PROJET EQUILIBRE
avancer ensemble

Analysis of the fuel consumption and CO_2 and NOx emissions of trucks powered by natural gas or diesel

Report - April 2018

SUMMARY

1. CONTEXT

As part of the Equilibre Project, 15 heavy goods vehicles (HGVs) weighing between 19 and 44 tonnes were fitted with a device analysing their environmental performance in real-life conditions. The data from 12 of them finally could be processed, in order to meet all the scientific criteria imposed by the specifications. The purpose of this project is to measure the fuel consumption and CO_2 and NOx emissions of HGVs powered by natural gas and diesel with a view to providing hauliers with guidance when making energy choices in line with their activities.
The vehicles fitted with the device travelled over one million kilometres in total between March 2016 and February 2018.

This report, which follows on from the mid-term report issued in April 2017, presents the new results achieved over the past 12 months. Although the methodology adopted by this study is not described here, it is outlined on the project's website:
www.projetequilibre.fr

This independent study has been certified by the CARA competitiveness cluster and was commissioned by a consortium of hauliers. It calls on the expertise of CRMT to fit the vehicles with the devices, and on IFSTTAR for processing the data.

2. INFLUENCING FACTORS

MAIN INFLUENCING FACTORS

Initial statistical analysis of the data by IFSTTAR highlighted three main influencing factors on average fuel consumption and pollutant emissions. These are:

- the frequency of acceleration (variations in speed), which depends on the type of road travelled (e.g. motorway, country road, urban road) through infrastructure and traffic conditions;
- the total ascent over the journey;
- the vehicle's total weight.

Detailed route analyses have been used to better profile how certain factors affect fuel consumption and emissions (e.g. road infrastructure, traffic and weather conditions previously covered by the acceleration frequency factor).

IMPACT OF ROAD INFRASTRUCTURE

With a view to understanding the impact of road infrastructure on emissions and fuel consumption, a more detailed analysis of a route was conducted on a 40-km-long stretch of motorway, encompassing a toll booth and roadworks requiring drivers to change lanes.

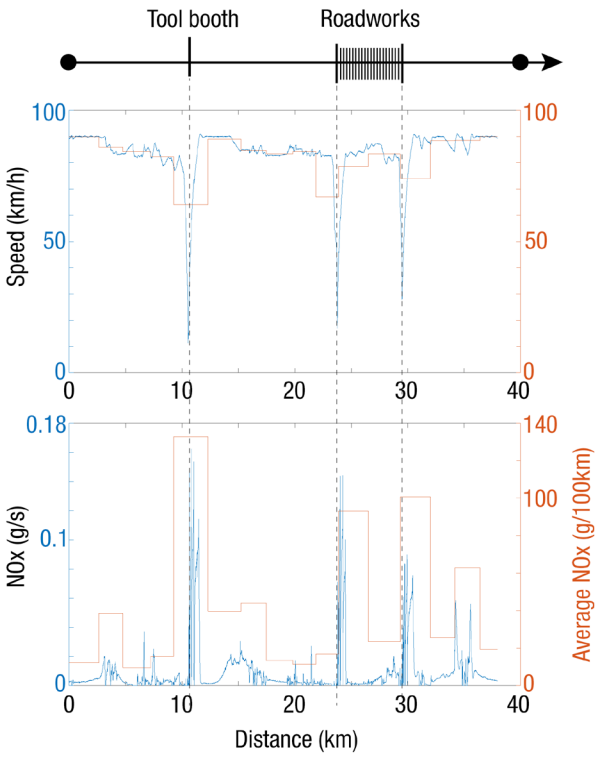
Fuel consumption on this section was measured over 30 separate journeys under similar load conditions (average GVWR of 26 tonnes). Regarding statistical representation, the results provided relate to a diesel vehicle, though the same patterns were observed in a 44-tonne natural gas tractor. The analysis of the results highlights the impact of road infrastructure on average fuel consumption and NOx emissions:

	Fuel consumption (L/100km)	NOx emissions (g/100km)
Journey without tool booth	27	15
Total normal journey	29	18
Total journey with roadworks	31	38

Including a toll booth or roadworks caused fuel consumption to rise by 7% and 15% respectively.

These areas of slowdown followed by acceleration have an even greater impact on NOx emissions, reflected in an increase in emissions of 20 and 150%.

As shown in the example opposite, over the 40-km-long section of road NOx was mainly emitted during transient phases at toll booths and when changing lanes. In other words, at a steady speed the device fitted on the vehicle showed that NOx emissions were under control, meaning that it was during transient phases (rapid acceleration) that most of the NOx was emitted; this is the same for both natural gas and diesel vehicles.



During these phases, engines naturally emit more NOx and the clean-up systems proved to be less efficient than when the vehicle was travelling at a steady speed.

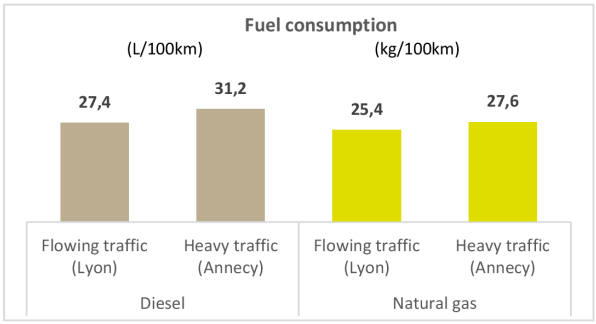
As such, the number of times a vehicle accelerates rapidly after slowing down on a journey has a major impact on its fuel consumption and NOx emissions.

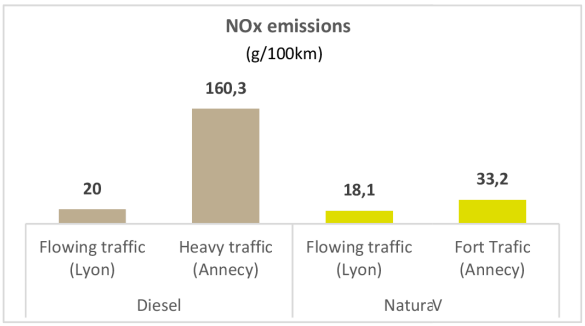
Given the difficulty in quantifying the number of times a vehicle accelerates (as this is too contingent on the driver and type of journey), the number of instances of stop&go over 100 km is the criterion chosen as indicator of a journey's severity, as it involves a vehicle having to start up and accelerate.

IMPACT OF TRAFFIC

Road traffic could be expected to affect fuel consumption and pollutant emissions. The Equilibre Project has documented and calculated this impact in greater detail.

The comparison of the results obtained from two similar sites highlights this impact. Over almost two years, data from 44-tonne tractors travelling along the ring roads of Lyon and Annecy were analysed and the results obtained over close to 18,000 km were summarised in the graphs below.





In heavy traffic, on identical sections of road, at similar elevations and with similar loads, HGVs driving on congested roads consumed 10% more fuel (diesel or natural gas) than when traffic is flowing smoothly.

It is important to note that driving conditions in Lyon and Annecy vary, which explains the differences in the flow of traffic. Vehicles in Lyon operate early in the morning or late at night, unlike in Annecy, where vehicles travel the ring road during the day.

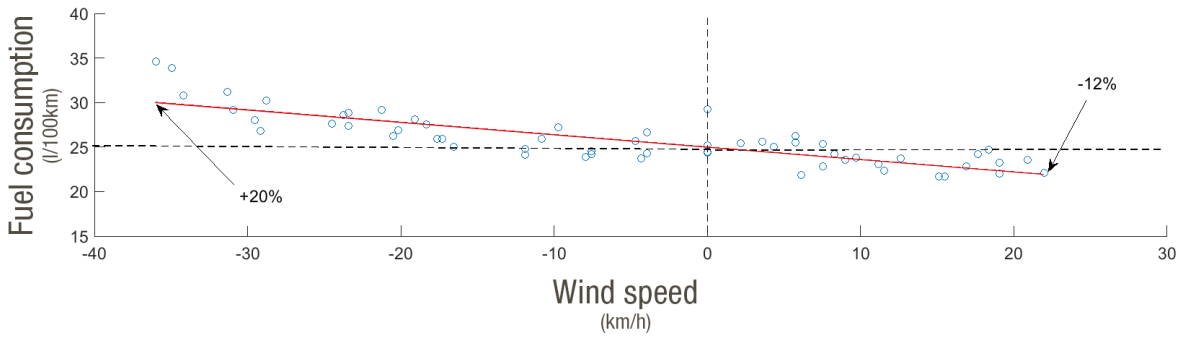
Though NOx emissions are comparable in flowing traffic for both types of engine (diesel and natural gas), in heavy traffic natural gas vehicles emit double the amount of NOx than in flowing traffic, while diesel vehicles emit eight times more NOx.

As such, having vehicles drive in flowing traffic could significantly limit NOx emissions.

IMPACT OF THE WIND

To understand the impact of the average wind speed, an extensive analysis was performed over 21 months on sections of the Orange-Valence motorway in both directions . This journey, taken 259 times in either direction in the same 44-tonne tractor, is regularly exposed to a north-south wind (i.e. hitting the middle of the road).

The graph below shows the consumption observed according to the direction and intensity of the wind (positive, downwind and negative, upwind).



[1] *The impact of gusts of wind was not studied during the project.*

Wind has a considerable impact on fuel consumption. When travelling downwind along the routes in question, consumption fell by 12%, while travelling upwind caused consumption to rise by 20%.

As for NOx emissions, the average wind speed did not appear to have an impact on the stretches of motorway in question, probably due to the optimum operation of the post-treatment system when driving at a virtually steady speed.

SUMMARY OF INFLUENCING FACTORS

Given the diversity of factors having an influence on fuel consumption and pollutant emissions, long-term measurements are needed to produce a representative overview of the average results produced by each vehicle and enable comparison. This is why the Equilibre Project is unique: having vehicles fitted with devices travel over one million kilometres means that the influence of factors such as traffic or certain weather conditions could be spread out, thus highlighting the intrinsic performance of the vehicles in real conditions for each use.

As such, the in-depth study of these factors (associated with infrastructure, traffic or wind speed) flagged up specific levers for vehicle operating conditions for each type of use with a view to reducing fuel consumption and pollutant emissions. These levers include the plotting and choosing of routes depending on the quality of infrastructure, incorporating traffic and the weather, the vehicle's aerodynamics or the number of stops or manoeuvres.

3. RESULTS

The experiment was performed over two years under operating conditions and involved three 19-tonne natural gas HGVs made by Iveco, Renault and Scania and nine 44-tonne natural gas and diesel tractors manufactured by Daf, Iveco, Scania and Volvo.

Since this study is not intended to compare different vehicle brands, the results were made anonymous by assigning a letter to each vehicle.

- A to C: 19-tonne natural gas HGVs only
- D to H: 44-tonne natural gas tractors
- I to L: 44-tonne diesel tractors

19-TONNE NATURAL GAS HGVS

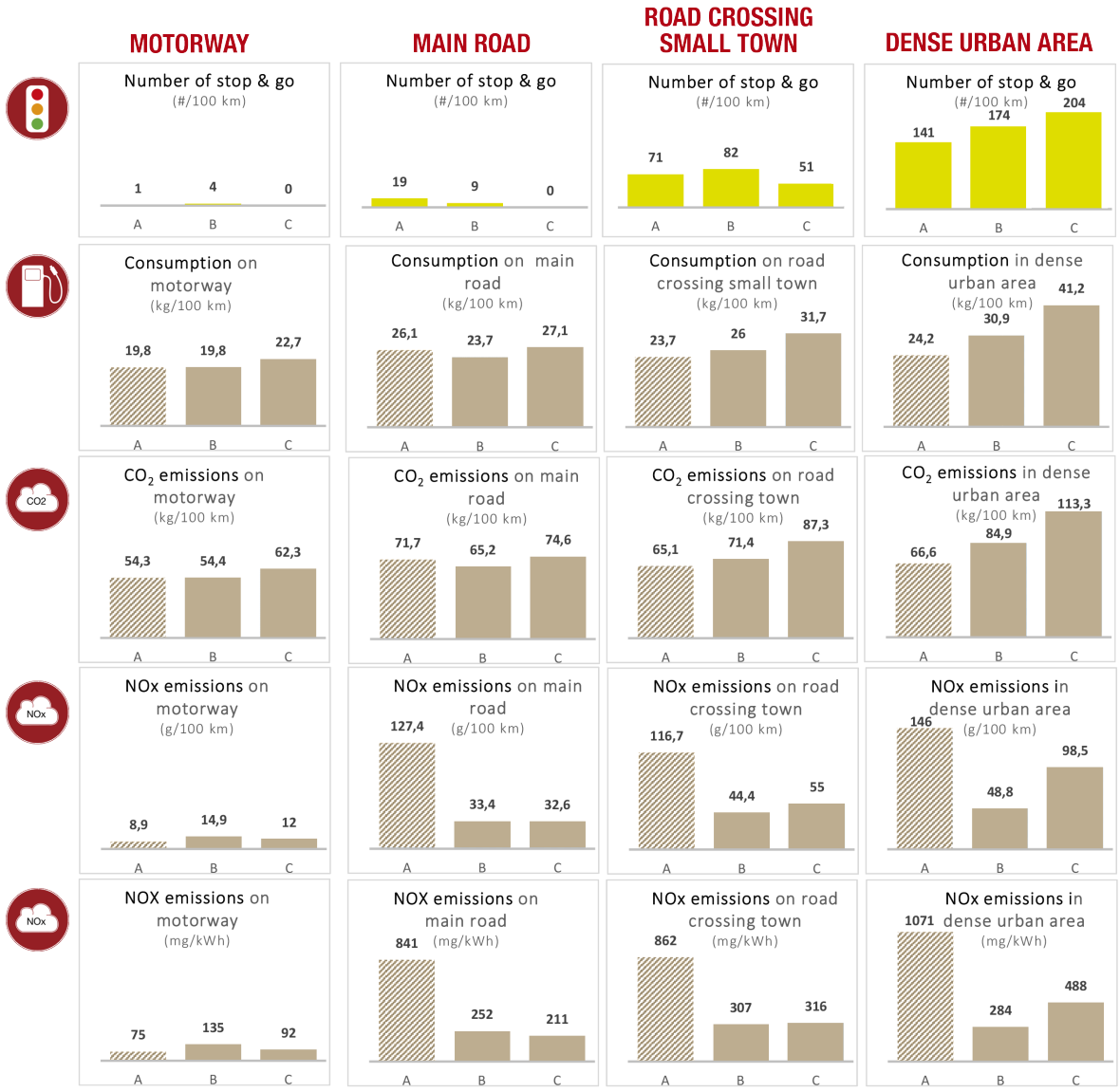
Each vehicle's fuel consumption and pollutant emissions were reviewed, with a distinction being drawn between the road categories (from all the influencing factors). The table below shows the distances travelled (in km) by each vehicle on each of the different road types:

	A	B	C
Category 1: Motorway	8385	27894	534
Category 2: Main road	1393	10375	4131
Category 3: Urban expressway	0	7197	4
Category 4: Road crossing a small town	26868	15767	11115
Category 5: Road in a dense urban area	500	6364	1551

DISTANCE TRAVELLED BY EACH VEHICLE ON EACH OF THE DIFFERENT ROAD TYPES (IN KM)

Where a value is shown in red, this indicates that the distance covered was too low for significant results to be obtained for the road category or vehicle. As such, these values were not included in the analysis.

As the average gross weight of the three vehicles fitted with devices were relatively similar (between 11.7 and 13.6 tonnes), they were not included in the table of results.



It is important to remember that these results do not include manoeuvring, or loading and unloading operations. As such, the number of instances of stop & go, particularly in dense urban areas, corresponds to the traffic conditions (congestion), the type of operations performed and the route taken (traffic lights, stop signs).

Vehicle A shows abnormally high NOx emissions. The Equilibre Project has alerted the manufacturer and is waiting for this issue to be rectified.

Without a 19-tonne diesel HGV, it is difficult to qualify the environmental performance of natural gas HGVs. However, with regard to the performances observed, it appears that fuel consumption and emissions worsen in built-up and dense urban areas. This corresponds to the most discriminatory type of road for comparing and highlighting the respective performance of the HGVs.

RESULTS OBTAINED FROM 44-TONNE NATURAL GAS AND DIESEL TRACTORS

Like for the 19-tonne HGVs, fuel consumption and pollutant emissions were assessed for each vehicle and road category. The following table details the distance travelled by each natural gas (in black) and diesel vehicle (in white).

In light of the measurements taken during the project and the abnormally high results concerning NOx emissions, the manufacturer was required to intervene with regard to vehicles F, G and I following an alert issued by the Equilibre Project. Vehicles marked with a * represent the results for the vehicles following the manufacturer's intervention.

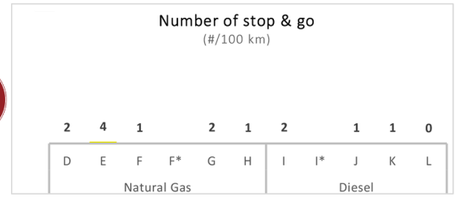
	D	E	F	F*	G	H	I	I*	J	K	L
Category 1: Motorway	14531	12606	54237	2870	1552	100814	70782	16779	139152	25187	50061
Category 2: Main road	17883	24257	3541	192	1081	13915	17295	6516	12978	1201	4405
Category 3: Urban expressway	56	605	518	0	297	12566	10561	2502	4133	69	1277
Category 4: Road crossing a small town	47899	27738	6041	335	1139	3246	12209	6753	23837	3980	8430
Category 5: Road in a dense urban area	5194	4249	238	5	220	10763	8104	1787	1470	203	431

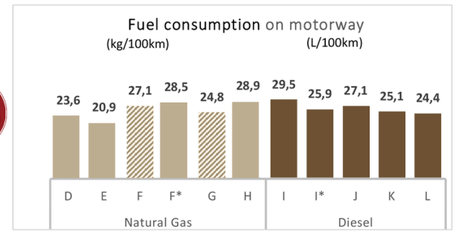
DISTANCE TRAVELLED BY EACH VEHICLE ON EACH OF THE DIFFERENT ROAD TYPES (IN KM)

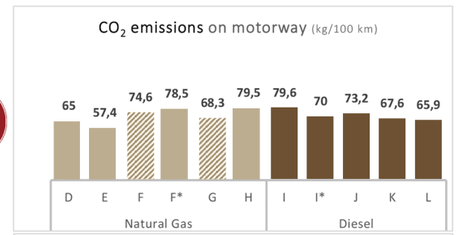
Where a value is shown in red, this indicates that the distance covered was too low for significant results to be obtained for the road category or vehicle. As such, these values were not included in the analysis.

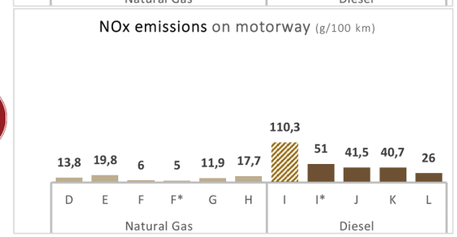
RAW RESULTS FOR THE 44-TONNE TRACTORS

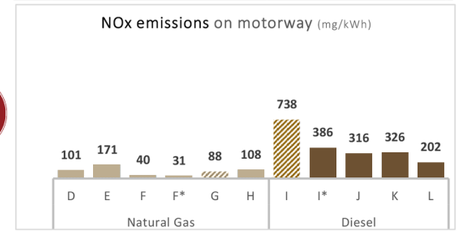
MOTORWAY



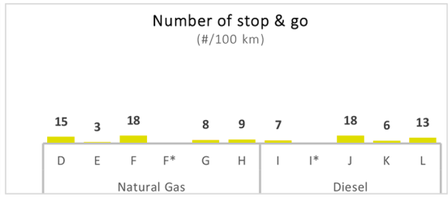


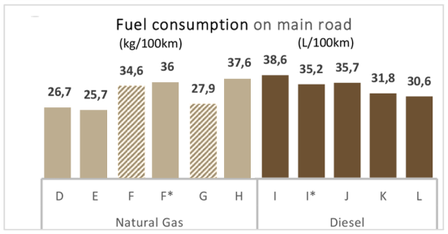


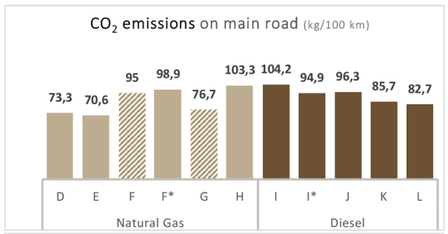


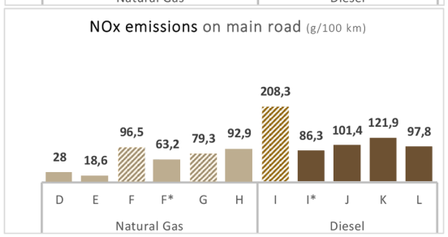


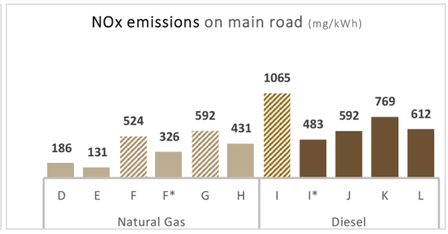
MAIN ROAD



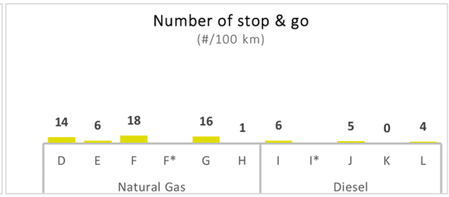


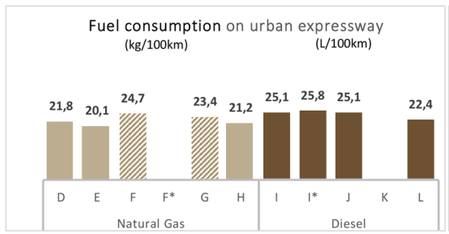


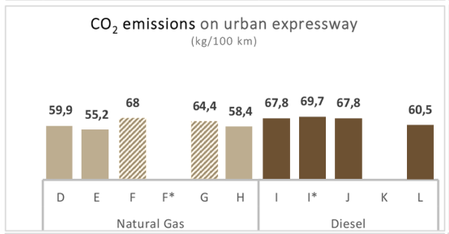


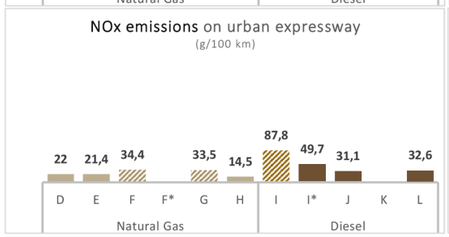


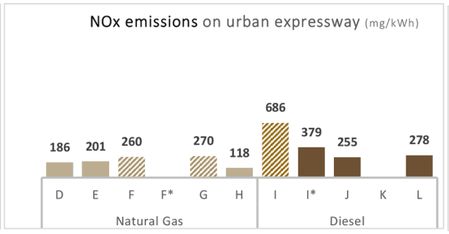
URBAN EXPRESSWAY



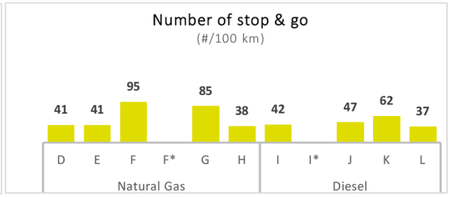


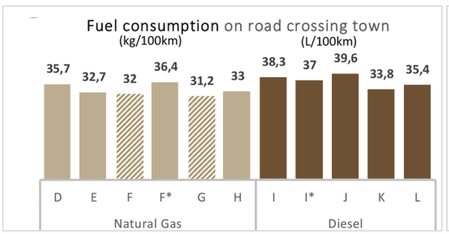


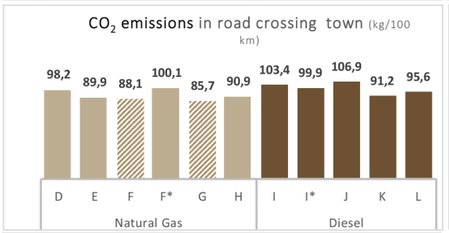


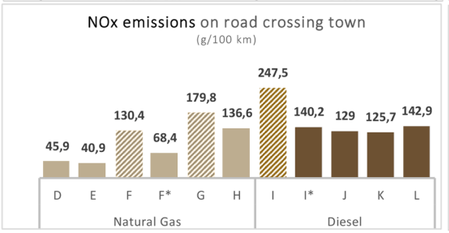


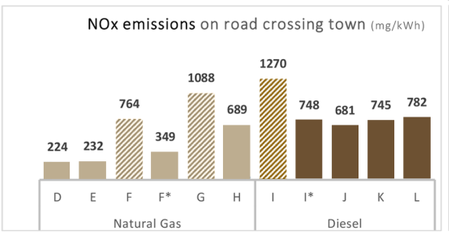
ROAD CROSSING A SMALL TOWN



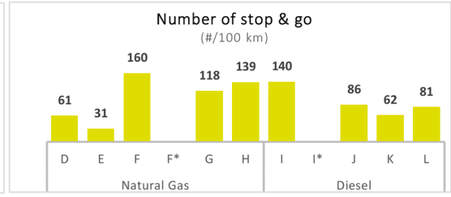


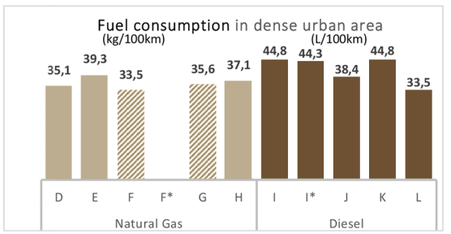


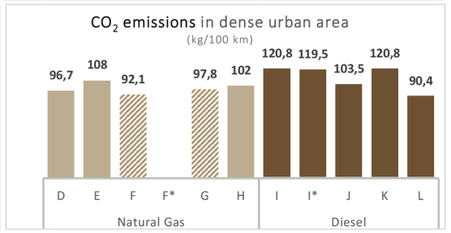


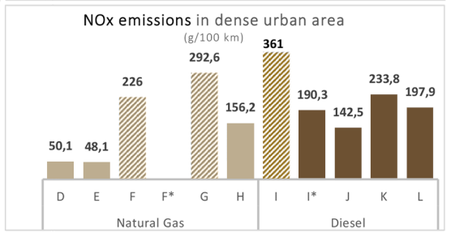


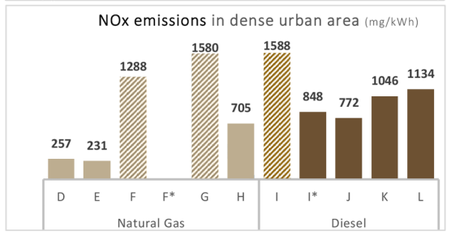
DENSE URBAN AREA











INTERPRETING THE RAW RESULTS

We note that the more a vehicle's behaviour varies (urban area vs motorway) the worse the CO_2 and NOx emissions. In contrast, though levels of fuel consumption and CO_2 emissions appear similar on the different types of roads, NOx emissions remain more contained in natural gas vehicles than diesel ones when conditions become more strenuous (dense urban area).

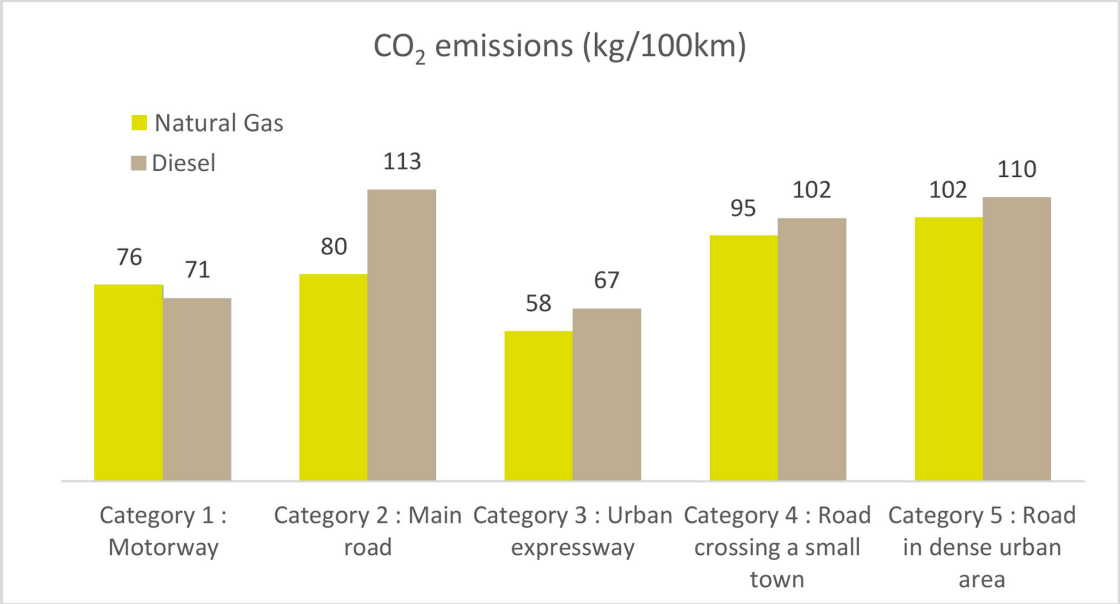
The previous report flagged up inconsistent data on one of the 44-tonne diesel tractors (vehicle I), resulting in abnormal levels of NOx emissions. Once the emission control system had been replaced, the performance noted (vehicle I*) again aligned with the rest of the results.

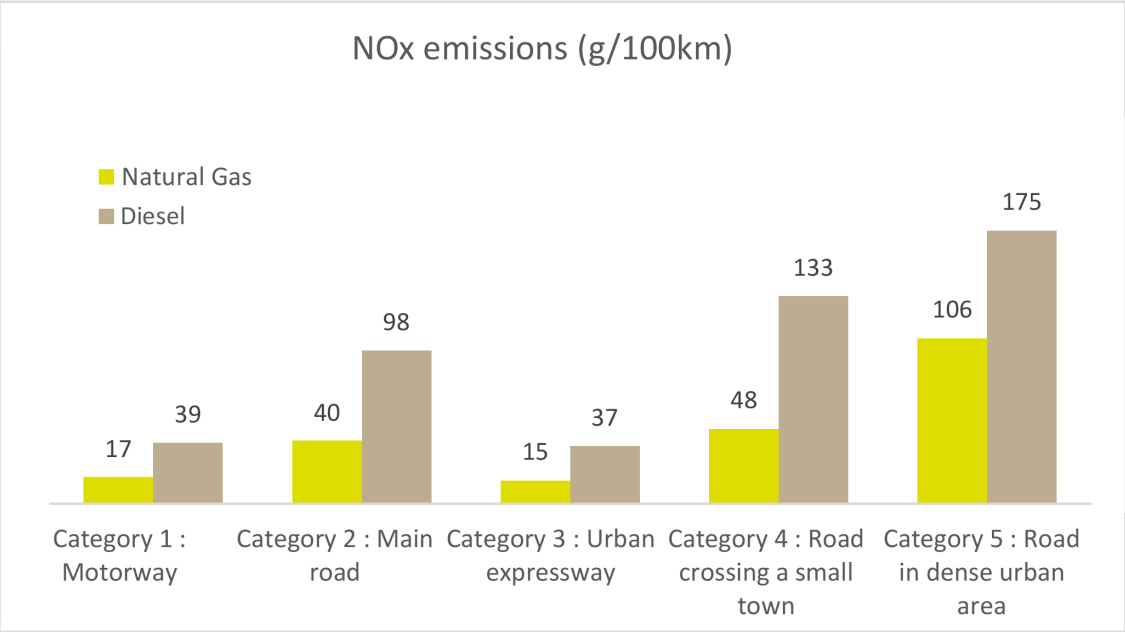
Vehicles F and G fell in line with the standard, though initial measurements revealed high levels of NOx in urban areas compared with the other vehicles in the study. Alerted by the Equilibre Project, the manufacturer developed a corrective solution and suggested testing it on vehicles F and G. Recent measurements of vehicle F (recorded as F*) show a drop in NOx emissions thanks to this solution. This improvement, observed over more than 3,000 km, will have to be confirmed with forthcoming results from vehicle G.

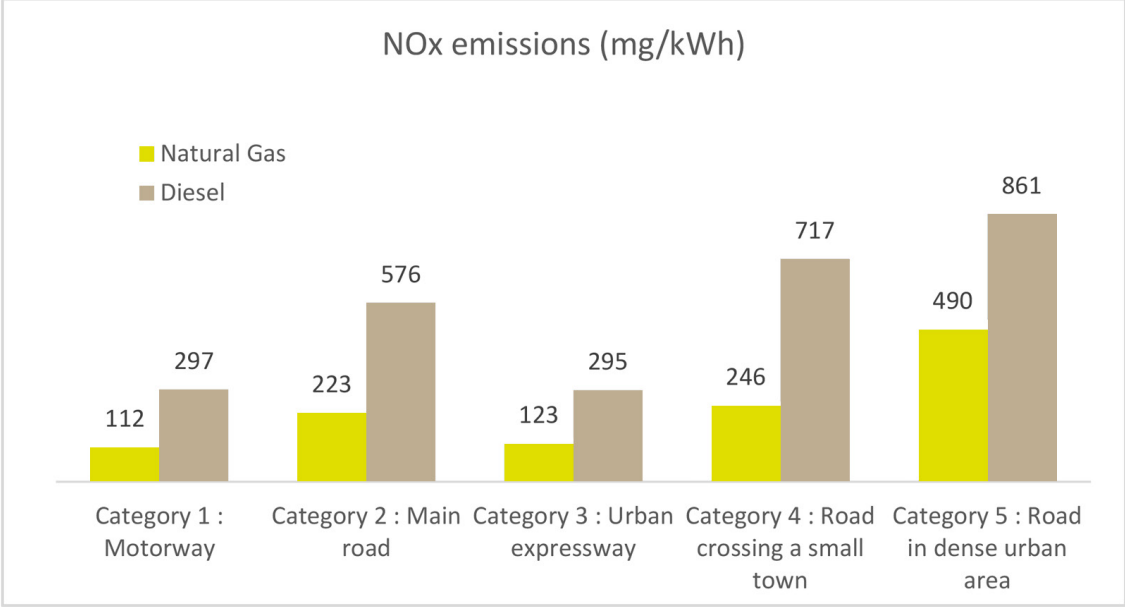
SUMMARY OF RESULTS FOR THE 44-TONNE TRACTORS

The duration of the study and the number of kilometres travelled by the vehicles enables comparison of the CO_2 and NOx emitted by natural gas and diesel vehicles by spreading the influence of certain factors having significant but intermittent impact under very specific conditions (e.g. weather, traffic, infrastructure).

These results, as shown in the graphs below, correspond to the weighted averages across all 44-tonne vehicles in the Equilibre Project, excluding the glitches noted.


CO_2 emissions (kg/100km)
Natural Gas
Diesel
76
71
80
113
58
67
95
102
102
110
Category 1 : Motorway
Category 2 : Main road
Category 3 : Urban expressway
Category 4 : Road crossing a small town
Category 5 : Road in dense urban area


NOx emissions (g/100km)
Natural Gas
Diesel
17
39
40
98
15
37
48
133
106
175
Category 1 : Motorway
Category 2 : Main road
Category 3 : Urban expressway
Category 4 : Road crossing a small town
Category 5 : Road in dense urban area


NOx emissions (mg/kWh)
Natural Gas
Diesel
112
297
223
576
123
295
246
717
490
861
Category 1 : Motorway
Category 2 : Main road
Category 3 : Urban expressway
Category 4 : Road crossing a small town
Category 5 : Road in dense urban area

CONCLUSION

The second year of the study honed the influencing factors and quantified the impact of types of infrastructure (toll booths, roadworks, traffic lights, stop signs) on fuel consumption and CO_2 and NOx emissions. The particular effect of the wind has also been quantified on a motorway, as has the impact of the flow of traffic on a stretch of urban expressway.

The summary of these results shows that 44-tonne natural gas tractors emit between 40 and 64% less NOx than 44-tonne diesel tractors depending on the type of road in question. CO_2 levels, mostly to the advantage of natural gas, totalled between +7 and -20%.

PROJECT TEAM PUTS THE RESULTS INTO PERSPECTIVE

The results provided in this report, which summarises close to two years of data collected in real-life situations and represents 1,000,000 kilometres travelled (500,000 of which were selected for analysis), highlight an element crucial to understanding the considerable variability in the energy consumption and emissions of HGVs: transient phases. These are periods during which a vehicle speeds up considerably, like when leaving a parking spot, moving away from a traffic light or stop signal, or when infrastructure (e.g. toll booths, roadworks, winding roads, roundabouts) or traffic (congestion) requires a vehicle to vary its speed.

As such, it should be kept in mind that these phases are not limited to urban areas; they can be encountered at any time in the day-to-day use of a vehicle. Hauliers are fully aware of this phenomenon. The Equilibre Project provides for a better understanding of these phases, which significantly impact a truck's fuel consumption and, in certain situations, pollutant emissions, and enables accurate profiling. The Equilibre Project's next and final publication will focus on ranking these influencing factors according to operating conditions.
This will take into account the results provided in this report, the different technologies and type of energy consumed, responding in different ways depending on the changes in speed.

The experiment shows that, when it comes to 44-tonne vehicles, diesel and natural gas have very similar levels of energy consumption in "billing units" (kilogrammes or litres). Looking at the current performance of gas engines, the advantage offered by natural gas as a fuel when it comes to CO_2 emissions is moderate, given the tank-to-wheel value. In contrast, things look very positive for NOx emissions: in all instances of use, natural gas demonstrated its potential in effectively reducing these emissions by using a relatively simple clean-up system.

The Equilibre Project has verified that the promise made by suppliers to hauliers was reliable and truthful and, when a problem was noted, resulted in a corrective solution from the manufacturer in question.
These already encouraging results could be amplified if:

- *Natural gas engines saw their energy yield improve (currently 37-38% for natural gas compared to 43-44% for diesel) - an increase of several percentage points would result in a very significant consumption gain;*
- *Natural gas engines evolved towards an ultra-low level of pollutant emissions (Ultra Low NOx project) to satisfy expectations at local level and align with the future direction of public policy.*

In light of the challenges faced by road freight, hauliers and manufacturers have a shared interest in making this a reality.

PROJET EQUILIBRE

A project by road hauliers, for road hauliers.

Participants

Transports Magnin – National & International
megevand Frères – Transport Logistique
PRABEL – www.prabel.com
SOTRADEL – les solutions logistiques
G7
JP Jacky Perrenot
ENGIE
TRANSALLIANCE

Partners

ADEME – Agence de l'Environnement et de la Maîtrise de l'Energie
GRDF
CARA – European Cluster for Mobility Solutions
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Liberté • Égalité • Fraternité – République Française – Direction régionale de l'Environnement, de l'Aménagement et du Logement – Rhône-Alpes
TRUCK ONLINE
GRANDLYON
CRMT Powertrain R&D
IFSTTAR
GNV – Association Française du Gaz Naturel pour Véhicules

Members of Equilibre association

Auchan
François Cholat – depuis 1877
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