to 1 are strong correlated. A point on the corners of the graphs is expected for a strong correlation between both principal components. Points close to X axis and 1 value means that a strong relation only with that principal component. The same happened with Y axis.

5 Conclusion

1. Ecuador has the potential to produce hydrogen through biomass and photo voltaic solar energy despite the different current barriers. Similarly, the possibility of implementing a Nuclear Plant to produce H_2. The goal is the cost of $ 2.15 per kilogram of hydrogen.
2. The hydrogen vehicle, Toyota Mirai, is the most accessible car for the implementation of this technology in the country due to its price. Commercial hydrogen cars not yet available in Ecuador are priced 2.62 times higher than the average price of the best-selling vehicles in the country in 2020.
3. The comparison of the Hyundai Nexo to H2 with the gasoline-powered Kia Sportage shows that if the first car circulated in Ecuador, it would have a Price-Range ratio of $ 0.12/km compared to $ 0.05/km of the second car. However, if one of the advantages of the Green Hydrogen Catapult project were applied, the ratio would be more favourable for the Hyundai Nexo with 0.02 $/Km.
4. The profit that a taxi driver would have after a workday of 8 to 10 h travelling 300 km approximately is $ 22.08 using a gasoline vehicle at $ 38.55 if using a hydrogen vehicle and with the advantage of the Green Hydrogen Catapult project or the Implementation of the Nuclear Plant.
5. The photo voltaic solar energy that is generated in the Province of Tungurahua would cover the demand of 2,055 city taxis in the city of Ambato. Furthermore, with the hydrogen-powered taxi fleet, the hydrogen chicken and Egg dilemma can be broken.
6. H2 Vehicle Simulation Framework is a three-dimensional scale that assesses the H_2 amount of the vehicle, the autonomy of the car and raw distance. This dimension will be important at the moment to buy an H_2 vehicle.
7. A strong correlation between two principal components can be appreciate on a graph where a point of X and Y axis should be in the corner because the values will be close to 1.

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Source. https://github.com/joffreespin/PaperH2

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