WAYS OF REDUCING CARBON DIOXIDE FROM ROAD TRANSPORT

FRANTIŠEK SYNÁK[1], JÁN GAŇA[2], VLADIMÍR RIEVAJ[3], LENKA MOKRIČKOVÁ[4]

Abstract

Climate change and the associated global warming affect all of us. These changes cause melting of the glaciers and consequently the increase in sea and ocean levels. This phenomenon threatens the existence of some of the island states. The warming causing all this was brought on by the economic activity of humans, with the greatest responsibility being attributed to the ever-increasing production of greenhouse gases. Transport generates large portion of these gases. When means of transport are in motion, they are affected by certain driving resistances which try to keep vehicle from moving. In order to overcome them, it is necessary to produce certain useful work equivalent to the measurement of driving resistances. An internal combustion motor is the most frequent source of such energy. It generates energy by oxygenating hydrocarbon fuels, and in addition to the useful work, it produces also unfavourable emission. The amount of such emissions equals to the amount of burnt fuel. Thus, levels of emissions can drop by reducing fuel consumption. The most commonly mentioned gas is CO_2. Reduction of CO_2 production is essential to affect the high level of CO_2. The article focuses on the possibilities of reducing CO_2 from road transport. The possibilities of reducing CO_2 from road transport are quantified in the form of mathematical model calculations.

Keywords: carbon dioxide; driving resistance; emissions; global warming

1. Introduction

Regular measurements have shown that the temperature of our atmosphere is increasing. Figure 1 shows the temperature index for land and oceans from 1880 to 2017.

[1] Department of Road and Urban Transport, University of Zilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia, e-mail: frantisek.synak@fpedas.uniza.sk

[2] Department of Road and Urban Transport, University of Zilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia, e-mail: gana@bte.sk

[3] Department of Road and Urban Transport, University of Zilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia

[4] Department of Road and Urban Transport, University of Zilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia

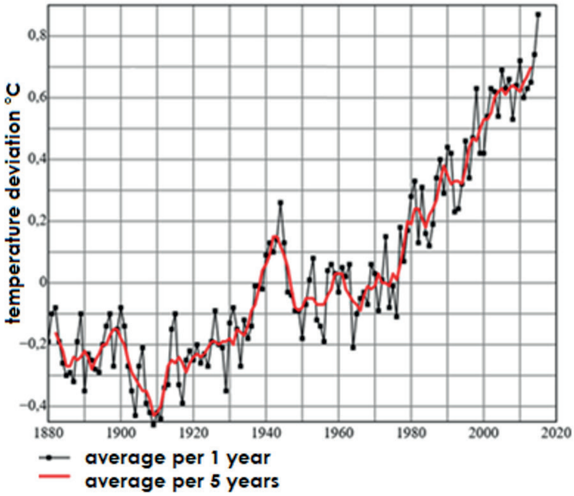

Fig. 1. Global land ocean temperature index [16]

While the temperature is changing, the trend line indicates an apparent increase. Compared to 1880, there was an increase in the maximum value for the measurement period [15, 29]. In Figure 1 is line chart of the global earth – ocean average temperature index, from 1880 to the present, to the base period 1951-1980. The black line is the annual average, and the red line is the five-year moving average. If the trend is maintained and we have no reason to think differently, we can assume that the average temperatures will not drop in the future [1, 11, 14]. Many scientists consider increased greenhouse gas production to be the cause of this adverse development. Others argue that this is an incorrect assumption and the cause must be looked for elsewhere. We do not want to be the judges, but for the sake of clarity, we attach the evolution of CO_2 levels over the history of the Earth. Figure 2 shows the atmospheric CO_2 concentration over the last 650,000 years according to past ice core information and instrumental measurements in recent years.

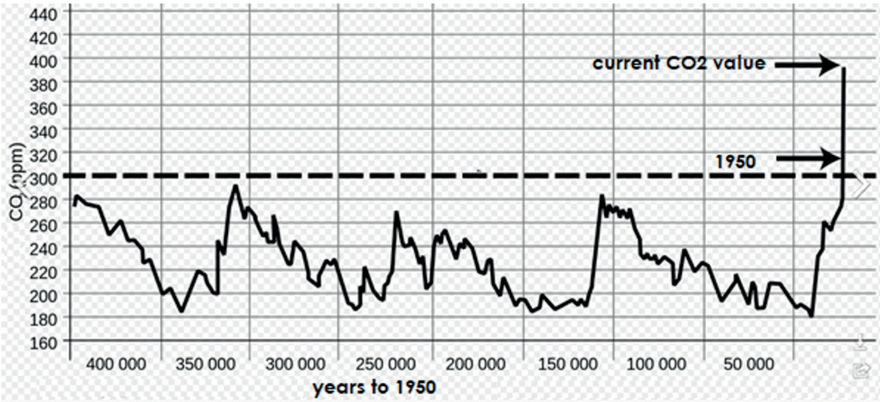

Fig. 2. Concentration of CO_2 on Earth [2]

The similarity of the charts is surprisingly accurate. Evidence that the content of CO_2 in the atmosphere is continually increasing is also provided in Figure 3. It shows the increase in CO_2 in the air in Hawaii, where the greenhouse gas content is not distorted by intensive industrial activity [13, 19, 22].

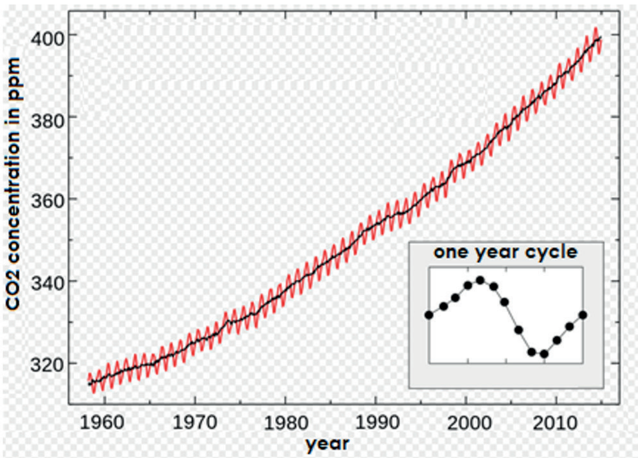

Fig. 3. CO_2 in Hawaii [2]

All three pictures correspond to each other and show the increase in free CO_2 in the air as time goes on. Reducing greenhouse gas production is certainly not a mistake. However, not all countries in the world approach this issue responsibly, Figure 4.

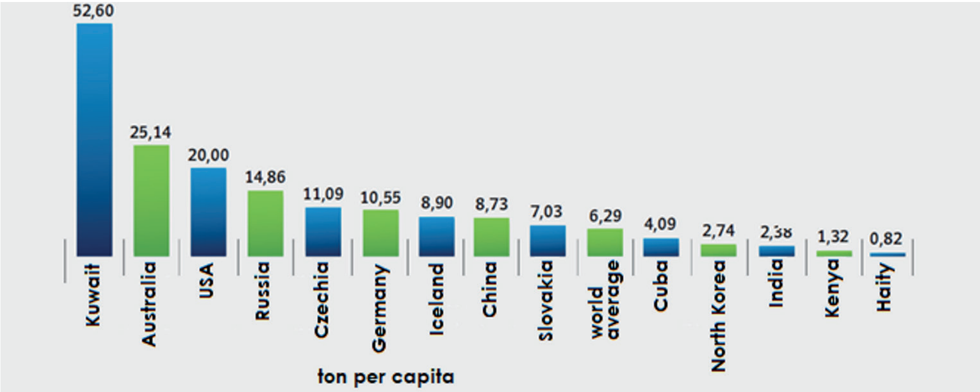

Fig. 4. Greenhouse gas emissions in tones per capita [2]

Table 4 shows which countries produce more greenhouse gases per capita than the world average. Without their responsible approach to the issue, improvement is impossible. Where should we focus our efforts and which human activity produces the most greenhouse gases? The answer will be given in Table 1. According to this table, transport is not the biggest greenhouse gas producer, but if we do not want the gloomy forecasts of climatologists to be fulfilled, we must try to reduce the production in road transport as well [7, 8, 21].

Tab. 1. Greenhouse gas emissions by economic activity, 2015 [5, 23]

	All economic activities	Agriculture, forestry and fishing	Mining and quarrying	Manufacturing	Electricity, gas, steam and air conditioning supply	Transportation and storage	Other services, water supply and construction	Households	Economic activities plus households
EU-28	3 563 578	530 948	79 518	843 475	1 144 807	492 506	472 325	868 828	4 432 406

Tab. 2. CO_2 emissions per litre of fuel at combustion (g/l) [18, 26, 29]

Type of fuel	CO_2 emissions
Petrol	2 500
LPG	1 600
Diesel	2.700

Road transport is dependent on the process of burning hydrocarbon fuels, which we consider to be a non-renewable energy source [9, 10]. Table 2 shows the amount of CO_2 produced by burning 1 litre of fuel. The best solution would be to take measures that reduce greenhouse gas emissions at the lowest cost incurred and so that they do not affect the productivity of the world economy. Thus, the simplest way of reducing CO_2 production would be to replace diesel and petrol with LPG [23]. It would be an effective solution, but it should be remembered that LPG is only a supplementary product and would not be able to cover the required fuel consumption. Another solution is to reduce vehicle consumption and thus reduce unwanted emissions. What options do we have? In addition to technical progress and legislation, it is also minimizing driving resistance [20].

2. Air resistace

The air resistance can be determined using the following equation:

$$O_v = 0{,}05 * c_x * S * V^2 \tag{1}$$

c_x – is a factor taking into account the shape of the body around which the air flows. It varies depending on the vehicle type. For modern passenger cars, its value is around 0.3, and the value for trucks and buses is around 0.7. The design of the vehicle determines it, but the operator can influence it using various accessories and additions (ski carrier, deflector, edge curvature, overlapping gaps between the vehicle and the load), distribution and coverage of the load and the like.

S – is the size of the frontal area of the vehicle [m^2]. The design of the vehicle also determines this parameter, but the operator can influence it using various accessories and additions (ski carrier, etc.), load distribution and the like.

V – is the vehicle's running speed, expressed in km/h.

Tables 3, 4 and 5 show the effect of changing individual parameters on air resistance, the power required to overcome it, and fuel consumption calculated in litres/100 km [24, 26]. They also provide information on the amount of CO_2 produced using the data in Table 2. We will calculate fuel consumption using the following equation [3, 27]:

$$Q = \frac{m_{pe} * P_{Ov} * t}{\rho * \eta_p} \tag{2}$$

Q – is the fuel consumption to overcome air resistance [l/100 km].

m_{pe} – is the specific fuel consumption [g/kWh]. We assume that the vehicle engine will operate in an optimal mode. For petrol, we consider a specific fuel weight of 745 g/dm^3 and specific fuel consumption of m_{pe} = 240 g/kWh. For trucks, we consider diesel with a specific weight of 845 g/dm^3 and specific fuel consumption of m_{pe} = 190 g/kWh.

P_{Ov} – is the power required to overcome air resistance [kW]. $P_{Ov} = O_v * V/3.6$.

ρ – is the specific weight of the fuel [g/dm^3]

η_p – is the efficiency of the transmission system. For passenger cars, we will consider the transmission system efficiency η_p= 93% and for trucks η_p = 90%.

t – is the time it takes to cover a distance of 100 km [h].

Tab. 3. Effect of change in air drag coefficient on fuel consumption

	Passenger vehicle, petrol			Passenger vehicle, diesel			Truck		
c_x [-]	0.30	0.35	0.40	0.30	0.35	0.40	0.6	0.7	0.8
S [m²]	2.1			2.1			9.18		
V [km/h]	90			90			90		
O_v [N]	255.2	297.7	340.2	255.2	297.7	340.2	2230.7	2602.5	2974.3
P_{OV} [kW]	6.38	7.44	8.51	6.38	7.44	8.51	55.77	65.06	74.36
Q [l/100 km]	2.46	2.86	3.27	1.71	2.00	2.29	15.48	18.06	20.64
CO_2 [kg]	6.14	7.16	8.18	4.63	5.40	6.17	41.80	48.77	55.73

This table provides information that even a small change in body shape can cause a significant change in fuel consumption, and thus, the number of greenhouse gases produced. Driving with the window open affects the resistance coefficient. The open side windows of a passenger car represent an increase in air resistance of 5% [6]. The installation of various attachments, such as the pressure wing, the roof rack, the national flags during hockey matches, the load on the vehicle, etc. also have a significant impact. Besides, these also change the size of the vehicle's frontal area.

Tab. 4. Effect of frontal area size change on fuel consumption

	Passenger vehicle, petrol			Passenger vehicle, diesel			Truck		
S [m²]	2.0	2.1	2.2	2.0	2.1	2.2	8.92	9.18	9.54
c_x [-]	0.30			0.30			0.6		
V [km/h]	90			90			90		
O_v [N]	243.0	255.2	267.3	243.0	255.2	267.3	2167.6	2230.7	2318.2
P_{OV} [kW]	6.08	6.38	6.68	6.08	6.38	6.68	54.2	55.77	57.96
Q [l/100 km]	2.34	2.46	2.57	1.63	1.71	1.80	15.04	15.48	16.09
CO_2 [kg]	5.85	6.14	6.43	4.41	4.63	4.85	40.62	41.80	43.44

This table also showed a significant impact of the vehicle's frontal area on fuel consumption and greenhouse gases produced. Tables 3 and 4 also provide a comparison of diesel and petrol engines in terms of fuel consumption and CO_2 emissions. The difference is due to the efficiency of the engines. Combustion in a diesel engine takes place at higher pressures than petrol, which provides higher efficiency of the diesel engine's thermal circuit. The higher specific weight of diesel compared to petrol also contributed to higher consumption of petrol engines. In Table 5, we only compare the impact of speed on the consumption of cars and trucks [27].

Tab. 5. Effect of driving speed change on air resistance and fuel consumption

Passenger vehicles petrol									
V [km/h]	50	70	90	100	110	120	130	140	150
S [m²]					2.1				
c_x [-]					0.30				
O_v [N]	78.8	154.4	255.2	315.0	381.2	453.6	532.4	617.4	708.8
P_{OV} [kW]	1.09	3.00	6.38	8.75	11.65	15.12	19.22	24.01	29.53
Q [l/100 km]	0.76	1.49	2.46	3.03	3.67	4.37	5.12	5.94	6.82
CO_2 [kg]	1.89	3.71	6.14	7.58	9.17	10.91	12.81	14.85	17.05
Truck Diesel									
V [km/h]	40	50	60	70	80	85	90	95	100
S [m²]					9.18				
c_x [-]					0.6				
O_v [N]	440.6	688.5	991.4	1349.5	1762.6	1989.8	2230.7	2845.5	2754.0
P_{OV} [kW]	4.90	9.56	16.52	26.24	39.17	46.98	55.77	65.59	76.50
Q [l/100 km]	3.06	4.78	6.88	9.37	12.23	13.81	15.48	17.25	19.11
CO_2 [kg]	8.26	12.90	18.58	25.29	33.03	37.28	41.80	46.57	51.60

The air resistance increases with the square of the speed, and the speed also appears when calculating the necessary engine power to overcome it. It is clear from the tables that by reducing the speed of passenger cars on the motorway from 130 km/h to 110 km/h, it is possible to save 1.45 litres of fuel per 100 km of driving and if the deceleration is only 120 km/h 0.75 litres per 100 km. It is a reduction in CO_2 production to 71.6% at a deceleration to 100 km/h or 85.2% at a deceleration to 120 km/h from the original value. For trucks, a deceleration from 90 km/h to 85 km/h means a reduction in diesel consumption of 1.67 litres of diesel per 100 km driving, and this would mean a reduction in CO_2 production to 89.2% from the original value. Of course, the time needed to cover the same distance will be extended, but it is not important. At a speed of 90 km/h in 4.5 hours, the vehicle will travel a distance of 405 km, at a reduced speed, 382.5 km, but it will produce 4.52 kg of CO_2 less for every 100 km of driving. A vehicle will need 16 minutes more to travel the same 405 km, but it will not produce 18.31 kg of CO_2.

3. Inertia resistance

Each moving body, and thus the vehicle, has certain movement energy. This energy increases in proportion to weight and squared speed. For acceleration, the vehicle engine provides energy. When the vehicle slows down, the vehicle's energy of movement in the brakes turns into heat. From this point of view, it is obvious that it would be most advantageous not to change the vehicle speed. When starting the vehicle, the vehicle engine must overcome not only the driving resistances but also the losses in the transmission system. To determine the energy intensity and hence the fuel consumption, we made a calculation model that summarized the work to overcome the rolling resistance, air resistance and inertia resistance. We calculated the consumption using the following equation:

$$Q_{litre} = \frac{J_{resistance} * s}{\rho * \eta_p * \eta_m * H_d} \tag{3}$$

$J_{resistance}$ – is the respective driving resistance [N],

s – is the path over which the given resistance (force) was applied [m],

ρ – is the specific weight of the fuel [g/dm^3],

η_p – is the efficiency of the transmission system. For passenger cars, we will consider the transmission system efficiency η_p = 93% and for trucks η_p = 90%.

η_m – is the efficiency of the engine. We determined this based on mpe – specific fuel consumption using the following equation: $\eta_m = \frac{kWh}{m_{pe} * H_d} * 100[\%]$

m_{pe} – is the specific fuel consumption [g/kWh]. We assume that the vehicle engine will operate in an optimal mode. For petrol, we consider a specific fuel weight of 745 g/ dm^3 and specific fuel consumption of m_{pe} = 240 g/kWh. For trucks, we consider diesel with a specific weight of 845 g/dm^3 and specific fuel consumption of m_{pe} = 190 g/kWh.

H_d – is the calorific value of the fuel. For diesel, it is 41840 kJ/kg and for petrol 42080 kJ/kg.

Calculations are given in Table 6.

Tab. 6. Fuel consumption (litres) for starting the vehicle from zero speed and CO_2 produced (kg)

Weight			30 km/h	50 km/h	70 km/h	90 km/h	110 km/h	130 km/h
40 tonnes	diesel	litres	0.141	0.406	0.851	1.592		
		kg CO_2	*0.381*	*1.096*	*2.298*	*4.298*		
		time (sec)	11.3	25.3	47.7	85.6		
		distance (m)	57.4	214.7	593.1	1453.9		
16 tonnes	diesel	litres	0.076	0.214	0.436	0.763		
		kg CO_2	*0.205*	*0.578*	*1.177*	*2.060*		
		time (sec)	7.6	14.2	23.8	37.0		
		distance (m)	33.9	109.6	270.7	569.8		
8 tonnes	diesel	litres	0.056	0.156	0.316	0.542		
		kg CO_2	*0.151*	*0.421*	*0.853*	*1.463*		
		time (sec)	6.4	10.8	16.7	23.7		
		distance (m)	29.1	77.6	176.9	336.7		
3 tonnes	petrol	litres	0.015	0.043	0.085	0.146	0.226	0.333
		kg CO_2	*0.038*	*0.108*	*0.213*	*0.365*	*0.565*	*0.833*
		time (sec)	3.4	7.6	13.3	20.6	27.5	37.5
		distance (m)	14.2	59.5	153.2	318.9	513.5	848.6
1.5 tonnes	petrol	litres	0.010	0.028	0.055	0.094	0.143	0.209
		kg CO_2	*0.025*	*0.070*	*0.138*	*0.235*	*0.036*	*0.523*
		time (sec)	2.4	5.2	8.7	13.1	16.5	22.0
		distance (m)	9.4	38.8	96.5	196.7	293.7	479.0

To make the results comparable, in the calculations, we used the same engines, and we only changed the weight of the vehicle. We also considered a constant specific fuel consumption, although this will vary with engine load. It can be seen from the calculations shown in the table that the weight of the vehicle has an essential influence on the consumption of the vehicle during starting. If we compare the situation in the city, when two passenger cars, one 3,000 kg (SUV) and the other 1,500 kg (conventional mid-size), stop at a crossroad, the heavier car produces at a speed of 50 km/h 137.8 grams CO_2 more than the lighter vehicle. If we do not allow heavy vehicles to drive in the city, we can immediately reduce the carbon footprint of road transport. The easily discernible weight of the wheel rims also affects the fuel consumption of the vehicle. When starting, the vehicle's engine must not only accelerate the weight of the vehicle in a linearly accelerated motion but also change the angular speed of the rotating wheels. Their weight is also important. Replacing 12 steel discs with forged aluminium saves 13.3 tonnes of CO_2 emissions over the life of the wheels (1.5 million km) [8].

4. Climb resistance

If the vehicle overcomes the climb, its weight can be divided into two components. One is perpendicular to the ground plane, the vehicle presses against the ground, and the other is parallel to the ground plane and counteracts the movement of the vehicle. To overcome it, the vehicle engine must provide some power. The magnitude of the climb resistance can be determined using the following equation:

$$O_s = m * g * sin\alpha \tag{4}$$

Os - is the climb resistances [N],

m - is the weight of the vehicle [kg],

g - is the gravitational acceleration [9.81 m/s^2],

α - is the slope of the travel plane [◦].

For the calculation of consumption, we will use the formulas and parameters described above. The results are summarized in Table 7.

Tab. 7. Fuel consumption (litres) to overcome a 5 km climb

Incline (%)		2	4	6	8	10	12
Consumption (l) at vehicle weight	1.5 t	0.10	0.20	0.30	0.39	0.49	0.59
	3 t	0.20	0.40	0.59	0.79	0.98	1.18
	8 t	0.54	1.09	1.63	2.17	2.71	3.24
	16 t	1.09	2.18	3.26	4.34	5.42	6.49
	40 t	2.72	5.44	8.16	10.86	13.55	16.22
CO_2 produced (kg)	1.5 t	0.267	0.533	0.799	1.064	1.328	1.590
	3 t	0.534	1.067	1.598	2.128	2.655	3.180
	8 t	1.470	2.939	4.404	5.864	7.317	8.761
	16 t	2.941	5.878	8.808	11.728	14.634	17.523
	40 t	7.352	14.695	22.021	29.320	36.585	43.807

During a 5 km climb with 10% incline, the vehicle climbed 497.5 meters. Such an elevation represents almost every mountain passage. The 40-tonnes weighing kit consumes 13.55 litres to get the vehicle to higher potential energy. Every climb means an increase in fuel consumption, even when driving straight ahead, the potential energy returns in lower driving resistance. At higher inclines, however, we lose energy in the brakes because there are many bends with a small radius on the roads. Besides, there is an additional force that prevents the movement of the vehicle, namely the force distribution component on the steering axle.

5. Curving

To determine the force that is generated as a result of steering wheels turning so that the vehicle goes through a bend with the desired radius, we assume that the wheels are perfectly rigid, and the vehicle is moving according to the steering angle. In practice, this condition does not apply, and the wheels have a specific directional stiffness. By acting on the axle, the centrifugal force of the wheels must produce an equally significant but inversely directed reaction. By turning them into the bend, this reaction breaks down into a component acting in the centre of the bend and a component that acts against the direction of movement of the vehicle. It is the driving resistance that the engine of the vehicle must overcome. Let's call it $F_{slowdown}$. The magnitude of this force and the impact on vehicle consumption and CO_2 production is shown in Table 8. For calculation, we used formulas and constants according to the previous text. We considered a wheelbase of 5 m for a 2.6 m car. We calculated the values only for diesel fuel [24, 25].

Tab. 8. Consumption of vehicle to overcome $F_{slowdown}$ on the runway of 1 km

Curve radius [m]	100	200	300	400	500
			Steering axle load 1000 kg		
$F_{slowdown}$	163	41	18	10	7
consumption [l]	0.011	0.003	0.001	0.001	0.0004
CO_2 [kg]	0.029	0.007	0.003	0.002	0.001
			Steering axle load 3000 kg		
$F_{slowdown}$	938	234	104	59	38
consumption [l]	0.063	0.016	0.007	0.004	0.003
CO_2 [kg]	0.170	0.043	0.019	0.011	0.007
			Steering axle load 6000 kg		
$F_{slowdown}$	1875	78	35	20	75
consumption [l]	0.126	0.005	0.002	0.001	0.005
CO_2 [kg]	0.340	0.014	0.006	0.004	0.014
			Steering axle load 9000 kg		
$F_{slowdown}$	2813	703	313	176	113
consumption [l]	0.189	0.047	0.021	0.012	0.008
CO_2 [kg]	0.510	0.128	0.057	0.032	0.020

Fast driving in sharp turns results in a significant increase in fuel consumption as well as tire wear [28].

6. Rolling resistance

Rolling resistance also has a significant impact on car consumption. Its size can be determined using the following equation:

$$O_f = m * g * f * \cos\alpha \quad (5)$$

m – is the weight of the vehicle [kg],

g – is the gravitational acceleration [m/s^2],

α – is the slope of the travel plane [∘],

f – is the rolling resistance coefficient [-].

The value of the rolling resistance coefficient depends on the design of the tires, the inflation pressure, the axle geometry and the substrate on which the tires roll. To facilitate the orientation of ordinary consumers, the legislation requires that tires be labelled at the dealer. This will provide information on the energy efficiency of a tire by classifying it in energy classes A to G [12, 25], the ability of the tire to brake on wet surfaces, also based on classifications A to G, as well as noise emissions during tire rolling. It also requires that the rolling resistance coefficient for C1 tires does not exceed 10.5 N/kN and for C2 the limit is 9.0 N/kN. For C3 tires, the limit is set at 8.0 N/kN and from 1. November 2020, it will be reduced to 6.5 N/kN. Table 9 shows the impact of a tire on fuel consumption and CO_2 production based on its energy class rating. The calculation will be made for the life of the tire, which depends on the type of traffic, way of driving and loading of the vehicle. We will assume flat driving; truck tire life of 120000 km and other parameters will be used as in the previous text.

Tab. 9. Effect of rolling resistance coefficient on fuel consumption over tire life of 120 000 km

Truck m = 40 000 kg			
f	0.004	0.0065	0.008
O_f [N]	1 569.6	2 550.6	3 139.2
A_{Of} [kJ]	188 352 000	306 072 000	376 704 000
Q [l]	16 604	26 982	33 209
CO_2 [kg]	44 831.5	72 851.2	89 663.1

In Table 9, the rolling resistance limit coefficients for C3 truck tires currently in force, which will be applicable from 2020, and the rolling resistance coefficient of peak tires were used. The difference in the amount of CO_2 produced is in 10 tonnes for the life of the tires [4, 17].

Tab. 10. Influence of weight on rolling resistance and fuel consumption over tire life of 120 000 km

Truck f = 0.0065 kg						
m [kg]	8000	16000	40000	1000	2000	3000
O_f [N]	510.12	1020.24	2550.6	63.765	127.53	191.295
A_{Of} [kJ]	61 214 400	122 428 800	306 072 000	7 651 800	15 303 600	22 955 400
Q [l]	5 396	10 793	26 982	675	1349	2024
CO_2 [kg]	14 570.2	29 140.5	72 851.2	1821.3	3 642.6	5 463.8

Table 10 has been calculated for the rolling resistance limit coefficient to be valid after November 2020 and for different vehicle weights. Here too, there is a significant difference in the amount of CO_2 produced. The columns for 1000 kg, 2000 kg and 3000 kg are intended to point out the saving of CO_2 produced by reducing the dead weight of the vehicle without using the vehicle equipment [29].

7. Conclusion

The fact that the country's climate is warming and that the cause of greenhouse gas production can be considered to be proven. Humanity must now take measures to reverse or at least slow down this unfavourable process. However, the solution must be global, not local, and especially, found in a short time. Solutions should be sought in all areas of human activity, of course in transport, but not only in road transport [26]. The article sets out measures that will make it possible to reduce vehicle consumption and hence greenhouse gas emissions almost immediately and without investing in infrastructure [30]. As stated above, it is obvious that driving resistances affect the fuel consumption of the vehicle. The exact choice of route, tire, vehicles, driving technique of drivers can significantly influence the fuel energetique. It is also directly linked not only to transport costs but also to production of Greenhouse gases and therefore affects the global warming. For example, by choosing the right truck tires, it is possible to produce approximately 44,000 kg of CO_2 less during the life of the tires. Also by reducing the speed of passenger cars on the motorway from 130 km/h to 110 km/h it is possible to save 1.45 litres of fuel per 100 km of driving and if the deceleration is only 120 km/h 0.75 litres per 100 km. It is a reduction in CO_2 production to 71.6%, at a deceleration to 100 km/h or 85.2% at a deceleration to 120 km/h from the original value. Thus, the absence of an upper speed limit on some sections of motorways may cause unnecessary CO_2 production from road transport.

By choosing a route, the driver can also reduce CO_2 production. If the driver chooses a straight section of the route instead of a 2% slope, he will produce about 7 kg less CO_2 over a 5 km section. At the same time, the 2% rise is very slight, almost unrecognizable to the eye. In some cases it is more environmentally friendly to choose a longer route, but without climbing. By applying the principles set out in this Article, up to 40% less CO_2 from road transport can be produced in some cases.

8. References

[1] Arellano B., Rivas D.: Coastal upwelling will intensify along the Baja California coast under climate change by mid-21st century: Insights from a GCM-nested physical-NPZD coupled numerical ocean model. Journal of Marine Systems. 2019, 199, DOI: 10.1016/j.jmarsys.2019.103207.

[2] Climate Change: How Do We Know? http://climate.nasa.gov/evidence/ (accessed on 01.08.2019).

[3] Čulík K., Kalašová A.: The impact of carpooling on the economy and road safety. Communications in Computer and Information Science. 2018, 897, 85–100, DOI: 10.1007/978-3-319-97955-7_6.

[4] Čulík K., Kalašová A., Kubíková S.: Simulation as an instrument for research of driver-vehicle interaction. In MATEC Web of Conferences. 2017, 134, DOI: 10.1051/matecconf/201713400008.

[5] Eurostat, Statistical books. Energy, transport and environment indicators. 2018 edition. ISBN 978-92-79-96509-8 ISSN 2363-2372 https://ec.europa.eu/eurostat/web/products-statistical-books/-/KS-DK-18-001 (accessed on 12.08.2019).

[6] Janoško I., Polonec T., Simor R.: Electronic encyclopedia of construction engine and vehicles. 41st International Scientific Conference of Czech and Slovak University Departments and Institutions Dealing with the Research of Internal Combustion Engines. KOKA 2010, Liberec, Czech Republic, 2010, 232–238, ISBN:978-80-7372-632-4.

[7] Kalašová A., Černický L., Hamar M.: New Approach to Road Safety in Slovakia. Communications in Computer and Information Science. 2012, 329, DOI: 10.1007/978-3-642-34050-5_44.

[8] Kalašová A., Faith P., Mikulski J.: Telematics Applications, an Important Basis for Improving the Road Safety. Tools of Transport Telematics. 2015, 531, 292–299, DOI: 10.1007/978-3-319-24577-5_29.

[9] Kalašová A., Kapusta J., Toman P.: A Model of Transatlantic Intermodal Freight Transportation Between the European Continent and the United States. Nase More. 2016, 63(1), 5–15, DOI: 10.17818/NM/2016/1.2.

[10] Kalašová A., Kubíková S., Čulík K. Smart city-Model of sustainable development of cities. 11th International Science and Technical Conference Automotive Safety, Automotive Safety. 2018, 1–5, DOI: 10.1109/AUTOSAFE.2018.8373309.

[11] Kalašová A., Mikulski J., Kubíková S.: The Impact of Intelligent Transport Systems on an Accident Rate of the Chosen Part of Road Communication Network in the Slovak Republic. Challenge of Transport Telematics. 2016, 640, 47–58, DOI: 10.1007/978-3-319-49646-7_5.

[12] Kalašová A., Kupčuljkaková J.: The future in the telematics applications as support for ncreased safety. Transport Problems. 2012, 7(1), 103–109. ISSN: 1896-0596.

[13] Konečný V., Petro F.: Calculation of emissions from transport services and their use for the internalisation of external costs in road transport. Procedia Engineering. 2017, 192, 677–682, DOI: 10.1016/j.proeng.2017.06.117.

[14] Kubíková S., Kalašová A, Černický L.: Microscopic Simulation of Optimal Use of Communication Network. International Conference on transport Systems Telematics. 2014, 471, 414–423, DOI: 10.1007/978-3-662-45317-9_44.

[15] Ma M., Chang Ry.: Temperature drive the altitudinal change in soil carbon and nitrogen of montane forests: Implication for global warming Catena. Catena. 2019, 182, DOI: 10.1016/j.catena.2019.104126.

[16] NASA Goddard Institute for Space Studies https://data.giss.nasa.gov/gistemp/graphs/customize.html (accessed on 01.08.2019).

[17] Ondruš J., Dicová J.: Potential of Prediction Quantification and Trends in Transport Requirements as Tool of Transport Management and Development. Transport and Telecommunication. 2013, 14(4), 316–324, DOI: 10.2478/ttj-2013-0027.

[18] Ondruš J., Kolla E.: Practical Use of the Braking Attributes Measurements Results. MATEC Web of Conferences. 2017, 134, DOI: 10.1051/matecconf/201713400044.

[19] Palúch J., Čulík K., Kalašová A.: Modeling of traffic conditions at the circular junction in the city of Hlohovec. Lecture Notes in Networks and Systems. 2019, 52, 65–76, DOI: 10.1007/978-3-319-98618-0_6.

[20] Poliak M., Šimurková P., Cheu K.: Wage Inequality Across The Road Transport Sector Within The Eu. Transport problems. 2019, 14(2), 145–153, DOI: 10.20858/tp.2019.14.2.13.

[21] Poliak M., Hammer J., Reuter N., Poliaková A.: The impact of the transport route on the cost of the transfer. 11th International Science and Technical Conference Automotive Safety, Automotive Safety. 2018, DOI: 10.1109/AUTOSAFE.2018.8373319.

[22] Poliak M.: Impact of road network charging system on pricing for general cargo transportation. Promet-Traffic & Transportation. 2012, 24(1), 25–33, DOI: 10.7307/ptt.v24i1.263.

[23] Poliak M., Poliaková A.: Relation of Social Legislation in Road Transport on Driver's Work Quality. Tools of Transport Telematics. 2015, 531, 300–310. DOI: 10.1007/978-3-319-24577-5_30.

[24] Poliak M., Semanová Š., Varjan P.: The importance of the risk in public passenger transport financing. Komunikacie. 2014, 16(2), 92–97.

[25] Regulation No 117 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of tyres with regard to rolling sound emissions and to adhesion on wet surfaces and/or to rolling resistance https://op.europa.eu/en/publication-detail/-/publication/48d3ed27-604f-11e6-9b08-01aa75ed71a1/language-en (accessed on 14.06.2019).

[26] Rievaj V., Gaňa J., Synák F.: Is hydrogen the fuel of the future? Transportation research procedia. 2019, 40, 469–474, DOI: 10.1016/j.trpro.2019.07.068.

[27] Skrúcaný T., Kendra M., Stopka O., Milojevic S., Figlus T., Csiszar C.: Impact of the Electric Mobility Implementation on the Greenhouse Gases Production in Central European Countries. Sustainability. 2019, 11(18), DOI: 10.3390/su11184948.

[28] Skrúcaný T., Semanová Š., Milojević S., Asonja A.: New Technologies Improving Aerodynamic Properties of Freight Vehicles. Journal of Engineering and Applied Sciences. 2019, 4(2), 48–54, DOI: 10.18485/aeletters.2019.4.2.2.

[29] Skrúcaný T., Šarkan B., Gnap J.: Influence of Aerodynamical Trailer Devices on Drag reduction Measured in a Wind Tunnel. Maintenance and Reliability. 2016, 18(1), 151–154, DOI: 10.17531/ein.2016.1.20.

[30] Šarkan B., Holeša L., Caban J.: Measurement of fuel consumption of a road motor vehicle by outdoor driving testing. Advances in science and technology – research journal. 2013, 7(19), 70–74, DOI: 10.5604/20804075.1062374.