energies

MDPI

Article

Experimental Study on Using Biodiesel in Hybrid Electric Vehicles

Juan Carlos Paredes-Rojas [1,*], Ramón Costa-Castelló [2,*], Rubén Vázquez-Medina [3], Juan Alejandro Flores-Campos [4] and Christopher Rene Torres-San Miguel [5]

1 Instituto Politécnico Nacional, Escuela Superior de Ingeniería Mecánica y Eléctrica, Unidad Culhuacán, Santa Ana 1000, Coyoacán, CTM Culhuacán, Ciudad de México 04440, Mexico
2 Institut de Robótica i Informática Industrial, IRI (CSIC-UPC), Parc Tecnológic de Barcelona, C/Llorens i Artigas 4-6, 08028 Barcelona, Spain
3 Instituto Politécnico Nacional, Centro de Investigación en Ciencia Aplicada y Tecnología Avanzada, Unidad Querétaro, Cerro Blanco 141, Col Colinas del Cimatario, Querétaro 76090, Mexico; ruvazquez@ipn.mx
4 Instituto Politécnico Nacional, Unidad Profesional Interdisciplinaria en Ingeniería y Tecnologías Avanzadas, Instituto Politécnico Nacional 2580, La Laguna Ticoman, Gustavo A. Madero, Ciudad de México 07340, Mexico; jaflores@ipn.mx
5 Instituto Politécnico Nacional, Escuela Superior de Ingeniería Mecánica y Eléctrica, Unidad Profesional "Adolfo López Mateos" Gustavo A. Madero, Col. Lindavista, Ciudad de México 07738, Mexico; ctorress@ipn.mx
* Correspondence: jparedes@ipn.mx (J.C.P.-R.); ramon.costa@upc.edu (R.C.-C.)

Abstract: Hybrid electric vehicles are essential in the automotive industry. Combining electric propulsion with biofuels to power the electric motor and the internal combustion engine offers enormous potential to reduce fuel consumption and polluting emissions. However, to operate efficiently, HEVs require an EMS that decides whether the vehicle is propelled by the combustion engine or the electric motor while managing power generation and the battery charge state. This work analyzes the use of biodiesel as a fuel in hybrid electric vehicles (HEVs). For this purpose, the mechanical behavior of a diesel engine was experimentally determined using a B10 blend to evaluate its power, torque, emissions, and operating behavior, such as temperatures and pressures. The engine used was a 2.5 L four-stroke with 131 hp at 3600 rpm to complete the efficiency map considering power, torque, and combustion. Finally, an energy management strategy based on an efficiency map is proposed. The results show that it is possible to use a specific operating range of the combustion engine with maximum efficiency while maintaining an optimal battery state of charge (SOC).

Keywords: hybrid electric vehicles; biodiesel blend; energy management strategy; battery state of charge

check for updates

Academic Editors: Sławomir Wierzbicki and Kamil Duda

Received: 20 January 2025
Revised: 11 March 2025
Accepted: 12 March 2025
Published: 24 March 2025

Citation: Paredes-Rojas, J.C.; Costa-Castelló, R.; Vázquez-Medina, R.; Flores-Campos, J.A.; Torres-San Miguel, C.R. Experimental Study on Using Biodiesel in Hybrid Electric Vehicles. *Energies* **2025**, *18*, 1621. https://doi.org/10.3390/en18071621

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The use of biofuels in HEVs offers significant potential to reduce fuel consumption and emissions; where biodiesel plays a key role in reducing greenhouse gas emissions, it is a sustainable alternative fuel for transportation. A recent study proposes a biodiesel blend from used cooking oil methyl ester and soybean oil methyl ester: this biodiesel-biodiesel blend was mixed with 15% ethanol to give a biodiesel–ethanol blend; the authors demonstrated that this proposal exhibited better emissions characteristics, achieving a decrease in NOx, particulate matter (PM), and hydrocarbons (HCs) compared to other biofuels [1]. Rimkus, A. et al. evaluated the energy and environmental performance of a Toyota Prius hybrid vehicle using different blends of gasoline and bioethanol. During the

experiment, they collected data from the dynamometer, the exhaust gas analyzer, the fuel consumption meter, and the ECU. The authors reached several conclusions:

1. They demonstrated that the performance of the hybrid vehicle's internal combustion engine is strongly influenced by the use of the electrical system, especially at low and medium speeds.
2. They observed that when the concentration of bioethanol increases, the ECU advances the ignition timing.
3. The concentration of 70% bioethanol improves the energy efficiency of the combustion engine; therefore, polluting emissions are drastically reduced [2].

On the other hand, Özgur, T. performed experimental studies on a compression engine using different biofuel–ethanol blends; the results were compared with the reference diesel fuel. The results show that the brake horsepower (BP) of the engine was reduced due to the lower calorific value, which caused a higher fuel consumption being needed to obtain the unit power. The emissions were reduced due to the additional oxygen content of the alcohols [3]. Sandaka, B. P., and Kumar, J., critically reviewed biofuels and their challenges for use as primary vehicle fuels; this study can be used as a quick reference for researchers and policy makers to make appropriate long-term decisions [4].

Regarding the automotive sector, one of its contributions has been the introduction of HEVs. New needs and issues have arisen because 100% of electric vehicles depend on the constant recharging of their battery cells. A significant advantage of HEVs is that they are still much more practical for long trips without the need to wait for a long time for the vehicle to recharge the battery, so different energy management strategies have been implemented, ranging from battery life, as demonstrated in 2023 by Wang et al. [5], to creating scenarios of vehicle tracking in traffic, as described in 2023 by Tang et al. [6]. However, no mention was made of the type of fossil fuel used in the HEV experiments. On the other hand, in the study of the optimization of HEVs through energy management strategies (EMSs), battery life was considered through simulation and calculation. For instance, Wang et al. [5] discovered that the fuel consumption was 4.218 L per 100 km when the battery was at 99.96% of its useful life. In parallel, the fuel economy and safety of HEVs in the following vehicle scenarios are sought to be improved using adaptive dynamic programming (ADP) and heuristic dynamic programming (HDP). Tang et al. [6] compared their results with several EMSs, showing that their proposal guarantees planning speed, good tracking, and reduced energy consumption. Non-linear mathematical models have been designed to explore practical strategies for battery smart grids to predict their lifetime and obtain simulations and estimations. In an attempt to optimize the use of smart grids in buildings for vehicle battery charging, Zhou [7] found that the capacity of the batteries went from a value of 0.934 to 0.982 in a theoretical way.

On the other hand, Ye et al. [8] proposed a Q-Learning-based mimicking strategy to optimize battery degradation and efficiency. They carried out experiments with an electric engine and a battery to measure its degradation, and their results showed a degradation in the battery of 26.36% with an energy efficiency of 3.83%. Another important aspect is to improve the safety and performance of HEVs' batteries to avoid possible damage to the battery caused by load variations. Through a simulation called RT LAB platform, Oubelaind et al. [9] showed how to improve safety, detect power supply failures, and identify and correct them with multi-stage energy management.

Another contribution was the study by Vignesh et al. [10], which attempted to improve the efficiency of the EMS for a biofuel-powered HEV through simulations using AECMS. In this study, they showed that using AECMS improved fuel economy by 3% and also found that 40–70% battery charge resulted in lower fuel costs. However, Chunyang et al. [11] investigated how to generalize EMSs to all types of HEVs by using a reinforcement learning

algorithm. They simulated various cases using theoretical data and calculations. They were able to generalize the variables that affect the behavior of HEVs and predict their behavior without having to test all of them. Furthermore, the fuel efficiency of a whole driving cycle of HEVs is of great importance by tracking another vehicle through simulation and calculation. According to Li et al. [12], a fuel efficiency of 3.5% can be achieved, considering that real traffic and traffic lights can affect the results.

In addition, Hu et al. [13] tried to improve the DRL algorithm to implement it in an EMS while avoiding the disadvantages of DRL. By means of theoretical calculations and methods and using DAML, they theoretically optimized the fuel consumption by 0.2–2.7%, and by using series-parallel arrays, they improved the fuel consumption by 9.6%. Another reasonable way to manage energy in PHEVs is to use EMS from theoretical prediction models. In this sense, Sun et al. [14] obtained a theoretical improvement between 3.81% and 5.6% of fuel efficiency. From another point of view, in 2023, Wang et al. [15] designed an MARL based on EMSs to meet the theoretical assumptions of energy saving. They achieved an efficiency of 15.8% in the system while maintaining the safety and comfort of the passengers when using cruise control. On the other hand, in 2022, Li et al. [16] implemented the prototype of an electrohydraulic mechanism that converts electric, mechanical, and hydraulic energy to distribute them in the HEVs efficiently. They achieved a 14.7% improvement in the electric energy recovery in the accumulator using an experimental model and distributed the torque among the motors.

Recently, Mittal, V., and Shah, R., performed an overview of current EMS systems for HEVs, highlighting the integration of algorithms such as DRL and DL. The analysis addressed technologies such as machine learning, cloud computing, computer vision, and swarm technology [17]. Jeyaseelan, T. et al. proposed optimizing biodiesel blends for use in medium-duty urban vehicles, using an ANN model, to predict performance, combustion, and emissions parameters. They also discussed considerations for choosing the optimal blend concentration to meet government targets [18].

On the other hand, in 2023, Li et al. [19] proposed an algorithm called HOSS to solve the problem of optimal operation and energy management in HEVs. By performing simulations and comparing data from other algorithms, they showed the effectiveness of their algorithm. Several authors, such as Zhang et al. [20], have stated that adaptive cruise control (ACC) and EMS can provide benefits, but at the same time, there are disadvantages in their implementation. One of them is the complex problem of inefficiency in HEVs. Experimental simulations by Zhang et al. [20] showed a 3% improvement when considering 600 experimental iterations. On the other hand, Lü et al. [21] comprehensively summarized the advantages and applicable scenarios of different prediction and solution methods in the EMS based on MPC in HEVs. In the study by Siddhartha et al. [22], the HEVs can be optimized. They showed that the SOC consumption was reduced by 5% using the E CSM2021 benchmark. Similarly, Dong et al. [23] proposed an EMS based on four stages of development for the practical application of HEVs: EM based on instantaneous driving cycles (S1); EM based on FDC prediction (S2); EM based on overall driving cycle prediction (S3); and EM based on autonomous speed planning (S4).

Based on previous analysis, several problems are observed in the incorporation of biofuels in hybrid electric vehicles: ensuring the power and torque of biofuels in demanding driving cycles, the requirement of a new energy management system, and avoiding the formation of oxidation and polymer particles. This work proposes and analyzes the use of biodiesel as fuel in an HEV. The mechanical behavior of a diesel engine using a B10 mixture was experimentally determined to evaluate its power, torque, emissions, and operating behavior, such as temperatures and pressures. A 2.5 L four-stroke engine with 131 hp

at 3600 rpm was used to determine the efficiency map considering power, torque, and combustion. Based on the efficiency map, an energy management strategy is proposed.

Thus, this work is structured as follows. Section 2 describes the hybrid vehicles and their operating configurations. Section 3 describes the methodology, materials, and equipment. Section 4 presents the results and discussion of experimental tests on power, torque, pollutant emissions, and energy management strategy based on a thermostat type (on–off). Finally, Section 5 presents the conclusions and possible future work.

2. Hybrid Electric Vehicles

Transportation is a fundamental activity for humanity, so technological development and innovation have been constant. In the case of land transport, there have been innovations in cleaner technologies such as hybrid vehicles. A hybrid electric vehicle (HEV) is one that contains an electric motor powered by energy stored in batteries. As an alternative to the electric motor, the HEV includes an ICE that, depending on its configuration, can drive a generator as well as directly drive the tires. In a hybrid vehicle, the internal combustion engine is the second option, giving priority to the electric motor, with its use determined by electronic control.

Types of Hybrid Cars

There are three types of powertrains or hybrids: series, parallel, and series-parallel.

(A) Series hybrid cars (SHCs)—In these cars, the electric motor is the only one connected to the transmission, providing traction, while the heat engine is the one that generates electricity to power the system's batteries.

SHCs were designed to be powered by an electric motor, which is powered by a stock battery and/or a motor/generator. The energy from both power sources is combined using a controllable electrical coupling device based on power electronics. The operating modes are varied and are used according to the power requirements of the driver [24].

(B) Parallel Hybrid Vehicles (PHVs)—In this configuration, unlike the series powertrain, the heat engine and electric motor can drive the vehicle as they are both connected to the transmission, allowing their mechanical power to be transmitted individually or together. There are two types of mechanical coupling: torque and speed coupling. The advantages of the parallel configuration are as follows:

- No generator is needed.
- A smaller combustion engine is used.
- Since only a portion of the motor–engine power goes through multiple power conversions, it can be said that the efficiency of parallel hybrid powertrains is higher than that of series configurations.

(C) Series-parallel hybrid cars (SPHVs)—This configuration complements the previous ones because the electric motor works alone at low speeds, while the thermal engine works together with the electric motor at high speeds. The only difference between this configuration and the previous ones is that it has another independent generator that produces electricity to power the electric motor.

3. Methodology

The experimental development of this study consisted of the simultaneous measurement of pollutant emissions, power, torque, and combustion efficiency in order to determine the engine efficiency map and, based on this, propose an energy management system. The experiment was carried out on a diesel engine test bench coupled to a dynamometer with a hydraulic brake. The blend B10 was used due to its higher combustion stability [25].

In this test, the pollutant emissions, such as carbon monoxide, carbon dioxide, nitrous oxides, hydrocarbons, and lambda factor (AFR), were measured, and then the combustion efficiency, power, and torque were estimated. In addition, operating parameters such as air and fuel consumption, air, water, oil temperature, and oil pressure were considered.

The information obtained from the experimental tests was used to determine the efficiency map of the diesel engine using B10 blends. Characteristic curves are often called efficiency maps because they define the behavior of an engine: torque, power, and specific consumption. Subsequently, the characteristic curve of the diesel engine with B10 as fuel was determined; based on this information, an EMS is proposed for its application in HEVs. Figure 1 shows the general methodology of this research.

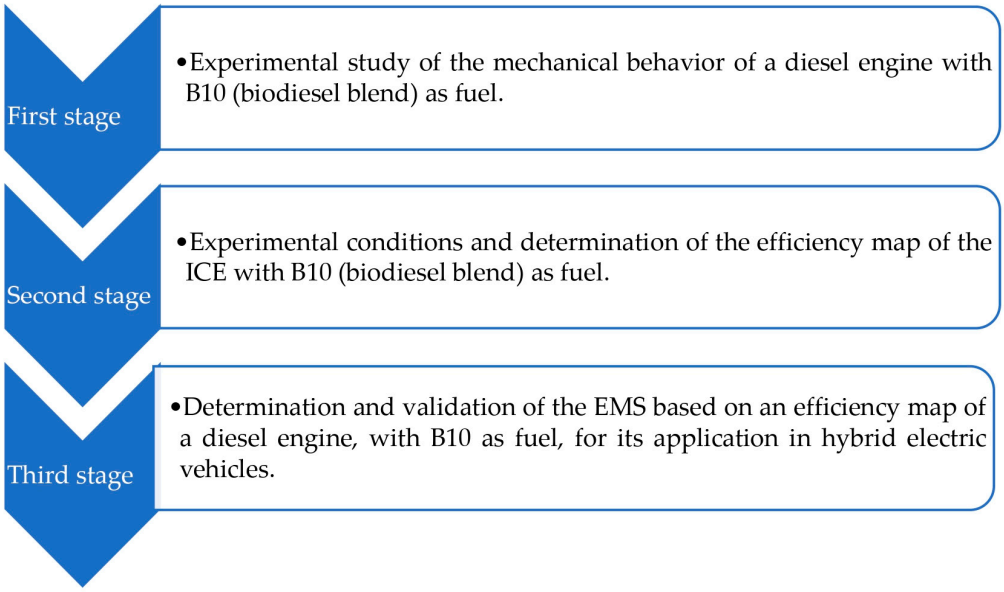


Figure 1. General research methodology.

3.1. First Stage: Experimental Study of the Mechanical Behavior of a Diesel Engine with B10

The experiments were carried out on a hydraulic brake dynamometer to measure the force of the combustion engine. An experimental bench was also used with sensors connected to the combustion engine, capable of determining essential parameters such as emissions, combustion efficiency, air consumption, fuel, and temperatures, among others. The experimental setup is shown in Figure 2.

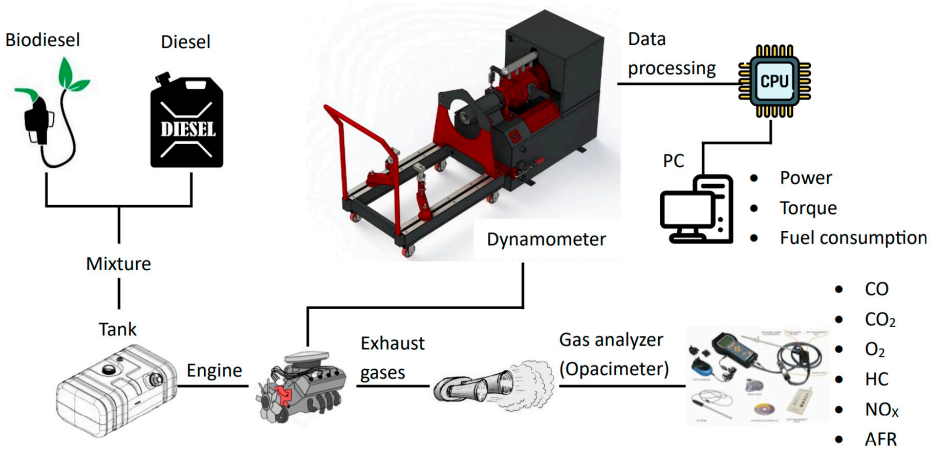


Figure 2. Scheme of the diesel engine experimental setup.

The internal combustion engine was a Nissan® YD25DDTi, 2.4 L displacement, common-rail, in-line 4-cylinder engine with a power output of 131 HP at 3600 rpm, a maximum torque of 304 Nm. at 2000 rpm, and a compression ratio of 16.5:1. This engine is the one used in the Nissan® NP300, Navara, and Frontier pick-up trucks, commercially known as NP300, Navara, and Frontier (see Figure 3). The engine parameters were analyzed using a test dynamometer with a hydraulic brake of the Saenz® brand, model DS3, whose capacity is 900 HP at 4000 rpm, manufactured by Saenz, located in Ingenieria en Dinamometros, Mar del Plata-Buenos Aires, Argentina. The maximum torque and power of the engine were obtained (see Table 1). This bench has its own software, which offers a large number of tools for the visualization and analysis of the tests. It also shows the power curves in real time during the development of the tests and experiments, which allowed us to analyze in detail what happened in the engine when using the B10 blend. With the data obtained, torque/speed and power/speed curves were generated, and a corresponding efficiency map was then constructed.

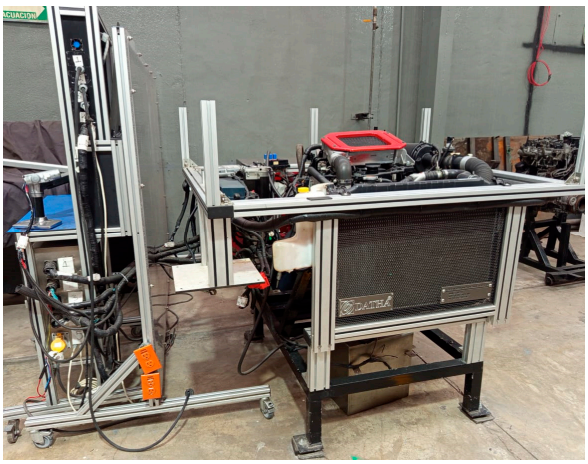


Figure 3. Diesel engine experimental setup, Saenz® DS3.

Table 1. Dynamometer characteristics.

Parameter	**Dynamometer**	**Nissan® YD25DDTi Engine**
Brand	Saenz®	Nissan®
Model	DS3	YD25DDTi
Software	Own, real-time analysis	-
Tests performed	Torque, power, and efficiency	-
Engine type	-	Diesel, common rail
Number of cylinders	-	4 in-line
Displacement	-	2.4 L
Maximum power	900 HP at 4000 rpm	131 HP at 3600 rpm
Maximum torque	-	304 N·m at 2000 rpm
Compression ratio	-	16.5:1
Vehicles in which it is used	-	Nissan® NP300, Navara®, Frontier®

Table 2 shows the chemical composition of fuels. The biodiesel used in this work is of a commercial nature, and has the following characteristics (see Supplementary Table S1).

Table 2. Chemical composition of fuels [25–28].

Properties	Diesel ASTM D975	Biodiesel ASTM PS 121 ASTM D6751-18
Kinetic viscosity at 40 °C (mm^2/s)	1.3–4.1	1.9–6
Specific gravity at 15 °C	0.85	0.88
Density (lb/gal)	7.079	7.328
Carbon (%)	87	77
Hydrogen (%)	13	12
Oxygen (%)	0	11
Sulfur (%)	0.05	0.0024
Flashpoint (°C)	60–80	100–70
Cetane number	−35–15	−15–10
Stoichiometric radio (air/fuel: parts air to 1 part fuel) (stratified)	40–55	48–65

A Snap-On® portable combustion emission analyzer, model HHGA5A, manufactured by Snap-On Inc., located in San Jose, California, United States, was used to measure the emissions of pollutant gases such as CO, NO, NO_2, and SO_2. This analyzer can measure up to 4 gases at the same time (see Figure 4).



Figure 4. Snap-On® Exhaust Gas Analyzer, Model HHGA5A. Source: Snap-On®.

The ranges and precisions of the Snap-On® gas analyzer for each pollutant are described in Table 3.

Table 3. Snap-On® Model HHGA5A gas analyzer pollutant gas estimation and accuracy ranges. Source: Snap-On®.

Pollutant Gas	Range	Precision
CO	0–5%	÷10%
CO_2		±
O_2	0–21%	≤5%
HC	0–2000 PPM	÷10%
NOx	0–1500 PPM	±10%

3.2. Second Stage: Experimental Conditions and Determination of the Efficiency Map of the ICE with B10

Figure 5 shows the procedure for carrying out experimental tests, describing the activity in each step. It is essential to highlight that tests were carried out only with a B10 blend (the B10 blend is a fuel containing 10% biodiesel and 90% diesel) because, in previous studies, this was the blend that had the best stability under operating conditions in an internal

combustion engine and had a great influence on the reduction of hydrocarbons, carbon monoxide and nitrous oxides, in addition to improving fuel economy [28]. Other studies of the B10 blend also demonstrated energy efficiency and emission reduction [29]. However, it is important to stabilize the biodiesel–diesel blend to prevent peroxide formation, oxidation, and polymer formation. Some blends are more easily oxidized, which would predict a relationship between reactivity and biodiesel concentration. This polymerization can cause clogging of filters and injectors [30]. A recent experimental study showed that B10 offers 1.9% more power and 6.6% more torque compared to conventional diesel. However, B20 and B50 decreased [31].

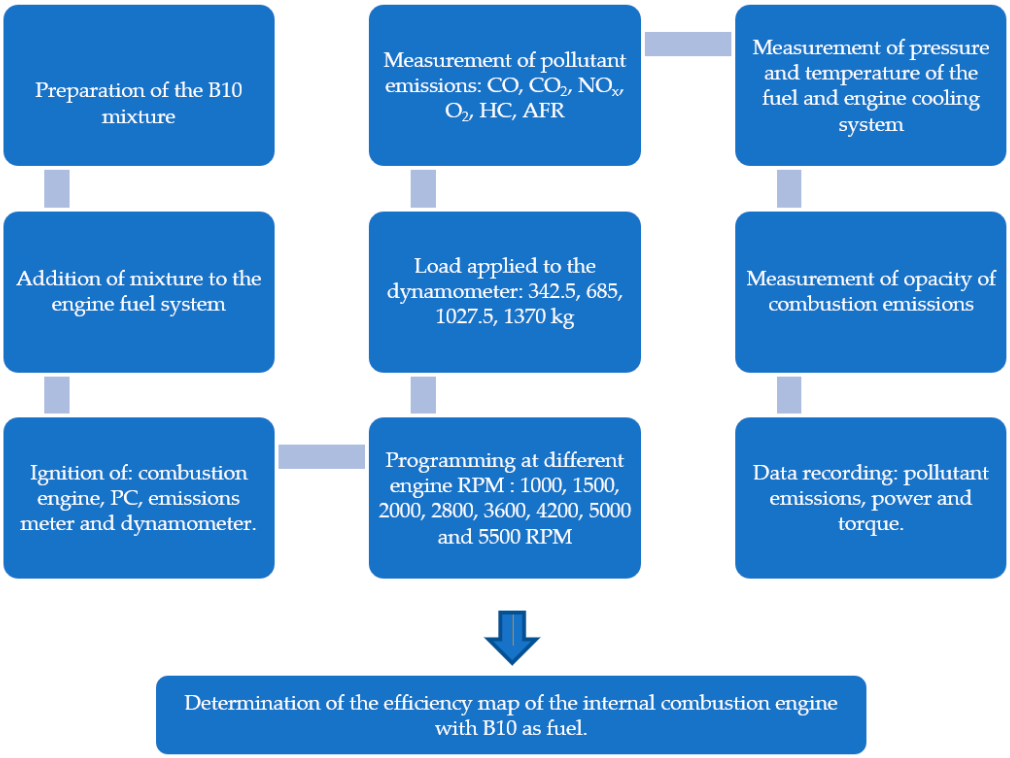


Figure 5. Experimental testing methodology.

Figure 5 shows the experimental process; this study was carried out on a hydraulic brake-type dynamometer; the experimental bench allows one to obtain real-time information on torque and power. The fuel used was a B10 blend. The characteristics of conventional diesel and biodiesel comply with the characteristics in Table 1. In the experimental tests, different engine speeds were set: 1000, 1500, 2000, 2800, 3600, 4200, 5000, and 5500 rpm. Different loads were added, according to the total load capacity of the engine: 25, 50, 75, and 100% (the total load capacity of the engine was 342.5, 685, 1027.5, and 1370 kg for each engine speed, respectively). A total of 7 repetitions of each experimental test were performed, for a total of 32 tests. At each of these points, the engine conditions were analyzed, such as temperatures and pressures, mass flow readings of air and fuel were taken, and, in terms of emissions, O_2, CO, CO_2, and NOx readings were taken. Biodiesel was characterized for density, viscosity, and higher calorific value and compared according to the criteria referred to in ASTM PS121-99 and ASTM D6751 standards [25,27]. The results obtained from the experimental tests were analyzed, the power, torque, and polluting emissions were verified, and they were compared with the original engine characteristics. Based on the results, the engine efficiency map was obtained with B10 as fuel.

3.3. Third Stage: Determine and Validate the Energy Management Strategy Based on an Efficiency Map of a Diesel Engine with B10 as Fuel for Its Application in Hybrid Electric Vehicles

The procedure for developing and validating the EMS is described below. The maximum and minimum power and torque ranges are defined, and an optimal operating range is defined in the efficiency map. The Advisor® software Version 2003, described later, was used for validation.

(a) Efficiency map of the combustion engine with B10.
(b) Determination of the maximum and minimum power and torque ranges.
(c) Election of the engine on–off control strategy for the combustion engine.
(d) Validation of the EMS with Advisor®.

4. Results and Discussion

4.1. Stage 1 Results

The experimental results for torque and power are shown in Figure 6. It shows the characteristic curve (power and torque) of the compression combustion engine with a B10 blend (10% biodiesel–90% fossil diesel). It can be seen that the use of the B10 blend does not significantly affect the behavior of the power and torque. Therefore, it can be said that it remains stable. In the following figures, the power and torque were compared with the real characteristic curves of the diesel engine [32].

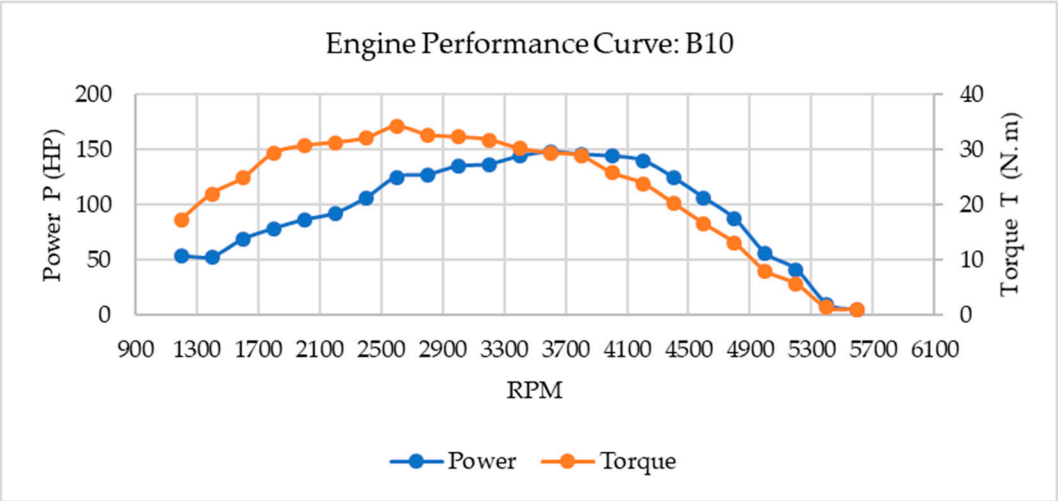


Figure 6. Power and torque curves, with B10 blend.

Figure 7 shows a comparison between both powers. The difference between both is notorious; the power developed by the engine with a B10 blend is slightly higher and obtained around 3500 RPM, while the real power of the engine is obtained at 3200 RPM. It is worth mentioning that this could be due to the calorific value of the biofuels. It could also be due to the physical characteristics of the combustion chamber, which are that the pistons of diesel engines usually have a concave shape to increase the turbulence inside the combustion chamber.

Figure 8 shows the torque of the B10 blend compared with the actual Nissan® engine torque [32]. It is observed that the B10 blend reaches 34 Nm of torque at 2600 RPM, while the real Nissan engine reaches 36 Nm at 1300 RPM. This difference in the maximum torque levels at different RPMs is necessary to carry out a more profound study, and there may be other factors that affect the development of torque, from the combustion quality to the properties of biodiesel, as mentioned by different authors in the literature. Different studies show that having biodiesel accumulated for long periods of time can cause instability in

its homogeneity, as well as the formation of solid particles or water that directly affect the system [30].

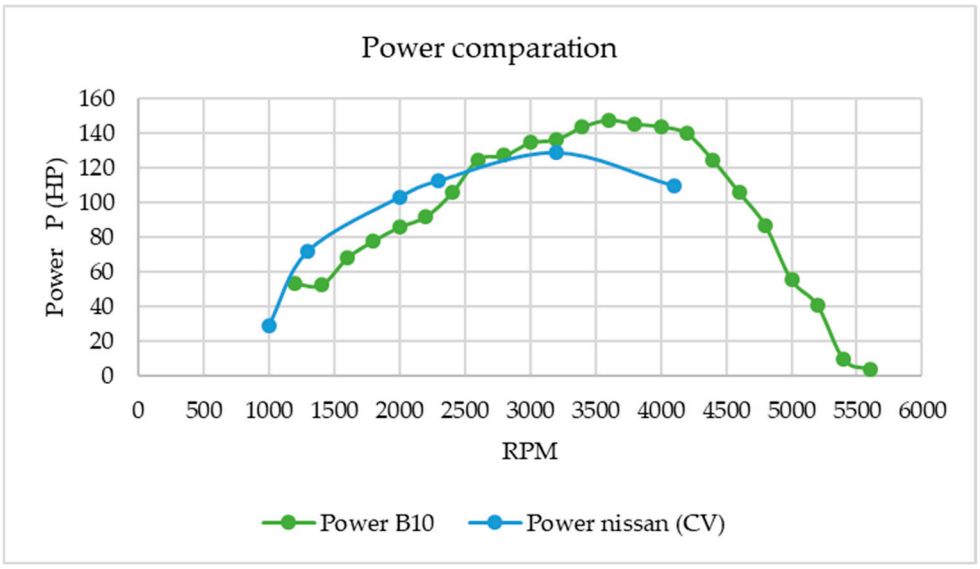


Figure 7. Comparation of B10 power vs. Nissan® power.

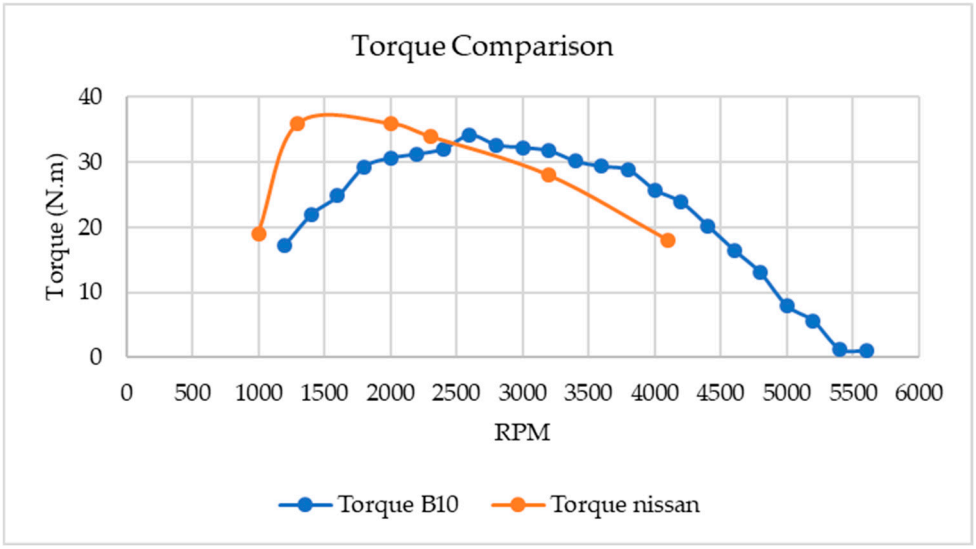


Figure 8. Comparison of B10 torque vs. actual Nissan® torque.

The results in Figures 9 and 10 show the combustion efficiency vs. power and torque, respectively. The combustion efficiency was determined from the % O_2 measured in the pollutant emissions. It is observed that there is a relationship between engine power and torque with the combustion efficiency of the engine. It is important to mention that, in general terms, a combustion efficiency greater than 75% is suitable for liquid fuel. To determine the specific fuel consumption and combustion efficiency, the following equations were used [33,34].

$$sfc = \frac{\dot{m}_f}{P}$$

With units,

$$sfc(\text{mg/J}) = \frac{\dot{m}_f(\text{g/s})}{P(\text{kW})}$$

where

$$sfc = specific\ fuel\ consumption$$

$$m_f = mass\ flow$$

$$P = power\ output$$

Fuel conversion efficiency, η_f, is given by

$$\eta_f = \frac{W_c}{m_f Q_{HV}} = \frac{(Pn_R/N)}{\left(\dot{m}_f n_R/N\right) Q_{HV}} = \frac{P}{\dot{m}_f Q_{HV}}$$

where m_f is the mass of fuel. A substitution for $P/\dot{m}_f$ is

$$\eta_f = \frac{1}{sfc\ Q_{HV}}$$

or, with units,

$$\eta_f = \frac{1}{sfc(\mathrm{mg/J})\ Q_{HV}(\mathrm{MJ/kg})}$$

The results of pollutant emissions are shown in the Supplementary Materials, as is the air–fuel consumption graph (Supplementary Figures S1 and S2).

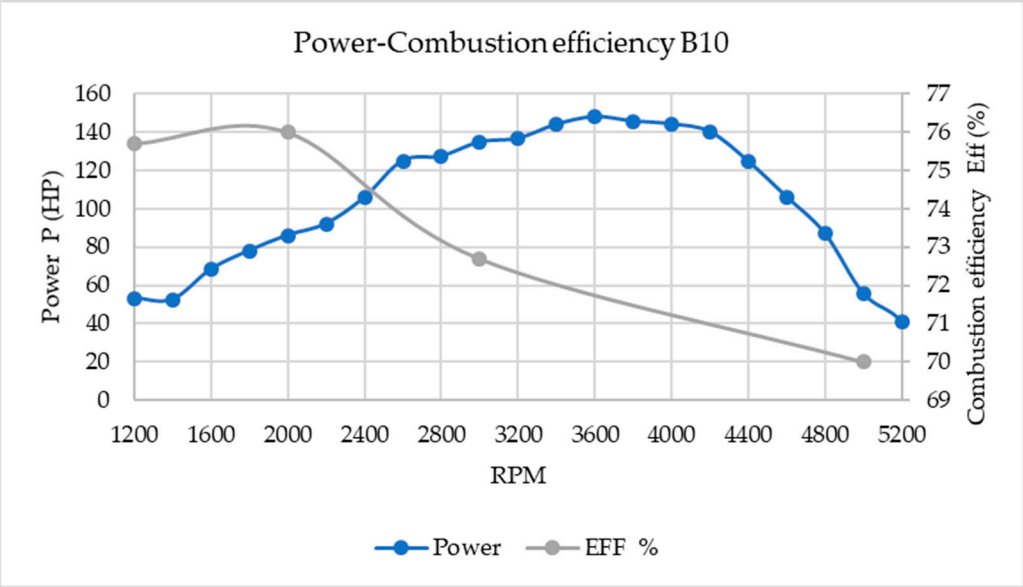


Figure 9. B10 power vs. combustion efficiency.

There are few works that perform experimental tests on hybrid vehicles using biodiesel as fuel. Recently, Javorski et al. [35] presented a multi-objective optimization for the design of the powertrain of an HBEV using fuzzy logic control. This proposal is based on an electrical system, whose battery is recharged by a generator coupled to a motor, fueled with ethanol. The advantages of using biofuel are fuel savings with low emission levels in real cycles, in addition to a fuel saving of 17.78% compared to a similar conventional vehicle.

There is no comparison between this work and the study developed by Javorski et al. [35] because the biofuels are different, but an aspect to highlight is the reduction in polluting emissions and fuel savings compared those from to a conventional car. It is essential to highlight that this work analyzes torque and power, which ensures the performance of the engine. In this work, an energy management strategy is proposed based on an efficiency map, as opposed to the fuzzy logic control proposed by Javorski et al. [35]. Dziubak, T, and Karczewski, M., carried out a study of the pressure drop in the intake air filter in

an internal combustion engine, directly affecting the engine power and insignificantly affecting turbocharged engines [36].

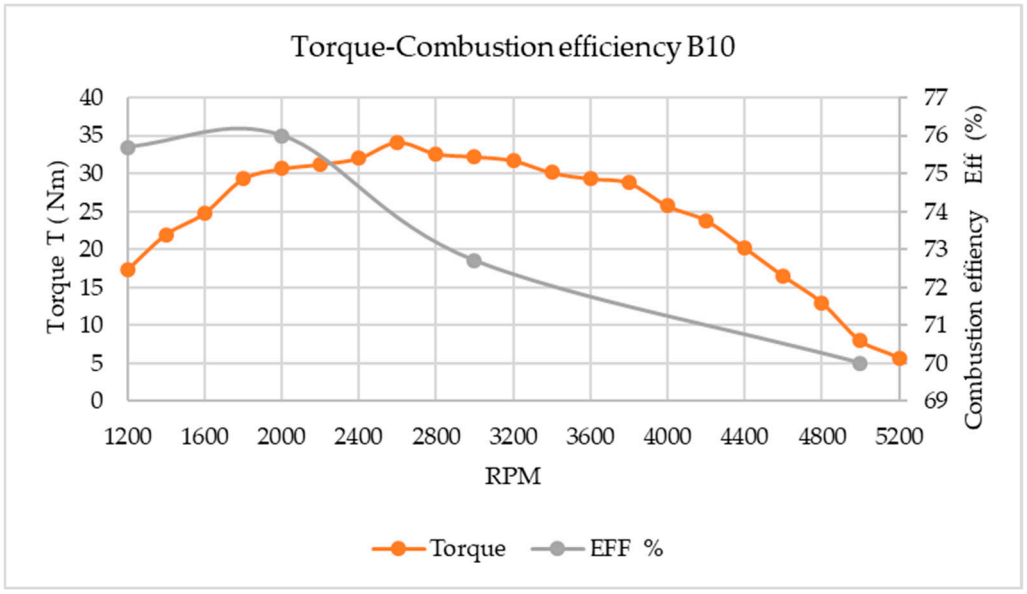


Figure 10. Torque B10 vs. combustion efficiency.

4.2. Stage 2 Results: Analysis of Results and Determination of the Efficiency Map

In the Results and Discussion Section, the graphs obtained in terms of power, torque, and combustion efficiency are shown; based on these results, an EMS has been proposed for a hybrid car (internal engine–electric motor). In Figure 11, the graphs are fitted to a third-degree polynomial curve with the purpose of finding the intersection point of both and numerically limiting the number of revolutions. A feasible working range is also observed where power, torque, and combustion efficiency are at their maximum points (as indicated by the region marked by the red vertical lines in Figure 11).

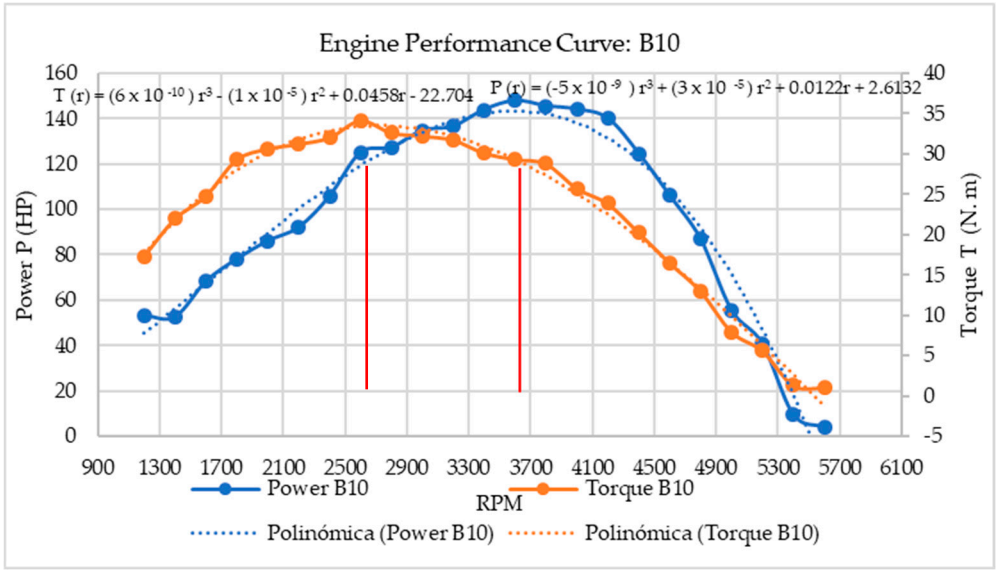


Figure 11. Feasible region of work.

The adjusted power and torque curves are as follows, where r represents the revolutions per minute (RPM).

$$T(r) = \left(6\ x10^{-10}\right)r^3 - \left(1\ x\ 10^{-5}\right)r^2 + 0.0458r - 22.704 \quad (1)$$

$$P(r) = \left(-5\ x\ 10^{-9}\right)r^3 + \left(3\ x\ 10^{-5}\right)r^2 + 0.0122r + 2.6132 \quad (2)$$

The maximum points of power and torque are the following, respectively,

$$P_{max} = 148\ C.V. \quad \text{with } 3680 \text{ RPM}$$

$$T_{max} = 140\ C.V. \quad \text{with } 2582 \text{ RPM}$$

$$P(r)_{min} \leq P(r) \leq P(r)_{max}$$

$$T(r)_{min} \leq T(r) \leq T(r)_{max}$$

Both power and torque are RPM-dependent.

$$RPM_{min} \leq RPM \leq RPM_{max}$$

$$0 \leq RPM \leq RPM_{max}$$

Therefore,

$$2582 \leq RPM \leq 3680$$

Therefore, the feasibility region is at 2582 and 3680 RPM. It is worth mentioning that the intersection point of the power and torque graphs is 3060 RPM. Now, we determine the power and the engine with 3060 RPM, obtaining the following values.

$$P(3060) = 33 \text{ CV}$$

$$T(3060) = 130 \text{ Kg.m}$$

Figure 12 shows the control sequence.

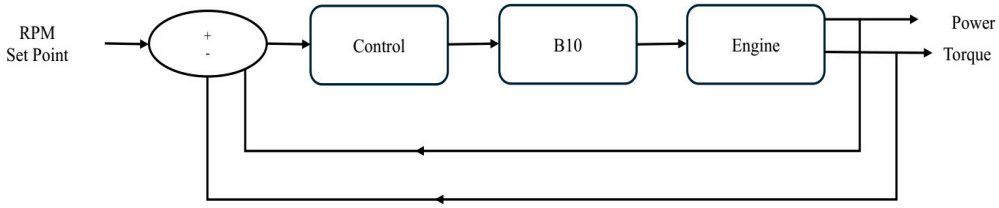


Figure 12. Control scheme.

4.3. Stage 3: Determination and Validation of the EMS Based on an Efficiency Map

4.3.1. Determination of the Energy Management Strategy Based on an Efficiency Map

An EMS based on a PHV configuration is proposed; the operation modes are as follows: motor drive, electric-only drive, hybrid drive, regenerative braking, and PPS charging from the motor. It is essential to use the operation modes to meet the traction torque levels, achieve optimal overall efficiency, have an SOC level, and recover the maximum amount of braking energy [23].

Figure 13 shows the overall control system. "It has a vehicle controller. Its function is to collect data from the driver and all components, such as required engine torque, vehicle speed, PPS state of charge, ICE speed, etc. Based on these data, component characteristics,

and EMS, the vehicle controller sends signals to each controller". Each component controller then operates according to the requirements of the drive train [23].

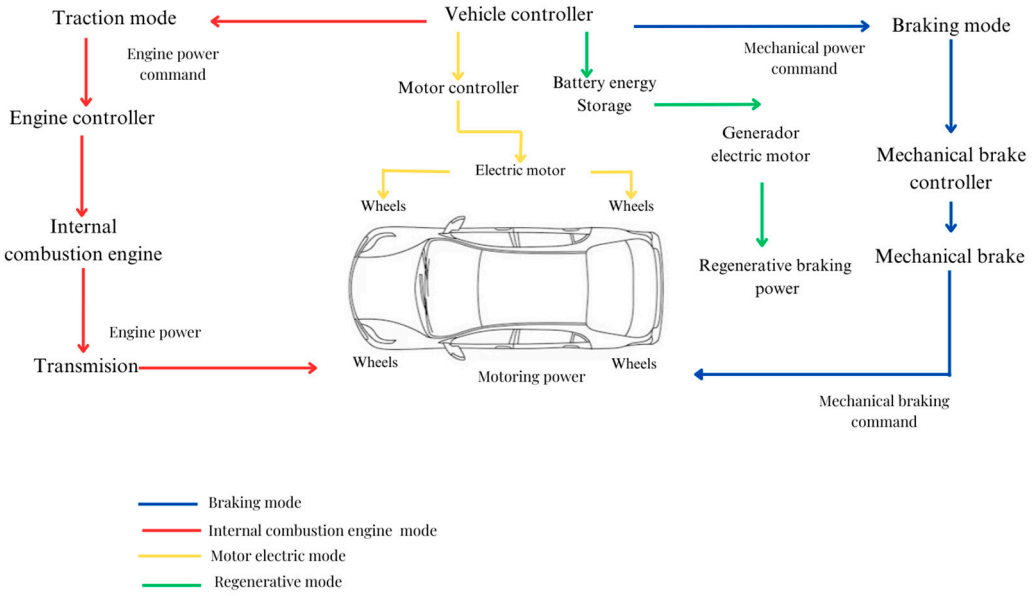


Figure 13. Control scheme of a hybrid electric vehicle.

The vehicle controller is very important for the proper operation of the drive train; it must comply with different operating modes; therefore, the EMS is key for the operation of the drive train [1–14,23]. The PPS Max operates when the load power is lower than the power produced. That is, the operating efficiency is optimal. Note that the PPS SOC control strategy forces the ICE to operate outside of its optimal operating range. Therefore, vehicle efficiency will be affected. It is better to use the engine on–off control strategy (thermostat). The EMS controls the engine turning on and off, thus controlling the SOC of the PPS, as shown in Figure 14. The EMS controls the SOC, keeping the electric motor in its optimal range. When the SOC reaches its maximum, the ICE is turned off, and the vehicle is propelled by the electric motor. When the SOC reaches its lower limit, the ICE is turned on. This EMS uses the electric motor as its main power source. Therefore, the operating efficiency of the combustion engine is optimized. This EMS requires an electric motor with sufficient power to meet the vehicle's requirements [23,24].

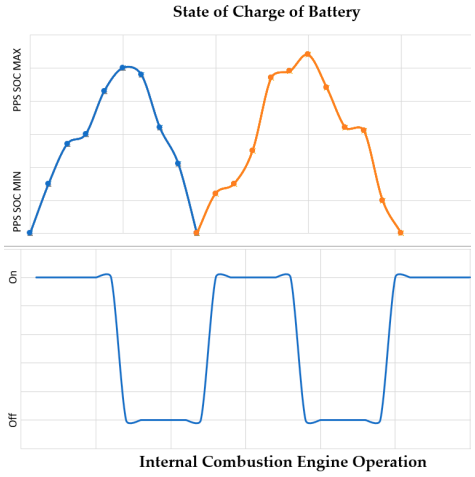


Figure 14. Engine on–off control strategy.

A recent review article on energy management strategies mentions a relevant aspect of the use of technologies in internal combustion engines.

According to Saiteja and Ashok [37], to meet stringent emission standards, conventional vehicles use advanced combustion technologies; therefore, with an HEV, the integration of these technologies is more complex. The development of an EMS to incorporate combustion technologies in the HEV using biofuels is evident.

Zhao et al. studied the effects of biodiesel injection as fuel, conducting experimental studies of the differences between diesel and biodiesel. Based on this information, they determined maps of torque, temperature, fuel, and emissions. They designed a supervisory controller based on the PC method to optimize and balance the fuel economy of the hybrid vehicle [38].

It is important to mention that the present work experimentally evaluates the mechanical behavior of the combustion engine. That is, the following were determined: power, torque, combustion efficiency, pressures, and temperatures. The B10 blend was used because it guarantees effectiveness in combustion engines without mechanically affecting the combustion engine, unlike the aforementioned article, which only evaluates B0 and B100, respectively.

Some works evaluate the electrical characteristics of nanoparticle-enhanced corn oil biodiesel for application in hybrid electric vehicles [39]. Numerical simulation and control studies also assess the environmental feasibility and performance of hybrid electric vehicles (HEVs) using biodiesel as fuel [40].

4.3.2. Validation of the EMS Based on an Efficiency Map

For the validation of the EMS system, the Advisor® software, developed by the US Department of Energy and based on the MATLAB® and Simulink® R2014b platforms, was used. Tables 4 and 5 show the design of the HEV that was designed in this software. Table 4 shows the technical characteristics of the designed vehicle. It is important to note that the combustion engine has the same capacity as the diesel engine used in the experiment. This design also highlights the configuration of the EMS system, where the operating limits of the combustion engine were proposed. Remember that these limits were defined in the range of $2582 \leq \text{RPM} \leq 3680$. Table 5 shows the power characteristics, peak efficiency, and mass of the components and the designed vehicle. The general scheme of the HEV parallel system is shown in Figure S3 (Supplementary Figures S3).

Results in the UDDS

Figure 15 shows the behavior of the HEV in the UDDS driving cycle. It is observed that the power and torque delivered by the ICE and the electric motor perfectly meet the profile requirements. It is also observed that the SOC of the battery is stable.

Figure 16 shows that the fuel converter (combustion engine) is the one that consumes the greatest amount of energy. Rolling resistance and mechanical torque coupling are two systems that stand out in terms of losing a large amount of energy. Figure 17 shows the amount of energy used in regenerative mode, that is, the amount of available energy that can be used. In this graph, the brake system and the electric motor stand out. It is important to highlight that the UDDS driving cycle was designed precisely to evaluate fuel savings in light vehicles. This means that the cycle describes an urban route where accelerations and braking are evident; it can be concluded that the design of the VHE meets the demands of this cycle, and the Advisor software, in this sense, is very optimistic about the results.

Table 4. The technical characteristics of the hybrid car are detailed in the table.

System	Technical Characteristics
Combustion Engine	2.5 L (88 kW) turbo diesel engine
Exhaust Aftertreatment	Close-coupled catalyst for CI engine
Energy Storage System	Internal resistance battery model; 28 Ah NiMH HEV battery (nickel metal hydride)
Powertrain Control	Parallel, multi-spd parallel electric-assist hybrid w/ electric launch
Motor Electric	75 kW (continuous) AC induction motor/inverter
Transmission	4-spd automatic transmission
Torque Coupling	Lossless belt drive
Wheel/Axle	Constant coefficient of rolling resistance model/axle assembly for SUV
Accessory	700 W constant
Powertrain Control	Efficiency mode operation
Traction	Rear wheel drive

Table 5. Characteristics of power, peak efficiency, and mass of components.

System	Max Power (kW)	Peak Eff	Mass (kg)
Vehicle			1408
Combustion engine	90	0.42	380
Exhaust after treatment			27
Motor electric	75	0.92	91
Transmission		1	114
Torque coupling		1	
Cargo mass			136
	# of modes	**V nom**	
Energy storage system	65	436	234
Calculated mass			2390

The HEV designed by Advisor® was simulated in two certified driving cycles: in the UDDS and in the NEDC.

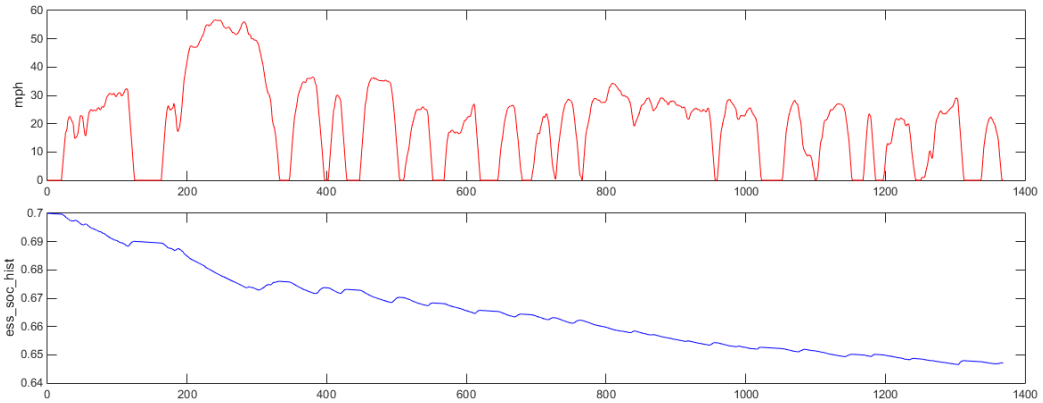


Figure 15. HEV simulation results in the UDDS cycle.

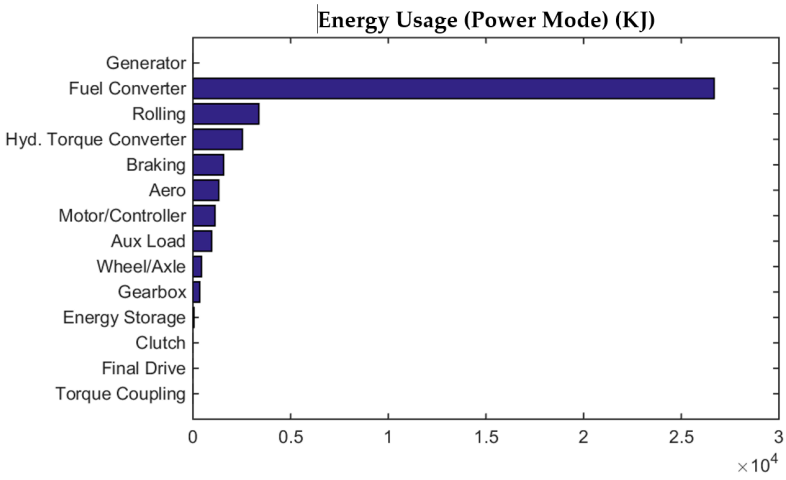


Figure 16. Energy used by HEV system advisor results—UDDS.

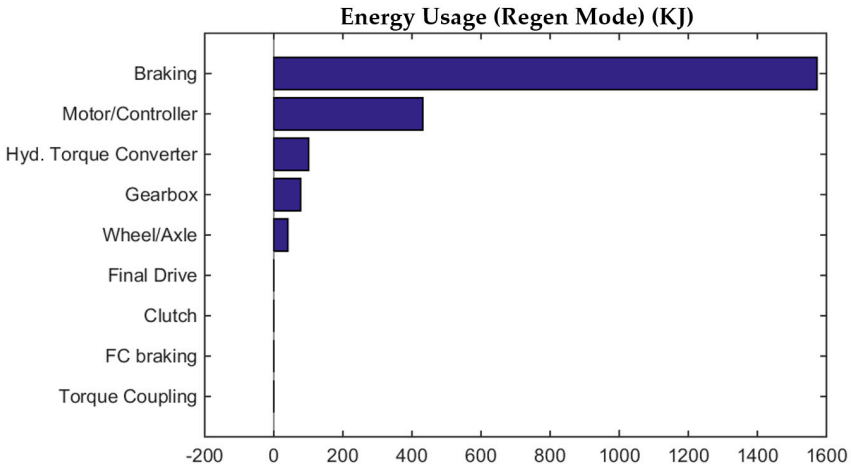


Figure 17. Energy is used in a regenerative mode of the HEV designed in advisor—UDDS.

Results in the NEDC

Figure 18 shows the behavior of the HEV in the NEDC driving cycle. It can be observed that the design of the HEV meets the power and torque requirements of the cycle. In the case of the SOC, it also complies. The NEDC cycle is an interurban cycle, which means that it is more stable than the UDDS cycle.

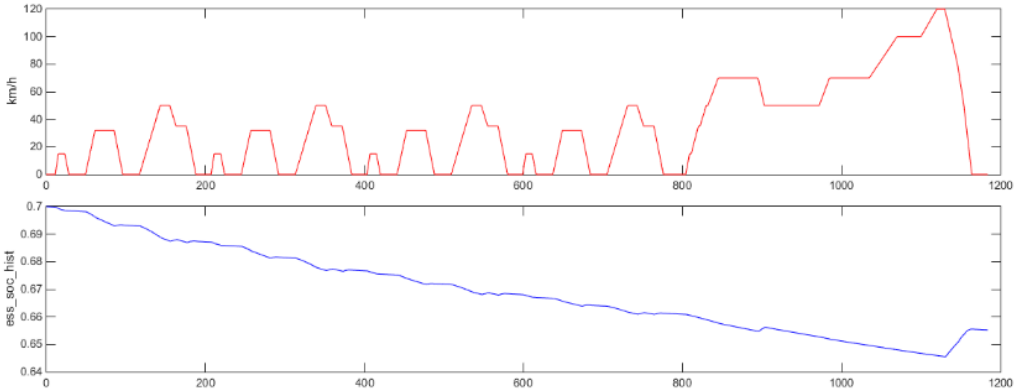


Figure 18. HEV simulation results in the NEDC cycle.

Figure 19 shows the energy consumed by the HEV and, like the UDDS results, it highlights the energy consumed by the internal combustion engine, but in this driving cycle, the combustion engine consumes less fuel, making it evident that the NEDC driving cycle is more stable. On the other hand, Figure 20 shows the energy that can be harnessed, highlighting the brake system with almost 900 KJ compared to the UDDS brake system of almost 1600 KJ, which means that the UDDS system is practically a low-speed urban cycle.

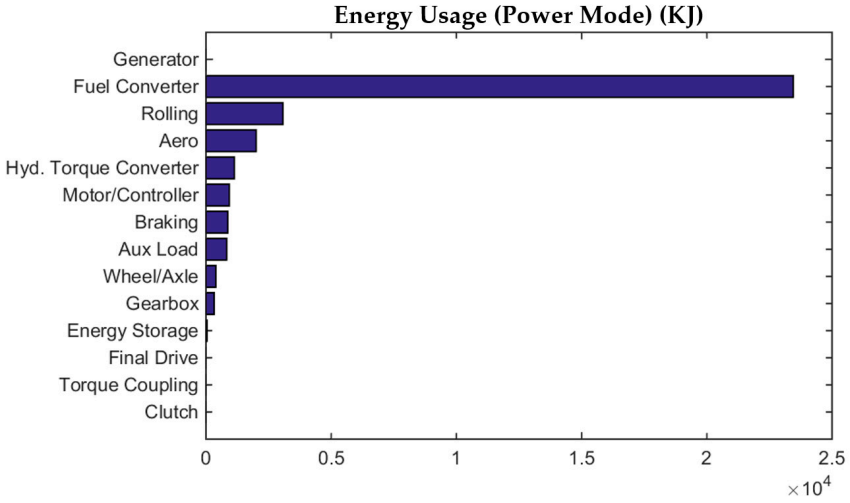


Figure 19. Energy used by HEV advisor results—NEDC.

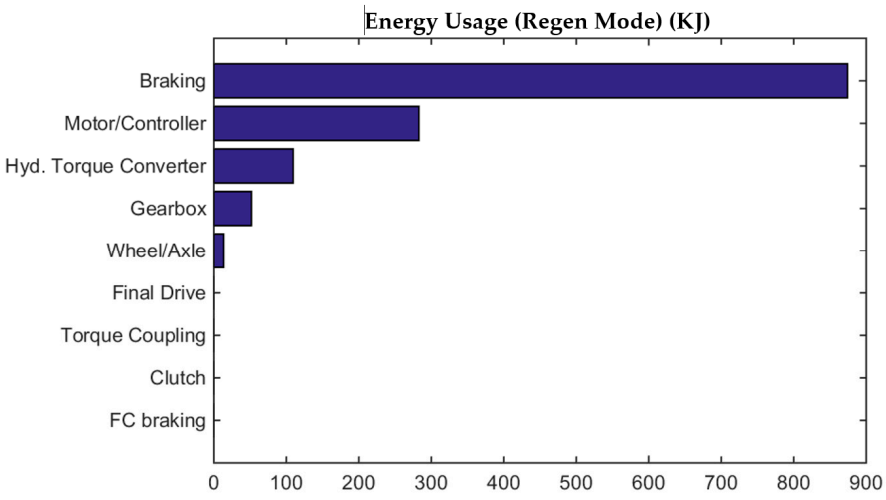


Figure 20. Use of energy in a regenerative mode of the HEV designed in Advisor®—NEDC.

5. Conclusions

In this work, experimental tests were performed on a four-stroke diesel engine using the B10 biodiesel blend, and an efficiency map based on power, torque, and combustion efficiency was determined. The results show that there is an optimal operating range ($2582 \leq \text{RPM} \leq 3680$) in which the maximum power and torque that the combustion engine can develop are obtained, and the combustion efficiency is also optimal in this range.

In this first part, the following can be highlighted:

1. The experimental power test with B10 presents a similarity with respect to the Nissan engine; there is very little variation.
2. The experimental torque test with B10 does present a decrease; this problem can be associated mainly with the physical and chemical characteristics of biodiesel.

3. The polluting emissions are stable; however, it is important to mention that the engine in the experimental test has a turbocharger and EGR system, which can help improve combustion.

Based on these data, an energy management strategy was determined to maintain an optimal state of charged (SOC) in a specific operating range. The EMS was validated using the Advisor® software, which is a software developed by the United States Department of Energy. This software uses the MATLAB® and Simulink® platforms simultaneously. To validate the EMS, an HEV was designed with technical characteristics of the combustion engine, electric motor engine, brake system, vehicle mass, tire type, powertrain configuration, energy generation, and storage system, among others. It is important to note that the combustion engine has the same capacity as the diesel engine used in the experiment. The HEV designed by Advisor was simulated in two certified driving cycles: UDDS and NEDC.

In this second part, the following can be highlighted:

1. An engine on–off control strategy with engine operating limits ($2582 \leq \text{RPM} \leq 3680$) was proposed, which was determined experimentally.
2. The UDDS cycle describes an urban route where acceleration and braking are evident; it can be concluded that the HEV design meets the requirements of this cycle.
3. In the UDDS cycle, rolling resistance and mechanical torque coupling are two systems that stand out in terms of losing a large amount of energy.
4. In the UDDS cycle, the amount of available energy that can be used also stands out, mainly in the brake system and the electric motor.
5. The performance of the HEV in the NEDC cycle meets the power and torque requirements. In the case of the SOC, it is more stable compared to the UDDS because it is an interurban cycle.

In the future, it is advisable to experimentally evaluate the use of biodiesel in these driving cycles.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/en18071621/s1. Figure S1, Consumption fuel and air; S2, Pollutant emissions graphs; Figure S3, General scheme of HEV in Advisor®; Table S1, Characteristics of the biodiesel [26,35–37].

Author Contributions: Conceptualization, R.C.-C. and J.C.P.-R.; methodology, R.C.-C. and J.C.P.-R.; software, J.A.F.-C. and R.V.-M.; validation, C.R.T.-S.M. and J.C.P.-R.; formal analysis, J.C.P.-R. and J.A.F.-C.; investigation, J.C.P.-R.; resources, C.R.T.-S.M.; data curation, R.C.-C.; writing—original draft preparation, J.C.P.-R.; writing—review and editing, C.R.T.-S.M. and J.C.P.-R.; visualization, J.A.F.-C.; supervision, J.A.F.-C.; project administration, J.C.P.-R. and R.V.-M.; funding acquisition, J.C.P.-R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Instituto Politécnico Nacional of Mexico through grants SIP20250033, SIP20241110, SIP20250150, SIP20250321, SIP20250106 and SIP20250288.

Data Availability Statement: The data used to support the findings of this study are available from the corresponding author upon request.

Acknowledgments: The authors thank the Secretaría de Ciencia, Humanidades, Tecnología e Innovación (SECIHTI) and Instituto Politécnico Nacional of Mexico. The authors acknowledge partial support through an EDI grant provided by SIP/IPN.

Conflicts of Interest: The authors declare that there are no conflicts of interest regarding the publication of this paper.

Abbreviations

HEVs	Hybrid Electric Vehicles
ICE	Internal Combustion Engine
EMS	Energy Management Strategy
EM	Energy Management
ECU	Engine Control Unit
ADP	Adaptive Dynamic Programming
HDP	Heuristic Dynamic Programming
ADP	Adaptive Dynamic Programming
AECMS	Adaptive Equivalent Consumption Minimization Strategy
DRL	Deep Reinforcement Learning
DL	Deep Learning
MARL	Multi-Agent Reinforcement Learning
ACC	Adaptive Cruise Control
PEMS	Proposed Energy Management Strategy
SHC	Series Hybrid Car
PHC	Parallel Hybrid Car
PHV	Parallel Hybrid Vehicle
DP	Dynamic Programming
SAC	Soft Actor–Critic
SAC-PL	Soft Actor–Criticism–Power Limit Constraint
DAML	Domain Adaptive Meta-Learning
MARL	Multi-Agent Reinforcement Learning
HOSS	Hierarchical Operation Switch Schedule
HBEV	Hybrid Biofuel Electric Vehicle
UDDS	Urban Dynamometer Driving Schedule
NEDC	New European Driving Cycle
ANN	Artificial Neural Network
MPC	Model Predictive Control
FDC	Forward Driving Cycle
PPS	Peak Power Source
PC	Predictive Control

References

1. Ramuhaheli, S.; Veeredhi, V.; Enweremadu, C. The Performance and Emission Characteristics Assessment of Hybrid Biodiesel/Ethanol Blends in a Diesel Engine. *Rigas Teh. Univ. Zinat. Raksti* **2022**, *26*, 670–683.
2. Rimkus, A.; Mejeras, G.; Dittrich, A.; Pukalskas, S.; Barta, D. Effect of the Concentration of Bioethanol Mixed with Gasoline on the Energy and Environmental Performance of a Hybrid Vehicle in the Worldwide Harmonized Light Vehicles Test Cycle (WLTC). *Appl. Sci.* **2024**, *14*, 10858. [CrossRef]
3. Özgur, T. A Study on the Performance and Emission Characteristics of a Diesel Engine Operated with Ternary Higher Alcohol Biofuel Blends. *Ing. E Investig.* **2023**, *43*, 1. [CrossRef]
4. Sandaka, B.P.; Kumar, J. Alternative vehicular fuels for environmental decarbonization: A critical review of challenges in using electricity, hydrogen, and biofuels as a sustainable vehicular fuel. *Chem. Eng. J. Adv.* **2023**, *14*, 100442. [CrossRef]
5. Wang, Z.; He, H.; Peng, J.; Chen, W.; Wu, C.; Fan, Y.; Zhou, J. A comparative study of deep reinforcement learning based energy management strategy for hybrid electric vehicle. *Energy Convers. Manag.* **2023**, *293*, 117442. [CrossRef]
6. Tang, W.; Wang, Y.; Jiao, X.; Ren, L. Hierarchical energy management strategy based on adaptive dynamic programming for hybrid electric vehicles in car-following scenarios. *Energy* **2023**, *265*, 126264. [CrossRef]
7. Zhou, Y. A regression learner-based approach for battery cycling ageing prediction—advances in energy management strategy and techno-economic analysis. *Energy* **2022**, *256*, 124668. [CrossRef]
8. Ye, Y.; Wang, H.; Xu, B.; Zhang, J. An imitation learning-based energy management strategy for electric vehicles considering battery aging. *Energy* **2023**, *283*, 128537. [CrossRef]
9. Oubelaid, A.; Khosravi, N.; Belkhier, Y.; Taib, N.; Rekioua, T. Health-conscious energy management strategy for battery/fuel cell electric vehicles considering power sources dynamics. *J. Energy Storage* **2023**, *68*, 107676. [CrossRef]

10. Vignesh, R.; Ashok, B.; Kumar, M.S.; Szpica, D.; Harikrishnan, H.J. Adaptive neuro fuzzy inference system-based energy management controller for optimal battery charge sustaining in biofuel powered non-plugin hybrid electric vehicle. *Sustain. Energy Technol. Assess.* **2023**, *59*, 103379. [CrossRef]
11. Qi, C.; Song, C.; Xiao, F.; Song, S. Generalization ability of hybrid electric vehicle energy management strategy based on reinforcement learning method. *Energy* **2022**, *250*, 123826. [CrossRef]
12. Li, J.; Wu, X.; Hu, S.; Fan, J. A deep reinforcement learning based energy management strategy for hybrid electric vehicles in connected traffic environment. *IFAC-Pap.* **2021**, *54*, 150–156. [CrossRef]
13. Hu, D.; Xie, H.; Song, K.; Zhang, Y.; Yan, L. An apprenticeship-reinforcement learning scheme based on expert demonstrations for energy management strategy of hybrid electric vehicles. *Appl. Energy* **2023**, *342*, 121227. [CrossRef]
14. Sun, X.; Fu, J.; Yang, H.; Xie, M.; Liu, J. An energy management strategy for plug-in hybrid electric vehicles based on deep learning and improved model predictive control. *Energy* **2023**, *269*, 126772. [CrossRef]
15. Wang, Y.; Wu, Y.; Tang, Y.; Li, Q.; He, H. Cooperative energy management and eco-driving of plug-in hybrid electric vehicle via multi-agent reinforcement learning. *Appl. Energy* **2023**, *332*, 120563. [CrossRef]
16. Li, L.; Zhang, T.; Hong, J.; Zhang, H.; Yang, J.; Zhang, Z.; Wu, K. Energy management strategy of a novel mechanical–electro–hydraulic power coupling electric vehicle under smooth switching conditions. *Energy Rep.* **2022**, *8*, 8002–8016. [CrossRef]
17. Mittal, V.; Shah, R. Energy Management Strategies for Hybrid Electric Vehicles: A Technology Roadmap. *World Electr. Veh. J.* **2024**, *15*, 424. [CrossRef]
18. Jeyaseelan, T.; El Samad, T.; Rajkumar, S.; Chatterjee, A.; Al-Zaili, J. A techno-economic assessment of waste oil biodiesel blends for automotive applications in urban areas: Case of India. *Energy* **2023**, *271*, 127021. [CrossRef]
19. Li, F.; Gao, L.; Zhang, Y.; Liu, Y. Hierarchical operation switch schedule algorithm for energy management strategy of hybrid electric vehicle using adaptive dynamic programming. *Sustain. Energy Grids Netw.* **2023**, *35*, 101107. [CrossRef]
20. Zhang, H.; Peng, J.; Dong, H.; Tan, H.; Ding, F. Hierarchical reinforcement learning based energy management strategy of plug-in hybrid electric vehicle for ecological car-following process. *Appl. Energy* **2023**, *333*, 120599. [CrossRef]
21. Lü, X.; Li, S.; He, X.; Xie, C.; He, S.; Xu, Y.; Fang, J.; Zhang, M.; Yang, X. Hybrid electric vehicles: A review of energy management strategies based on model predictive control. *J. Energy Storage* **2022**, *56*, 106112. [CrossRef]
22. Siddhartha, P.; Sujeeth, T.; Shiva, B.; Ramprabhakard, J. Integration of renewable energy sources with power management strategy for effective bidirectional vehicle to grid power transfer. *Procedia Comput. Sci.* **2023**, *218*, 9–23. [CrossRef]
23. Ehsani, M.; Gao, Y.; Longo, S.E. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*, 2nd ed.; Fundametals, Theory, and Design; CRC Press: Boca Ratón, FL, USA, 2018.
24. Dong, P.; Zhao, J.; Liu, X.; Wu, J.; Xu, X.; Liu, Y.; Wang, S.; Guo, W. Practical application of energy management strategy for hybrid electric vehicles based on intelligent and connected technologies: Development stages, challenges, and future trends. *Renew. Sustain. Energy Rev.* **2022**, *170*, 112947. [CrossRef]
25. *ASTM PS121-99*; Provisional Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels. ASTM International: West Conshohocken, PA, USA, 2017.
26. *ASTM D975-20*; Standard Specification for Diesel Fuel. ASTM International: West Conshohocken, PA, USA, 2020.
27. *ASTM D6751-18*; Standard Specification for Biodiésel Fuel Blend Stock (B100) for Middle Distillate Fuels. ASTM International: West Conshohocken, PA, USA, 2018.
28. Paredes Rojas, J.C.; Torres San Miguel, C.R.; Vázquez Medina, R.; Leal Naranjo, J.A.; Ortiz Hernández, F.E.; Costa Castelló, R. Pollutant emissions and combustion efficiency assessment of engines using biodiesel. *Appl. Sci.* **2020**, *10*, 8646. [CrossRef]
29. Naik, N.S.; Balakrishna, B. A comparative study of B10 biodiesel blends and its performance and combustion characteristics. *Int. J. Ambient. Energy* **2017**, *39*, 257–263. [CrossRef]
30. Wäring, J.; Svanberg, K. Characterization of Chemical Decomposition of Biodiesel, with a Focus on B10, B30 and B100 Blends. Master's Thesis, Division of Applied Surface Chemistry, Chalmers University Of Technology, Gothenburg, Sweden, 2012.
31. Mu, Z.; Fu, J.; Zhou, F.; Yuan, K.; Yu, J.; Huang, D.; Cui, Z.; Duan, X.; Liu, J. A Comparatively Experimental Study on the Performance and Emission Characteristics of a Diesel Engine Fueled with Tung Oil-Based Biodiesel Blends (B10, B20, B50). *Energies* **2023**, *16*, 5577. [CrossRef]
32. Nissan Yd25Ddti/L4 Dohc (Diesel) 2.5 L, Manual Repair and Service. 2012. Available online: https://www.nissan.co.th/content/dam/Nissan/th/owners/Navara_EN_Owner_Manual.pdf (accessed on 10 March 2025).
33. Cengel, Y.A.; Boles, M.A. *Termodinámica*, 8th ed.; Mc Graw Hill: Ciudad de México, Mexico, 2015; pp. 60–783.
34. Heywood, J.B.L. *Internal Combustion Engine Fundamentals*; McGraw-Hill: New York, NY, USA, 1988.
35. Eckert, J.J.; Silva, F.L.; da Silva, S.F.; Bueno, A.V.; de Oliveira, M.L.; Silva, L.C. Optimal design and power management control of hybrid biofuel–electric powertrain. *Appl. Energy* **2022**, *325*, 119903. [CrossRef]
36. Dziubak, T.; Karczewski, M. Experimental Studies of the Effect of Air Filter Pressure Drop on the Composition and Emission Changes of a Compression Ignition Internal Combustion Engine. *Energies* **2022**, *15*, 4815. [CrossRef]

37. Saiteja, P.; Ashok, B. Critical review on structural architecture, energy control strategies and development process towards optimal energy management in hybrid vehicles. *Renew. Sustain. Energy Rev.* **2022**, *157*, 112038. [CrossRef]
38. Zhao, J.; Chen, P.; Ibrahim, U.; Wang, J. Comparative Study and Accommodation of Biodiesel in Diesel-Electric Hybrid Vehicles Coupled with Aftertreatment Systems. *Asian J. Control* **2016**, *18*, 3–15. [CrossRef]
39. Pakalapati, J.; Surakasi, R.; Kilari, A.; Nagamani, K.; Tamvada, K. Nano-dispersed Corn Oil Biodiesel: An Analysis of its Potential for usage in Hybrid Electric Vehicles. *Int. J. Veh. Struct. Syst.* **2024**, *16*, 83–88. Available online: https://www.researchgate.net/profile/Raviteja-Surakasi/publication/378804290_Nano-dispersed_Corn_Oil_Biodiesel_An_Analysis_of_its_Potential_for_usage_in_Hybrid_Electric_Vehicles/links/65eadaf3b1906066b274e7cb/Nano-dispersed-Corn-Oil-Biodiesel-An-Analysis-of-its-Potential-for-usage-in-Hybrid-Electric-Vehicles.pdf (accessed on 10 March 2025).
40. Mourad, M.; Mohamed, F.; Mahmoud, K.; Nouh, A. Influence of Biodiesel Fuel on Performance Characteristics of Hybrid Electric Vehicle According to Urban Driving Cycle. In Proceedings of the Fifth International Renewable Energy Congress IREC, Hammamet, Tunisia, 25–27 March 2014.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.