THE EFFECT OF INTERMODAL TRANSPORT ON THE REDUCTION OF CO_2 EMISSION

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INTRODUCTION

Oxides of carbon CO_2 and CO, methane CO_4 and volatile organic compounds represent serious atmosphere pollutants by creating the so-called “greenhouse efect”. Over the last 250 years there has been a constant increase of total concentration of carbon dioxide from various sources in the world.

Table 1 Overview of CO_2 concentration and mass in the period 1750-2100

Year	CO_2 imission (ppmv)			Mass of fractions (%) CO_2 (ppm)	Mass of CO_2 in the atmosphere (t)
1750	A		278	422.2	2.173E+12
1960	B		310	470.8	2.423E+12
2014 (March)	C		399	581,7	2.993E+12
2100	D	(i)	541	821.7	4.228E+12
		(ii)	970	1473.2	7.581E+12

Source: CO2 Home, “ppm” stands for "parts per million", "ppmv/w" stands for "ppm by volume/water" ppmv = (mg/m3)(273.15 + °C) / (12.187)(MW)

The period from 1750 represents pre-industrial era characterized by low concentration of CO_2; from 1750 to 1860 the concentration had increased by 250 000 million tons of CO_2, that is, 1190,48 million tons per year. From 1960 to 2007, new 570 000 million tons of CO_2 were emitted in the atmosphere, that is, 12 127,7 milllion tons per year, which is almost ten times more than in the previous two centuries (Table 1).

According to US EPA, the total emissioin in 2012 amounted to around 6 526 million of metric tons of CO_2, 28 % of which is transport. In EU-27 average emissions by sectors point to the fact that transport has a share in emissions 19,6 % - 21 % varying from one state to another; 6% of this number falls on freight vehicles due to the impact of different factors in road transport: roads (traffic density, maximum vehicle weight, climate conditions, topography, driving style, etc.), Figure 1.

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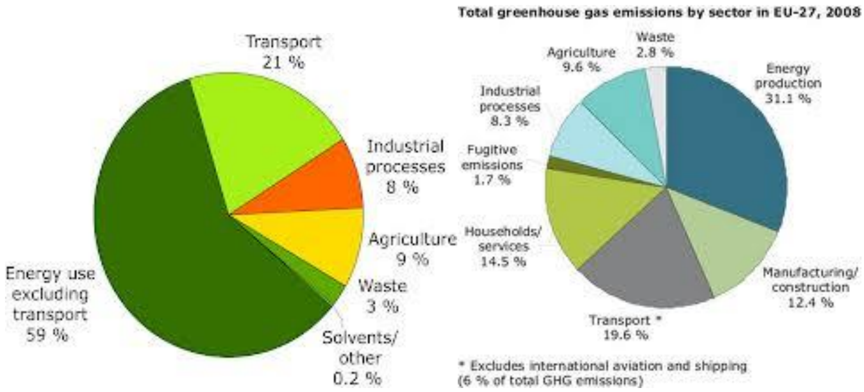
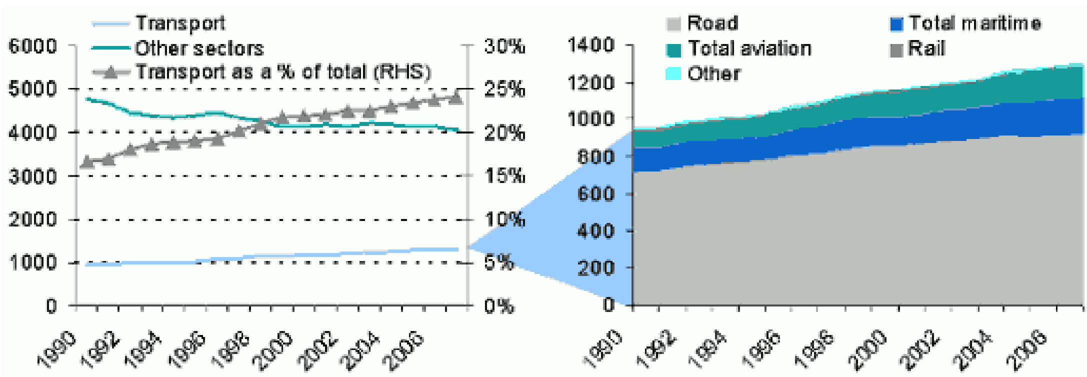


Figure 1 Total emission by sector in EU-27, 2007/08

Considering the types of transport, the biggest emission comes from air transport, followed by road transport, Figure 2. The intensity of the emission in railway transport is affected by: percentage of electrified railways, freight and free rails, density of terminals within the network, etc. In internal waterways the following factors have the biggest impact on emission: weight and age of the vessel, draft depth, density of terminals within the network, weather conditions, etc.



Source: EEA

Figure 2 Emission by types of transport in EU, 1990-2006

In order to reduce the emission, it is necessary to apply new technologies, redirect technological operations to "greener" types of transport that emit the lowest amount of CO_2 per tkm or other unit of measurement. It is essential to connect and optimize transport chains, improve the planning process, increase the exploitable carrying capacity, minimize the movement of freight vehicles without load, etc. On the other hand, it is very important to increase the efficiency of fuel combustion and reduce the share of carbon in fuel.

CURRENT RESEARCH OF CO2 EMISSION IN INTERMODAL TRANSPORT

A significant number of studies, projects and articles published in the world show applied methodologies and main results from different aspects of the effect of intermodal technologies on the air quality and the possibility of reducing the negative effect of CO2.

According to [2], the study (IFEU and SGKV, 2002) compares the energy consumption and CO_2 emissions between road and road-rail combined transport on 19 different European routes in container transportation. The study shows that 3 of 19 routes demand higher energy consumption than in road-rail combined transport; in eight cases the demand for fuel in combined transport is 20 % lower than that of road transport, in six cases it is 20 % - 40 % lower, and in two cases it is lower by more than 40 % which resulted in lower gas emission by 20-50%. The differences occur when using different ways of organizing rail transport (types of trains, lengths of trains where 700 m long trains consume 60 % less energy), PPH distances of heavy goods vehicles (HGV), age of the vehicle and fuel consumption, conditions on the roads, possible return trips, etc. The study is limited to comparing technologies and performance of adopted networks and operative features: length of the distance of main intermodal transport at around 450 km, trains have 21 – 28 cars (with maximum train length of 400-550 m), barges are Neo Kompenaar (32 TEU) and European barge (208 TEU). The study finds a quite low fuel consumption, 29 litres per 100 km, of tugboats (IRU/BGL: 34 liters/100 km). Road vehicles transport goods in both directions. “Transport en Logistiek Nederland” have come to the conclusion that space occupation in intermodal rail door-to-door transport is three times bigger than in road transport, table 2.

Table 2 Ecological performance of intermodal and unimodal transport

Technology Performance	Rail-maritime transport	Rail-road transport	Barge-maritime transport	Barge-road transport
Energy need	Favourable	Non-favourable	Non-favourable	Non-favourable
CO_2	Favourable	Non-favourable	Non-favourable	Non-favourable
NOx	Favourable	Slightly favourable	Non-favourable	Non-favourable
SO_2 and suspended particles	Non-favourable	Non-favourable	Non-favourable	Non-favourable
Land occupation	Non-favourable	Non-favourable	-	-

The paper, "Comparison of external costs of rail and truck freight transportation” (Forkenbrock, 2001), demonstrates that if external costs were included in total transport costs, the costs of freight delivery would be increased by around 13% (0,86 $/tkm +8,42 $/tkm) in road transport, and 9,3%-22,6% in rail transport.

Table 3 External costs for goods transport via road vehicle and railway ($/tkm)

External costs Means of transport	Accidents	Air pollution	Greenhouse effect	Noise	Total
Road vehicle	0,59	0,08	0,15	0,04	0,86
Heavy unit train	0,17	0,01	0,02	0,04	0,24
Mixed freight train	0,17	0,01	0,02	0,04	0,24
Intermodal train	0,17	0,02	0,02	0,04	0,25
Double-stack train	0,17	0,01	0,02	0,04	0,24

The study concludes that based on the transport operation (tkm) transport via road vehicle has higher external costs that go up to three times higher than any other means of transport in railway traffic, table 3.

In paper "Combined transport is environmentally friendly; fiction or reality?" (De Leijer i Ruijgrok, 1990) the authors note that external costs of transport (pollutants emission and fuel consumption) should be compared based on technical characteristics of technologies (loading capacity, degree of vehicle exploitation, type of vehicle in use, distance of pre- and post-haulage PPH, geographical and topographical conditions of the routes, congestion on the road, etc.) by tons transported per km. However the problem is that this is not always suitable grounds for comparison. For instance, in algebra, 1000 tons transported over 10 kilometres is the same as 10 tons transported over 1000 kilometres. Even so, the selection of operations, vehicles and operative costs of transport-manipulative means would be different in both cases.

In paper "Transport by rail, comparison between the emissions of unimodal road transport and combined road-rail transport" (Van Binsbergen and Shoemaker,1993), the authors compare emissions of combined container rail-road transport depending on a load per distance (table 4). It is shown that variation of vehicle load led only to the increase of SO_2 emission while the emissions of other polluters decreased.

Table 4 *Emissions of intermodal rail-road transport compared to unimodal road transport*

Trip with load in both directions	Depart trip with load and return wihtout load	Depart trip without load and return trip with load
NO_x, aerosols, C_xH_y up to 80% reduction	NO_x, aerosols, C_xH_y up to 81% reduction	NO_x, aerosols, C_xH_y up to 83% reduction
CO_2, CO reductions between 36% - 52%.	CO_2, CO reduction between 38% - 53%.	CO_2, CO reduction between 39% - 58%.
SO_2: increase of 52%	SO_2: increase of 47%	SO_2: increase of 46%

In the paper "Emissions of combined transport" (Walstra et al., 1995), the authors compare the emissions and energy consumption between unimodal road transport and combined transport, from the theoretical aspect. The results clearly showed that combined transport is more favourable to the environment, despite the facts that its pre- and post-haulage produces a lot of emissions. The study, also, shows that the differences in emissions between road-barge and road-rail transport are very small. CO_2 emissions are always lower in barge transport than rail transport, while the NOx, CO, CxHy and aerosol emissions are always higher. In rail freight transport on electrified lines the emissions of CO2 are practically insignificant (0,001%). If the electrical energy is "green", i.e., produced by water plants or nuclear plants than the emissions can be disregarded.

There are other projects from various countries supported by EU (Recordit, Externe, QUITS, PETS etc.), from which we can see that the analyses were done for specific routes and modalities with specific technical characteristics of vehicles and the origin of primary energy with different effects of emissions. Additionally it can be concluded that:

- countries have different ambitions when it comes to reduction of CO2 according to modalities,
- the countries have policy instruments in the transport sector, these policies are not intended to directly reduce CO2 emissions, however they have indirect influence on potential reduction of carbon dioxide emissions (safety measures),
- countries make different decisions in the selection of instruments of the policy of the reduction of carbon dioxide emissions,
- some countries involve target groups in the process of defining the policy and in decision-making process,

- the effects of non-transport policy with the effects of transport emissions are usually not considered in the policy of reduction of carbon dioxide emissions,
- CO2 emissons produced by transport have increased and they vary from one country to another,
- the differences in emission trends seem more connected to specific circumstances in countries than the policy of the reduction of carbon dioxide emissions,
- comparison of national policies in their attempt to reduce the effect of transport regarding CO2 is becoming a complex matter in most countries,
- the emissions produced by fuels without CO2 have not been analysed.

The analyses show that there are no significant differences in emissions (from -2 % to +3 % according to the average value) between EU countries on annual basis, and that other European countries have adopted the policy of reduction of transport impacts on the environment.

NECESSARY DATA AND EMISSION FACTORS IN INTERMODAL TECHNOLOGIES

The analysis of the effect of intermodal transport on the reduction of carbon dioxide emission consists of 5 steps:

- Step no. 1 Defining the goals of the research
- Step no. 2 Choosing assessment approach and defining research limits
- Step no. 3 Collecting data and choosing emission factors
- Step no. 4 Emission calculation
- Step no. 5 Verification and presentation

Basically, there are three levels of specification: (1) the lowest level which determines the emission based on average carrying capacity, type of engine, type of fuel and ballast factors for all the vehicles used for transportation, (2) medium level which analyzes homogenous vehicle types and defines average engine type, fuel type, and ballast factor for each type of vehicle, and (3) the highest level which analyzes more details and determines CO2 emission for each vehicle. Total emission of CO2 is expressed in different units of measurement (g/veh, g-kg-t/km, g-kg-t/tkm, kg/TEU, kgCO2/kg diesel etc.) and in the unit of measurement that expresses capacity in a specific chain and defined time period (day, month, year). In road freight transport, emission depends on several factors: type of the vehicle, type of the road, fuel consumption, steering techniques, fuel quality, velocity, etc. The calculation of warm emission of CO2 for a road vehicle in an undefined time period can be calculated through the following equation (1).

$$CO_2 \text{ Emission} = Nvoz \cdot Ef \cdot lpr \cdot .Fm \ \ (g/veh) \qquad (1)$$

where: Nvoz is the number of trips in a certain period of time; Ef – emission factor,(g/km); lpr – mileage per trip, (km); Fm is ballast level, (%)

Models of the emission factors are based on a unique factor for specific modalities, types of vehicles and transport technology which perform transport process in specific driving conditions. Emission factors are determined as a mean value of total emission’s repeated measurements through the driving cycle that is usually defined as a mass of pollutant produced per distance unit or any other unit used for defining emission.

In the calculation of emissions, emission factor (Ef) can be used as 'standard' that is in accordance with 2006 IPCC principles or through Life Cycle Assessmet (LCA), which takes into consideration whole life cycle of an energy carrier. In transport, it is expressed by different units of measurement and the unit which defines total emission is used. CO2 emission is proportional to fuel consumption in general, so 1 l of consumed diesel fuel normally produces approximately 2,64 kg of CO_2 for diesel fuel mass density 0.84 kg/l and it applies under the condition that the amount of carbon in the fuel completely oxidizes into CO_2. Conversion basis for emission calculation 1 g/km CO2 for diesel fuel =0,043103448275862 l/100 km, conversion base: 1l/100 km = 23,2 g CO2/km. Value of the emission factor in road transport varies depending on the exploitation degree of vehicles' carrying capacity and empty vehicle mileage and ranges from 0.780 kg/km to 0.884 kg/km on average.

If total emission in road transport is evaluated in g/tkm, then standard emission factor is 62 gCO_2/tkm (61.9) (table 5). This value is formed based on the 80 % usage of 40 t - 44 t vehicle's carrying capacity of 40 t - 44 t and 25 % mileage of vehicle when without load. With the increase of load weight inside a vehicle and the decrease of mileage without load, significant decrease of CO2 emission occurs which can be characterized as negative exponential distribution.

Table 5 Emission factor changes depending on load weight and covered road structure in gCO_2/tkm

Load weight (t)	Percentage of covered distance without load in total covered distance (%)										
	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
10	81,0	84,7	88,8	93,4	98,5	104,4	111,1	118,8	127,8	138,4	151,1
11	74,8	78,2	81,9	86,1	90,8	96,1	102,1	109,1	117,3	127,0	138,6
12	69,7	72,8	76,2	80,0	84,3	89,2	94,7	101,1	108,6	117,5	128,1
13	65,4	68,2	71,4	74,9	78,9	83,4	88,5	94,4	101,3	109,5	119,3
14	61,7	64,4	67,3	70,6	74,2	78,4	83,2	88,7	95,1	102,7	111,8
15	58,6	61,0	63,8	66,8	70,3	74,2	78,6	83,7	89,7	86,8	105,3
16	55,9	58,2	60,7	63,6	66,8	70,5	74,6	79,5	85,1	91,7	99,7
17	53,5	55,7	58,1	60,8	63,8	67,2	71,2	75,7	81,0	87,2	94,7
18	51,4	53,5	55,8	58,3	61,2	64,4	68,1	72,4	77,4	83,3	90,4
19	49,6	51,5	53,7	56,1	58,8	**61,9**	65,4	69,5	74,2	79,8	86,5
20	48,0	49,8	51,9	54,2	56,8	59,7	63,0	66,9	71,4	76,7	83,0
21	46,6	48,3	50,3	52,5	54,9	57,7	60,9	64,5	68,8	73,9	80,0
22	45,3	47,0	48,8	50,9	53,3	55,9	59,0	62,5	66,5	71,4	77,2
23	44,2	45,8	47,6	49,6	51,8	54,3	57,2	60,6	64,5	59,1	74,7
24	43,2	44,7	46,4	48,3	50,5	52,9	55,7	58,9	62,7	67,1	72,4
25	42,3	43,8	45,4	47,3	49,3	51,7	54,3	57,4	61,0	65,2	70,3
26	41,5	42,9	44,5	46,3	48,3	50,5	53,1	56,0	59,5	63,6	68,5
27	40,8	42,2	43,7	45,4	47,3	49,5	52,0	54,8	58,1	62,1	66,8
28	40,2	41,5	43,0	44,6	46,5	48,6	51,0	53,7	56,9	60,7	65,3
29	39,7	41,0	41,4	44,0	45,7	47,8	50,1	52,7	55,8	59,5	63,9

Ballast level (Fm) depends on vehicle's carrying capacity (t), weight of loaded cargo (t), and weight of internal cargo within certain company, and in road transport its value is approximately 0.75 with high frequency transportation and 0.50 with a single trip. If carrying capacity of a vehicle is 10 t and load weight 8 t, then the usage of nominal carrying is 0.80. In groupage transport, it can occur that out of 8 t of loaded cargo, 5 t belongs to another sender, so the usage is 0.50, and by dividing 0.5/0.8=0.63 we get correction factor. If the emission factor is 0.78, mileage is 100 km, number of rides is 10, with the correction factor which is 0.63, then the total emission is 487.5 kg of CO_2. If the cargo belongs to one sender, then correction factor is equal to static vehicle utilization coefficient. The higher vehicle utilization factor is, total emission is lower, table 6.

Table 6 *CO_2 emission of road vehicle depending on ballast percentage*

Existing exploitation of vehicle's carrying capacity	Increase of carrying capacity %	Saving in CO_2 emission in %
40%	50	16
	60	27
	70	34
50%	60	13
	70	22
	80	29
60%	70	10
	80	18
	90	24

In road traffic, total emission can be assessed based on the equation:

$$CO2\ Emission = Eg \cdot lpr \cdot Ef\ (kg) \qquad (2)$$

where: Eg – fuel consumption for specific vehicle ballast, (l/km); lpr – total mileage per vehicle, (km); Ef – emission factor of the fuel, (kgCO2 / l fuel)

Theoretical fuel consumption (Eg) in road transport (HGV>3.5 t) is defined by the manufacturer and it has following values: MAN trucks, from manufacturer OAF & Steir, using Euro 3, or older Euro 2 diesel fuel have the consumption from 33 to 37 l/ 100 km (loaded) and 29 to 32 l/ 100 km (empty). Renault vehicles using Euro 3 have the consumption of diesel between 29.3 and 33.4 l/ 100km (loaded). Scania vehicles have the consumption of Euro 3 from 31to 32.6 l / 100 km (fully loaded) and from 22 to 23 l/ 100 km (empty). Volvo vehicles which use Euro 3 have the consumption from 29 to 32 l/ 100 km (loaded) and 18 to 20 l /100 km (empty). Because of the age and state of the vehicles, analyses should use average consumption of 39 l/100 km for a loaded vehicle and 29 l/100 km for an empty vehicle. According to (7), actual average fuel consumption of heavy goods vehicle with carrying capacity of 16 to 32 tones is from 210 to 251 g/km and for the vehicles over 32 tones is from 251 to 297 g/km.

In freight road transport emission is defined with the following relation:

$$CO_2\ emission = U \cdot Ef\ \ (g) \qquad (3)$$

where: U – cargo amount transported,(tkm); Ef - emission factor (g/tkm).

Approximate emission values of subcategorized HGV are: <7,5 t (452), 7,5 t-14 t (294), 14-20 t (294), >20 t (218), road train <20 t (161), 20-28 t (133), 28-32 t (128), >32 t (128) semitrailer truck <32 t (114) i >32 t (111), acerage of 147 gCO2/tkm.

In railroad transport, total emission for engines that are diesel or electric-powered can be estimated based on the equation:

$$TE = Q_c \cdot l \cdot \frac{EF_{CO_2}}{1 \cdot 10^6} \cdot \frac{153.07 \cdot f_t \cdot Q_v^{-0.5}}{FO} \quad TE = \sum_z Q_c \cdot l_z \cdot \frac{EF_{Z,CO_2}}{1 \cdot 10^6} \cdot \frac{675 \cdot f_t \cdot Q_v^{-0.5}}{FO \cdot (1 - TI)} \tag{4}$$

where:TE – total emission; (t CO2); Qc – cargo weight, (t); l – transport distance, (km); Efco2 – emission factor for diesel-powered engines, (kgCO2/kg diesel); Ef z-CO2 – emission factor for electric-powered engines, (kg CO2/KWh); ft – terrain factor (for the flat terrain, it should be decreased by 20%, for the hilly terrain there is no alteration and for mountainous terrains, it should be increased by 20 %); Qv – total train weight, (t); FO – ballast factor (0,72 for bulk cargo, 0,58 for general cargo and 0,44 for high volume cargo); TI – percentage of energy loss due to transportation losses; z – country.

Energy consumption and therefore CO2 emission in railroad transport depends on: type of engine power (diesel or electric) and the length and gross weight of a train (train with the gross weight of 1500 t consumes 17.6 (Wh/brtkm), of 1000 t consumes 21.0 (Wh/brtkm), of 600 t consumes 26.7 (Wh/brtkm), (NTM Rail, 2008), type of the engine and consumption, type of cargo, spatial position of the railroad, valid transport limitations, number and condition of frigo cars (with power between 10 and 2 kW). Additional emission occurs when the interior of a car and/or container is cleaned with the use of steem (for the consumption of 189 kWh emission is 38 kg CO2 per car or container).

It was estimated that for cargo transportation by international fully loaded container train consumption is 30 kWh/veh.-km, and 20kWh/veh.-km for the empty containers transport. It is presumed that electric-powered engines cover 75% of railways, and diesel-powered engines 25% in most European countries. If there are no data about share (in percentage) of individual systems within diesel-electrical power matter, then for the rough emission of electrical-powered engines we can use emission of diesel-power multiplied by 0.25 and then add calculated emission based on the equation of electric power multiplied by 0.75. In railroad transport, the value of the emission factor based on realized gross tkm ranges from 1.8 g CO2/tkm to 19 g CO2/tkm for electric and from 21 kg CO2 /tkm to 55 kg CO2/tkm for diesel power. Since it is very hard to determine the value of the emission factor in the calculations of rough emission, its average value of 22 g CO2 /tkm can be used.

In water transport total emission can be calculated with following equation:

$$TE = PG \cdot l \cdot EFCO2 \tag{5}$$

where: TE – total emission of CO2, (kgCO2); PG - fuel consumption, (t/km); l – transportation distance, (km); EFCO2 – emission factor (kg CO2 per ton of fuel).

Recommended average value of the emission factor in national water transport of barges in container transportation is 31 g CO2/tkm or 0.367 kg/km, although there are differences depending on whether the transport is upstream or downstream, or on the canal, and depending on the size of barges (small 90 TEU, medium sized 208 TEU and big 500 TEU). The bigger the barge, and if it is going downstream, the factor is lower (for example, small barges going upstream have the emission factor of 63.4 g CO2/tkm or the big barge going downstream has the emission factor value of 10.2 gCO2/tkm. In maritime transport, depending on the size of a ship, the emission factor value is 13.5 g CO2/tkm for small ships (up to 2500 t), for those of medium size, it is 11.5 g CO2/tkm, and for the big ships it is 8.4 g CO2/tkm. The emission factors vary depending on the ships, (table 7).

Table 7 Estimation of emission factors for cargo ships in gCO2/tkm

Ship type	Carrying capcity	Emission factor
Tankers	0 - 60000 + dwt	5,7 – 45,0
Chemical tankers	0 - 20000 + dwt	8,4 - 22,2
LPG carriers	0 - 49,999 + m^3	9 – 43,5
LNG carriers	0 - 200.000 m^3	11,9 – 14,5
General cargo	0 - 9.999+ dwt + TEU	11,9 – 19,8
Reefer ship	Svi	12,9
Container ship	8000 + TEU	12,5
Container ship	5000 - 7999 TEU	16,6
Container ship	3000 - 4999 TEU	16,6
Container ship	2000 - 2999 TEU	20,0
Container ship	1000 - 1999 TEU	32,1
Container ship	0 – 999 TEU	36,3
Ro-Ro ship	2000 + Im	49,5
Ro-Ro ship	0 – 1999 Im	60,3

If in water transport the emission factor is expressed based on covered distance, then its average value is around 0,357 kg/km. Correction factor in water transport has average value of 0.80 with direct transportation, 0.50 with shuttle transportation and 0.80 with air freight transport.

EMISSION ESTIMATION ACCORDING TO TRANSPORTATION CHAINS

Application of intermodal technologies represents one of the organizational measures which give significant results in reduction of emissions. Without plunging too deep into detailed analysis of possible variations of intermodal technologies we should identify transportation chains and within them applied technologies by organizational structure and types of transported commodities. If we take into consideration only land technologies 'vehicle-vehicle' there are 4 types of road-rail (Version A, B, C and Bi-modal), while at land-water, and entirely water more types exist. Version B (unaccompanied), represents transportation of road semitrailers by special rail vehicles, and along with the version C (unaccompained, shipping containers) represents the most commonly used land combined technology. In order to make simpler estimation, approximate values of total distance of 500 km and the amount of the load (1000000 t) are used.

Also, it is necessary to take into consideration the emission caused by the transhipment in the starting and finishing point of operation. In most of the land terminals load, as well as shipping containers, are transhiped (loading, unloading and/or transhipment) by container crane electrically powered by 100kW to 250kW whose average emission is around 0.002t CO2 / operation or in case of shipping containers diesel-powered cranes (RTGC, SCU/UC et.al) are used as container handlers. Their emission is 0.007t CO2 /operation. In the work with shipping pallets emissions are lower since lifting trucks with low power engines 20kW to 100kW (diesel, electrical energy or gas) are used. In determining the emission factor for means of mechanisation, apart from the installed power, the number of effective working hours per day/shift (6-12-18h) should be considered as well as average load of the crane hook in precentages (50%). Average emission factor of different types of cranes (100kW to 600kW) used in transportation chain has an approximate value of 567 gCO2 /kWh of work. In one hour of operating, cranes can make 24-180 operations in a shift, depending on technological demands. In foreign literature, emissions at starting and finishing points of operations, that is, at terminals are separately shown.

EXAMPLE 1. Unimodal chain

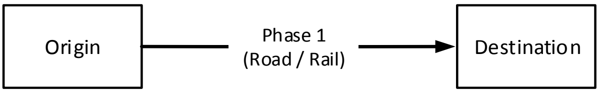


Figure 3 Direct unimodal land chain

In the case of a direct transportation of state-of-the-art freight units by unimodal transportation, transportation chain is simple and it practicaly represents an emission of a single type of transportation in which there are two tranships with their emissions (Figure 3). Estimated emission in road transport was performed based on formula (3) and previously mentioned emission factors (table 5). The difference in emissions indicates that the same amount of cargo weight at the same distance produces less emission by rail transport than by road transport.

Table 8 The estimation of CO2 emission in unimodal transport per ton-kilometer

Modality/technology	Load weight (t)	Distance (km)	Cargo amount transported (tkm in 10^3)	Em.factor (gCO_2/tkm)	Emission CO_2 (t)
Road	100000	500	50000	62	3100
Rail	100000	500	50000	22	1100

In case of a more detailed estimation of the total emission in one chain in which more subcategories of HGV (heavy goods vehicle) circulate, it is necessary to conduct the calculation of emisions per each subcategory by lenght of the transportation and add their emissions in observed time period.

Furthermore, it is necesarry to know exact statistical data on fuel (mass or volume), consumption by subcategories (Conventional, EURO I to EURO IV and EUROV-VI), number of the vehicles, average distance covered, amount of carbon in conventional fuel and fuel enhanced with additives, structure of the road covered, age of the vehicle, etc., by which the total emission could be estimated more precisely. With transhipping, given emission is related to one t-operation. In case of cargo unitization it is necessary to turn the amount of cargo into a number of containers or manipulation pallets.

EXAMPLE 2. BIMODAL CHAIN

When the emissions in bimodal land chain are estimated, the procedure is the same except for the fact that the single emissions of both types which participate in transportation are estimated by the same dimension and then added to each other. In intermodal land technologies, road transportation is used for the purposes of transporting the cargo to and from certain destination, and rail is used for the long distance transportation, Figure 4.

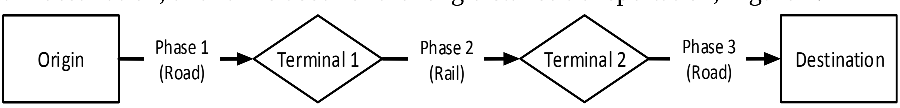


Figure 4 Bimodal land transport chain

As the value of the emission factor in road transportation depends on the exploitation of useful carrying capacity of the vehicle and length of the transportation without load, the value of emission factor in land bimodal chain depends on the length of road vehicle transportation in chain, table 9. Based on the total mileage covered in bimodal technology, in many European countries road traffic has a share of approximately 10% in total traffic.

Table 9 *Emission factor of rail vehicles in land bimodal chain*

	Means of transport	Distance in road transport in % according to the toal distance of the transportation			
		5%	**10%**	15%	20%
		gCO$_2$/tkm			
Combined technology Road-Rail-Road	Rail (average)	24.0	**26.0**	28.0	30.0
	Electrical power (average EU)	21.2	**23.3**	25.2	27.6
	Diesel power	25.9	**27.8**	29.7	31.6
	Ro-Ro – Rail	38,3	**39,5**	40,8	42,0

The change of distance from 5% to 20% of the total planned length of the transportation chain often occurs in road transportation and it influences the value of the emission factor. It is recommended to use the deviations of 10% of total planned length of the transportion by road vehicles, which changes the value of the emission factor, table 10. If shipping conatainers are transported, the procedure is the same except it is necessary to know the weight of the specific shipping container, type of the load that is transported, whether the load is palleted or not, which type of palletes are used in a shipping container, etc. Characteristics of bimodal chain are: loading into a road vehicle at sender's location, two transhiping from road vehicle to rail car in both terminals and one unloading at receiver's location. Should there be more containers, then three loadings and unloadings should be considered.

Table 10 Estimation of CO_2 emission CO_2 in bimodal land chain

Modality/Technology	Load weight (t)	Distance (Km)	Cargo amount transported (tkm)	Em.factor (gCO$_2$/tkm)	Emission CO_2 (t)
Road	100000	2 · 25	5000000	53,7	2685
Rail	100000	450	45000000	23,3	9786

EXAMPLE 3. TRIMODAL CHAIN

Trimodal chains (road, water and rail) are much more complex in their structure and length of the distances, kinds and types of means of transport and mechanization, types of the load which is transported, etc., Figure 5. For every specific transportation chain it is important to know the technical characteristics of the means which are part of the chain. With water technologies there are other transport-manipulative diesel-powered means, whose functions in terminals are: locotractors which pull classic or LUF semitrailers, container handlers, different types of stakers, pneumatic and/or band transporters, air compressors, pumps (10kW to 70 kW), etc.

Figure 5 Trimodal transportation chain

As with bimodal chain, it is necessary to take into consideration the distance which road vehicle crosses in the total length of the transport. Based on the total distance covered with trimodal technology, in many countries of the world, road traffic takes aproximately 5% of the total traffic, table 11.

Table 11 Emission factor according to trimodal technologies

Intermodal technology	Means of transport	Distance in road transportation in % according to the total length of the transport			
		5%	10%	15%	20%
		gCO_2/tkm			
Road-Barge		**32,6**	34.1	35.7	37.2
Road-maritime short-distance technologies	RoRo-Ship	**49,7**	50.3	51.0	51.6
	RoRo-Rail	**38.3**	39.5	40.8	42.0
	Small tanker ships (up to 844 t)	**22.1**	24.2	26.3	28.4
	Big tanker ships (approximately 18371 t)	**7.9**	10.7	13.6	16.4
	Small bulk carrier (approximately 1720t)	**13.6**	16.1	18.7	21.2
	Big bulk carriers (14201 t)	**9.8**	12.5	15.3	18.0
	Small container carriers (approximately 2500 t)	**15.9**	18.4	20.8	23.2
	Big container carriers (20000 t)	**14.0**	16.6	19.1	21.6
	Other short-distance carriers	**18.3**	20.6	22.9	25.2

Table 12. gives total values of carbon dioxide emissions for the trimodal transportation chain given in Figure 5.

Table 12 *CO_2 emission estimation in trimodal land chain, road-water-rail-road*

Modality/Technology	Load weight (t)	Distance (km)	Cargo amount transported (tkm)	Em.factor (gCO_2/tkm)	Emission CO_2 (t)
Road	100000	$2 \cdot 25$	5000000	53,7	2685
Rail	100000	200	20000000	23,3	4660
Water	100000	250	25000000	18,3	4575

Depending on applied technology, using intermodal transport can make savings of 13% of CO_2 emission in comparison to all-road transport. Significant savings can be observed on the example of unaccompanied transport (versions B and/or C). In one closed block-train 32 trailers are transported on average (Version B), if there are two pairs of trains, 8 in total (4 at the departure and 4 at the arrival) per week, then the weekly capacity is 256 semi-trailers. One hauler pulls a semi-trailer (23800 kg) and spends 0.34 l/km on average. While burning one liter of diesel fuel it produces around 2.9 kg of CO_2, which shows that at every 100 km a hauler produces more than 91,8 kg of CO_2, 0,24 kg of NOx, around 0,003 kg PM etc. With this transport technology emission is around 40% of the total emission of the road transport (100%), which, in turn, creates a significant saving of 60%. If we would use accompanied transport (Version A) emission could be around 77% of the total emission of road transport, with which it would be possible to make a saving of 23%, Figure 6 [1]. If during 45 weeks of the year 11600 trailors are transported, 1 290 000 of trees are needed for the absorption of CO_2 emission, which is equivalent to 3 225 ha of forest, which would be enough for the recovery of the emission caused by road vehicles (one tree absorbes around 22 kg of CO_2, which means that there should be around 400 trees on one ha) which is practicaly impossible.

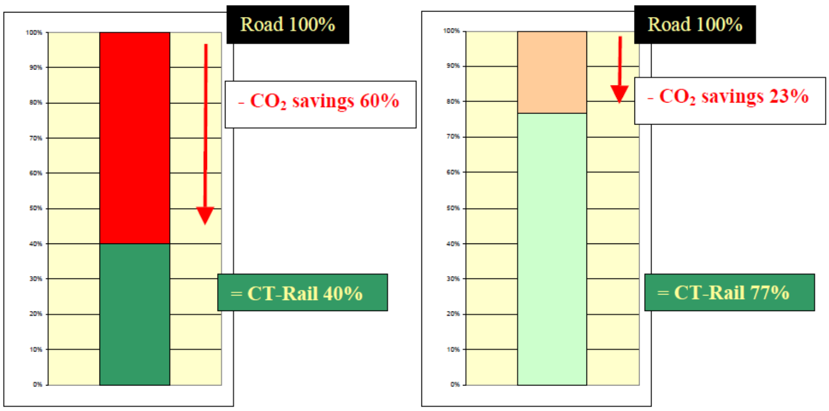


Figure 6 *Comparison of savings in CO_2 emissions with accompanied and unaccompanied transport*

There are various softwares for the estimation of CO_2 emission: ADMS Road, CORSIM based on Trafficware-Synchro 4 (Traffic Signal Coordination Software), VISUM/GIS, SoFi offered by PE INTERNATIONAL's, E coPorts self-diagnosis Method, EcoTransit calculator etc. which, along with the world's best quality databases on sustainability, provide intereseted parties with data on emission, financial effects of the sustainability, suggestions on how to improve sustainability of the operations, supply chains and/or the quality of the product. For the estimation of the emission from passenger vehicles 'electronic calculators' (Myclimate, Alpha Vehicle, WRI et al.) can be used, which include information on distance of the trip and fuel consumption per 100km.

CONCLUSION

The aim to increase security, protect the environment, improve and stimulate all types of clean technologies in traffic represent the basis of state policies, which also applies to stimulating the use of "clean" technologies. Guidelines for this kind of development are defined at the level of EU transport system (ECMT Council, Prague 2000) and based on reduction of harmful effects of transport on the environment, using the "3i" principle, application of modern information technologies and rational use of available capacities.

Carbon dioxide emissions and the lack of fossil fuels represent key guidelines for automotive development in the near future. Regarding road vehicles, in recent years the end goal is Zero Emission Vehicle (ZEV), even though it is known there is no human product that has zero effect on the environment, since the man alone produces around 4 tCO_2 per year. Only recently, new goals were introduced regarding emissions form vehicles: *NZEV* – Near *ZEV* i.e. near minimum emission and *EZEV* – equivalent zero emission vehicle.

There are different ways of affecting high emission from transport: improvement of technical chracateristics of vehicles by modalities, development of sustainable fuel with reduction of carbon intensity and the intensity of propulsion systems, rational use of vehicles and infrastructure through improved traffic management by using information systems (e.g. ITS, SESAR, ERTMS, SafeSeaNet, RIS), selecting the most favourable transport modality that produces less CO_2 per ton-km or crossed km, optimal SCM management (harmonization of requirements, quality contracts, optimal route planning, making less mistakes in the delivery on transport networks etc.), by increasing the carrying capacity of vehicles, limiting vehicle speed, minimising load-free rides etc.

Several methodologies for estimating CO_2 emissions in intermodal transport were presented in a range of international projects: ARTEMIS (Appendix 4, CO_2 Emission Estimation Methodology for Road Transport, 2008), STREAM (Study on the TRansport Emissions of All Modes), EcoTransIT, GHG Protokol, NTM (Road methodology 2007, NTMWater 2008 i NTM NTMRail 2008 etc.), and all estimates of the emissions of CO_2 were based on standards ISO 14064:2006, ISO 14067:2013 and EN 16258:2011 Methodology For Calculation And Declaration On Energy Consumptions And Ghg Emissions In Transport Services (goods and passengers). In our country, in accordance with requirements defined by The European Monitoring and Evaluation Programme (EMEP) under *The Convention on Long-range Transboundary Air Pollution* and European Environment Agency (EEA), the model COPERT 4 version 10, based on MS Windows [7] is used for calculation of emissions in road transport for heavy goods vehicles (HGV, diesel 16-32 t, Euro I-1991 to Euro IV-2005, diesel >32 t, Euro V-2008 and Euro VI-2012). The project COFRET (Carbon Footprint of Freight Transport) has a particular significance in the calculation of emissions in freight transport and it was used for development of harmonized methodology of emissions calculation.

It is concluded that there is a high correlation between emissions in intermodal modalities depending on the length of road vehicle trip in overal distance and the degree of vehicle load. Further research should be focused on characteristics of diesel fuel in HGV according to the structure of transport chains, with classification of vehicles by types, technologies, logistics providers, etc. This research should be supported by a detailed database about the technical characteristics of technological elements, variations in the values of variable emission factors, which are used in calculation, with special attention paid to comparison of emissions according to technologies, modalities and directions. Such approach would lead to sustainable and safe transport.

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