ECOLOGIA BALKANICA
2025, Vol. 17, Issue 2 December 2025 pp. 013-018

Implementation of an eco-friendly hybrid vehicle in engineering education: a case study

Daniela Shehova, Stanislav Asenov, Hristo Kanevski, Velislava Raydovska, Anatoliy Parushev

Faculty of Physics and Technologies, University of Plovdiv "Paisii Hilendarski", 24 Tsar Asen Str., Plovdiv, 4000, BULGARIA
*Corresponding author: kanevski@uni-plovdiv.bg

Abstract. This paper aims to present the integration of an ecological hybrid car test bench allowing for real-environment measurements and analyses into engineering education. The hybrid car test bench – Toyota C-HR Hybrid 1.8 (2019), equipped with the Hybrid Synergy Drive system, has been tested in the training of students from the Bachelor programs "Automotive Electronic Systems" and "Automotive Engineering" at the Faculty of Physics and Technology of Plovdiv University "Paisii Hilendarski" (Bulgaria). The implementation of the hybrid platform in a learning environment proved its potential as a teaching and technological tool, providing opportunities for students to measure exhaust gases emissions, fuel mixtures, fuel consumption and plan models related to the recovery. The inclusion of the hybrid platform in engineering education creates conditions for the development of knowledge and skills related to electromobility, energy efficiency and sustainable technologies, which directly correspond to the optimization of the environmental characteristics of hybrid vehicles.

Key words: hybrid cars, engineering education, sustainable development, environmental technologies.

Introduction

In the face of growing climate challenges and an increased focus on sustainable development, the automotive industry is moving towards new technologies that are focused on environmental protection, seeking a balance between environmental friendliness and practicality, and developing of low-emission transport technologies is becoming a priority (Asenov et al., 2025).

Hybrid electric vehicles (HEVs) offer a transitional model between traditional internal combustion engines and fully electric vehicles. The production of hybrid cars is driven by their positive impact on the environment, as they emit less CO_2 and other pollutants compared to traditional gasoline cars. This is due to their improved fuel efficiency and the use of electric power at lower speeds. Hybrid cars also reduce dependence on fossil fuels. The fuel economy of hybrid cars is their main advantage. The reduction in fuel consumption and CO_2 emissions is due to the fact that they run mainly on electricity at low speeds.

Despite their environmental and energy potential, the integration of HEVs into engineering education is still limited. The testing of an eco-friendly hybrid vehicle in engineering education is an important aspect of training specialists who will take into account the need for sustainable development and minimizing harmful emissions. In recent years, hybrid vehicles, combining traditional engines with electric ones, have established themselves as an alternative to conventional means of transport. Their main benefit is reported to be increased fuel economy compared to vehicles powered entirely by internal combustion (Kolesnikova et al., 2020). It is important to emphasize that hybrid technologies are constantly improving in response to growing competition from gasoline cars, but the exact advantages may vary depending on the specific model and operating conditions (Kolesnikova et al., 2020; Bazhynov & Tkachov, 2020).

The testing of environmental technologies in the education of engineering students implies the integration of practical knowledge and skills related to the new requirements for energy efficiency. Through practical classes, students can learn about the design of hybrid systems and the specifics of their management, as suggested by a number of studies emphasizing the importance of computer simulations and modeling of transport flows (Klimovich & Shuts, 2018). Methodological approaches in engineering education provide an opportunity for in-depth knowledge of transport flow management and adaptive methods, which is supported by studies emphasizing the importance of new technologies in traffic management (Klimovich & Shuts, 2018; Kosenko et al., 2024).

In the context of engineering education, it is necessary to include modern teaching methods that allow students to become familiar not only with the theoretical aspects of hybrid technology, but also with practical applications, including work in laboratories and research projects. The educational sector is oriented towards collaborations between universities and the automotive industry, which provides opportunities for students to participate in real projects for the creation and improvement of hybrid cars, aimed at the ecological prosperity of the students.

In addition to the technical challenges associated with hybrid vehicles, it is important to focus on the environmental aspects of their operation. Studies show that the implementation of infrastructure innovations, together with engine optimization, can lead to a significant reduction in CO_2 emissions from vehicles (Kaizer & Lebedeva, 2023). These data highlight the need to include subjects in curricula that connect theory with practice, preparing students for a future in environmentally sustainable automotive engineering and transport system management.

In summary, the testing of the ecological hybrid vehicle in engineering education not only provides the necessary knowledge and skills to students, but also integrates innovations that meet the needs of the modern world. Future engineers will be better prepared to deal with the challenges of the energy transition and the strengthening of environmental regulations, thanks to the implemented projects and established practices in education.

Many universities lack curricula and laboratory modules that actually demonstrate the functioning of such systems. The present study aims to present a training stand based on a real hybrid car, Toyota C-HR Hybrid 1.8 (2019), and to analyze its testing in the education of engineering students.

Materials and methods

Hybrid vehicles combine an internal combustion engine and an electric motor, controlled by an intelligent energy optimization system. Well-known examples are the Toyota Prius, Hyundai Ioniq, and Chevrolet Volt.

The training stand is based on a real hybrid car Toyota C-HR Hybrid 1.8 (2019), equipped with the Hybrid Synergy Drive system (Fig. 1).

Fig. 1. Hybrid electric car stand – Toyota C-HR Hybrid 1.8 (2019).

The ecological hybrid car stand provides a positive impact from the inclusion of electric and hybrid technologies in the learning process, especially in the education of students in the Bachelor programs "Automotive Electronic Systems" and "Automotive Engineering" at the Faculty of Physics and Technology of Plovdiv University "Paisii Hilendarski". This also corresponds to the Sustainable Development Goals:

- SDG 7 – access to clean and affordable energy;
- SDG 9 – industrialization, innovation and sustainable infrastructure.

The main technical characteristics of the ecological hybrid car test stand used are:

- engine: 1.8-liter gasoline (code 2zr-fxe), 4-cylinder, inline
- hybrid system: full hybrid (FHEV) with 53 kW (72 hp) electric motor, total system power 122 hp
- electric motor: synchronous AC motor powered by NI-MH battery
- combined power: 90 kW
- recovery: braking energy recovery system
- torque: 142 NM at 3600 rpm
- gearbox: automatic E-CVT
- drive: front (FWD)
- battery type: nickel-metal hydride (NIMH)
- capacity: 1.3 kWh
- battery weight: 40 kg
- maximum speed in electric mode: up to 45 km/h
- electric range: about 2 km

The training stand is equipped with the following safety equipment:

- safety systems: Toyota Safety Sense (automatic emergency braking, pedestrian detection, lane keeping assist, adaptive cruise control)
- parking assistants: rear camera, parking sensors
- interior: air conditioning, dab radio, Android Auto / Apple Car Play, navigation (optional)
- external equipment: LED headlights, 17" or 18" alloy wheels (depending on version).

Results and Discussion

The Toyota C-HR Hybrid 1.8 (2019) hybrid car bench provides the opportunity to conduct the different types of research as presented in Table 1. It serves as an effective demonstration site for environmental engineering, and it is important to note that real-time measurements improve student engagement and their understanding of the need for sustainable transportation solutions.

Table 1. Conducting research with the ecological hybrid car test bench.

No.	Research type	Methodology	Measured parameters
1	**Energy balance**	Comparison between urban and highway cycle (WLTP standard)	Consumption (l/100 km), SOC, recovered energy
2	**CO_2 and HC emissions**	Portable gas analyzer (Bosch BEA 350) at different speeds and loads	CO_2(g/km), HC (ppm)
3	**Transition optimization**	Study of hysteresis control during transition from EV to ICE and vice versa	Transition time, energy efficiency
4	**Temperature effect**	Testing at -10°C and +25°C in an air-conditioned laboratory	Battery capacity, consumption, regeneration efficiency

To measure the concentrations of main harmful emissions emitted by the hybrid vehicle test bench, the gas analyzer model: Kane AUTO plus was used. The results obtained from a series of studies are presented in Table 2. Based on the analysis of these data, the following conclusions can be made:

- The values in the "charge sustaining" columns indicate emissions under steady-state conditions (the battery is not actively charging) under laboratory conditions;
- At low temperature (0 C) CO and HC increase sharply, and NO_x reaches 4.23 mg/km — although it remains well below the permissible limit of 60 mg/km;
- In real-driving conditions (RDE), emissions are very low — CO ~27–34 mg/km, NO_x ~1.4–1.7 mg/km — showing excellent performance outside the laboratory;
- Fine particulate matter is also minimal: PM only 0.03–0.063 mg/km, PN within 10^{10}–10^{11} particles/km.

Table 2. Pollutant and CO_2 emissions table for Toyota CHR Hybrid 1.8 (2019), based on official laboratory and real-driving measurements.

Indicator	WLTC lab. charge sustaining	WLTC 0°C	WLTC hot	RDE real road (cold)	RDE real road (hot)
CO (mg/km))	62.04	373.4	32.5	33.95	26.86
HC (mg/km)	9.26	67.3	6.81	-	-
NMHC (mg/km)	7.85	64.5	5.82	-	-
CO_2 emissions	86g/km	-	-	-	-
PM (mg/km)	0.03	0.063	0.05	-	-

Testing the ecological laboratory stand Toyota C-HR Hybrid 1.8 (2019) in engineering education demonstrates the reporting of significantly low CO, HC emissions, especially powder particles, as the values are far away under regulatory limits (Euro 6) and in real conditions. CO_2 emissions are among the lowest for the SUV hybrid class – around 86 mg/km WLTP.

Of particular importance for the use of the ecological hybrid car stand Toyota C-HR Hybrid 1.8 Toyota C-HR Hybrid 1.8 (2019) in engineering education is that it uses a parallel hybrid system (Hybrid Synergy Drive), in which recuperation is a process of converting kinetic energy during braking into electrical energy, which is stored in a NiMH battery. Students form knowledge about the principle of recuperation, which is expressed in the following:

- when the accelerator pedal is released, the electric motor (MG2) switches to generator mode;
- the kinetic energy of the rotating wheels is converted into electrical energy;
- during light braking (up to ~0.3 g), only regenerative braking is used;
- during hard braking, the mechanical disc brakes are also activated;
- шhe battery is charging, but cannot accept power if it is above ~80% SoC or too cold/warm.

Recuperation in hybrid cars is their significant advantage, as it leads to more efficient use of energy and reduced fuel consumption, respectively contributing to the reduction of CO_2 emissions.

Conducting research for recuperation aims at quantitative measurement of the recovered energy under different conditions, efficiency of recuperation at different speeds and gradients, and comparison between regenerative and classic mechanical braking. For this purpose, the trainees develop skills in working with measuring equipment, such as OBD-II analyzer with data logging (for example OBD Link, ELM327 + software such as Torque, Car Scanner, or professional CAN-Bus analyzer), dynamometer – for simulation of differrent loads, speeds and gradients, GPS module and accelerometer – for validation of kinematic parameters, voltmeter and ampere meter on the hybrid battery, temperature sensors (for the influence of temperature on recuperation). The tests that can be performed are shown in the Table 3 and the results are delivered in Table 4.

The analysis of the presented results gives grounds to draw the following conclusions:

- When the vehicle is driven in the city, when moving at low speeds or stuck in heavy traffic, ordinary gasoline cars keep the engine running, which at the same time produces exhaust gases, causing extremely high air pollution.
- The same situation, when applied to hybrid cars, they intelligently switch to an electric motor, resulting in zero fuel consumption and zero air pollution. This not only contributes to financial savings, but also to a greener and healthier environment.

Table 3. Recovery tests.

Condition	Description
City driving	Braking from 50 → 0 km/h on level ground
Suburban	Braking from 80 → 0 km/h
Slope descent	Regeneration at constant speed
Low battery	SOC < 40%
High charge	SOC > 80% (limited recuperation)

Table 4. Test results.

Speed (km/h)	ΔSOC (%)	Recovered energy (Wh)	Efficiency (%)
50 → 0	1.5	~120Wh	~50–70%
80 → 0	2.8	~220Wh	~60–75%

The energy balance of the Toyota C-HR Hybrid 1.8 (2019) hybrid car test bench when driving is characterized by:

- at low speeds (< 50 km/h) – the car uses mainly the electric motor;
- during acceleration – both the gasoline engine and the electric motor work;
- when stopping/decreasing – the regenerative system captures kinetic energy and charges the battery;
- when stationary, the engine is switched off when it is not needed (start/stop system).

The efficiency and economy of a hybrid car compared to a gasoline car are presented in Table 5. These data proves that the Toyota C-HR Hybrid 1.8 is manufactured with a high percentage of recyclable materials and reduced use of heavy metals, as a result of which it offers a good energy balance (high efficiency in the city), a low carbon footprint during operation, no need for charging from the socket (useful for users without a home charger) and is good ecological solution for urban and mixed environment

Table 5. Efficiency and economy.

Indicator	Value	Comparison with a gasoline car
Energy efficiency	~35–40% (system)	~20–25%
Urban consumption	~3.8 – 4.5 l/100 km	~7–9 l/100 km
Kinetic energy recovered	Up to ~60% when stopped	0%
Battery power (electric mode)	~1 – 2 km purely electric.	-

The implementation of hybrid technologies in the educational process requires an interdisciplinary approach - a combination of knowledge in mechanics (operation of an internal combustion engine), electronics (power electronics in cars, inverters), ecology and energy (emissions and ecological footprint), information technology, mechatronics (integrated control systems), sustainable development (energy efficiency in transport). Practical work with a real car enriches theoretical knowledge and contributes to the development of technical intuition and engineering thinking. In addition, it educates values related to sustainable development.

During the work, students learn about the principles of energy recovery, efficiency in different operating modes, and the influence of driving style on emissions. In addition to technical measurements, students conduct observations on the operation of the electrical and thermal systems, estimate the time for switching from electric to gasoline mode, and analyze the data using software.

The testing of the ecological hybrid stand in higher education supports the concept of STEM (Science, Technology, Engineering, Math) education through:

- simulations of real scenarios – testing during braking, acceleration, inclination;
- processing of real data – from loggers or diagnostics;
- creating models – physical and electronic diagrams of energy flows;
- project development – for example, "Energy Management in Urban Traffic".

The training stand based on a real hybrid car Toyota C-HR Hybrid 1.8 (2019) is also distinguished by its environmental and social impact on students, by increasing their environmental culture, as it provides opportunities for emissions analysis and sustainable transport. Students develop skills for sustainability assessment by comparing hybrid cars, internal combustion engines and electric cars according to their ecological footprint. Last but not least, in the context of the green transition, the social responsibility of future engineers is increased, prepared to meet the expectations of the automotive industry.

Conclusions

The global trend towards electrification of transport and the drive towards zero emissions require a rethinking of traditional engineering programs. Hybrid vehicles are an intermediate and strategic step in this transformation. Their inclusion in engineering education creates conditions for the development of knowledge and skills related to electromobility, energy efficiency and sustainable technologies.

The testing of a hybrid car in engineering education has proven its effectiveness as an effecttive tool for modern and innovative training in sustainable technologies. The results show that such an approach supports not only the professional training of future engineers, but also their motivation and commitment to "green" technologies. It is recommended to apply such methods more widely in the technical universities.

The application of such platforms in engineering provides an opportunity for students to conduct multidisciplinary research, who receive not only theoretical knowledge, but also practical experience with a real platform that meets modern environmental requirements.

Hybrid cars area key transitional technology that allows for significant reductions in emissions and fossil fuel consumption, without complete reliance on charging infrastructure. They offer a balance between environmental friendliness and practicality, making them particularly suitable for today's conditions, both in urban and interurban environments. Despite some limitations, hybrids are a step in the right direction on the path to sustainable transport.

Acknowledgments

This study is financed by the European Union - NextGenerationEU, through the National Recovery and Resilience Plan of the Republic of Bulgaria, project DUECOS №BG-RRP-2.004-0001-C01.

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Received: 29.08.2025
Accepted: 22.09.2025