rail systems; environmental performance;
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RAIL ENVIRONMENTAL IMPACT: ENERGY CONSUMPTION AND NOISE POLLUTION ASSESSMENT OF DIFFERENT TRANSPORT MODES CONNECTING BIG BEN (LONDON, UK) AND EIFFEL TOWER (PARIS, FR)

Summary. This paper is set within the framework of the RailNewcastle Summer School program 2014 run by Newcastle University. It attempts to explore the sustainability credentials of railways when compared with other transport modes connecting central London with central Paris, two of Europe's largest metropolis. Specifically, the study compares the energy consumption and noise pollution of a rail-only travel option with two other alternatives using a combination of public transport modes. The analysis includes defining the regulatory framework, sourcing and aggregating energy consumption from a number of references as well as creating noise maps for key nodes using validated tools available. The results suggest that the rail-only option has the best performance of the three options in terms of energy consumption while a bus-coach-metro combination seems to have lower noise levels than the rest. Assumptions due to lack of meaningful data made in the calculation of underground rail services are thought to have influence on the lower than expected performance of rails systems in terms of noise. The authors conclude that considering the combined outcomes of both assessments, the rail-only option is the preferred choice from a sustainability credentials perspective.

PORÓWNANIE ZUŻYCIA ENERGII ORAZ EMISJI HAŁASU DLA RÓŻNYCH ŚRODKÓW TRANSPORTU UŻYTYCH W POŁĄCZENIU POMIĘDZY BIG BENEM (LONDYN, UK) A WIEŻĄ EIFFLA (PARYŻ, FR)

Streszczenie. Artykuł powstał w ramach szkoły letniej RailNewcastle prowadzonej przez Uniwersytet w Newcastle. W pracy poruszono problemy związane z zużyciem energii oraz hałasem emitowanym przez kolej w odniesieniu do innych środków transportu. Jako materiał badawczy wybrano trzy możliwości podróży między dwoma największymi metropoliami Europy - Londynem a Paryżem. Analiza zawiera regulacje prawne wytwarzania i zużywania energii, a także mapy wraz z pomiarem hałasu dla wybranych węzłów komunikacyjnych. Wyniki sugerują, że kolej jest najkorzystniejszą opcją pod względem zużycia energii, podczas gdy konfiguracja autobus – autokar – metro wydaje mniej hałasu niż pozostałe opcje.

1. INTRODUCTION

Transport is an energy-intensive sector requiring significant amounts of energy not only to run but also to be set up and built. It is responsible for approximately a quarter of the EU's global CO2 emissions. Of this quarter, less than 2% is attributed to railways [1]. Rail is already one of the cleanest and safest modes of transport, but it cannot afford to rest on its reputation. The automotive industry for instance has demonstrated that better technology can reduce emissions while maintaining vehicle performance [1]. The level of greenhouse gas emissions (GHG) of railways depends largely on whether these are electrified or not. In the case of electrification, GHG are directly linked to the energy-mix of the country/region [1] which can vary substantially from one to another.

Railway noise pollution can be either i) air-borne or ii) vibration-induced. Transport noise and its effects on health particularly on urban areas have been extensively studied for instance [2 - 5].

In order to understand the sustainability credentials of railway, this paper offers a comparison between transport modes connecting central London with central Paris. Specifically, the study compares the energy consumption and noise pollution of a rail-only travel option with two other alternatives using a combination of modes.

2. THREE OPTIONS FOR TRAVEL

There are many possible routes of travel from London to Paris. Big Ben in central London and the Eiffel Tower in Paris have been chosen as the origin and final destination points respectively. For the purpose of this study three options are proposed: A rail-only and two multi-modal combinations, one with an emphasis on road (bus) and the other on plane.

The average time between travels were estimated using the website facilities of RATP ("Régie Autonome des Transports Parisiens"), TfL ("Transport for London"), Airfrance, IDBus and Eurostar. The following table summarises these travel options.

Table 1

Summary of travel options

	Departure	Arrival	Type of transportation	Time travel
Option 01	Westminster (UK)	St. Pancras (UK)	Metro	13min
	London St Pancras Domestic (UK)	Paris Nord (FR)	Train (Eurostar)	2h16min
Option 02	Gare du Nord (FR)	Ecole Mil. (FR)	Metro	25min
	Parliament Square, Westminster (UK)	Victoria Coach Station (UK)	Bus	17min
	Victoria Coach Station (UK)	Paris, France (FR)	Bus	8h
	Bercy(FR)	Ecole Militaire (FR)	Metro	24min
Option 03	Westminster (UK)	Paddington (UK)	Metro	22min
	Paddington (UK)	Heathrow (UK)	Bus	45min
	Heathrow (UK)	Paris Charles de Gaulle (FR)	Plane	1h20min
	Paris Charles de Gaulle (FR)	Champs de Mars Tour Eiffel (FR)	RER	35min

3. TRANSPORT AND THE ENVIRONMENT

Transport, especially urban transport, is considered to be responsible for approximately 25% global CO_2 emission [6]. According to [6] sources of air pollution can be divided into two categories 1) movable sources e.g. road vehicles, locomotives and aircraft 2) immovable sources e.g. industry.

3.1. Emissions of CO_2, NO_x and PM

For the purpose of this paper the emissions of carbon dioxides (CO2), nitrogen oxides (NOx) and particle matter (PM) have been calculated using the online tool Travelfootprint.org. It has been assumed that values for London Underground are similar to those from the metro in Paris and that all transport modes were on 100% capacity for comparison purposes. The results are shown in table 2

Table 2

Values of emissions carbon dioxides (CO_2),
nitrogen oxides (NO_x) and particulate matter (PM) for the three options considered

	Departure	Arrival	Type of transportation	CO_2 (grams per person)	NO_x + PM emission(grams per person)
Option 01	Westminster (UK)	St. Pancras (UK)	Metro	80.8	0.2
	London St Pancras Domestic (UK)	Paris Nord (FR)	Train (Eurostar)	5400	11,9
	Gare du Nord (FR)	Ecole Mil. (FR)	Metro	22	0.049
Option 02	Parliament Square, Westminster (UK)	Victoria Coach Station (UK)	Bus	47.5	0.2
	Victoria Coach Station (UK)	Paris, France (FR)	Bus	10600	42.5
	Bercy (FR)	Ecole Militaire (FR)	Metro	29	0.064
Option 03	Westminster (UK)	Paddington (UK)	Metro	105,2	0,2
	Paddington (UK)	Heathrow (UK)	Bus	819,9	4
	Heathrow (UK)	Paris Charles de Gaulle (FR)	Plane	65800	89,5
	Paris Charles de Gaulle (FR)	Champs de Mars Tour Eiffel (FR)	RER	139	0,34

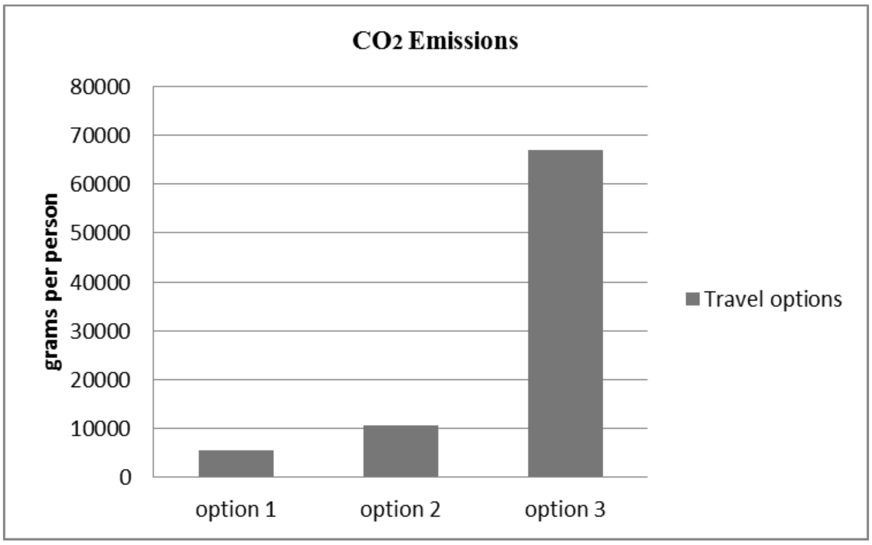


Fig. 1. Emissions CO_2 – three options for travel
Rys. 1. Emisja CO_2 – trzy opcje podróży

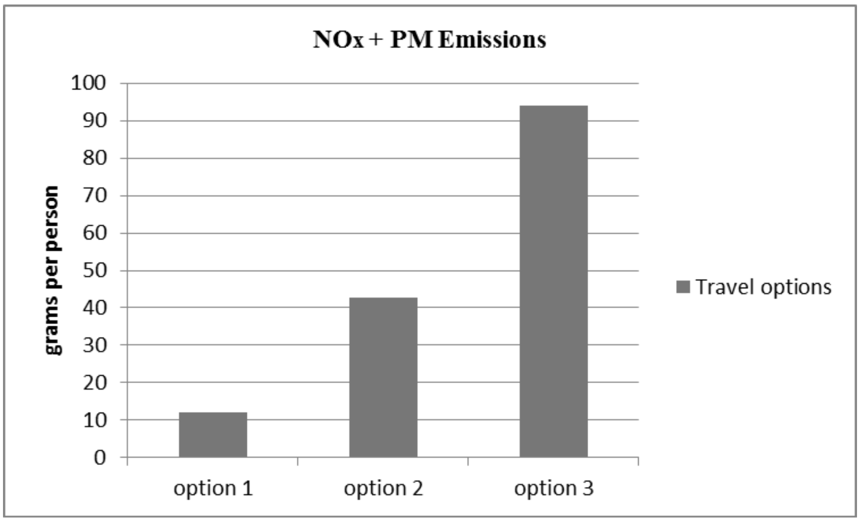


Fig. 2. Emissions NOx and PM – three options for travel
Rys. 2. Emisja NOx and PM – trzy opcje podróży

4. ENERGY CONSUMPTION

Transport is the sector with the highest final energy consumption (fig. 3). At the year of 2011, the transport sector represented a total of 33% of the total of the energy consumption in Europe, being the sector with the biggest value, followed by the Industry sector with 26% and the Residential sector with 25% of the total energy consumed [7]. Energy demand is satisfied essentially from five main sources: oil, gas, coal, renewable energies and nuclear. A significant percentage of the energy used in this sector comes from diesel fuels. The combustion of these fuels emits CO2 as well as NOx and other harmful components to the environment. Nuclear and renewables (wind, biomass and hydro) only account for 14% of the total energy consumption in transport, although this value is expected to rise to 20% by the year of 2020 [7].

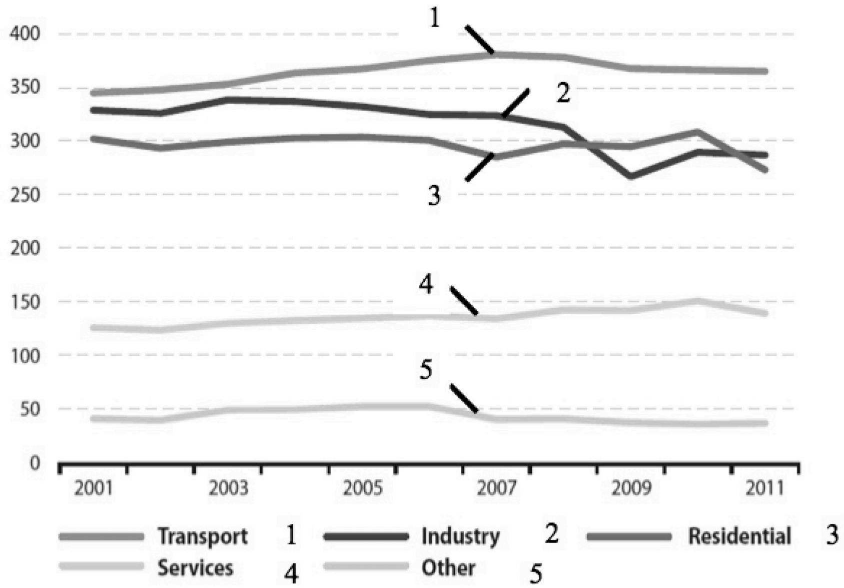


Fig. 3. Final energy consumption by sector EU-28 Mtoe [7]
Rys. 3. Zużycie energii przez sektor EU-28 Mtoe [7]

Data available indicate that railways (at least in Europe) have the lowest energy consumption when compared to other transport modes (fig. 4).

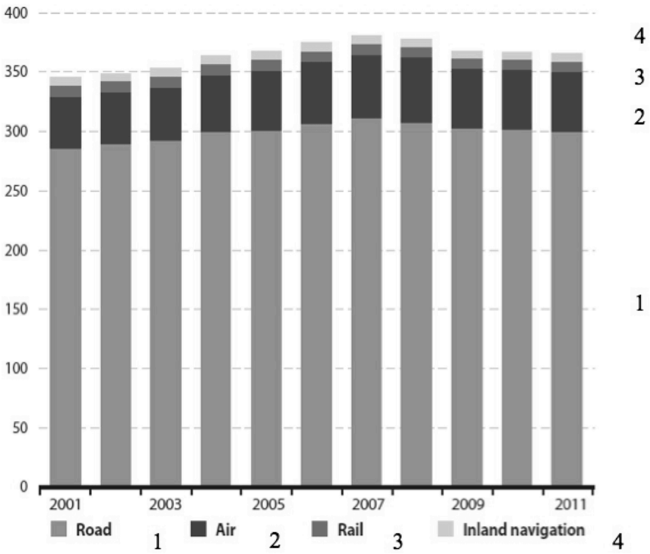


Fig. 4. Final energy consumption by mode of transport EU-28 Mtoe [7]
Rys. 4. Zużycie energii przez poszczególne środki transportu - sektor EU-28 Mtoe [7]

Electrified railways are considered to be more environmentally friendly than other types of transport, given their ability to effectively not polluting at source. However, their actual environmental impact is dependent on the sustainability credentials of the fuel used to generate the electricity required to run the railways which in turn depends on the energy mix of a given region/country. Rail is the only transport mode which is capable of shifting from fossil fuels to renewable energy sources by changing the energy source in the electric energy production. For instance France has almost 90% of its energy produced by nuclear sources, allowing its railways to generate less GHG emissions than the United Kingdom for example, which has more than 60% of its energy mix coming from fossil fuels [8].

The extent of importance of the energy mix used to produce electricity can be found in analysing the example of the high speed train operator Eurostar, one of the chosen services in this study (option 01). Eurostar announced in 2007 that it would aim to reduce carbon dioxide emissions by 25% per passenger by 2012 [9]. Nonetheless this target was already achieved by 2010. This result was possible due to a combination of different factors such as an increase in the efficiency of driving (eco-driving) and turning around the trains and an increase in loading factors. However, the main contributor to achieve this goal in such a short period of time was the strategic decision made by the operator to switch energy supplier from the UK to France which became the sole source of electricity for the Channel Tunnel section running between the two countries. Previously the energy was supplied equally between the two counties.

Table 3 shows the different values for energy consumption by mode of transport for the United Kingdom that were used to analyse the energy consumption for the three options [10]

Table 3

Primary energy consumption by mode for the United Kingdom

Transport mode	[MJ/passenger-km]	[MJ/seat-km]
Metro (underground)	0.88	0.25
Bus	1.39	0.3
Eurostar	0.92	0.45
Airplane	2.57	1.8
Local train	0.83	0.3

All of these values presented are strongly dependent on the occupancy levels (loading factors) estimated. These values assume that the airplane occupancy is 70%, the metro (underground) 29%, rail 36% and Eurostar 49%. The bus has an occupancy estimation of around 24%.

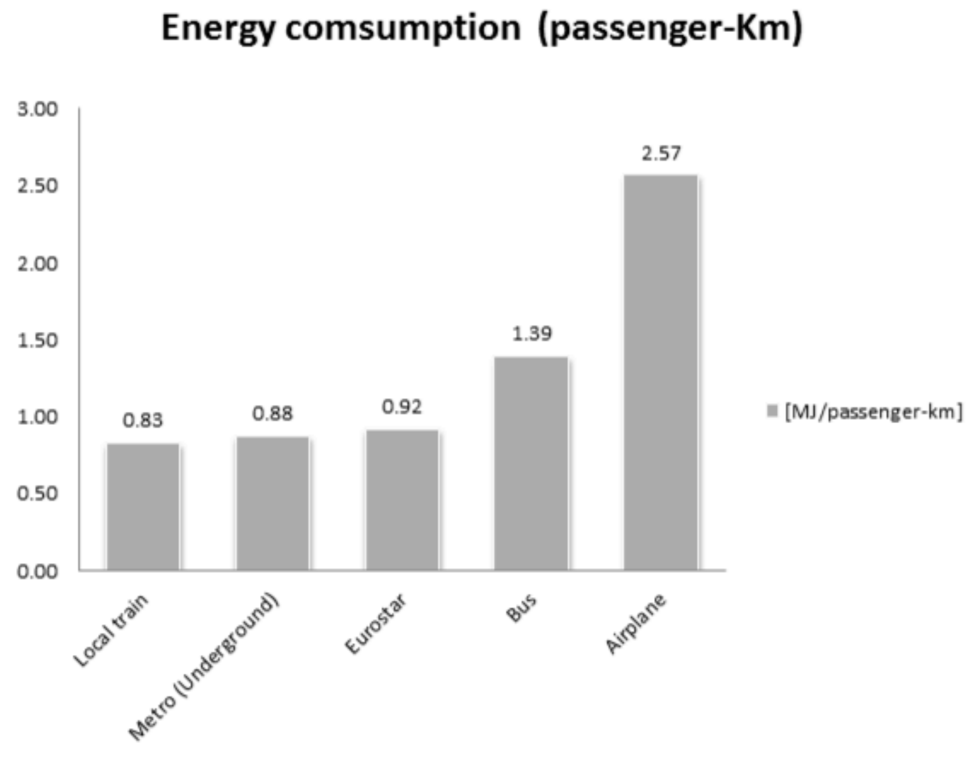


Fig. 5. Energy consumption MJ/Passenger-Km for the transport modes in options 01-03

Rys. 5. Zużycie energii w MJ/Pasażer-km dla różnych środków transportu użytych w projekcie

These results show that the Eurostar rail service (option 01) has better energy efficiency than coach (option 02) and airplane (option 03). It is worth indicating that the results also indicate than the airplane option is almost three times less efficient than rail.

To determinate the total energy consumed per passenger during the whole journey for each one of the three options the distance between every stations has been estimated and added to the outcomes in Fig. 5. The results are presented in Fig. 6.

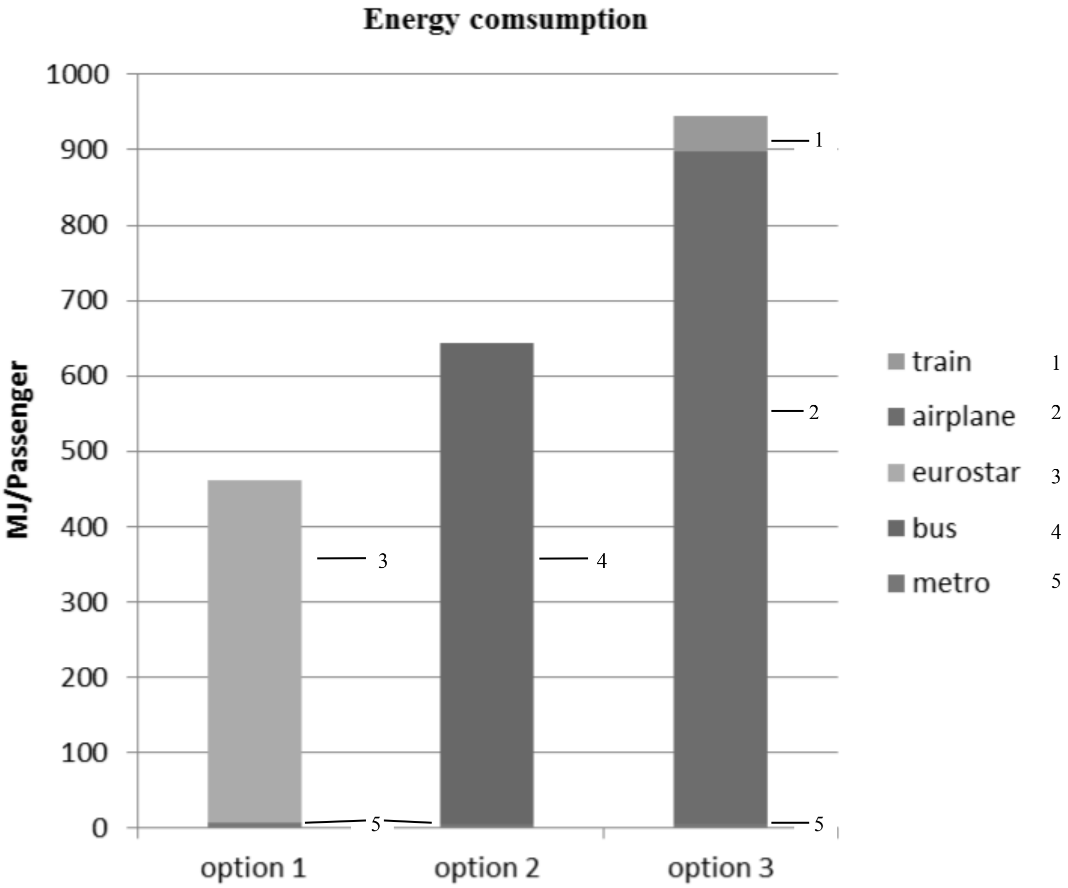


Fig. 6. Energy consumption MJ/Passenger for the three combinations of transport modes
Rys. 6. Zużycie energii w MJ/Pasażer dla trzech kombinacji z użyciem różnych środków transportu

The widely accepted measurement of energy consumption per passenger also indicates that option 01 is the most efficient as a whole and that the long distance rail service is the best choice of the three modes with air being the least energy efficient.

5. NOISE POLLUTION AND ITS EFFECTS: BACKGROUND AND RESULTS

Environmental noise is understood as unwanted (disturbing/annoying) or harmful outdoor sound created by human activity, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity [11]. Transport is considered to be a main contributor to environmental noise. According to the World Health Organisation (WHO) "*ambient sound levels have steadily increased as a result of growing number of road trips and kilometres driven in motor vehicles, higher speeds in motors vehicles, and the increased frequency of flying and use of larger aircraft. Noise is a problem in Europe*" [12]. An estimated 40% of the EU's population is exposed to road traffic noise exceeding 55 dB(A) daytime, and 20% are exposed to levels exceeding 65 dB(A) [13]. As an example, the relationship between noise pollution and population annoyance has been assessed by the European Commission [14] showing rail as the least annoying and air as the most polluting (Fig. 7). Long-term night level (L_{night}) has been used as metric.

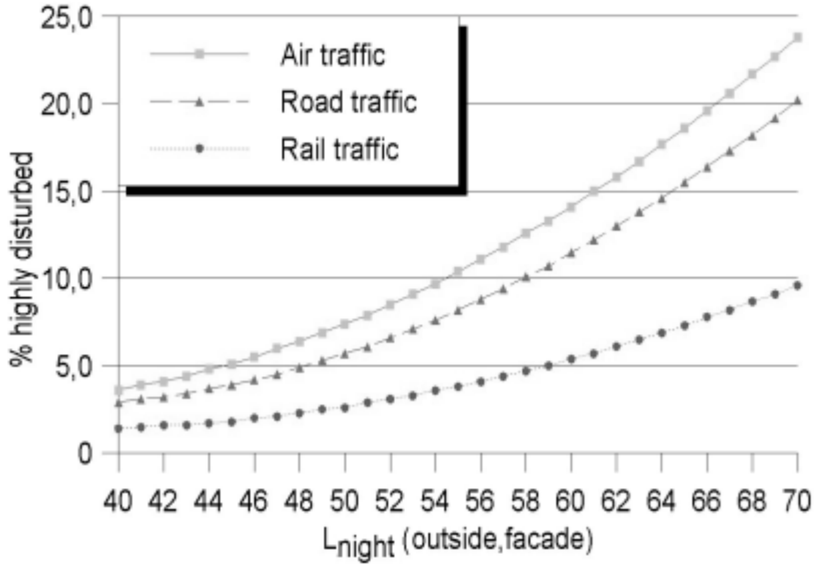


Fig. 7. Noise annoyance for L_n [dB] for different modes of transport
Rys. 7. Wartości hałasu L_n [dB] dla różnych środków transportu

5.1. Regulation

Following a proposal by the Commission adopted in 2000, the European Parliament and Council adopted *Directive 2002/49/EC* more commonly known as the Environmental Noise Directive (END) [11]. The END is one of the main instruments to identify noise pollution levels and to trigger the necessary action both at Member State and at EU level.

Directive 2002/49/EC concerns noise from road, rail and air traffic and from industry. It focuses on the impact of such noise on individuals, complementing existing EU legislation which sets standards for noise emissions from specific sources. The END requires:

- the determination of exposure to environmental noise, through noise mapping;
- provision of information on environmental noise and its effects on the public;
- adoption of action plans, based upon noise mapping results, which should be designed to manage noise issues and effects, including noise reduction if necessary;

According to the Directive the most important noise indicators are:

- "L_{den}" (day-evening-night noise indicator) - the noise indicator for overall annoyance
- "L_{day}" (day-noise indicator) - the noise indicator for annoyance during the day period (07.00 - 19.00)
- "$L_{evening}$" (evening-noise indicator) - the noise indicator for annoyance during the evening period (19.00 - 23.00)
- "L_{night}" (night-time noise indicator) - the noise indicator for sleep disturbance (23.00 - 07.00)
- Additional indicators might be used as well.

In order to analyse the noise situation in Europe, following current EC legislation, the Member States have to provide noise maps and noise action plans. Noise action plans describe the measures taken to lower environmental noise for identified affected inhabitants. However, legal conditions differ widely across Europe as Member States have different limits or threshold limits for environmental noise emissions, and usually these limits are tested only when building new infrastructure or during major redevelopment.

An attempt to homogenise the noise abatement approach in the railway sector and to overcome differences between the Member States, the European Railway Agency (ERA) implemented 'Technical Specifications for Interoperability' (TSIs) [15]. Particularly TSI 96/48-ST 05 specifies noise levels. In the TSIs the EU enacts noise creation limits for railway vehicles, both for new rolling stock as well as for renewed or upgraded rolling stock. Different values are defined for the various types of rolling stock (i.e. freight wagons, locomotives, multiple units, coaches) as well as for different operating situations (i.e. pass-by, stationary, starting and interior noise). This TSI includes noise emission limits for wagons with retrofitted braking systems.

5.2. Noise pollution: Travel options methodology and results

To analyse the noise pollution for each of the three travel options proposed in this paper noise maps have been assessed and in some cases, created.

For the purposes of this paper the analysis has been focused on noise levels at key nodes and stations given the difficulty in producing credible noise maps for the whole length of the route. The following tools and data have been used to produce such maps: Information from Department for Environment, Food and Rural Affairs (DEFRA) responsible for the UK's noise mapping [16], noise action plans and from Mairie de Paris [17] and the official website of Charles de Gaulle airport [18]

Option 01: rail-only (metro and train)

Fig. 8 - 12 show the noise mapping results for the rail-only option 01. Both L_{den} and L_{night} have been obtained.

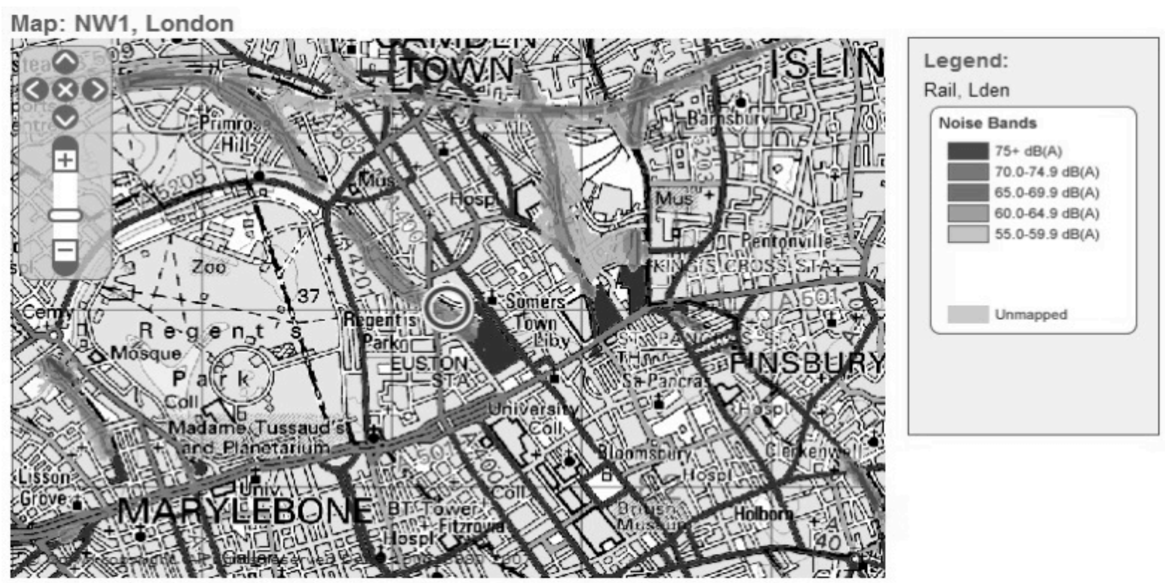


Fig. 8. Kings Cross St. Pancras underground station (source: DEFRA) [16]
Rys. 8. Stacja metra Kings Cross St. Pancras (źródło: DEFRA) [16]

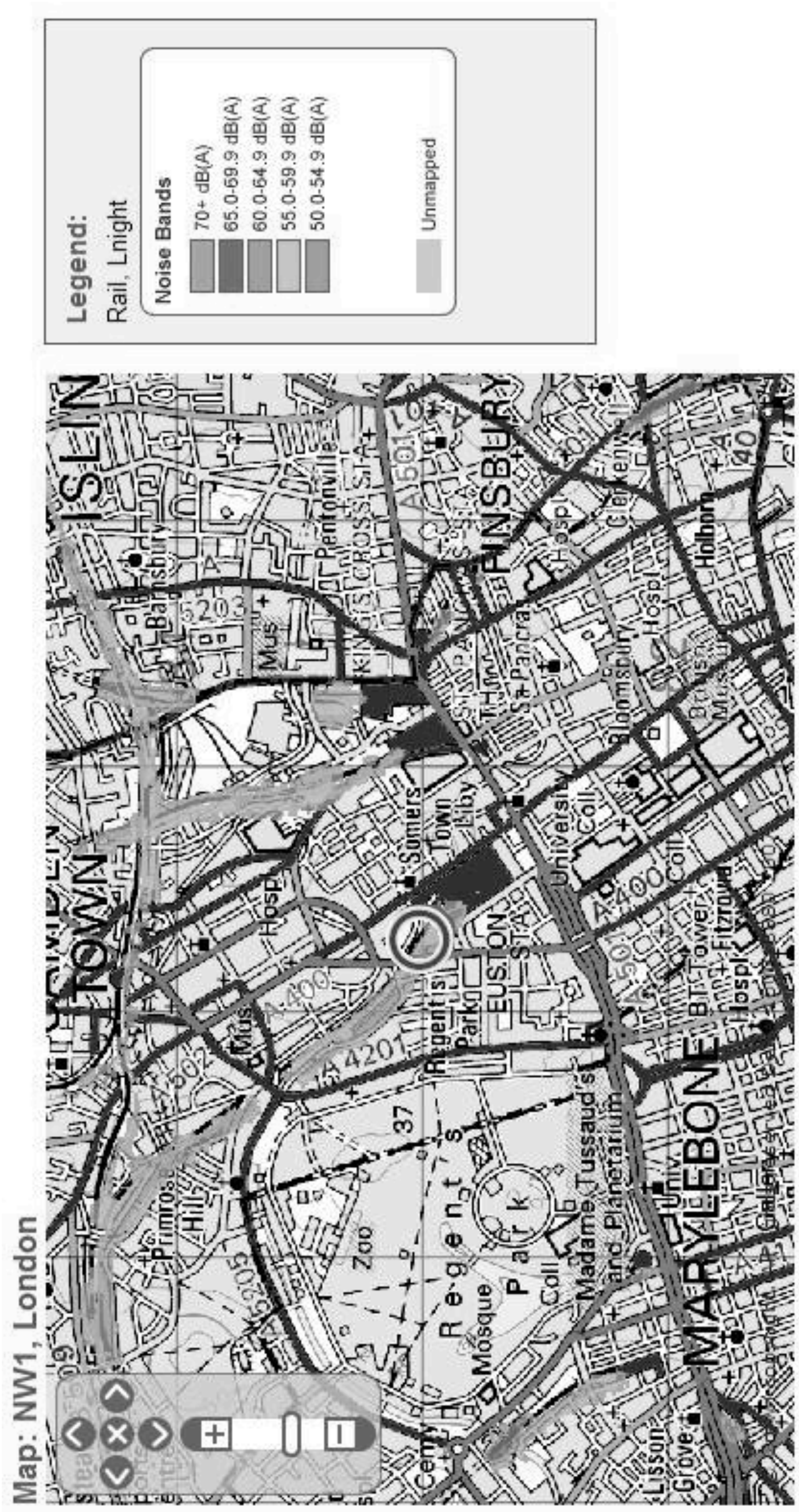
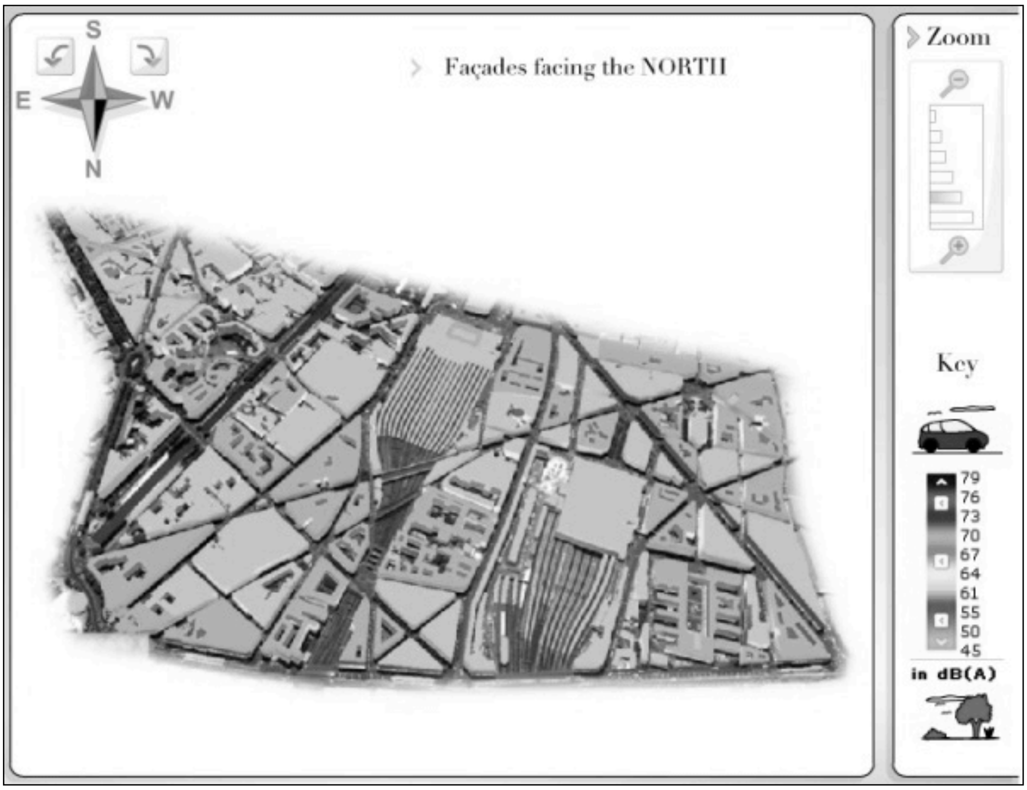
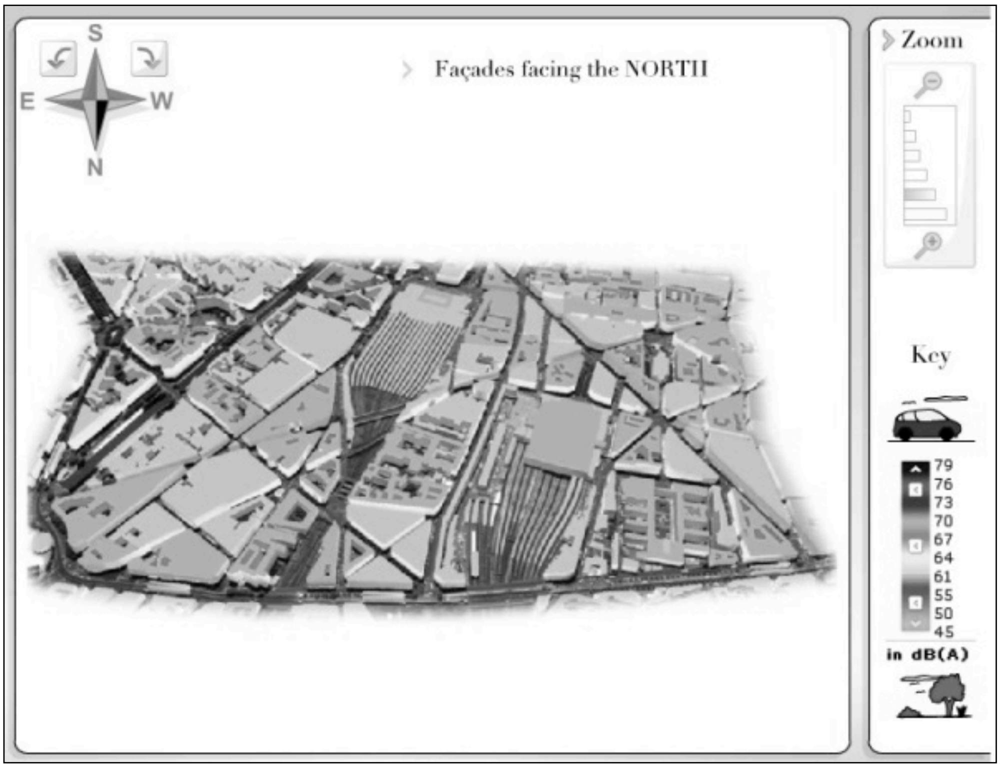


Fig. 9. Kings Cross St. Pancras underground station (source: DEFRA) [16]
Rys. 9. Stacja metra Kings Cross St. Pancras (źródło: DEFRA) [16]



L_{den}



L_{night}

Fig. 10. Metro Gare Du Nord (source: DEFRA) [16]
Rys. 10. Stacja metra Gare Du Nord (źrodło: DEFRA) [16]

Fig. 11. Present indicator: L_{night} (Champs – 1, Ecole – 2, Bercy – 3) from 6:00 till 18:00 [17]
Rys. 11. Prezentacja wskaźników (Champs – 1, Ecole – 2, Bercy – 3) od 6:00 do 18:00 [17]

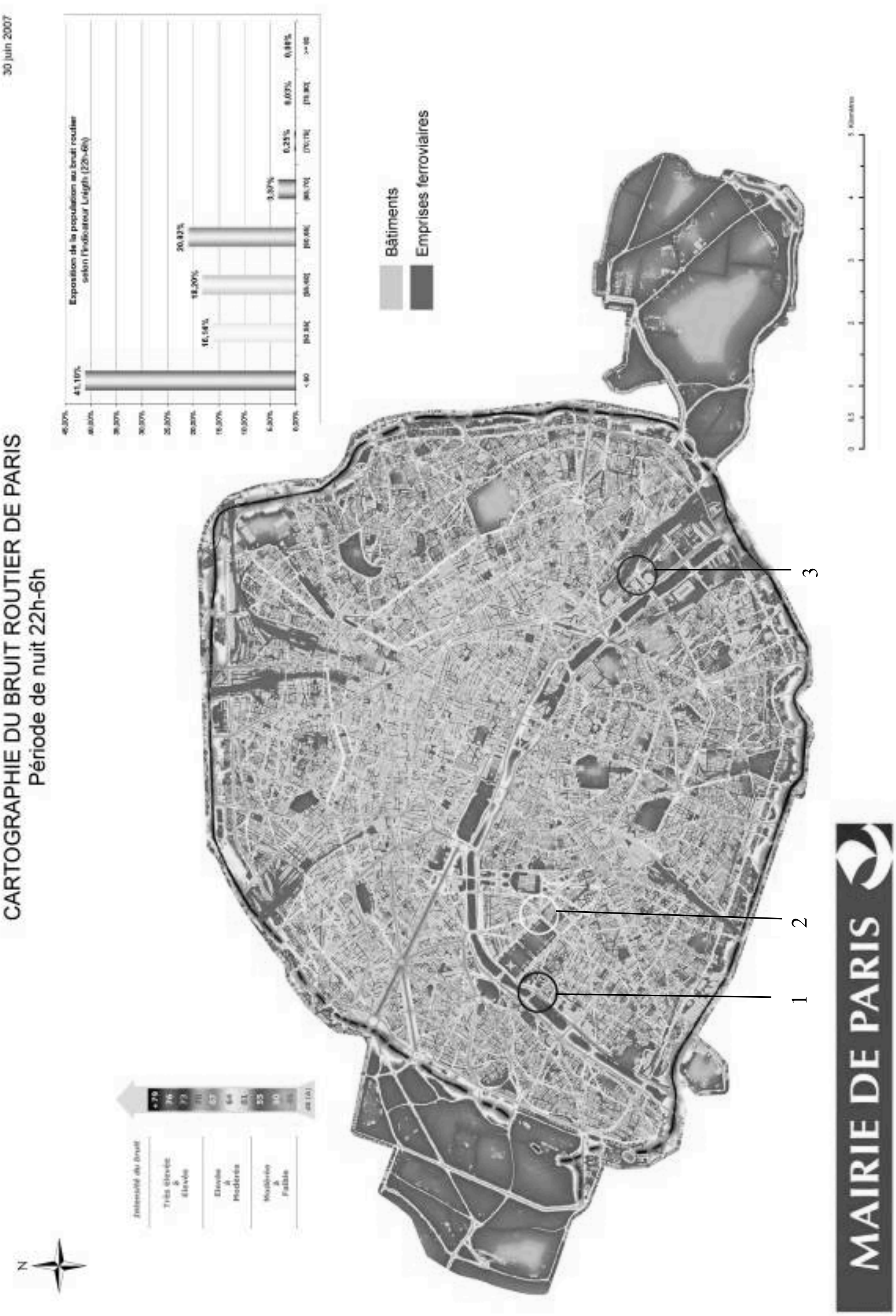
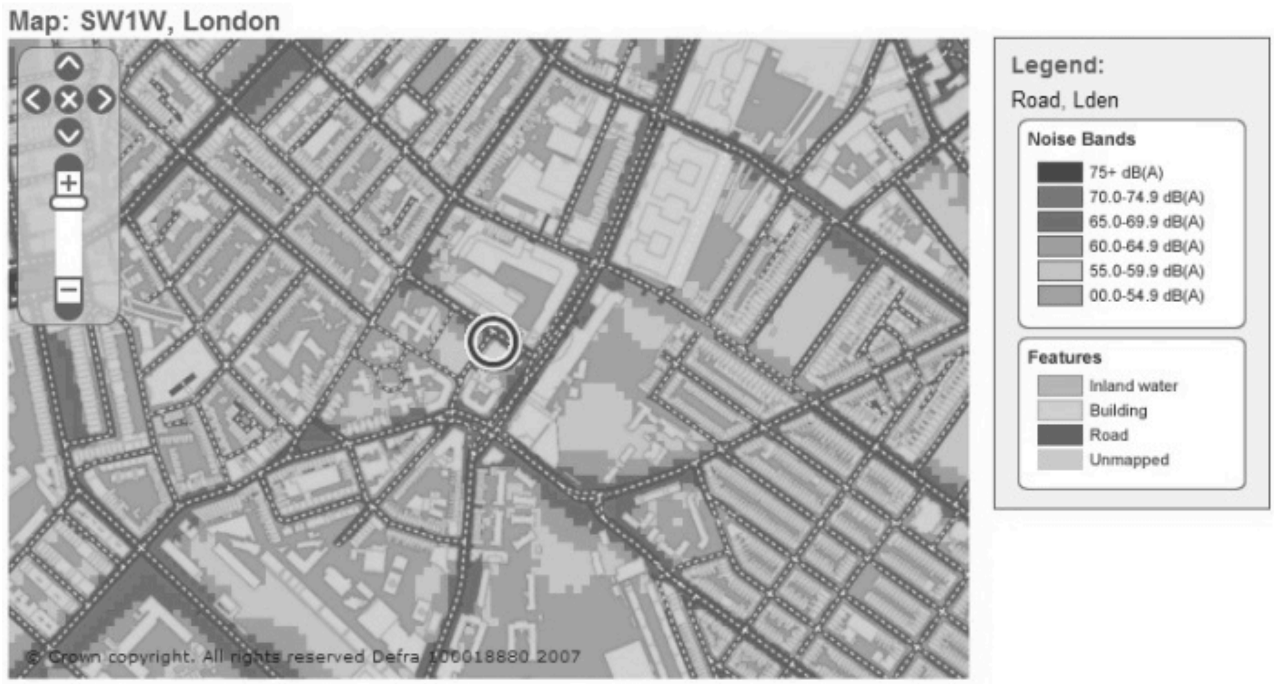


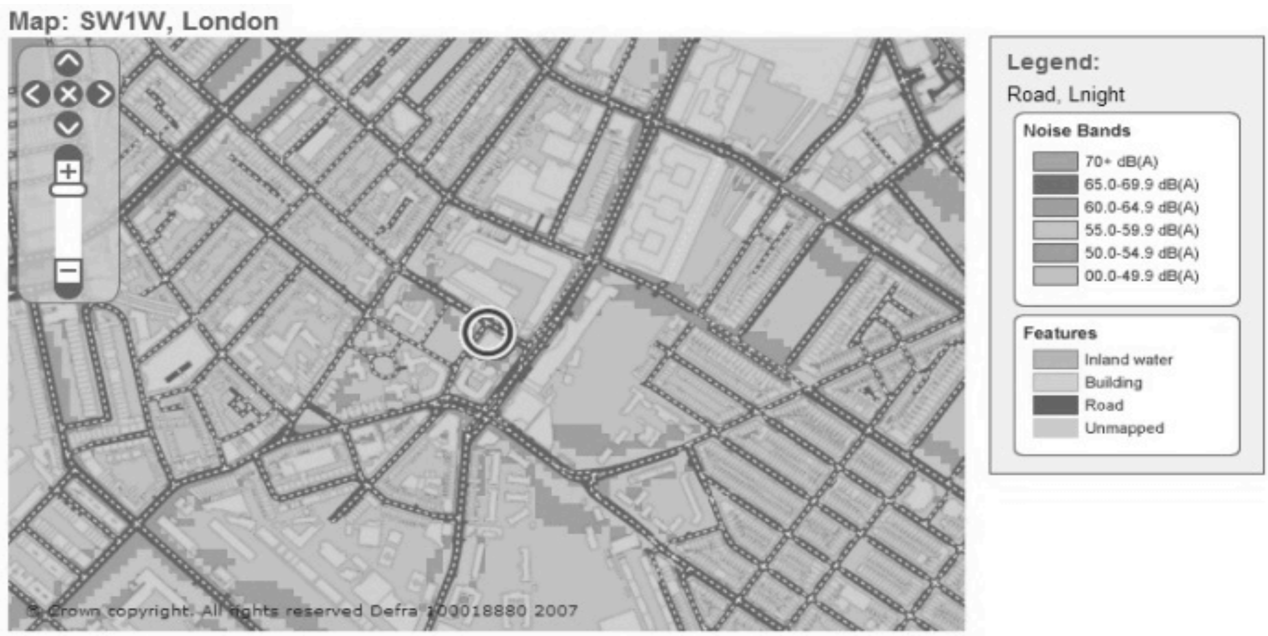
Fig. 12. Present indicator: L_{night} (Champs – 1, Ecole – 2, Bercy – 3) from 22:00 till 6:00 [17]
Rys. 12. Prezentacja wskaźników (Champs – 1, Ecole – 2, Bercy – 3)) od 22:00 do 6:00 [17]

Option 02: metro and coach

Fig. 13 shows the noise mapping results for the rail-coach combination in option 02. Both L_{den} and L_{night} have been obtained.



L_{day}

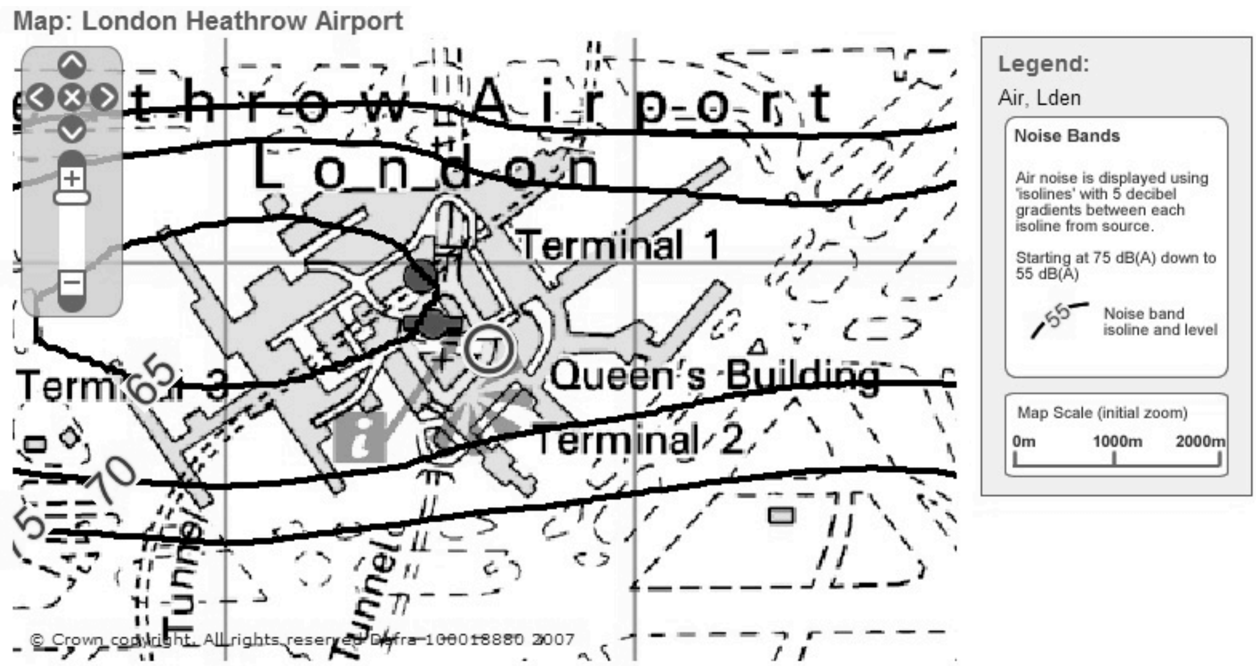


L_{night}

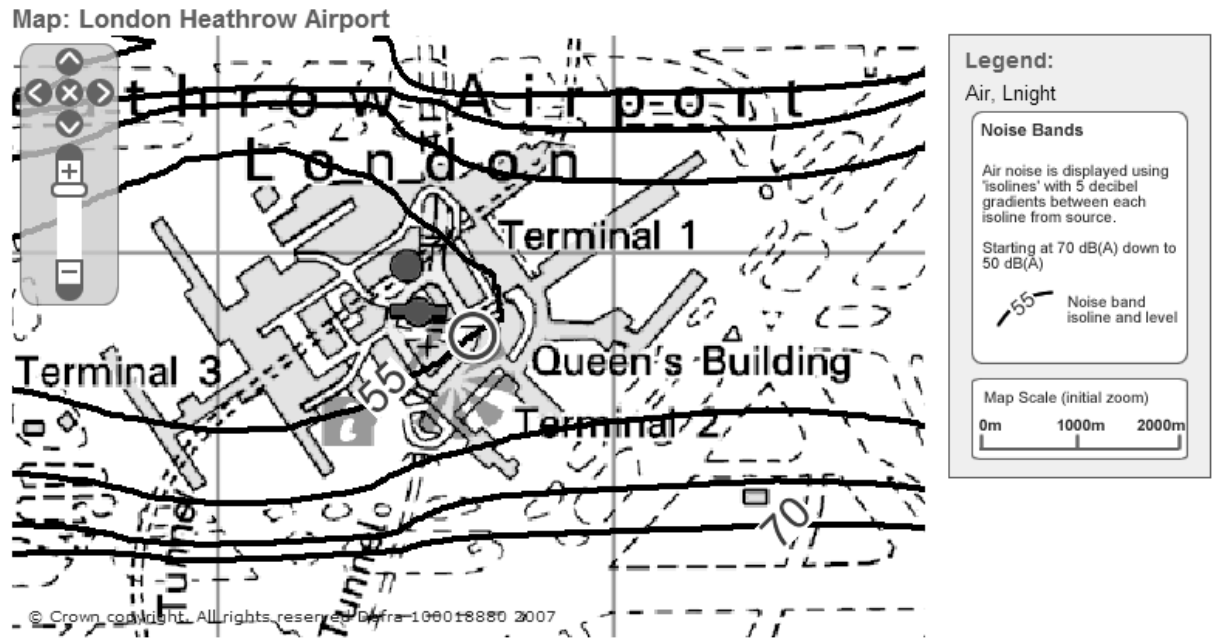
Fig. 13. Present indicator: L_{day} and L_{night} - Victoria Coach Station (source: DEFRA) [16]
Rys. 13. Prezentacja wskaźników L_{day} and L_{night} - Victoria Coach Station (źródło: DEFRA) [16]

Option 03: metro and airplane

Figs. 14 and 15 show the noise mapping results for the rail-air combination in option 03. Both L_{den} and L_{night} have been obtained.



L_{den}



L_{night}

Fig. 14. Present indicator: L_{day} and L_{night} - Heathrow Terminal 1 (source: DEFRA) [16]
Rys. 14. Prezentacja wskaźników L_{day} and L_{night} - Heathrow Terminal 1 (źródło: DEFRA) [16]

A summary of the results per option is shown in Fig. 16.

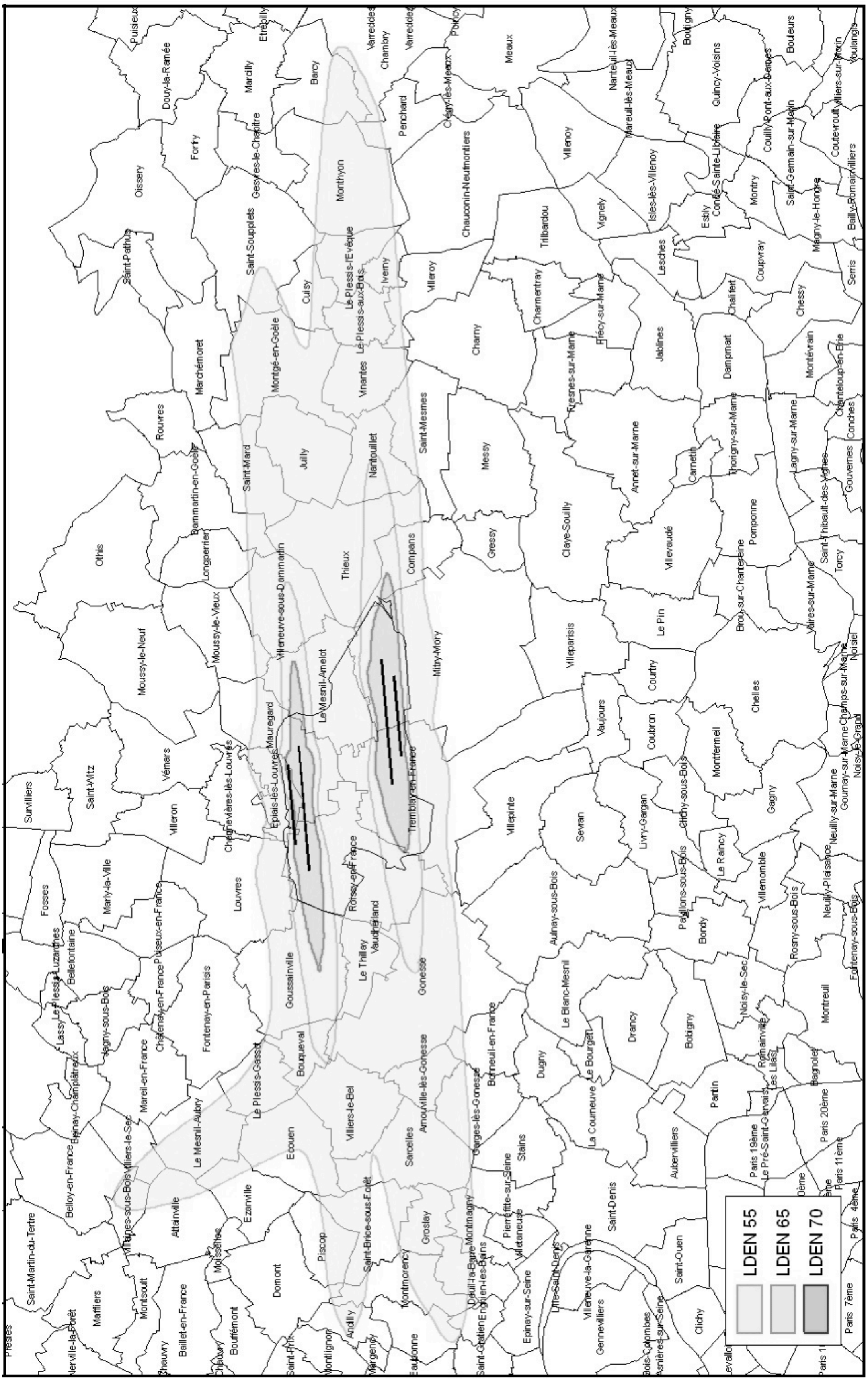


Fig. 15. Present indicator: L_{day} - Charles de Gaulle (CDG) [18]
Rys. 15. Prezentacja wskaźników L_{day} - Charles de Gaulle (CDG) [18]

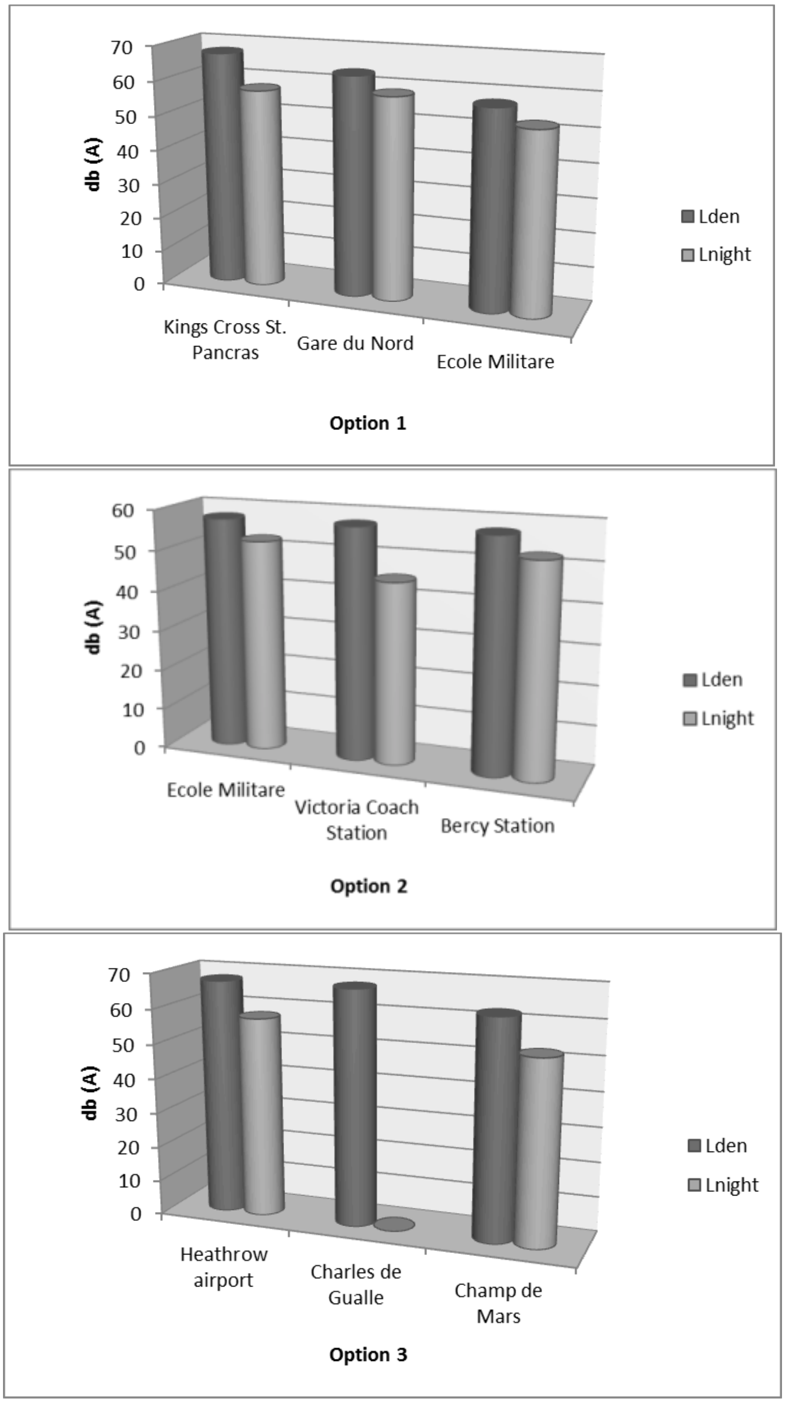


Fig. 16. Level of noise pollution – three options for travel
Rys. 16. Poziom hałasu – trzy warianty podróży

The outcomes show option 02 is the preferred choice. However, given the assumptions made there is a high possibility that the results might be distortioned leading to certain inaccuracies. For instance, there is no sufficent information on the noise propogation of underground services meaning that only station noise data has been used for the urban rail sections of the trips.

In determining the best option and the most environmentally friendly transport, the following issues have to be also considered in addition to the noise levels presented here.

- Railway noise is less annoying than that produced by the road and air transport;

- Railway noise is usually restricted to narrow corridors and limited to areas around railway lines in comparison with road and air transport which has a wider spatial use and reach;
- Railway produce less noise per journey than road: Comparisons of modal split versus noise show that railway noise affects significantly fewer people per transported person or tonne carried [14];
- Railway in the UK (including London) operate under different technical specification from the rest of Europe. This is a legacy of the pre-Channel Tunnel period where no direct links with the continent was available. This meant that the types of brakes used already produce a mitigation effect making them a very effective noise abatement measure [19]

6. CONCLUSION

This paper has attempted to show the environmental characteristics of railways when compared with other modes on a specific travel corridor. The results show that a rail-only option for travelling between central London and central Paris is the most environmental choice when combining the energy and emissions performance with noise pollution levels. Option 01 is four times less CO2 intensive compared to option 02 (coach as main transport mode) and eight times less intensive compared with the airplane option (option 03). NOx and PM values are also much lower in option 01 compared with the other two.

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