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Original scientific paper

Exploration of the Diversified Path of Energy Economic Transformation Based on the Perspective of Hydrogen Energy Industry Innovation

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Abstract: This analysis explores the usage of hydrogen as oil in the vehicle part with the goal of promoting economic decarbonization. Hydrogen vapor is a powerful means of pollutant emissions reduction, environmentally friendly technology support, and international accords compliment, such as the Paris Agreement and the Glasgow resolutions. The whole hydrogen manufacturing process is presented from generation to vehicle fuel consumption at 100% pure by renewable energy sources like solar and wind, forecasting hydrogen use, considering new and current infrastructure for distribution, storage, and production, necessary to expect in future energy demands. The study provides a reference for stakeholders to develop effective designs for the phased integration of hydrogen fuel cell cars for hydrogen generation. Wind energy generates 6 MWh per unit/year, generating 45,139.70 GWh/year, and involves 7,523,282.6 components. This strategy tackles the optimization challenge by reducing manufacturing costs and environmental effects, while the EU framework for economic decarbonization and the automotive industry's shift adheres to a fleet of non-polluting vehicles.

Keywords: economic decarbonization; electric vehicles; emissions of pollutants; green economy; hydrogen energy

1 INTRODUCTION

The principal aim of this study is to act as a catalyst for the expedited expansion of the hydrogen energy industry and to investigate various approaches to fostering a modern energy economy. An extensive inquiry is conducted to explore diverse approaches, state-of-the-art technologies, and regulatory structures that may facilitate the growth of the hydrogen sector. An exhaustive examination of the current state of hydrogen production, storage, and distribution technologies is essential to the success of this endeavor. The primary objective of this analysis is to ascertain the existing condition of these technologies and detect any potential barriers, which could hinder the industry's accelerated expansion. Innovative and creative solutions are anticipated to tackle these challenges and expedite the sector's progress [1]. The research expands its scope beyond technological factors to encompass an in-depth investigation of the social, environmental, and economic consequences linked to the incorporation of hydrogen hooked on the broader liveliness scheme. Acknowledging hydrogen's diverse and multidimensional potential to promote a more sustainable energy economy, this study aims to illuminate the comprehensive ramifications of incorporating hydrogen into energy systems. Through an exhaustive analysis of diverse methodologies, this study aims to offer practical insights and implementable recommendations [2]. These insights guide policymakers, industry stakeholders, and academics, enabling them to make well-informed decisions and facilitating the hydrogen energy sector's efficient and effective expansion. Fundamentally, this study functions as a strategic guide, compiling a comprehensive comprehension of the obstacles and prospects of establishing a modern energy economy.

Moreover, it establishes a basis for judicious decision-making, guaranteeing the triumph of the hydrogen energy industry amidst the ever-changing energy terrain [3]. The COP (CONFERENCE OF THE PARTIES) 26 resolutions and the Paris Agreement represented significant turning points in adaptation, finance, and climate change mitigation [4]. Nevertheless, these vehicles' hydrogen production or electricity source influences their greenhouse gas (GHG) emissions. HFCVs and EVs, positioned as environmentally favorable alternatives to conventional vehicles, are expected to contend with one another in the automotive industry, impacting its future with digital transformation [5]. Hydrogen-powered fuel cell vehicles (HFCVs) have several benefits compared to electric vehicles (EVs). These include a range that is similar to that of internal combustion engine vehicles (ICEVs), the ability to be refueled rapidly, a high efficacy in converting energy into carbon-free emissions, and a variety of storage and conveyance alternatives [6]. The problems with earlier studies are as follows, the widespread adoption is currently impeded by increased expenses, insufficient infrastructure, a restricted range of vehicle choices, and consumer inclinations.

Significant and ongoing renewable energy production is required to meet the escalating demand for hydrogen in the automotive, refining, ammonia, synthetic fuels, and steel industries [7]. To achieve the EU ambitious goals for 2030 and 2050, a comprehensive approach is necessary to tackle the emerging energy demands in the automotive industry while simultaneously complying with the environmental and sustainability principles delineated in the EU's Paris Agreement commitment. The main objective of this education is to ascertain the most effective strategies for meeting the energy demands of the automotive sector in a manner which is consistent with the goals of the European Union and aids in the transition to a decarbonized economy.

This study contributes greatly to hydrogen energy sector and the quest for a more diverse and sustainable energy economy in the current world. The report gives significant insights into technology breakthroughs, legislative frameworks, and prospective solutions to overcome current hurdles by looking into measures to expedite industrial growth. The present condition and potential of the business may be understood by thoroughly examining the technologies in hydrogen production, storage, and delivery [8]. The contribution sheds light on the many facets of a sustainable energy transition by looking at the economic, environmental, and social repercussions of incorporating hydrogen into the energy landscape. Through a comprehensive examination of other routes, the report offers concrete suggestions for policymakers, business leaders, and academics to use in supporting the fast expansion of the hydrogen energy sector. This study aims to catalyze revolutionary changes towards a more sustainable and diverse energy future by exploring the problems and possibilities linked with hydrogen, adding depth to the conversation on contemporary energy economics.

2 LITERATURE REVIEW

In recent years, much academic discussion has been on the pressing need to quicken the pace of progress in the hydrogen energy business and investigate alternative routes towards a more robust and sustainable energy system. Hydrogen's potential as an integral part of the transition to sustainable energy systems has been highlighted by environmental concerns, technological breakthroughs, and shifting global energy landscapes. Hydrogen and its related technologies, especially in the automobile industry, have been highlighted by scholars [9] as drivers for a change in basic assumptions in response to the consequences of climate change and international mitigation efforts. This idea is in keeping with the objectives of the Paris Agreement and the resolutions of COP (CONFERENCE OF THE PARTIES) 26. These documents detail essential steps for combating, adapting to, and funding the effects of climate change. The effects of hydrogen synthesis and subsequent usage in different contexts are discussed here. EVs and HFCVs are two examples of promising new technologies [10]. The need stressed to know where the power for these vehicles comes from. The ability of these technologies to decrease greenhouse gas (GHG) emissions depends on the energy source utilized. This fact emphasizes the significance of assessing the environmental impact of hydrogen-based energy systems.

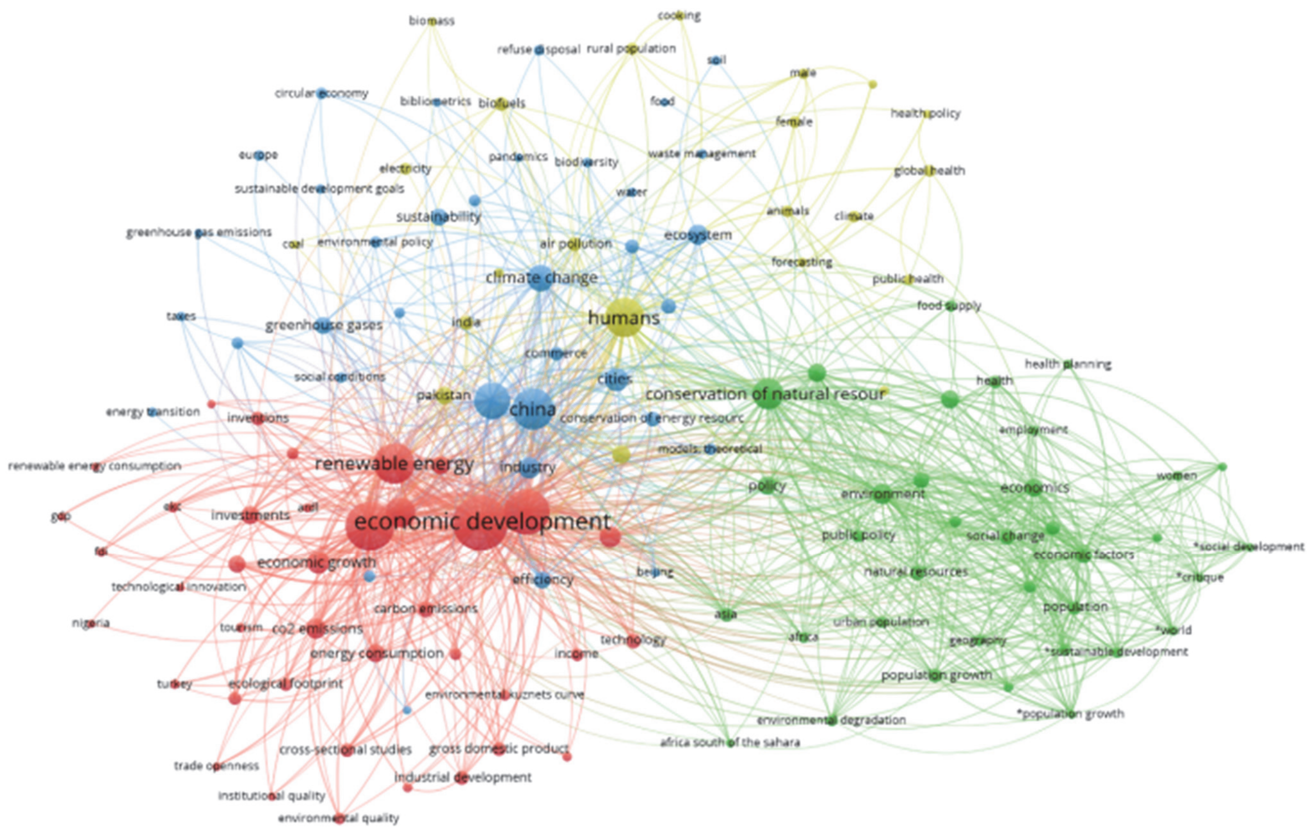

Figure 1 Co-occurrence of keywords in published research studies

The automobile industry's importance is growing as hydrogen becomes a serious competitor in the move towards a green economy. Electric cars (EVs) and hydrogen fuel cell vehicles (HFCVs) are seen as environmentally benign technical alternatives to conventional automobiles [11]. All highlight the ongoing competition among these alternatives within the automobile market, highlighting the transformative potential of these technologies in shaping the future of the automotive industry. Digital transformation, as explained by ref. [8], is set to leave an indelible imprint on the automobile industry, further emphasizing the industry's already disruptive trajectory.

Hydrogen fuel cell vehicles (HFCVs) are the subject of much discussion due to their perceived benefits over electric vehicles (EVs). According to [12] HFCVs have a range comparable to traditional Internal Combustion Engine Vehicles (ICEVs) without the need for regular refueling, making them an attractive option for consumers who worry about being stranded. In addition, HFCVs are more appealing as a practical option since their refueling time is much less than that of batteries [13]. Hydrogen is seen favorably among clean energy solutions due to its high energy conversion efficiency and absence of carbon-based emissions. According to [14], its adaptability has bolstered, where it can be stored in various ways, transported over great distances, and converted into several other fuels. However, HFCVs are not without hurdles, including increased vehicle prices, poor infrastructure, restricted vehicle alternatives, and a lack of customer demand. Hydrogen is in high demand in the car industry, conventional refining, ammonia manufacturing, synthetic fuels, and the steel sector. [15]. Underline the need for large-scale, continuous generation of low-cost renewable energy to keep up with this rising demand. A steady supply of hydrogen is crucial to moving towards more environmentally friendly energy practices as it plays an increasingly important part in the push to decarbonize the economy.

The European Union (EU) has established aggressive goals for 2030 and 2050, highlighting the need for a comprehensive technique to meet the evolving energy requirements of the automobile sector. Ref. [16] calls for a holistic strategy that considers environmental and sustainability criteria based on the Paris Agreement to match EU goals. While recognizing the complexity of the energy transition in the automotive sector, the methodology seeks to identify promising avenues for moving forward with the pledge to decarbonize the economy [17]. There is an active and multidisciplinary discussion reflected in the literature on the growth of the hydrogen energy business and the investigation of alternative routes towards a more sustainable and prosperous energy economy. The study emphasizes the necessity for all-encompassing assessments, considering environmental, economic, and social factors as technological developments and global imperatives drive this shift. Understanding the synergies and difficulties of hydrogen-based energy systems is important for policymakers, industry stakeholders, and researchers as they navigate the changing energy environment.

3 DATA AND METHODOLOGY

3.1 Theoretical Background

One way to plan for a smooth transition to a more sustainable and diverse energy environment is to speed up the development of the hydrogen energy business and investigate alternative routes for a contemporary energy economy. Hydrogen's ability to cut carbon emissions across industries is becoming increasingly widely acknowledged as more people learn about the benefits of this clean and flexible energy carrier. The theoretical foundation for this title is understanding the critical need to act swiftly to combat climate change and transition away from fossil fuels and towards renewable energy. To expedite the growth of the hydrogen energy business, research and development activities should concentrate on enhancing hydrogen production, storage, and transportation technologies [18]. Increased international cooperation and public-private partnerships may benefit knowledge sharing and resource accumulation. Including power generation, transportation, and industrial processes, hydrogen integrated into pre-existing energy systems is one way to diversify pathways for a contemporary energy economy.

The theoretical basis stresses the significance of policy frameworks encouraging regulatory environments favorable to hydrogen infrastructure investment. Green hydrogen from renewable sources and blue hydrogen from carbon capture storage are two examples of diversifying your options that may help you reach your goals faster. To combat climate change and promote economic development, this strategy is congruent with the larger objective of building a robust and sustainable energy environment [19].

3.2 Comparison between Hydrogen and Petrol as Fuel Sources for Automobiles

Two important characteristics of hydrogen highlight its potential to precisely determine the motorized liveliness of each kg that separates an electric motor driven by an oil cell from a heat engine powered by gasoline. Careful calculations were carried out using thermodynamic data that was obtained from reputable and trustworthy sources such as [20]. With an engine's expected efficiency of 0.35 and gasoline's lower heating value (LHV) of 44.5 MJ/kg, the total mechanical energy produced by a gasoline engine is calculated as $E - G$ = 15.57 MJ/kg/kg of gasoline. On the other hand, a fuel cell-powered hydrogen vehicle, where the hydrogen has a higher heating value (HHV) of 120 MJ/kg, is the focus of an alternative energy scenario. This vehicle is rechargeable gas-powered with a normal productivity of η_m = 0.9 and a fuel cell with an average efficiency of η_b = 0.7. As a result, the overall system efficiency, η_T, is calculated as ηm multiplied by η_b, which equals 0.63. This means that for every kilogram of hydrogen, the vehicle generates an energy output of E_{H2} = 75.6 MJ/kg. The calculations demonstrate a significant disparity in mechanical energy production per unit mass between the two systems, underscoring the huge benefits of hydrogen as an energy carrier. Directly converting hydrogen into electrical energy using a fuel cell increases efficiency, making it an attractive and environmentally friendly alternative to conventional petrol engines. This represents a major advancement towards sustainable energy solutions.

By comparing these data, we calculate the relationship as follows.

$$\text{Energy Ratio:} R_{\mathrm{E}} = \frac{E_{\mathrm{H2}}}{E_{\mathrm{gasol}}} = 5.03 \tag{1}$$

The energy efficiency calculations show that the hydrogen-powered car has a significant fuel-saving advantage. The hydrogen-powered car would use 5.03 periods less oil. The study displays that, even though the hydrogen-powered car has a significant advantage in mass-based fuel usage, the material's low density might be a disadvantage in volume. In order to ensure hydrogen's practical feasibility in real-world applications and support its further integration as a sustainable energy carrier, creative storage, and transportation solutions must be developed to address the volumetric constraints associated with hydrogen.

$$V_{\mathrm{gasol}} = \frac{5.037 \text{ kg}}{680 \text{ kg} / \text{m}^3} = 0.0074 \text{ m}^3 \tag{2}$$

Consequently, the ratio of volume would be:

$$R_{\mathrm{V}}=\frac{V_{\mathrm{H2}}}{V_{\mathrm{gasol}}}=1,502.7 \tag{3}$$

This implies that a hydrogen storage tank must be 1500 times larger than its petrol counterpart to attain an equivalent range, despite the hydrogen's higher calorific value and the potential for improved energy efficiency. This emphasizes the critical need for high-pressure storage in mobile applications. However, under 700 bars of pressure, the density significantly rises to ρ_{H2} = 62.93 kg/m³. As a result, the volume required to store 1 kilogram of hydrogen would be diminished, alleviating the volumetric difficulties associated with its storage.

$$V_{\mathrm{H2}}=\frac{1\ \mathrm{kg}}{62.93\ \mathrm{kg/m^3}}=0.016\ \mathrm{m}^3 \tag{4}$$

Consequently, the new volume ratio at 700 bar is as follows.

$$R_{\mathrm{V'}}=\frac{V_{\mathrm{H2}}}{V_{\mathrm{gasol}}}=2.16 \tag{5}$$

When comparing each other, the latter would need a fuel tank that holds around 108 liters on average. Despite being bigger, this is a significant advancement and has started to provide a more realistic picture of hydrogen storage in automobiles.

3.3 Performance on the Highway of a Few Hydrogen and Fuel Cell Cars

Here are some examples of the energy use statistics for certain fuel cell and hydrogen vehicles: Toyota Mirai uses 19.49 kWh for every 100 skm. This vehicle uses between 18 and 18.3 kWh of energy per 100 km, or 1 kilogram of H2 [22]. According to the research, Honda Clarity Fuel Cell (178 horsepower): 3.46 liters of fuel (or 0.22 kg of hydrogen) are used for every 100 km. This car uses one kilogram of hydrogen for every 100 km of travel.

3.4 The Fuel Cell Efficacy and Electrical Output Produced By 1 Kilogram of Hydrogen

The equation for calculation is ($W = n \cdot F \cdot E$), where the symbol "n" denotes the number of electron spins (e^-) that are current in each infiltrator of hydrogen complex in the feedback.

F represents Faraday's continual.

$$F=96,485\frac{\mathrm{c}}{\mathrm{mol\ of\ e^{-}}} \tag{6}$$

E denotes the charge cell's potential: E = 0.7 V

$$\begin{aligned} W=n\cdot F\cdot E=2\frac{\mathrm{mol\ of\ e^-}}{\mathrm{mol\ of\ H_2}}\cdot 96,485\frac{\mathrm{C}}{\mathrm{mol\ of\ e^-}}\cdot 0.8\mathrm{V}= \\ 154,376\frac{\mathrm{C\cdot V}}{\mathrm{mol\ of\ H_2}}=154,376\frac{\mathrm{J}}{\mathrm{mol\ of\ H_2}} \end{aligned} \tag{7}$$

The Toyota Mirai consumes 70.16 MJ of energy per 100 km (154 hp), which enables it to travel 110 km on 1 kg of H_2 fuel, presuming a fuel cell efficiency of 100%.

3.5 Production of Hydrogen for Vehicles

Pure hydrogen is not naturally occurring and must be produced via various processes. Reforming and electrolysis are the principal industrial processes utilized in the operation of hydrogen. The more widely used method, reforming, entails the hydrocarbon (usually natural gas or coal) reacting with water vapor at elevated temperatures and pressures. Nevertheless, despite its environmental friendliness, this process yields an estimated 10 kg of CO_2 per kilogram of hydrogen produced [20].

On the other hand, electrolysis, an industrial process that accounts for a mere 1% of worldwide hydrogen production, is far more environmentally friendly. Water is decomposed by utilizing an electric current, producing 8 kilograms of oxygen for each kilogram of hydrogen. Despite requiring considerable energy, electrolysis can eradicate carbon dioxide (CO_2) emissions. This characteristic aligns with environmentally conscious practices.

3.5.1 Electrolytic

Using electricity, an electrolyze facilitates the chemical process of electrolysis, which produces hydrogen by separating the oxygen and hydrogen molecules in water. Ref. [23] emphasizes that this carbon dioxide-free, sustainable way of producing hydrogen has the potential to be the cornerstone of a decarbonized economy.

3.5.2 Electricity use of the Electrolyze

The energy required to divide the sea into (H and O) is represented as ($W = n \cdot F \cdot E$), in line with Faraday's principles. The reaction's reversible probable is represented by the symbol (E = 1.23 V), but to get past obstacles, a probable between 1.6 and 1.8 V, or, for example, 1.7 V, must be practical. Given that every electrolyzed water molecule produces two electrons.

$$\begin{aligned} W=n\cdot F\cdot V=2\frac{\mathrm{mol\ of\ e^-}}{\mathrm{mol\ of\ H_2}}\cdot 96,485\frac{\mathrm{C}}{\mathrm{mol\ of\ e^-}}\cdot 1.7\ \mathrm{V}= \\ 328,049\frac{\mathrm{C\cdot V}}{\mathrm{mol\ of\ H_2}}=45.46\frac{\mathrm{kWh}}{\mathrm{kgH_2}} \end{aligned} \tag{8}$$

With the electrolyte's efficiency (η = 0.8), its consumption is:

$$E_{\mathrm{Electrolyz}}=\frac{W}{\eta}=\frac{45.76\frac{\mathrm{kWh}}{\mathrm{kgH_2}}}{0.8}=56.825\frac{\mathrm{kWh}}{\mathrm{kgH_2}} \tag{9}$$

3.5.3 Gas Compression Energy

As explained in Section 2, providing hydrogen under pressure is crucial for several reasons. Significant energy usage is indicated by raising the gaseous H_2 pressure to 700 atm (70 MPa), a factor that has to be carefully considered.

$$E_{\text{com}} = \frac{\gamma}{\gamma-1} p_0 \cdot V_0 \cdot \left[\left(\frac{p_1}{p_0} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \tag{10}$$

Wherever, E is the energy (J/kg) needed to compress the gas. The starting pressure in Pa is represented by p_0. p_1 is the total heaviness in Pa. The original precise size (m³/kg) is represented by V_0. At 20 °C, hydrogen's adiabatic coefficient equals $\gamma = 1.41$. Since the hydrogen generated by the electrolyze departs at atmospheric pressure (° 0 = 1 p_0 = 1 atm ≈ 105 105 Pa), the method above may be used to calculate the liveliness needed to bandage it to 700 atm.

$$E_{\text{com}} = \frac{1.41}{1.41-1} 10^5 \,\text{Pa} \cdot 12.225 \frac{\text{m}^3}{\text{kg}} \cdot \left[\left(\frac{70 \cdot 10^6}{10^5} \right)^{\frac{1.41-1}{1.41}} - 1 \right] = 24 \cdot 10^6 \,\text{J/kg} \tag{11}$$

$$E_{\text{com}} = 24 \cdot 10^6 \frac{\text{J}}{\text{kg}} \cdot \frac{1\text{kW}}{1{,}000\text{W}} \cdot \frac{1\text{h}}{3{,}600\text{s}} = 6.7\text{kWh / kgH}_{2(\text{at}\,70\text{MPa})} \tag{12}$$

Measured in Wh/m³:

$$E_{\text{com}} = 6.7 \cdot \frac{\text{kWh}}{\text{kgH}_{2(\text{at}\,70\text{MPa})}} \cdot \frac{1\text{kg}}{1{,}000\text{g}} \cdot 2 \frac{\text{g}}{\text{mol}} \cdot \frac{1}{24.45} \frac{\text{mol}}{\text{l}} \cdot \frac{1{,}000\text{l}}{\text{m}^3} = 548 \cdot \frac{\text{Wh}}{\text{m}^3} \tag{13}$$

If the electrolyzing process produces 2.73 Nm³/h, the compressor power has to be:

$$P_{\text{compressor}} = 548 \cdot \frac{\text{Wh}}{\text{m}^3} \cdot 2.7 \cdot \frac{\text{Nm}^3}{\text{h}} = 1.5\text{kW} \tag{14}$$

It is important to remember that many electrolytes are designed to provide hydrogen straight to the user at the needed pressure. Consequently, the power requirements must be modified depending on the electrolyze used. Hydrogen is often provided at two standard pressures: 35 MPa and 70 MPa, depending on the production nation. For a car traveling shorter distances, especially in an urban environment, 35 MPa of hydrogen could be enough. This emphasizes how hydrogen supply pressures may be adjusted according to the electrolyte's capabilities and the operating environment.

3.5.4 Hydrocarbon and Hydrogen Consumption Equivalencies

It is critical to comprehend the energy potential in each case in order to evaluate the challenge of moving from a fossil fuel-based economy, which is non-renewable and detrimental to the environment, to a decarbonized economy powered by renewable energies.

Table 1 Calorimetric information for various substances

Oily rate	L.H.V / MJ/kg	H.H.V / MJ/kg
Propane	55.5	50
Methane	50.3	45.6
Diesel	47.3	44.5
Gasoline	44.8	42.5
Hydrogen	142.5	120

Tab. 1 shows the calorimetric data for several chemicals, including their oily rate, L.H.V., and H.H.V. in Mega Joules per kilogram (MJ/kg). There is a 55.5 MJ/kg L.H.V and a 50 MJ/kg H.H.V for propane. The L.H.V. of methane is 50.3 MJ/kg, whereas the H.H.V. is 45.6 MJ/kg. The L.H.V. of diesel is 47.3 MJ/kg, and the H.H.V. is 44.5 MJ/kg. The L.H.V. of gasoline is 44.8 MJ/kg, whereas the H.H.V. is 42.5 MJ/kg. The L.H.V. of hydrogen is 142.5 MJ/kg, whereas the H.H.V. is 120 MJ/kg.

Table 2 Calorie contents of commonly used natural gases

Oily rate H.H.V	kWh/l	kWh/kg
Usual gas (0 °C)	15.75	0.0117
Liquefied natural gas (L.N.G)	15.75	2.5
L.P.G (Liquefied petroleum gas)	15.75	6.79
Compressed natural gas (C.N.G)	13.8	7.73
Gasoline	12.44	10.26
Diesel	15.75	0.0117

Commonly utilized natural gases and their flow rates and energy values are shown in Tab. 2. The oily rate for regular gas at zero degrees Celsius is 15.75, with an energy content of 0.0117 kWh/l. Compared to the oil rate (15.75), the energy value of Liquefied Natural Gas (L.N.G.) is greater, at 2.5 kWh/kg. The oil content of Liquefied Petroleum Gas (L.P. G), often known as LPG, is 15.75, and its energy content is 6.79 kWh/l. CNG has an oil rate of 13.8 and an energy value of 7.73 kilowatt hours. The oil content of gasoline is 12.44, and its energy content is 10.26 kWh. Like the oily rate of Usual gas, which is 15.75, diesel has an energy value of 0.0117 kWh/l.

4 RESULTS AND DISCUSSION

4.1 The Annual Energy Usage of Spain's Fleet of Automobiles

Based on a mid-range passenger car's energy consumption (kWh), the energy demand per 100 kilometers driven is EN = 15.60 kWh. This estimate is predicated on the idea that the car maintains a regular speed of 80 km under typical wind and temperature conditions. m/h. With a vehicle figure of 1850 k. g, the energy wanted to drive it is thoroughly linked to the dynamic energy wanted to reach and preserve this velocity [24]. This computation accounts for energy losses mostly caused by temporary resistance and aerodynamic services on the automobile. It also considers inefficiencies in internal combustion engines and losses from mechanical gearboxes, recognizing that engine performance is not at its best.

Dynamic translational energy is shown as follows:

$$E_{\text{CT}} = \frac{1}{2} \cdot m \cdot v^2 = 0.5 \cdot 1{,}850 \cdot \left(80 \cdot \frac{1{,}000}{3{,}600} \right)^2 \cdot \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} = = 246{,}913.57\text{N} \cdot \text{m}(\text{J}) = 0.247\text{MJ} \tag{15}$$

Since the kinetic energy of the wheels' rotation may be disregarded, the kinetic energy is as follows.

$$E_{\mathrm{C}} = E_{\mathrm{CT}} \tag{16}$$

Energetic aerodynamics is as follows:

$$E_{\mathrm{a}} = \left(\frac{1}{2}\cdot C\cdot S\cdot\rho\cdot v^2\right)\cdot d = 0.5\cdot 0.29\cdot 2.5\cdot 1.225\cdot \cdot\left(80\cdot\frac{1,000}{3,600}\right)^2\cdot 100\cdot 1,000\cdot\frac{\mathrm{kg}\cdot\mathrm{m}^2}{\mathrm{s}^2} = = 28,734,567.86\mathrm{J} = 28.73\mathrm{MJ} \tag{17}$$

Kinetic energy from tire-to-road friction:

$$E_{\mathrm{r}} = f_{\mathrm{r}}\cdot W\cdot d = 0.015\cdot 1,850\cdot 9.81\cdot 100\cdot 1,000 = = 50,000,000\mathrm{J} = 27.22\mathrm{MJ} \tag{18}$$

Energy as a whole: $E_{\mathrm{T}} = E_{\mathrm{C}} + E_{\mathrm{a}} + E_{\mathrm{r}} = 56.197$ MJ.

Since 1 liter of petrol pays 9.23 kWh/l and the engine's efficiency of $\mu = 0.25$, the car would need 2.3 kWh/l, which is the same as 6.78 liters of gasoline. For diesel-powered cars, 1 liter of diesel adds 10.26 kWh/l. If you shoulder that the engine is effectual at $\mu = 0.25$, it needs 2.56 kWh/l, which is the same as 6.08 liters of diesel. For cars that run on LPG, 1 liter of LPG gives off 6.79 kWh/l, and a train with an efficacy of $\mu = 0.25$ needs 1.69 kWh/l, the same as 9.23 liters of LNG. Hydrogen-powered cars would need 29.49 kWh/kg, or 0.52 kg of hydrogen, since 1 kg of hydrogen gives off 39.33 kWh/kg and a rechargeable gas-powered and oil prison cell have an efficacy of $\mu = 0.75$. A similar method must be used to figure out how much fuel is needed for any trip. The energy used must be broken down into parts for a W. L. T. P. type allowed trip. Tab. 3 shows the results of all the above estimates by the average fuel use for each fuel type.

Table 3 Calorie contents of commonly used natural gases

100 km	Mass	Measure	Physique
L.P.G	0.52 kg	0.0893 kg/m^3	5.52 m^3
Diesel	5.08 kg	0.750 kg/l	6.78 l
Gasoline	5.16 kg	0.850 kg/l	6.08 l
Hydrogen	5.16 kg	0.560 kg/l	9.23 l

The caloric content of some of the most often utilized natural gases is included in Tab. 3, together with information on their typical size, weight, and volume use. Liquefied petroleum gas (LPG) has a density of 0.0893 kg/m3, making its physical volume 5.52 m3. Diesel, which has a density of 0.750 kg/l and a body weight of 5.08 kg, consumes 6.78 liters [25]. With a density of 0.850 kg/l, gasoline needs 6.08 gallons to transport a body weighing 5.16 kilograms. Hydrogen has a density of 0.560 kg/l and weighs 5.16 kg, which takes up a volume of 9.23 liters due to its size.

Analysis 2 figures out how much fuel is needed each year to move Spain's fleet of vehicles.

Tab. 4 shows the breakdown of this figure, which looks at different types of vehicles, their usual trip lengths, lives, and fuel consumption rates.

Table 4 A Review of Spain's vehicle stock for the year 2020

Vehicles	Elements	km/y	Usual feasting/100 km	Full feasting
Cars	3,514,751 (< 3000 = 2,213,662) (> 3000 = 301,088)	< 3000 kg = 14,467 > 3000 = 47,543	25 2 40 2	8.095·1011 2 6.725·1011 2
Vans	73,388	62,952	28 2	8.397·1010 2
Buses	3,516,178	24,468	11 2	5.004·1011 2
Trucks	34,716,897 (G = 10,992,737) (D = 13,724,163)	22,267	(G = 7.6 2) (D = 5.6 2)	2.024·1012 2 8.427·1011 2
Tractors	4,735,921	3904	4.4 2	5771·1010 2
Motorcycles	335,512	2101	110 2	6440·1010 2

Tab. 4. provides an overview of the vehicle fleet in Spain in 2020, broken down by category. There are a total of 3,514,751 vehicles, and their components are separated into those with lighter loads (3000 kg) and those with heavier loads (> 3000 kg), with a typical cost per 100 km. In addition to cars, vans, buses, trucks (split into Gasoline (G) and Diesel (D) categories), tractors, and motorbikes are covered with data points such as annual mileage and average and maximum fuel capacity [26]. The information that was gathered is shown in Tab. 5. It includes average numbers for average fuel use, average thickness, and normal journey ways for each type.

Tab. 5 offers typical yearly energy usage from several sources, defining the mass, feasting in kg, and feasting. With a density of 0.0893 kg/m^3, Liquefied Petroleum Gas (LPG) has a yearly consumption rate of 16,200 kilograms, or 16,200 kilograms worth of food. With a density of 0.750 kg/l, diesel produces 56.2 tons per year, or 75,000 liters. With a mass of 0.850 kg/l, gasoline yields an annual feast of 70,125 kg or 82,500 l. Hydrogen, which weighs 0.560 kg/l, has an eating rate of 73,920 kg/year, or 132000 l/year.

Table 5 Mean annual energy use from various sources

Variable	Feasting kg	Mass	Feasting 1
L.P.G	26,202 kg/y	0.0894 kg/m^3	26,201 kg/y
Diesel	56,250 kg/y	0.751 kg/l	75,000 l/y
Gasoline	70,125 kg/y	0.852 kg/l	82,500 l/y
Hydrogen	73,920 kg/y	0.563 kg/l	132,000 l/y

Table 6 Average fuel consumption trends for all vehicle types

Variable	Yearly feasting in kg	Yearly feasting in kWh	Vehicles navy
L.P.G	9.44·1011 kg/year	204.46·1011 kWh	15 mil.
Diesel	8.0126·1011 kg/year	95.15·1011 kWh	10 mil.
Gasoline	8.3921·1010 kg/ year	202.02·1010 kWh	1 mil.

Tab. 6. shows generalized trends in fuel economy for all vehicles. With 15 million cars on the road, annual LPG usage is 9.44 × 1011 kg, or 204.46 × 1011 kWh. For 10 million automobiles, diesel uses 8.0126 × 1011 kg/year, which is equivalent to 95.15 × 1011 kWh. Gasoline uses 8.3921 ×1010 kg/year, which is equivalent to 202.02 × 1010 kWh [27]. Based on this study, the overall number of

kWh (Q_2) that would be needed to replace with hydrogen is as follows.

$$Q_2\left(\text{MWh}\right)=199.79\cdot10^{11}\,\text{MWh} \quad (19)$$

Analysis 3 figures out the total amount of fuel used each year.

Table 7 2019 Statistics on tonnage usage in Spain, as reported by the DGT in 2021

Y.	L.P.G / T	Gasoline / T	Diesel / T
2019	31,566,516	86,016	5,385,452

Tab. 7 presents the DGT's 2021 report on 2019 tonnage consumption in Spain. Total LPG production is 31 566 516 tons, gasoline production is 86 016 tons, and diesel is 5 385 452 tons.

4.2 Needs for Hydrogen in the Auto Industry

Needs for hydrogen in the auto industry are shown below:

$$M_{\text{H}_2}\left(\text{kg}\right)=\frac{5385452\cdot10^3\cdot x+31566516\cdot10^3\cdot y+86016\cdot z}{W} \quad (20)$$

wherever:

$$X=12.4\cdot\frac{\text{kWh}}{\text{kg}};\ Y=12.1\cdot\frac{\text{kWh}}{\text{kg}};\ Z=13.8\cdot\frac{\text{kWh}}{\text{kg}};\ W=39.3\cdot\frac{\text{kWh}}{\text{kg}} \quad (21)$$

In order to work, the kg of hydrogen wanted are as follows.

$$M_{\text{H}_2}\left(\text{kg}\right)=1,706,204,836\ \text{kg}=1,706.2\cdot10^6\,\text{kg}=1,706,204.836\ \text{T} \quad (22)$$

Taking into account that an electrolyze is used:

$$W=45.46\frac{\text{kWh}}{\text{kgH}_2} \quad (23)$$

To make the amount of hydrogen M_{H2} (kg), the amount R (kWh) is needed:

$$R\left(\text{kWh}\right)=1706204836\ \text{kg}\,/\,45.5\frac{\text{kWh}}{\text{kg}}=7.756\cdot10^{10}\,\text{kWh} \quad (24)$$

In addition, an additional energy of S (kWh) is compulsory to bandage the gas to 700 atm:

$$S\left(\text{kWh}\right)=1,706,204,836\text{kg}\cdot6.7\ \text{kWh}\,/\,\text{kg}=1.14315\cdot10^{10}\,\text{kWh} \quad (25)$$

Completing the task would require the generation of Q_3 (MWh):

$$Q_3\left(\text{MWh}\right)=R\left(\text{kWh}\right)+S\left(\text{kWh}\right)=8.899\cdot10^7\,\text{MWh} \quad (26)$$

4.3 Evaluating the Output of Electricity from a Hydroelectric Plant, Solar PV Farm, and Wind Farm

A wind machine that is 138 meters tall and has blades that are 126 meters in diameter produces 6 megawatts of electricity annually.

$$P_{\text{wt}}=6\ \text{MW} \quad (27)$$

4.3.1 Photovoltaic Solar Power

A typical planetary board can crop 250 W and 300 W of control and grip up to 500 W of power [28]. This means that every hour of sunshine will help make electricity. On a sunlit coil day in a sunny area, the solar piece should be talented enough to make much energy.

$$P_{500\text{Wday}}=500\text{W}\cdot5\frac{\text{h}}{\text{day}}=2500\frac{\text{Wh}}{\text{day}}=2.5\frac{\text{kWh}}{\text{day}} \quad (28)$$

If there are 300 days of 5 hours of sunlight a year, it is possible to guess how much power is made each year. Here is a different phrase.

$$P_{500\text{Wyearly}}=2.5\frac{\text{kWh}}{\text{day}}\cdot300\frac{\text{day}}{\text{year}}=0.75\frac{\text{MWh}}{\text{year}} \quad (29)$$

4.3.2 Mechanical Hydraulics

The measurement of the power generated by a hydroelectric influence herbal is customarily expressed in (MW), and the computation entails the utilization of the subsequent formula.

$$P_{\text{h}}=\rho\cdot g\cdot\eta_{\text{t}}\cdot\eta_{\text{g}}\cdot\eta_{\text{m}}\cdot Q\cdot H \quad (30)$$

ρ - density of the fluid (kg/m³); g - gravitational acceleration (m/s²); η_{t} - efficacy of hydraulic turbines (varying between 0.75 and 0.94); η_{g} - efficacy of the electric generator (ranging from 0.92 to 0.97); η_{m} - mechanical efficacy of the turbine-alternator coupling (with values between 0.95 and 0.99) [29]; Q - flow rate of the turbine in m³/s; H - obtainable cranium change (m) amongst striving and downriver of the dam. Consider a hydroelectric facility that emits a discharge rate of $Q=50\cdot10^2\,\frac{\text{m}^3}{\text{s}}$. At an altitude of 200 meters, the power generated is:

$$P=997\frac{\text{kg}}{\text{m}^3}\cdot9.81\frac{\text{m}}{\text{s}^2}\cdot0.75\cdot0.92\cdot0.95\cdot50\frac{\text{m}^3}{\text{s}}\cdot200\text{m}=6,411.163\text{kW} \quad (31)$$

The annual energy production can be approximated as shadows:

$$E = p \cdot t = 3077.35 \text{ MWh} \quad (32)$$

4.4 CO_2 Production from Gas and Coal-Fired Power Plants Calculated

The sum of CO_2 bent during the energy group stage is a critical restriction in the optimization procedure described below. We do several procedures to calculate this number. First, we look at the energy values for compressed natural gas and coal, as shown in Tab. 8.

Table 8 Comparison of compressed natural gas and coal energy density metrics

Produce	kcal/kg	MJ/kg
Anthracite coal	32.72	8194
CNG	56.25	11,990

Tab. 8 shows the differences and similarities between CNG and Anthracite coal in energy density measurements. The energy density of anthracite coal is 32.72 kcal/kg (or 8194 MJ/kg), whereas that of compressed natural gas (CNG) is 56.25 kcal/kg (or 11,990 MJ/kg). We then review a breakdown of how much CO_2 is created per kWh using different materials.

4.4.1 Anthracite and Carbon Combustion Stoichiometry

The following is the stoichiometric equation that regulates the combustion of coal (Anthracite):

$C + O_2 \rightarrow CO_2 + 32.72$

$12\text{g } C + 32 \text{ g } O_2 \rightarrow 44 \; CO_2$

$1\text{kg } C \rightarrow 3.67 \text{ kg } CO_2$

In the case of lignite and other varieties of coal, an analogous methodology is utilized to compute the energy discharged during the combustion process and the consequent carbon dioxide emissions [30].

Also, concerning CO_2 emissions:

$$3.18 \cdot \frac{\text{kWh}}{\text{kgC}} \cdot \frac{1\text{kgC}}{3.66\text{kgCO}_2} = 0.868 \cdot \frac{\text{kWh}}{\text{kgCO}_2} \quad (33)$$

According to the derived connection, 1.152 kg of CO_2 is produced for every 1 kWh power generated. This correlation is crucial for assessing the sum of CO_2 bent relative to the power plant's energy group. It makes it easier to add a penalty term to the optimization problem, which takes care of the CO_2 production part of the optimization procedure.

4.4.2 Stoichiometric Theory for Burning Natural Gas

Compressed Natural Gas (CNG), which is mostly methane (95% to 99%), is used in the same way that LPG (a mixture of propane and butane) is used to figure out energy output and CO_2 emissions.

Natural gas (methane) can be burned by following this stoichiometric equation:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + 56.25 \text{ MJ/kg}$

$16 \text{ g } CH_4 + 64 \text{ g } O_2 \rightarrow 44 \text{ g } CO_2$

$16 \text{ g } CO_2 + 64\text{g } O_2 = 44 \text{ g } CO_2$

$1 \text{ kg } CH_4 \rightarrow 2.75 \text{ kg } CO_2$

Natural gas burning gives off 15,625 kWh/kg of energy, the same as 56.25 MJ/kg. For a gas-thermal power plant with an efficiency of 0.35 · = 0.35, the useful energy from natural gas is 5468 E, equal to 5468 kWh/kg. Also, when it comes to CO_2 emissions:

$$5,468 \cdot \frac{\text{kWh}}{\text{kgCH}_4} \cdot \frac{1\text{kgCH}_4}{2.75\text{kgCO}_2} = 2,053 \cdot \frac{\text{kWh}}{\text{kgCO}_2} \quad (34)$$

According to the set ratio, about 0.487 kg of CO_2 is made for every 1 kWh of electricity made from natural gas. This correlation is very helpful for figuring out how much CO_2 the power plant produces compared to how much energy it makes. It makes it easier to add a penalty term to the optimization problem, which considers the CO_2 generation part of the optimization process.

4.5 Costs of Producing Energy (kWh) by Technology

The expected expenses (MWh) bent, liable on the liveliness cause used, are shown in Tabs. 9 through 13. These datasets are essential elements that must be applied to the optimization issue.

Table 9 Production associated costs

Renewable energy sources		Non-Renewable energy sources	
Power plant	Price €/MWh	Power plant	Price €/MWh
Nuclear	65.87	Wind	81.37
Coal	126.76	Solar photovoltaic	81.65
Combined cycle	120.34	Hydro	68.12

Various power plants' output costs (€/MWh) are shown in Tab. 9. Nuclear power incurs €65.87/MWh, whereas wind energy costs €81.37/MWh [31]. Coal is the most expensive non-renewable energy source at €126.76/MWh, followed by solar photovoltaic at €81.65/MWh and combined cycle at €120.34/MWh. Hydropower is the most expensive renewable energy source, coming in at €68.12/MWh.

Table 10 Cost of fuel and carbon emissions per megawatt-hour (€/MWh)

Renewable energy sources		Non-Renewable energy sources	
Power plant	Price €/MWh	Power plant	Price €/MWh
Atomic/Nuclear	8.67	Wind	0.00
Coal	53.27	Solar photovoltaic	0.00
Integrated circuit	85.08	Hydro	0.00

The price of fossil fuels and carbon emissions is broken down per Megawatt-Hour (€/MWh) in Tab. 10. Nuclear power costs €8.67/MWh, whereas renewable energy sources like wind and solar PV cost nothing per megawatt hour [32]. Coal has the highest cost per megawatt hour (€53.27), followed by Integrated circuital €85.08

Operations and Maintenance costs are compared per megawatt-hour in Tab. 11. Nuclear power incurs

€6.2/MWh, whereas wind energy costs €15.3/MWh. Coal costs €8.48/MWh, solar photovoltaic costs €8.24/MWh, and combined cycle costs €6.67/MWh, non-renewable energy sources. In addition, the price of hydropower in the renewable section is €9.28/MWh.

Table 11 O&P expense metrics comparison (€/MWh)

Renewable energy sources		Non-Renewable energy sources	
Power plant	Price €/MWh	Power plant	Price €/MWh
Nuclear	6.2	Wind	15.3
Coal	8.48	Solar photovoltaic	8.24
Combined cycle	6.67	Hydro	9.28

Table 12 Marginal cost values for different products (€/MWh)

Renewable energy sources		Non-Renewable energy sources	
Power plant	Price €/MWh	Power plant	Price €/MWh
Nuclear	15.87	Wind	15.3
Coal	51.75	Solar photovoltaic	8.24
Combined cycle	81.73	Hydro	9.28

The marginal costs of various products are shown in Tab. 12. (Euros per megawatt-hour). Compared to wind energy's €15.3/MWh price tag, nuclear power's is €15.87/MWh. Coal is the most expensive non-renewable energy source at €51.75/MWh, followed by solar photovoltaic at €8.24/MWh and combined cycle at €81.73/MWh. In addition, the price of hydropower in the renewable section is €9.28/MWh.

Table 13 Transmission and loss cost analysis (€/MWh)

Renewable energy sources		Non-Renewable energy sources	
Power plant	Price €/MWh	Power plant	Price €/MWh
Nuclear	31.428	Wind	31.377
Coal.	35.659	Solar photovoltaic	31.742
Integrated circuit	38.357	Hydro	30.835

Transmission and loss costs are broken out in Tab. 13. (€/MWh). Nuclear power costs €31.428/MWh, whereas wind energy costs €31.377/MWh among renewable options. Coal is expensive non-renewable energy source at €35.659/MWh, solar photovoltaic is the more expensive at €31.742/MWh. Integrated circuit is the most expensive at €38.357/MWh. Hydropower is the most expensive renewable energy source, coming in at €30.835/MWh.

4.6 Enhancement of the Energy Blend

The goal is to figure out how many megawatts (MW) can be produced from an apiece energy foundation to harvest adequate energy to produce hydrogen, which is then used in the automobile sector to power hydrogen-powered electric vehicles instead of traditional ones. To do this, an optimization problem has been created, and the annual earnings to maximize are represented by the objective function, indicated by the letter *B* [33]. The optimization problem includes penalties for CO_2 generation as well as sustainability requirements. The best way to solve this issue is to reveal how much electricity each energy source needs to meet the car industry's hydrogen needs.

It is stated in the following equation.

$$B = A_o \cdot B_T - C_T \tag{35}$$

In the optimization problem: That is right, A_o stands for the opportunity cost of putting money into making energy. What does BT stand for? It is the total gross profit that the company made from selling goods m. The letter "*C*" stands for the costs of making greenhouse gases. The objective of the optimization problem is to discover the best value for function *B* while considering these factors and sustainability limits, such as penalties for CO_2 production.

This is one way to say "A_o".

$$A_o = \frac{1}{(1+r)^T} \tag{36}$$

In Eq. (33), *r* is the annual notice amount, and *T* is the number of the commercial ages it has been profitable. *r* is set to 0.03, and *T* is set to 20 years for this study. This information is then used to determine the total gross profit (B_T).

$$B_T = \sum_{m=1}^{n} B_m \tag{37}$$

In the equation, B_m is the gross profit from a certain energy source or method to make electricity, denoted by m. The number n is the total amount of energy bases, or pieces of knowledge, used to make current. The phrase for "B_m" can be written in the following way:

$$B_m = \sum_{m=1}^{n} b_m \cdot Q_m \tag{38}$$

m is the unit uncivilized income associated with producing electricity from a specific energy source or technology, and in the equation, $m = P_m - C_m$ symbolizes the unit gross profit. The difference between the unit manufacturing cost (C_m) and the unit sale price (P_m) is used to compute this unit gross profit. Specifically, C_m considers several factors, including where $b_m = P_m - C_m$ represents the unit revenue profit generated from the technology or source *m* to produce electricity. It is calculated by subtracting the unit cost of production C_m from the unit sell price P_m. We take P_m to be €205/MWh. Cm considers the subsequent factors: C_1 represents the expense associated with the production of the corresponding fuel CO_2. C_2 accounts for the cost of operation and maintenance. C_3 accounts for the marginal cost. C_4 accounts for the cost incurred due to transmissions and losses. The values of the terms above are detailed in Tabs. 9, 10, 11, 12, and 13.

$$C_m = C_1 + C_2 + C_3 + C_4 \tag{39}$$

Q_m signifies the yearly electricity generation in megawatt-hours (MWh) originating from the specified source or technology within the framework of the optimization problem. The cost of CO_2 production and nuclear waste management is succinctly represented by the acronym C_T. The cost in question can be defined by the subsequent model.

$$C_{\mathrm{T}} = \sum_{m=1}^{n} k_m \cdot Q_m \tag{40}$$

The pollution rate is expressed as k_m, which represents the environmental effect associated with each energy source. Notably, energy from sources like wind, solar, and hydropower is categorized as clean energy. These technologies have no pollutants. On the other hand, pollution is introduced by energy produced by nuclear, coal, and combined cycle (CC) power plants. However, the pollutants are different. Nuclear power facilities, for example, create radioactive waste, which complicates management and poses safety issues while not releasing greenhouse gases. This factor is included in the section on limitations.

$$B = \frac{1}{\left(1+r\right)^{T}} \cdot \sum_{m=1}^{n} \left(P_m - \left(C_1 + C_2 + C_3 + C_4\right)\right) \cdot Q_m \tag{41}$$

Several restrictions have been considered in the optimization problem to guarantee a sustainable and well-balanced energy production system. a) there is a predetermined threshold (U_1) that must be exceeded by the quantity of electricity produced by wind energy (Q_1), and a minimum threshold (U_2) must be exceeded by the quantity of electricity produced by solar photovoltaic sources (Q_2). b) the energy generated both by nuclear power (Q_4) and hydropower (Q_3) must exceed their corresponding threshold levels (U_3 and U_4). Conversely, the total power generated from other sources (Q_R) should exceed a certain threshold (U_5). c) the total amount of energy produced from all other sources must be less than the amount of electricity produced by nuclear power (Q_4) (Q_R). The overall quantity of CO_2 generated must remain below a certain level to have no negative environmental effects. One kilogram of coal and one gram of compressed natural gas (CNG) have CO_2 emissions that are considered. The restrictions are based on how much energy these emissions can be converted into in gas and coal power plants, which have an efficiency of 35% [34]. These limitations direct the optimization process toward a solution that balances resource efficiency, environmental effect, and power generation. To articulate the supplementary limitations and the optimization process as follows: d) Extra limitations on the generation of energy: The maximal energy requirements must be satisfied by the total energy generated (Q_m) from each source. e). A further financial restriction. There must be no spending beyond the whole amount allotted for energy generation. f) Considering threshold values: the 2020 data on electricity output for each energy source is the basis for determining the threshold values utilized in the optimization process. Using the Generalized Reduced Gradient (GRG) technique, a Nonlinear Programming strategy addresses the optimization issue. Beginning with a viable solution (referred to as the beginning point), this method attempts to traverse across the feasible area to maximize the value of the objective function [35]. Two features of the solutions obtained by this method must be noted. The algorithm can reach a local optimum that differs from the global optimum. The selected beginning point determines the local optimum that is reached. The amounts Q_m, or gigawatt-hours (GWh) generated annually by each energy source, are specified in Tab. 14, which presents the optimization problem's conclusions.

Table 14 Annual GWh production by energy source *m* herp

Renewable energy sources		Non-Renewable energy sources	
Power plant	Invention / GWh	Power plant	Invention / GWh
Nuclear	16,842.73	Wind	45,139.70
Coal	1497.04	Solar photovoltaic	4216.375
Combined cycle	12,834.75	Hydraulic	8465.312

Tab. 14 depicts the yearly GWh output by energy source. Wind energy output is 45,139.70 GWh, whereas the output of nuclear power reactors is just 16,842.73 GWh. Coal generates 1,497.04 GWh, solar photovoltaic adds 4,216.375 GWh, and the complete cycle yields 12,834.75 GWh of electricity. In addition, 8,465.312 GWh comes from hydropower.

Table 15 Data on national power generation in 2020

Renewable energy sources		Non-Renewable energy sources	
Power plant	Invention / GWh	Power plant	Invention / GWh
Nuclear	55,757	Wind	54,899
Coal	5022	Solar photovoltaic	15,289
Combined cycle	44,023	Hydraulic	30,614

Tab. 15 provides an effective comparison between the optimization process results and the national power production figures for 2020. This comparison offers insightful information about how the suggested model fits within and could improve the current energy production environment.

Tab. 15. shows national power generation statistics for the year 2020. Wind energy provided 54,899 GWh, while nuclear power reactors produced 55,757 GWh. Coal accounts for 5,022 GWh, solar photovoltaic for 15,289 GWh, and the combined cycle for 44,023 GWh of the world's non-renewable energy supply. In that year, 30,614 GWh came from hydropower. A significant transformation endeavor is necessary to decarbonize the automobile industry, particularly concerning the transition from internal combustion engine cars to electric vehicles fueled by hydrogen. Computations have been done to find the best way to ease this shift by different technologies, such as hydroelectric, solar, and wind power. Tab. 16 provides a full breakdown of the computation findings and suggests units for each technology to help achieve the desired transformation.

Table 16 Metrics for the generation of renewable energy

Renewable energy source	MWh per unit/year	Invention / (GWh)/year	Elements
Wind	6	45,139.70	7,523,282.6
Solar photovoltaic	0.912	4216.375	4,623,218.21

Measures of renewable energy production are shown in Tab. 16. Wind energy generates 6 MWh per unit/year, generating 45,139.70 GWh/year, and involves 7,523,282.6 components. Using 4,623,218.21 components each year, solar photovoltaic power generation yields 4216.375 GWh annually. Hydrogen production is expected to come mostly from renewable sources, including nuclear, solar photovoltaic, wind, and hydroelectric power plants, after a transitional phase that aims to phase out coal and gas power facilities. This tactical change aligns to reduce environmental effects and promote cleaner energy options. It shows a commitment to low-carbon and sustainable energy solutions. The updated MWh production under such circumstances is shown in Tab. 17.

Table 17 Annual power generation: nuclear vs. renewable sources

Sources of renewable energy	Year of invention / GWh	MWh annual per unit	Elements
Wind	6	57,344.61	8,557,434.67
Solar photovoltaic	0.912	6342.861	7,954,891.45
Nuclear		8465.312	
Hydraulic		16,842.73	

Power output from nuclear plants and renewables is shown in Tab. 17. An annual output of 6 GWh from wind power equals 57,344.61 MWh per unit or 8,557,434.67 individual components. With 7,954,891.45 individual components, solar photovoltaics generate 0.912 GWh annually, or 6342.861 MWh per unit per year. Without defining the number of components, the table lists 8465.312 GWh and 16,842.73 MWh for nuclear and hydraulic sources, respectively. There are plans to avoid using nuclear energy at a later stage as well [36-38]. The issues surrounding radioactive waste created by nuclear power plants are what drove this choice. The shift intends to gradually remove nuclear energy from the hydrogen generation process in recognition of the complexity and challenges involved in controlling such waste, underscoring a commitment to sustainable and controllable energy sources.

4.7 Robustness Analysis

Conducting a thorough analysis of robustness is crucial to accelerate the progress of the hydrogen energy industry and investigate various avenues toward a contemporary energy economy. The present state of hydrogen generation techniques, which includes electrolysis and steam methane reforming, necessitates a thorough assessment of their maturity and dependability. Concurrently, an investigation into nascent advancements that may improve efficiency and decrease expenses is required. An in-depth examination of the economic dimensions necessitates a thorough evaluation of present and projected costs and an assessment of how government subsidies and incentives may impact the viability of the endeavors [39-41]. Regulatory compliance and safety considerations should be incorporated into every assessment of the current infrastructure, which includes manufacturing, transportation, and distribution. Maintaining a resilient hydrogen ecosystem is contingent upon thoroughly comprehending market demand in critical sectors, including transportation, industry, and power generation [42, 43]. This requires proactive cooperation from research institutions, industry stakeholders, governments, and industry participants. Long-term private investment is critical to securing a comprehensive evaluation of the consistency and stability of regulatory frameworks. It is critical to assess the environmental impact of hydrogen production processes, encompassing carbon emissions and water consumption, to determine its viability as a sustainable energy resource. After conducting a thorough robustness analysis, stakeholders will possess enhanced capabilities to influence a forward-thinking and resilient hydrogen energy sector. This will involve mitigating potential risks such as geopolitical uncertainties and market volatility, which investigates opportunities for international cooperation.

5 CONCLUSION AND POLICY RECOMMENDATIONS

The United Nations 2030 Agenda for Sustainable Development provides a solid grounding for the worldwide commitment to battle climate change and achieve a completely decarbonized and emission-free economy. These accords facilitate sustainable global development, emphasizing low greenhouse gas emissions, reinforced by the Sustainable Development Goals (SDGs) and the European Green Pact. Hydrogen has a wide range of sources, is clean and zero carbon, which is conducive to increasing the proportion of renewable energy consumption. Energy structural optimization is greatly significant for promoting energy transformation and responding to global climate change. Long-term plans will phase out combined cycle and gas power plants, while shorter-term efforts will focus on shutting down coal-fired power stations. In this context, hydrogen becomes crucial, especially green hydrogen generated by electrolysis using renewable energy sources. This article presents the results of an optimization approach used to calculate the required hydrogen production in Spain as part of an effort to phase out internal combustion engine automobiles in favor of hydrogen-powered electric vehicles by 2030. The goal is to switch to renewable energy sources and completely phase out coal, gas, and nuclear power as electricity generators. Wind, solar PV, hydro, nuclear, coal, and gas are only some of the energy sources included into the optimization's three stages, each of which phases out more polluting options.

The results highlight wind power as the most viable option, followed by nuclear, PV solar, and hydro. As the report emphasizes, much work must be done before the car sector can meet its lofty goals of using renewable hydrogen and electric power. The results also serve as a Decision Support System (DSS), which provides helpful information on the dangers, challenges, and opportunities of the energy transition in the automobile industry. The study highlights the need for future legislative measures among the complexities of waste management in nuclear energy, the labor-intensive transition from conventional sources, and the economic ramifications for the automobile sector. Strong frameworks were used for financing renewable energy sources, encouraging R&D in hydrogen technologies, and addressing the societal and economic impacts of the car industry's shift that should all be at the forefront of these projects.

In the future, the road toward a modern energy economy will involve a comprehensive plan and international collaboration. Waste management difficulties and economic effects are only two examples of the constraints that call for flexible policy solutions. Future work should expand upon these results by making regional and cross-country comparisons within the global vehicle sector. Policymakers can design a road toward a resilient and environmentally aware energy future by working through the complexity and obstacles that stand in the way of a completely decarbonized global economy.

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