RESEARCH OF CHANGE IN FUEL CONSUMPTION USING ECO-DRIVING RULES

Manvydas Bagavičius
Šiauliai State University of Applied Sciences
Lithuania

Annotation

Research examines the fuel consumption of a gasoline engine. Eco-driving is described in theoretical terms. The making of an additional fuel tank system is described which is used to accurately determine fuel consumption. Routes A-E have been developed and tested by driving the car conventionally and in accordance with the principles of eco-driving. Fuel consumption for all routes was obtained and fuel savings were calculated. The ecological and financial benefits of eco-driving have been calculated.

Keywords: Eco-driving, ecology, fuel consumption, petrol engine, fuel system.

Introduction

Transport is an integral part of the modern world. The better developed the transport system, the faster the cargo will be delivered and the passengers will reach their destination. All of this comes at a cost, as vehicles are one of the main sources of air pollution and a major contributor to climate change. To avoid the consequences of climate change, various strategies are being developed to reduce air pollution, one of which is eco-driving.

Eco-driving (efficient driving) is a modern responsible and rational driving style, where the driver pays attention to the traffic flow and is safe; the car can be operated without repairs for a longer time and uses less fuel. [1].

There are many different steps you need to take to adapt your eco-driving style to driving, both before and after driving, as each will reduce your overall fuel consumption.

Purpose of the research. To make an additional fuel tank system to measure the amounts of fuel consumed on the routes A-E and then calculate the ecological and financial benefits of eco-driving.

1. Eco-driving rules, principles and benefits

Benefits of eco-driving:

• Security
- Increasing road safety;
- Improving drivers driving skills.

• Environmental
- Reducing greenhouse gas (CO_2) emissions;
- Reduces local air pollution;
- Noise level is reduced.

• Financial
- Fuel / money savings (long-term savings of 5–15 %);
- Lower vehicle operating costs;
- Lower accident costs.

• Social
- More responsible driving;
- Less stress while driving. [1]

The concept of eco-driving is different from definition to definition but the common goal is to reduce the negative impact from driving. [6]

The driving should be done smoothly and without stress to help reduce sudden changes in velocity which often means that energy was wasted in order to get the vehicle moving in a short burst. [5]

To achieve the benefits of eco-driving, certain rules and principles need to be applied. They can be:

- Proper gear shifting. Each car will have a different engine speed limit, but the limit should not exceed 2000 rpm when driving. While driving at 50 km/h fourth or fifth gear should be engaged.

- Maintaining a constant speed while driving. The speed of the car must be as constant as possible while driving. Fuel consumption will be lower if the accelerator and brake pedals are pressed as infrequently as possible. The highest fuel consumption is when the car accelerates.
- Environmental monitoring. When driving, you should observe what is happening in front of and around the car. If an obstacle is visible, it will be possible to bypass it and there will be no need to stop, which would increase fuel consumption.
- Stopping the car without the brake pedal. If the driver can see an obstacle in front that will force the car to stop, such as a red traffic light, the driver should release the accelerator pedal and roll with gear engaged until he rolls to the obstacle. There is a chance that when the green traffic light comes on, the car will not have stopped yet, so the car will need less fuel to accelerate again.
- If the engine is on, car should drive and not stand still. If the car has stopped and will be there for 1-2 minutes or more the engine should be switched off.
- Electrical devices in the car. Electricity, for devices such as: car radio, air conditioner, electric windows, heated seats and others is obtained by burning additional fuel. The fewer appliances switched on, the lower the fuel consumption.
- Car maintenance. The car should be serviced regularly. Regular replacement of engine fluids, spark plugs, belts, filters and other components will help the engine to operate optimally.
- Tire pressure. It is very important to constantly check the tire pressure. Tire pressures can significantly increase fuel consumption.
- Car smoothness. The sleeker the car, the lower the air resistance with the air, thus reducing fuel consumption. The car may become less sleek due to the bike racks, trunks, cargo, etc. attached to the car. Even a car that is washed regularly will be smoother than a dirty car.
- Car weight. The heavier the car, the more fuel it will consume. The car should be inspected and cleaned of unnecessary items / loads.
- Route planning. An optimal route should be established before departure. Using modern technology, it is possible to create a route without road repairs or additional unwanted stops. It should be remembered that the shortest route will not always be the fastest or most environmentally friendly.

2. Research on change in fuel consumption using eco-driving rules

While searching for the information on the topic of eco-driving, several types of studies have been found that attempt to compare the fuel consumption of conventional driving and eco-driving. The method of determining the change in fuel in those articles often raises many questions. There are two main ways in which the change in fuel was calculated. They can be named as follows:

1. Full fuel tank test;
2. Investigation of on-board computer readings.

The car selected during the full fuel tank test is filled with a full tank of fuel. After the car makes a certain route it goes to the gas station and refills the full tank. The amount of fuel required to refill the fuel tank a second time is counted as the fuel consumption for this route.

During the investigation of on-board computer readings, the car needs to be equipped with on-board computer. Current fuel consumption readings must be recorded and from this data the fuel consumption of the certain route can be calculated.

Both methods are quite inaccurate. In the first case it is impossible to fill the fuel tank with the same amount of fuel two times in the row. The amount of fuel in full fuel tank can vary from a few tens to several hundred milliliters or even a liter, so it is not clear how much fuel was burned during the certain route.

In the second case, using on-board computer readings, the results are also inaccurate because fuel consumption is a constantly changing dimension. Each press of the speed or brake pedal increases or decreases the consumption and that data changes every second and taking the average consumption of one route will result in very inaccurate results.

In order to carry out the study as accurately as possible and to determine the difference between the fuel consumption of conventional driving and eco-driving the idea was to produce a fuel system that would allow getting accurate results of fuel consumption. A separate fuel tank was used for this purpose which could be weighed before and after the test to find out exactly how much fuel was burned during the route. The study was conducted on five different routes. Each route consisted of two journeys, one conventional, the other applying the principles and rules of eco-driving.

3. Peugeot 206 technical specifications and the making of new fuel system

To carry out this research a car was purchased and an additional fuel tank was installed in it. By doing that it was possible to determine the exact fuel consumption. Several requirements have been raised for a car for research:

- Engine by fuel type - petrol;
- Good access to the in tank fuel pump;
- Construction of the in tank fuel pump.

A gasoline engine has been chosen because the pumps in the diesel fuel system are more vulnerable. Also, fuel in diesel systems often settles in the fuel tank and because of the air stuck in the fuel system lines it is harder to start the car. The fuel pump in the tank in this model is mounted under the rear seat on the right side. The pump housing can be seen by lifting and removing the metal cover (Fig. 1).

Fig. 1. In tank fuel pump

There is an electrical connection at the top of the pump and two fuel lines - supply and return. The car met all the requirements that were raised before it was purchased and was suitable for this research. More technical data of the purchased Peugeot 206 is given in Table 1.

Table 1

Peugeot 206 technical specifications [4]

Year of manufacture	2000
Engine displacement, cm3	1124
Fuel type	Petrol
Engine power, kW (HP)	44 (59)
Maximum speed, km/h	158
Acceleration 0-100 km/h, sec	15,4
Drive wheels	Front
Gearbox type	Mechanic
Number of gears	5
Weight, kg	885
Fuel consumption in the city 100km, l	8,3
Fuel consumption on the highway 100km, l	5,2
Average fuel consumption 100km, l	6,2
Fuel tank capacity, l	50
CO_2 emissions, g/km	148

The data in the Table 1 show that the car has a 59-horsepower engine and weighs only 885 kg. The average fuel consumption per 100 kilometers is 6.2 liters. When registering this car, the pollution tax was calculated with the registration tax calculator and was €0. If the tax had been set on the basis of technical data that CO_2 emissions were 148 g / km, the pollution tax would have been €30,06.

When choosing a new fuel tank, its external and internal dimensions were taken into account. The inside of the tank had to be large enough to accommodate the fuel pump and from the outside the tank had to be as compact as possible so that it could be conveniently connected, disconnected, secured and lifted out of the car to be weighed. A 12-liter tank was purchased. In order to install a fuel pump in it, it was necessary to modify its cover by cutting a hole in it. The tank is shown in Figure 2.

Fig. 2. A 12-liter tank for fuel

A used fuel pump was found and bought, which was removed from the same car Peugeot 206 with a 1.1-liter engine. This pump was used in the new fuel tank. Fuel pump mounted in the lid of the tank is shown in Figure 3.

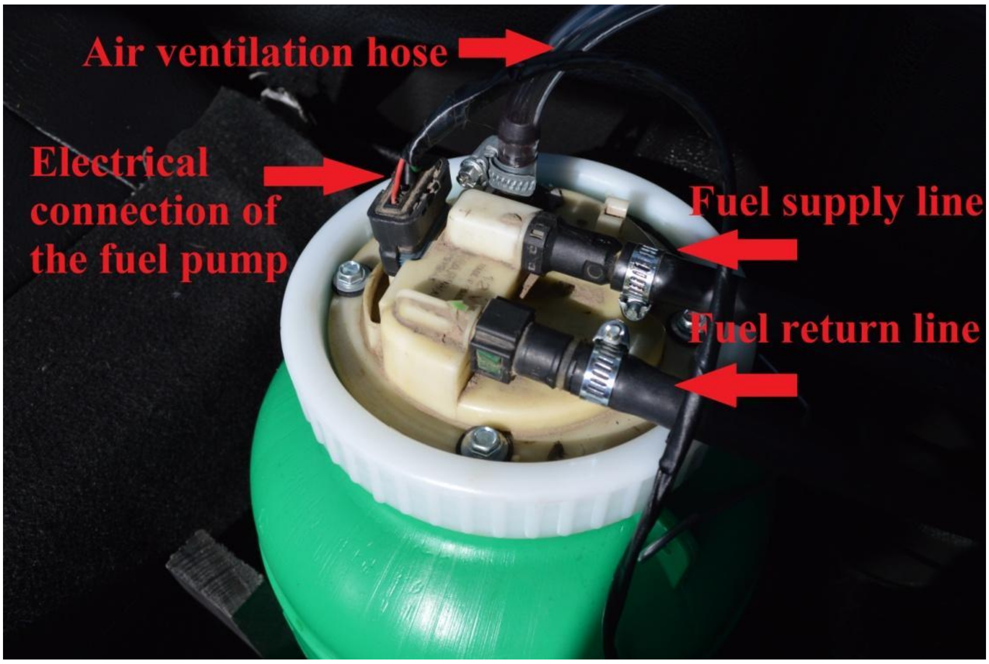

Fig. 3. Fuel pump mounted in the lid of the tank

A separate fuel tank was mounted in the rear of the cabin on the right side under the "passenger's feet". This location was chosen because it was the closest location to the location where the original fuel pump was installed. The only thing that was modified on the car is a second electrical connection soldered to the original fuel pump power cord. This was chosen to do because the original cable was too short to connect to a new fuel tank. It was extended by about 50 centimeters. The fuel supply and return lines were also too short so 50 centimeters extensions were made. New fuel system is shown in Figure 4.

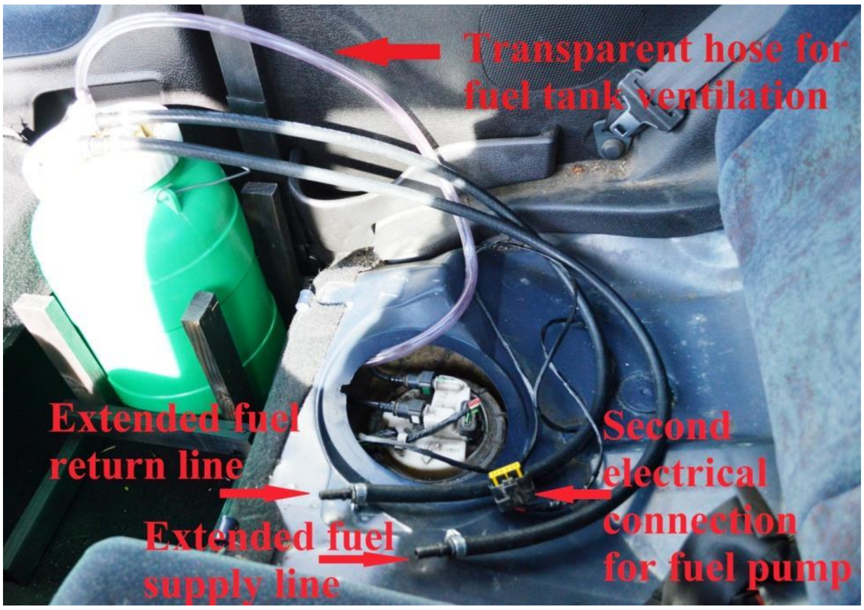

Fig. 4. New fuel system

Fuel tank ventilation was also installed. A transparent hose was used for ventilation, one side of which was connected to the tank and the other end led out through a hole in the body to the outside of the car. In order to connect the new fuel tank, it was necessary to disconnect the original fuel supply connections and the electrical connection, then to connect the extensions to the car's fuel supply lines and to connect the extended electrical connection to the new pump. A frame was made of wooden beams in which the new fuel tank was placed to keep it stable. Connected new fuel tank is shown in Figure 4.

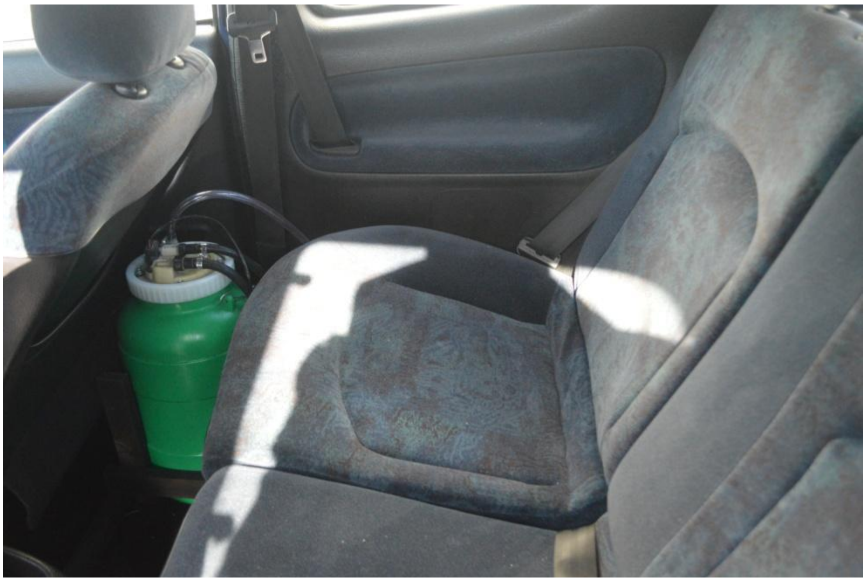

Fig. 4. New connected fuel tank

4. Description of routes used in the research

Routes were made in the city, on the country roads, as well as on paved asphalt concrete roads and gravel roads and on roads with different speed limits from 30 to 90km/h. The aim was to obtain different fuel consumption figures as some routes had more traffic lights and others had fewer. There were also gravel sections on some routes while on other roads there were country roads with 90km/h speed restrictions.

Each route were driven two times, one time conventionally and second time using eco-driving rules. It was practically impossible to drive them with the same number of stops. Stops can be caused by unregulated pedestrian crossings, traffic lights, and buses leaving the bus stops, drivers driving on one lane roads much slower than it is allowed and so on. There have been cases where on conventional driving routes there were practically no stops and on eco-driving route it was necessary to stop at almost all traffic lights. Such stops and accelerations increase fuel consumption.

Five different routes A - E were used in the research. The rides were started from the 6th Metal Garage Community on Gegužių Street because the car used in the investigation was stored there. Information about the routes A-E is given in Table 2.

Table 2

Routes A-E information

Route name	Route length, km	Route road surface	Possible stops on the route	Speed limits on the route, km/h
A	8,5	Asphalt concrete	21	50, 70
B	6,4	Asphalt concrete, gravel road	5	40, 50, 70
C	17,1	Asphalt concrete, gravel road	41	30, 50, 70
D	23,4	Asphalt concrete	51	30, 40, 50, 70, 90
E	9,3	Asphalt concrete	21	50

Total distance of routes A-E is 64.7 kilometers. This distance was covered twice: by driving conventionally and by applying eco-driving rules. Map of routes A-E is made by the Google Maps application and is shown in Figure 5.

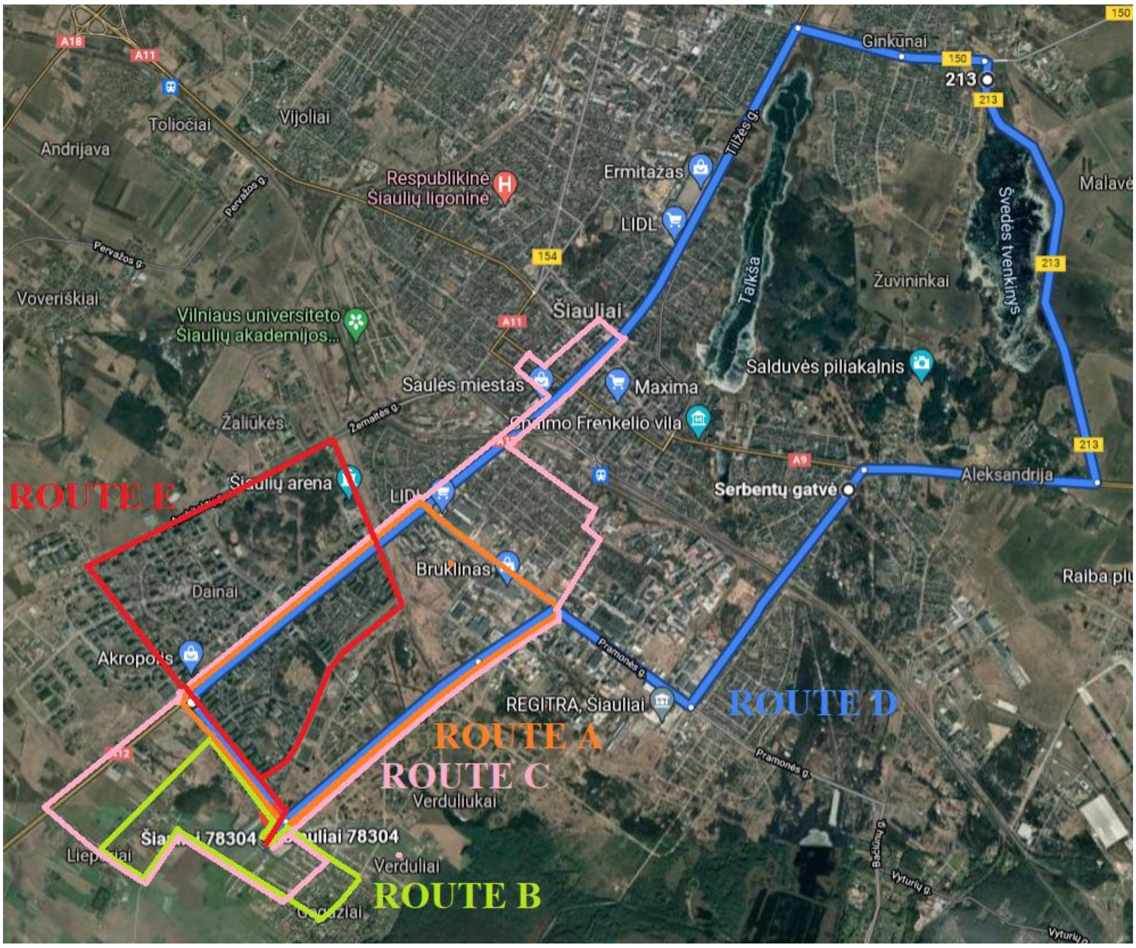

Fig.5. Map of routes A-E

89.49% (57.9 km) of the entire route was paved with asphalt concrete and 10.51% (6.8 km) was a gravel roads. There were 139 possible stops on routes A-E, so there are about 2 possible stops per kilometer driven. All possible stops on the route are shown in Figure 6.

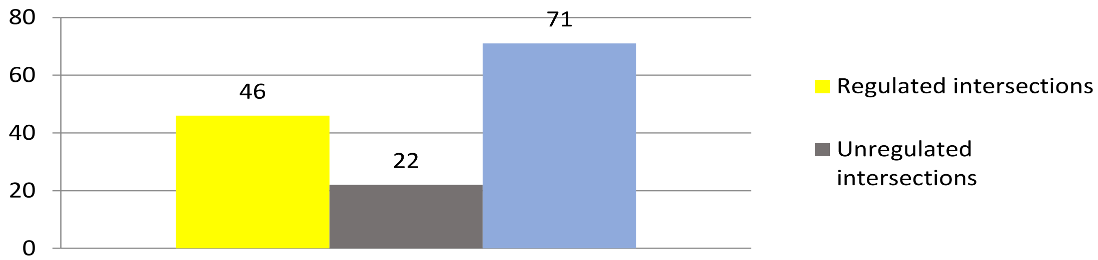

Fig.6. Possible stopping places on routes A-E

As can be seen from the Figure 6 most of the potential stops in this research could be expected at pedestrian crossings. In second place - regulated intersections and in third place - unregulated intersections. It should be mentioned that these are predictable stopping places. There are also stops on the route that are impossible to predict. The more often you need to stop or brake and start moving again the higher fuel consumption will be.

Main focus in this research is to see how driving style can change the fuel consumption while driving. Main differences of driving routes A-E conventionally and in eco-driving style in this research are given in Table 3.

Table 3

Differences of driving conventionally and in eco-driving style

Eco-driving	**Conventional driving**
Car was driven at around 2000rpm. For example: driving with this car in fourth gear at 50km/h is about 2000rpm.	Car was driven at around 2500-3000rpm mark. For example: driving with this car in third gear at 50km/h is about 2500rpm.
Trying to stop the car without the brake pedal.	Stopping the car with the brake pedal.
Trying to monitor the environment and attempt to maintain constant speed while driving.	Not monitoring the environment and not maintaining constant speed.
All the electrical devices are off (unless the windows fog up).	Electrical devices like car radio, air conditioner, rear window heater were turned on the whole time.
All windows were closed.	All the windows were opened about 50 percent to increase air resistance.
No cargo.	Additional cargo weighing about 30kg is carried in the trunk.

All the results of differences in conventional and eco-driving styles get in this research will be because of these differences written in Table 3.

5. Fuel consumption results of routes A-E

To measure fuel consumption, scales were purchased that could withstand a certain weight and measure to the nearest thousandth of a kilogram, that is, to the nearest 1 gram. Scales that can weigh up to 20 kilograms have also been selected, as the new fuel tank holds 12 liters of liquid and the weight of the fuel pump, fasteners, fuel and ventilation hoses and the new fuel tank must also be added. The study was conducted in October-November 2020, when the average outdoor temperature was 5°C. At this temperature a 1 liter bottle filled with petrol weighs 0.743 kilograms. This figure will be used as a factor in converting the test results from kilograms to liters. Fuel consumption in conventional driving and eco-driving routes in liters is shown in Figure 7.

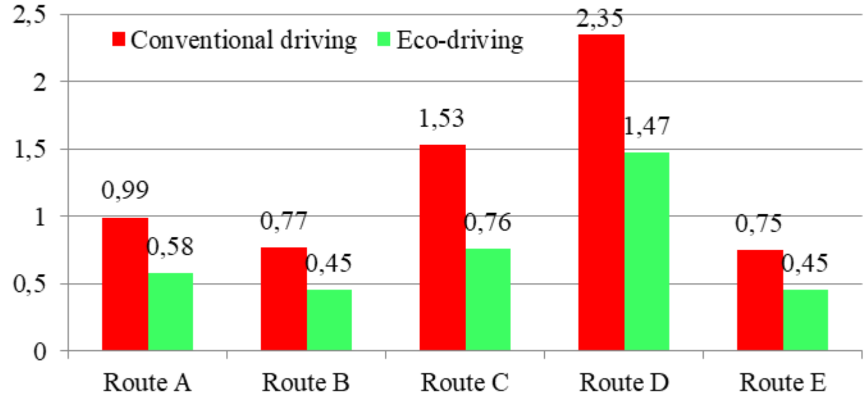

Fig.7. Fuel consumption in liters for conventional driving and eco-driving routes

Figure 7 shows that on all routes A to E, fuel consumption was reduced if eco-driving principles were applied. Fuel consumption in liters per 100 kilometers was calculated and is shown in Figure 8.

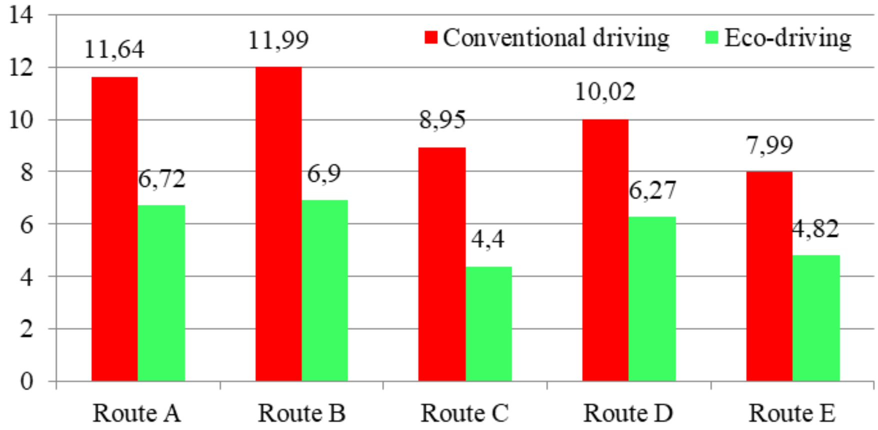

Fig.8. Fuel consumption of conventional driving and eco-driving routes in liters per 100 kilometers

During the study, the highest consumption per 100 kilometers was 11.99 liters and the lowest 4.4 liters. Eco-driving fuel consumption has never exceeded conventional driving fuel consumption.

The smallest difference between normal and eco-driving costs for a distance of 100 kilometers is obtained on route D. Fuel consumption of route D is 10.02 and 6.27 liters with a difference of 37.49%. Even the smallest savings would save more than a third on fuel costs.

The largest difference between conventional and eco-driving consumption for a distance of 100 kilometers is obtained on route C. Fuel consumption of route C is 8.95 and 4.4 liters and the difference is 50.89%, which is more than half.

This shows how a car's fuel consumption can vary and how it changes not just because of characteristics of the route but also because of the driver's driving style. The averages of the results of the study of routes A – E are presented in Table 4.

Table 4

Comparison of conventional and eco-driving fuel consumption of routes A-E

Routes A–E	Conventional driving, l	Eco-driving, l	Difference, l	Difference, %
Fuel consumption of routes A–E	6,37	3,67	2,7	42,39
Average fuel consumption per 100 kilometers	10,11	5,81	4,3	

The application of eco-driving principles on routes A – E has reduced fuel consumption by 2.7 liters or 42.39%. Average fuel consumption per hundred kilometers decreased by 4.3 liters or 42.39%.

6. Ecological benefits of eco-driving

Eco-driving helps to save fuel and protect the environment by emitting fewer pollutants into the air. This research found that the application of eco-driving principles reduced fuel consumption by 42.39%. Using the order of the Ministry of Environment of the Republic of Lithuania: "Methodology for the assessment of pollutants emitted into the atmosphere from machines with internal combustion engines" [3], it is possible to calculate how much pollutants were emitted into the air during the study. A comparison of emissions from normal driving and eco-driving is given in Table 5.

Table 5

Comparison of conventional and eco-driving pollutant emissions of routes A-E

Type of pollutant	Conventional driving pollutants, kg	Eco-driving pollutants, kg	Difference, kg
Carbon monoxide (CO)	2,96	1,708	1,252
Hydrocarbons (CH)	0,613	0,354	0,259
Nitrogen oxides (NOX)	0,126	0,073	0,053
Sulfur dioxide (SO2)	0,009	0,005	0,004

Table 5 shows that eco-driving has reduced emissions of all pollutants. Calculations shows that by using eco-driving rules everyone can contribute to the reduction of air pollution.

7. Financial benefits of eco-driving

Table 4 shows that the fuel consumption of eco-driving routes is about 2.7 liters lower than in conventional driving. The price of A98 petrol on October 16, 2020 when the fuel was purchased was €1,03 per liter. The application of eco-driving principles is estimated to save €4,32 per hundred kilometers.

Lrt.lt conducted a survey on how many kilometers Lithuanians travel per year. The respondents of the survey mostly chose the answer variant, which marked 10–20 thousand annual mileage. This answer was chosen by 39 percent of drivers who answered questions in this survey [2].

If average Lithuanian travels about 15 thousand kilometers per year with a car, it is estimated that using the principles of eco-driving can save €648 per year. That amount of money would be saved just by changing driving habits and starting to use eco-driving rules.

Conclusions

- An additional fuel tank system has been developed to measure the exact amount of fuel consumed and to accurately calculate the difference in fuel consumption.
- Eco-driving routes A-E had lower fuel consumption than conventional driving. After all five routes the average consumption per hundred kilometers was reduced by about 4.3 liters or 42.39%.
- Calculations show that eco-driving has reduced emissions of carbon monoxide (CO), hydrocarbons (CH), nitrogen oxides (NOX) and sulfur dioxide (SO2).
- If average Lithuanian would travel about 15 thousand kilometers per year with this car, it is estimated that using the principles of eco-driving would save about €648.

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Received: 4 November 2021
Accepted: 27 January 2022