The Environmental Impact Of Reduced Fuel Consumption On Railways.

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1. Rail transport fuel consumption

In UK during 2018-19 financial year, passenger rail services consumed 3,976 million kWh of electricity and 469 million litres of diesel. Of the total 15,847 km of route open for trains (31,091 km of tracks) 38% is electrified (ORR, 2019a). So Diesel Multiple Units (DMUs), trains powered with diesel, are used because part of the lines are not electrified.

The Class 220 Voyager is a diesel-electric multiple-unit manufactured by Bombardier Transportation that operates in Country Cross network. In fact, all Country Cross trains are powered with diesel and 34 trains of the total 92 train sets are Class 220 Voyager.

The main characteristics of this train related to fuel consumption are:

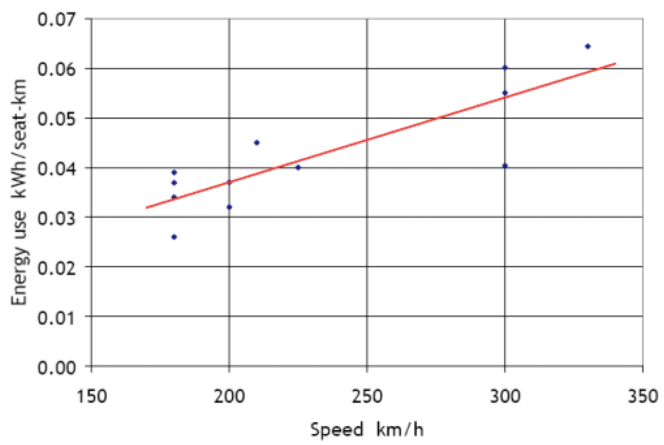
- 4 cars per trainset
- Each car is equipped with a Cummins QSK19 diesel engine of 750 hp (560 kW) at 1800rpm
- Each car is equipped with a fuel tank of 1,300 litres of diesel
- Maximum range of approximately 1,350 miles (2,170 km) between each refuelling
- Class 220 operates at a top speed of 125 mph (200 km/h)
- It contains 200 seats

In order to calculate fuel consumption of Class 220, we used the amount of fuel that a train carries in the 4 cars and the maximum distance between each refueling.

With this calculation, a Class 220 Voyager, consumes on average **3.85 litres of diesel per mile.**

It has to be considered that the consumption is directly dependent on the speed. In Figure 1 it is presented the linear relationship between speed and energy used by trains, so at more speed, more energy used. But also other factors will determine the fuel consumption: train weight, seat capacity, the amount of stops during the route.

Figure 1 Relationship between energy usage and speed. Source: RSSB, 2007



In this section the fuel consumption and its impact is analysed. The assumptions made, based on data from RSSB, are:

- A passenger train in UK runs 330 days a year
- A Class 220/2201/222 runs an average 640 miles per day and power car

- A Class 220/2201/222 runs each day 15.1 hours

In the next table the assumed fuel consumption is presented.

Table 1 Fuel consumption per mile, 1 month, 1 year and 5 years.

	Diesel consumed per trainset (litres)
1 mile	3.85
1 month	67,793
1 year	813,511
5 years	4,067,556

The related environmental impacts of current average fuel consumption is presented below.

Table 2 Environmental impacts of fuel consumption (fuel production and combustion) per 1 mile, during 1 month, 1 year and 5 years.

Environmental impact category	**Units**	**One Class 220 Voyager trainset**			
		1 mile	**1 month**	**1 year**	**5 years**
Climate change	kg CO_2 eq	11.3	198,040	2,376,481	11,882,407
Stratospheric ozone depletion	Kg CFC11 eq	5.97E-06	0.11	1.26	6.31
Ionizing radiation	kBq Co-60 eq	0.077	1,364	16,368	81,840
Ozone formation, human health	kg NOx eq	0.18	3,239	38,864	194,319
Fine particulate matter formation	kg $PM_{2.5}$ eq	0.024	416	4,996	24,982
Ozone formation, terrestrial ecosystems	kg NOx eq	0.19	3,276	39,316	196,579
Terrestrial acidification	kg SO_2 eq	0.074	1,307	15,688	78,440
Freshwater eutrophication	kg P eq	4.28E-06	0.08	0.90	4.52
Terrestrial ecotoxicity	kg 1.4-DBC e	7.90	138,979	1,667,746	8,338,731
Freshwater ecotoxicity	kg 1.4-DBC e	3.14E-03	55	663	3,314
Marine ecotoxicity	kg 1.4-DBC e	8.06E-03	142	1,702	8,508
Human carcinogenic toxicity	kg 1.4-DBC e	1.20E-03	21	253	1,265
Human non-carcinogenic toxicity	kg 1.4-DBC e	0.17	2,929	35,146	175,732
Land use	m^2a crop eq	2.21E-03	39	468	2,339
Mineral resources scarcity	kg Cu eq	4.31E-05	0.76	9.11	46
Fossil resource scarcity	kg oil eq	3.5	60,868	730,418	3,652,089
Water consumption	m^3	0.015	258	3,097	15,486
Cumulative energy demand	MJ	153	2,691,906	32,302,868	161,514,339

According to UK Department for Transport, the carbon dioxide emissions per type of rutes in UK are:

- Intercity: 14.48 kg CO_2eq/mile
- LSE (London and South East): 10.62 kg CO_2eq/mile
- Regional: 8.05 kg CO_2eq/mile

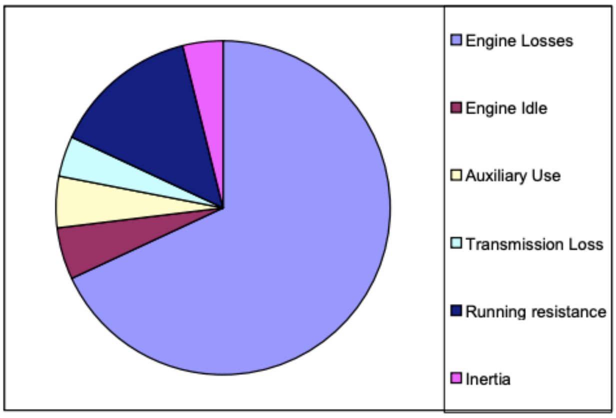
So, Class 220 Voyager has a consumption inside the average type of trains.

2. Aerodynamic drag reduction benefits

Of all energy consumed by diesel DEMU, 68% is used by the engine to operate the train, 5% to provide auxiliary services to the train, such as ventilation and control, lightning and climatization, but 27% is lost, as it is shown in Figure 2, which means that strategies avoiding energy losses can result in a significant reduction on fuel consumption.

Figure 2 Energy usage on diesel Intercity DEMU (e.g. Class 221 Super-Voyager (200 km/h)) for the GB rail network. Source: RSSB, 2007

Intercity DEMU	%	GWh
		2200
Engine Losses	68%	1496
Engine Idle	5%	110
Auxiliary Use	5%	110
Transmission Loss	4%	88
Running resistance	14%	308
Inertia	4%	88
	100.0%	2200



The inclusion of nozzles at front and base of a Class 220 Voyager results very effective in reducing the drag coefficient, 22.34%. This means that it is possible to reduce 11.17% fuel consumption.

In this section the environmental benefits of 11.17% fuel reduction is analysed.

Considering that a Class 220 Voyager consumes 3.85 litres of diesel per mile, the potential savings are:

- 0.43 litres of diesel saved per mile and train
- 7,572 litres of diesel saved per month and train
- 90,869 litres of diesel saved per year and train
- 454,346 litres of diesel saved in a 5 years period and train

This potential fuel consumption reduction can be translated into emissions savings. In the following table, the potential impacts saved are presented:

Table 3 Environmental impacts saved due to 11.17% fuel reduction in one Class 220 Voyager train.

Environmental impact category	Units	One Class 220 Voyager trainset			
		1 mile	1 month	1 year	5 years
Climate change	kg CO_2 eq	1.26	22,121	265,453	1,327,265
Stratospheric ozone depletion	Kg CFC11 eq	6.67E-07	1.17E-02	0.14	0.70
Ionizing radiation	kBq Co-60 eq	8.66E-03	152	1,828	9,142
Ozone formation, human health	kg NOx eq	2.06E-02	362	4,341	21,705
Fine particulate matter formation	kg $PM_{2.5}$ eq	2.64E-03	47	558	2,790
Ozone formation, terrestrial ecosystems	kg NOx eq	2.08E-02	366	4,392	21,958
Terrestrial acidification	kg SO_2 eq	8.30E-03	146	1,752	8,762
Freshwater eutrophication	kg P eq	4.79E-07	8.42E-03	0.10	0.51
Terrestrial ecotoxicity	kg 1.4-DBC e	0.88	15,524	186,287	931,436
Freshwater ecotoxicity	kg 1.4-DBC e	3.51E-04	6.17	74	370
Marine ecotoxicity	kg 1.4-DBC e	9.00E-04	16	190	950
Human carcinogenic toxicity	kg 1.4-DBC e	1.34E-04	2.36	28	141
Human non-carcinogenic toxicity	kg 1.4-DBC e	1.86E-02	327	3,926	19,629
Land use	m^2a crop eq	2.47E-04	4.4	52	261
Mineral resources scarcity	kg Cu eq	4.82E-06	0.08	1.02	5.1
Fossil resource scarcity	kg oil eq	0.39	6,799	81,588	407,938
Water consumption	m^3	1.64E-03	29	346	1,730
Cumulative energy demand	MJ	17	300,686	3,608,230	18,041,152

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Annex. Impact categories description

Environmental impact category	Unit	Description
Climate change	kg CO_2 eq	An increased atmospheric concentration of greenhouse gases will increase the radiative forcing capacity leading to an increase in the global mean temperature (°C). Increased temperature ultimately results in damage to human health and ecosystems.
Stratospheric ozone depletion	Kg CFC11 eq	Emissions of Ozone Depleting Substances ultimately lead to damage to human health because of the resultant increase in UVB radiation. Chemicals that deplete ozone are relatively persistent and have chlorine or bromine groups in their molecules that interact with ozone (mainly) in the stratosphere. This increased radiation negatively affects human health, thus increasing the incidence of skin cancer and cataracts.
Ionizing radiation	kBq Co-60 eq	Anthropogenic emissions of radionuclides are generated in the nuclear fuel cycle (mining, processing and waste disposal), as well as during other human activities, such as the burning of coal and the extraction of phosphate rock. Exposure to the ionizing radiation caused by these radionuclides can lead to damaged DNA molecules and thus affect human health.
Ozone formation, human health	kg NOx eq	Ozone is not directly emitted into the atmosphere, but it is formed as a result of photochemical reactions of NOx and Non Methane Volatile Organic Compounds (NMVOCs). This formation process is more intense in summer. Ozone is a health hazard to humans because it can inflame airways and damage lungs.
Fine particulate matter formation	kg $PM_{2.5}$ eq	Air pollution that causes primary and secondary aerosols in the atmosphere can have a substantial negative impact on human health, affecting the upper part of the airways and lungs when inhaled.
Ozone formation, terrestrial ecosystems	kg NOx eq	Ozone is not directly emitted into the atmosphere, but it is formed as a result of photochemical reactions of NOx and Non Methane Volatile Organic Compounds (NMVOCs). Ozone can have a negative impact on vegetation, including a reduction of growth and seed production, an acceleration of leaf senescence and a reduced ability to withstand stressors.
Terrestrial acidification	kg SO_2 eq	Atmospheric deposition of inorganic substances, such as sulphates, nitrates and phosphates, cause a change in acidity in the soil. This change in acidity can affect the plant species living in the soil, causing them to disappear
Freshwater eutrophication	kg P eq	Freshwater eutrophication occurs due to the discharge of nutrients into soil or into freshwater bodies and the subsequent rise in nutrient levels, i.e. phosphorus and nitrogen. Environmental impacts related to freshwater eutrophication are numerous. They follow a sequence of ecological impacts offset by increasing nutrient emissions into fresh water, thereby increasing nutrient uptake by autotrophic organisms such as cyanobacteria and algae, and heterotrophic species such as fish and invertebrates. This ultimately leads to relative loss of species.
Terrestrial ecotoxicity	kg 1.4-DBC e	Human toxicity and ecotoxicity accounts for the environmental persistence (fate), accumulation in the human food chain (exposure), and toxicity (effect) of a chemical. This can result in affected species and disease incidences, leading finally to damage to ecosystems and human health.
Freshwater ecotoxicity	kg 1.4-DBC e	
Marine ecotoxicity	kg 1.4-DBC e	
Human carcinogenic toxicity	kg 1.4-DBC e	
Human non-carcinogenic toxicity	kg 1.4-DBC e	
Land use	m^2a crop eq	Land use includes the direct, local impact of land use on terrestrial species via change of land cover and the actual use of the new land. Change of land cover directly affects the original habitat and the original species composition accordingly.
Mineral resources scarcity	kg Cu eq	Assessment of consumption of natural resources (distinguished in two indicators depending on whether the resources are energy or non-energy) including a weighting of these resources according to their scarcity and the speed of their exploitation. The more the resource is considered as scarce and
Fossil resource scarcity	kg oil eq	

		exploited, the more the value of the indicator increases and the more the product contributes to the depletion of resources.
Water consumption	m^3	Water consumption is the use of water in such a way that the water is evaporated, incorporated into products, transferred to other watersheds or disposed into the sea. Water that has been consumed is thus not available anymore in the watershed of origin for humans nor for ecosystems
Cumulative energy demand	MJ	The Cumulative Energy Demand represents the direct and indirect energy use throughout the life cycle, including the energy consumed during the extraction, manufacturing and disposal of the raw and auxiliary materials.