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# ENERGY CONSUMPTION AS AN IMPORTANT FACTOR FOR DECISION ON PROPER TRANSPORT MODE SELECTION

**Abstract**

*This paper deals with energy consumption as one of critical factors for transport mode selection. The comparison was made in passenger and cargo transport on selected model situations. The results in case of passenger transport show the advantage of the road transport vehicle (bus). In case of cargo transport the best values are for the rail transport but in practice it is very difficult to use only this transport mode alone. For the real case it is better to compare two modes – direct road transport and the combined transport. So the best choice in cargo transport is the combined transport.*

## INTRODUCTION

Mobility is one of the most important human needs throughout the centuries. Number of trips and the travelled distance is constantly growing. Depending on type and distance of transported cargo or passengers a question of right transport mode selection becomes important. We can say that the good or bad choice for a most appropriate mode of transport is a kind of a business risk.

There are number of factors affecting the proper selection of means of transport – purchase cost, maintenance costs which are close related with reliability and maintenance systems, operational costs, where major role has energy consumption, etc. [1, 2, 3, 4]

Energy consumption is one of the key factors that influence this decision. Energy consumption affects the costs (profit) as well as impact on the environment (emissions). Today transportation is largely dependent on oil, as the vast majority of vehicles are driven by engines combusting oil products - hydrocarbon fuels. Railway transport represents a mode of transport where most vehicles are nowadays powered by electric traction motors, so the rate of dependence on oil is lower than in case of other transport modes (road, air, water). But the fact is that in most countries the electricity is produced by burning oil or gas products or coal. All of these are non-renewable natural resources and their volumes have been steadily declining.

Considering the above, there is an effort to streamline the transport of energy dependence, as suggested by the legislative measures such as the White Book on a European level or different policies and programs at national governmental level. Energy intensity of transport modes to the greatest extent represents the energy consumption of vehicles. Comparison of consumption and consumption of handling and support activities are more described to this study.

## 1. STANDARD EN 16258: 2012 AND ITS USE IN CALCULATIONS

This European Standard specifies general methodology for calculation and declaration of energy consumption and greenhouse gas emissions (GHG) in connection with any services (cargo, passengers or both). It specifies general principles, definitions, system boundaries, methods of calculation, allocation rules (allocation, assignment) and recommendations on information to support standardized, accurate, reliable and verifiable declarations regarding energy consumption and greenhouse gas emissions associated with any freight services. It also contains examples of these principles use.

The calculation for one given transport service must be performed using the following three main steps:

Step 1: Identification of the various sections of the service;

Step 2: Calculation of energy consumption and greenhouse gas emissions for each section;

Step 3: Sum the results for each section [5]

The standard does not consider only the production of the energy consumed during the combustion of the fuel (energy conversion from fuel to mechanical energy) but as well as primary, incurred in the extraction, production and distribution:

ew well-to-wheels energetic factor for defined fuel,

et tank-to-wheels energetic factor for defined fuel,

Well-to-wheels is "well on wheels" and also covers primary and secondary emissions and consumption. This factor is somewhere also called as LCA (life-cycle-analysis).

Tank-to-Wheels factor is considering only the secondary emission and consumption.

This Standard specifies general methodology for calculation and declared value for the energetic factor must be selected in accordance with Annex A of the standard [5].

## 2. MODEL SITUATION: PASSENGER TRANSPORT

In this case study we consider the passenger transport on the route between Žilina (administrative centre and capital city of north-western region of Slovakia) and small town Rajec. On this route two modes of passenger transport are used in parallel – railway and road. Railway track is not electrified. The route has north-south orientation with distance of 21,3km and average gradient of 5‰. The highest gradient is 13‰ except a small hill in front of the station in Žilina where the gradient reaches 17‰ but only for a short distance. Speed limit on the railway is 60 km/h but some sections are limited to 50 or 40 km/h. Transportation time of the train on this track is 37 minutes.

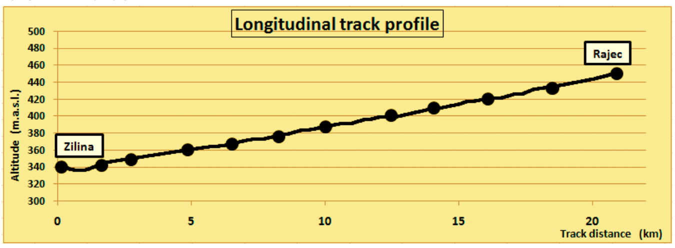


*Fig. 1. Elevation track profile with stations*

Simulation of energy consumption has been made for the real vehicles used for this track.

*Tab. 1. Basic technical parameters of the vehicles*

| vehicle | Train unit 813-913 | Bus Karosa C 954 |
|---|---|---|
| combustion engine | MAN D 2876 LUE 21 | Iveco Cursor F2 B |
| power system | Diesel | Diesel |
| power transmission | Hydromechanical | Mechanical |
| drive arrangement | 1´A´ + 1'1' | rear-wheel drive |
| design rate | 257 kW | 228 kW |
| maximum speed | 90 km/h | 105 km/h |
| tare weight | 39 t | 10,8 t |
| gross weight | 53 t | 18 t |
| vehicle length | 28 820 mm | 11 990 mm |
| number of seats | 78 + 5 | 49 |
| maximum number of standing passengers | 120 | 39 |

***Fig. 2.** Train set series 813-913*

***Fig. 3.** Bus – type Karosa C 954*

### 2.1. Calculation of energy consumption

For calculation of the energy consumption of the selected train the Railway dynamics software has been used. This software works with imported maps and elevation profiles of railway lines (track sections) and uses selected parameters (locomotive type, train weight, train length, axle load, number and location of stops) to calculates the energy consumption in kWh or litres. The software is able to calculate energy consumption and operating times or ride of any train on any railway line, but it is necessary to import the data of the train and the route. For relevant comparison of the results for different types of consumed energy it is necessary to use the principle well-to-wheels.

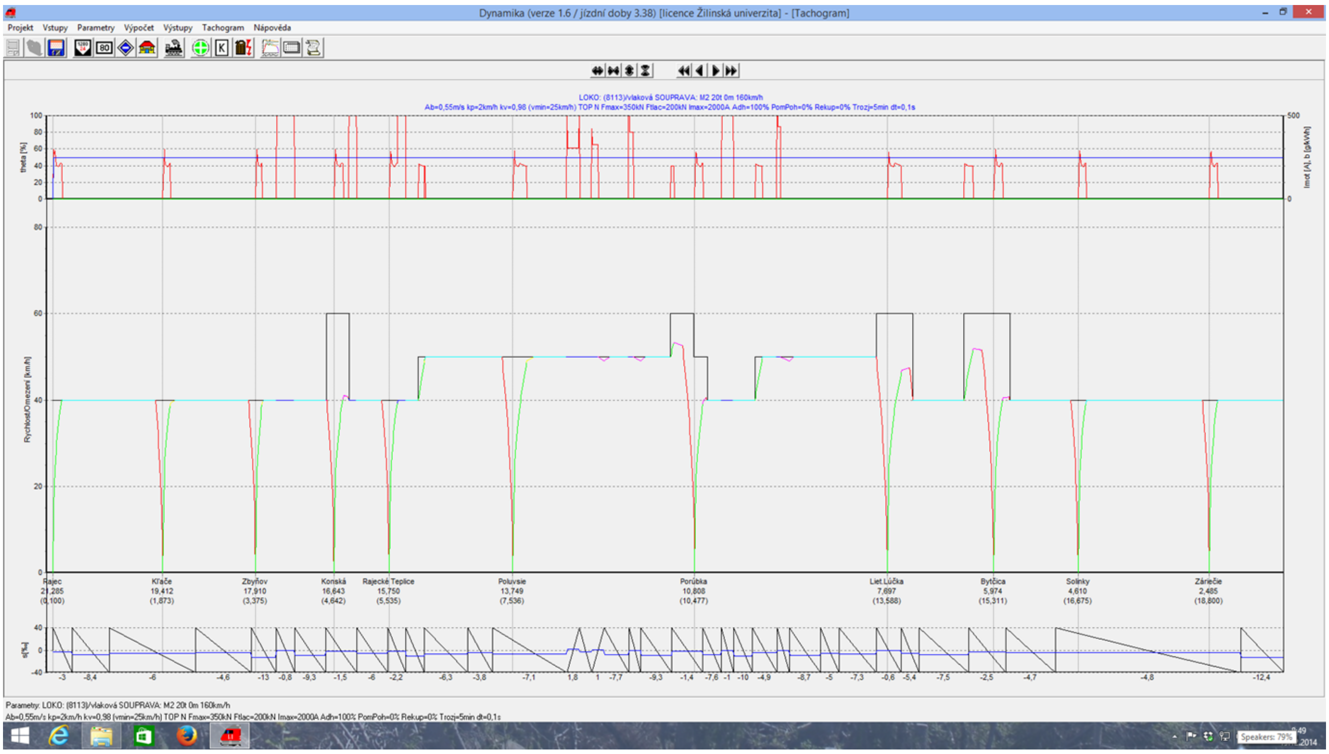

***Fig. 4.** Output data from the software Railway dynamics*

Calculation procedure for the diesel train using the simulation software is as follows. In calculation the appropriate factors and forms for the procedure of EN 16258:2012 for the diesel train are used. The fuel consumption should be multiplied by a factor of energy for this fuel from Annex A of the standard to calculate the total energy consumption.

$$E_{TF} = FC_V \times e_W = [(E_{ME} \times BSFC) \times 1/\rho_F] \times e_W \qquad (1)$$

where:
$E_{TF}$– total energy consumed by diesel vehicles [MJ]
$FC_V$– fuel consumption of vehicle [l, dm$^3$]
$E_{ME}$– mechanical energy consumed by the movement of the train (train dynamics software result) [kWh]
$\rho_F$ – fuel (diesel) specific weight (density) [g/dm$^3$]
$e_W$ – energetic factor "wtw" for defined fuel [MJ/dm$^3$]
$BSFC$– break specific fuel consumption of the engine [g/kWh]

Energy consumption for the bus we obtained from the bus operator who makes regular measurement of fuel consumption. So the real value of average fuel consumption in real load is known.

$$E_{TB} = FC_V \times e_W = [(FC_A \times L)/100] \times e_W \qquad (2)$$

where:
$E_{TB}$– total energy consumed by bus [MJ]
$FC_V$– fuel consumption of vehicle [l, dm$^3$]
$FC_A$– average fuel consumption [l/100km]
$L$ – driven distance [km]
$e_W$ – energetic factor "wtw" for defined fuel [MJ/dm$^3$]

### 2.2. Evaluation

The calculations for this model study were carried out on the track in both directions. The results are shown in figure and graph.

***Tab. 2.** Final evaluation*

| State | Vehicle | Fuel consumption (L) | Total energy consumption (MJ) | Passenger number | Energy per passenger (MJ / person) |
|---|---|---|---|---|---|
| All seats occupied | train | 22,98 | 981,2 | 83 | 11,82 |
| | bus | 12,48 | 532,9 | 49 | 10,88 |
| Real passenger number | train | 17,72 | 756,6 | 32 | 23,65 |
| | bus | 11,76 | 502,2 | 26 | 19,31 |

Tab. 2 shows the advantage of the road transport vehicle (bus). It is caused by train tare weight, which is 39t and is about 28t more than about 11t of bus tare weight.

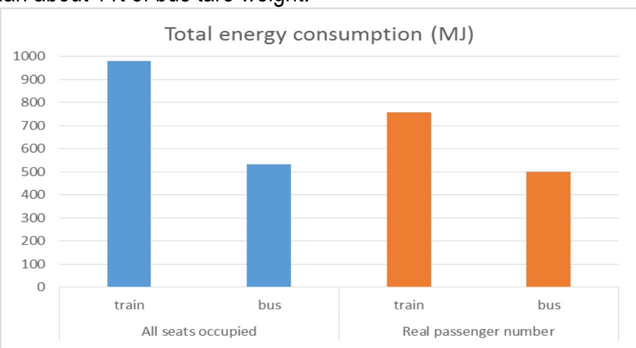


***Fig. 5.** Evaluation of energy consumption*

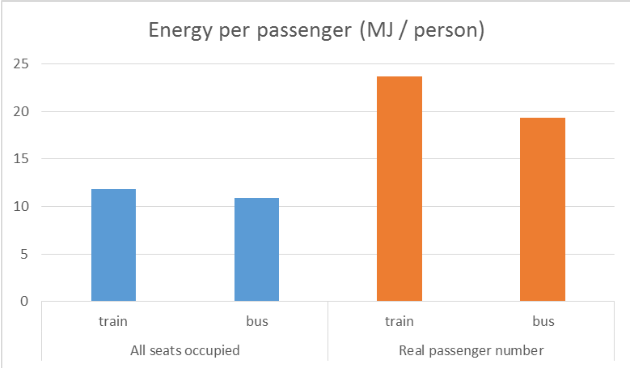


***Fig. 6.** Evaluation of energy consumption*

The simulated fuel consumption of the diesel train was compared to the real consumption of this train operated on this track. This simulated result was validated because the simulation error was only -8%. So every consumption results were increased of the value 8% to be closer to the reality. The total energy consumption of the bus represents only 54 - 66 % of the train consumption, according to the actual capacity usage. In the unit expression (MJ/prs) the difference is lower on account of higher capacity and passenger number values regardless of the effectiveness reached by the road vehicles.

## 3. MODEL SITUATION: CARGO TRANSPORTATION

In this study, we consider freight transport on the route Bratislava - Trnava - Žilina - Poprad - Košice on the rail and road. Road vehicles priority used highways and expressways situated parallel to the rail.

The route distance is 445km by rail and 449km by road. To this length we have to add additional distance from the station to the place of loading and unloading of railway wagon. In first case we add 4km for direct rail transport and 7km for direct road and combined transport. In second case we add 20km for direct rail transport and 25km for direct road and combined transport. We will consider two different locations with different distances and different transportation modes. Loading locations are located in industrial zones of the towns in the first case and in nearby villages in second case.

Loading process provide front loader. That operates in cycles. Cycle length depends on the distance between vehicle and goods. The goods are stored in a pile, from which they were collected and loaded onto vehicles.

Unloading is realized by spillage of cargo space vehicle at the landing location. Energy consumption of this action is included in the average energy consumption of the vehicle.

As goods that are transported in vehicles we consider compost. This product can be stored and transported in open air. Bulk density of compost is 1200 – 1400 kg.m$^{-3}$ but also depends on the humidity of the substrate. In the calculation we used 1300 kg.m$^{-3}$.

Road vehicles are articulated semitrailer sets with dump body made of aluminium. Their empty weight is 13 t, the payload 27 t and the body capacity 24 m$^3$. Considering the maximal weight limit (40 t) it is possible to load only 20,8 m$^3$ of cargo (87 % of capacity).

The train is composed of 30 Faccs wagons and locomotives Skoda E69 and E 479. The locomotives are used according to the track elevation (needed higher pulling power). The train is 430 m long and its gross weight is 2428 t. The payload represents 1482 t. One train (1482 t of cargo) equates to 55 articulated vehicles – semitrailer sets.

Front loader is equipped with a volume of 5 m$^3$ bucket. With this device the loader is able to load up to 6.5 tons of material in one bucket.

### 3.1. Calculation of energy consumption

To calculate the energy consumption of the train software Railway dynamics has been used.

The 5 train stops were envisaged during transporting. That is the average value of operating on the defined route and the distance. The output data consumption was calculated for further calculations and comparisons.

Calculated energy is the mechanical work needed to move the train. After transformed it into units of MJ, it can be subsequently converted to total consumed energy by an overall energy efficiency of equation.

$$E_{CE} = \left(E_{VD} \times 3{,}6\right) \times \eta_{CE} \quad (3)$$

where:

$E_{CE}$– energy consumed by electric traction [MJ]

$E_{DV}$–mechanical energy consumed by the movement of the train (train dynamics software result) [kWh]

When calculating the energy consumption of road transport consumption of 28 l/100km fuel at long distances was considered. On shorter distance this value rises because the vehicle consumes more energy to start-up and for standby operating mode. The constant speed is kept a short time or not at all. Increased fuel consumption values were chosen for the start and end of freight for combined transport (35 and 40 l/100km). The selected values represent the average figures for the type of vehicle and traffic.

Handling of bulk materials is carried out by wheeled front loader. It is equipped with a bucket of 5 m3 volume. With this device the loader is able to load up to 6.5 tons of material. When loading articulated vehicles, the average time of a single turnover (cycle) is 40 seconds. When operating wagons one cycle takes 120 seconds. This is due to a longer period of driving the loader from the place of storage material to coaches about the length of the train. Wheel loader with such equipment has an average hourly fuel consumption of 17 l. Cycles for a given fuel consumption reaches 0.3 l/t (road transport) and 0.9 l/t (rail transport).

To calculate the total energy consumption, the amount of consumed fuel should be multiplied by energy factor for that fuel from Appendix A of the standard.

$$E_{CPV} = \left[\left(S_{km} \times L\right)/100\right] \times e_W \quad (4)$$

where:

$E_{CPV}$– total energy consumed by vehicles [MJ]

$S_{km}$– vehicle fuel consumption [l/100km]

$L$– driven distance [km]

$e_W$ – energetic factor "wtw" for defined fuel [MJ/l]

$$E_{CPN} = \left(S_t \times Q\right) \times e_W \quad (5)$$

where:

$E_{CPN}$– total energy consumed by loader [MJ]

$S_t$– loader fuel consumption [l/t]

$Q$ – loaded mass of cargo [t]

$e_W$ – energetic factor "wtw" for defined fuel [MJ/l]

Each route consists of several operations (loading, unloading, transport), because the expression of energy consumption for the transport, we added up all the values of the partial activities.

$$E_C = \sum E_{CEi} + \sum E_{CPVi} + \sum E_{CPNi} \quad (6)$$

For the calculations I chose the basic units of MJ because a declared value in the standard. However, for better comparison and expression, it is able to expressed individual amounts in other units, in the case of proportional expressing quantities (see the evaluation).

### 3.2. Evaluation

Fig. 7 and 8 describe the values of energy consumption of each transport mode. The left columns are in an absolute expression of GJ. But better comparative value has the right columns expressed by kJ/tkm. This unit considers driven distance and cargo weight. The direct road transport represents the largest consumption. The best values reaches the rail transport but in practice it is very difficult to use only this one transport mode because it is not the door-to-door mode. Often is a necessary to use a support action (road transport) and then it is connected with another action with cargo. For the real case it is better to compare only two ways – direct road transport and the combined transport. From two cases of CT we chose the 2nd because of higher probability in practice (the driven distance by road transport is longer).

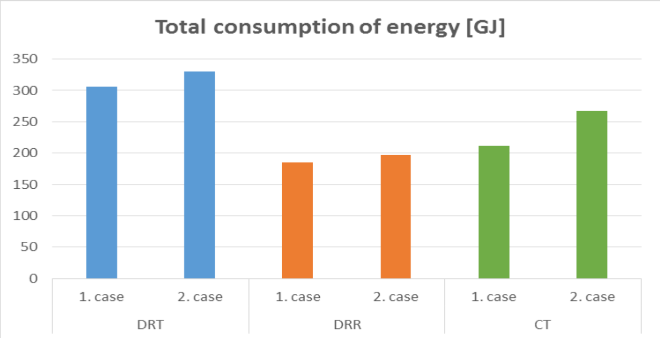


***Fig. 7.*** *Total consumption of energy. DRT (direct road transport), DRR (direct rail transport), CT (combined transport)*

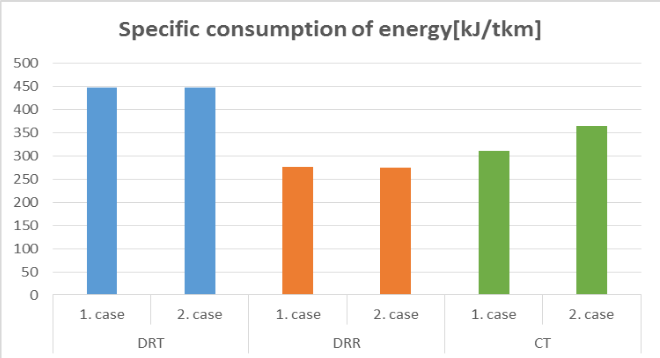


***Fig. 8.*** *Total consumption of energy. DRT (direct road transport), DRR (direct rail transport), CT (combined transport)*

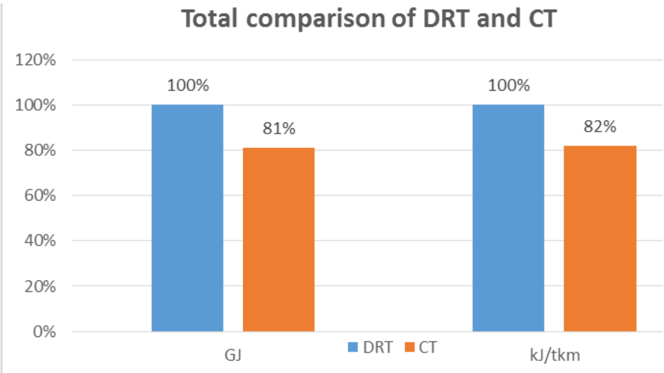


***Fig. 9.*** *Total comparison of DRT (direct road transport) and CT (combined transport)*

Fig. 9 shows that CT has lower energy consumption. It seems approximately 19% less of energy. The difference decreases with increasing driven distance of road transport. Also this comparison is made only of this one model case, so we do not consider driving the vehicle for empty returns and the coefficient of vehicle drives utilization should be used. In the global point of view, with this taken into account when rail shall reach higher values of empty rides, the results came out in favour of road transport. It is mainly because there are more possibilities to utilize the road vehicle on the reverse route than the railway.

## CONCLUSIONS

This paper consider energy consumption as one of critical factors in transport mode selection. The comparison was made in passenger and cargo transport.

In passenger transport we compared diesel train unit and bus on the route between Žilina and Rajec. In calculations we use real conditions on this route. The results shows the advantage of the road transport vehicle (bus). The total energy consumption of the bus represents only 54 - 66 % of the train consumption, according to the actual capacity usage. In the unit expression (MJ/prs) the difference is lower on account of higher capacity and passenger number values regardless of the effectiveness reached by the road vehicles.

In cargo transport we compared three types of transport (direct rail transport, direct road transport and combined transport) on the route between Bratislava and Košice. The best values reaches the rail transport but in practice it is very difficult to use only this one transport mode because it is not the door-to-door mode. Often is a necessary to use a support action (road transport) and then it is connected with another action with cargo. For the real case it is better to compare only two ways – direct road transport and the combined transport. CT has lower energy consumption. It seems approximately 19% less of energy. The difference decreases with increasing driven distance of road transport. In the global point of view, with this taken into account when rail shall reach higher values of empty rides, the results came out in favour of road transport. It is mainly because there are more possibilities to utilize the road vehicle on the reverse route than the railway.

Besides the technical aspects of energy consumption – selection of transport mode and types of vehicles, certainly a major role plays a transport logistics and planning. The best technically working system can be not effective if operates empty (no passengers, without cargo). But this is not subject of this study.

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