PROJET EQUILIBRE
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# Analysis of the fuel consumption and CO2 and NOx emissions of 44-tonne natural gas and diesel semi-trailer trucks

Mid Term Report | April 2017

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# BACKGROUND

A study has been launched on the environmental performance and fuel consumption of various diesel and natural gas vehicles as part of the Equilibre project. The aim is to measure the fuel consumption and CO2 and NOx emissions of a fleet of fifteen vehicles (ten natural gas vehicles and five diesel vehicles) under actual operating conditions over a period of one year.

The study is independent and was commissioned by a consortium of hauliers.

This is a mid-term report, which covers the first six months of tests and sets out the preliminary results obtained from data for the first six trucks (three diesel and three natural gas), all of which had a GCWR of 44 tonnes[1].

For more information about the Equilibre project, visit : **www.projetequilibre.fr**

[1] *Gross Combination Weight Rating*

# METHODOLOGY

The first six Euro VI vehicles selected for analysis were three CNG/LNG semi-trailer trucks and three diesel semi-trailer trucks. The manufacturers of these vehicles were DAF, Iveco, Scania and Volvo.

## INSTRUMENTS ON BOARD THE VEHICLES

CRMT[2] and TruckOnline[3] equipped each vehicle with the instruments needed to gather the information required for the study throughout the entire duration of the testing phase (12 months). Each vehicle is fitted with a built-in box that retrieves information from the vehicle's computers, picks up the signals from the NOx probes installed in the exhaust system for the purposes of the test, and records the exact location of the truck using information provided by a GPS sensor specially installed for the study. The built-in system records these data every 200 milliseconds.


## DATA SOURCE

The analysis in this report is based on three data sources:

- » information supplied by the vehicles' on-board computers and the special instruments installed for the study;
- » information collected from logbooks (coupling, uncoupling, loads transported, refuelling, and so on);
- » information about the journey type (road type, public/private).

The information that was collected was linked to 'basic sections'. The 400,000 km of road analysed for the study was divided into 3,600,000 different 'basic sections', which may be identified based on data from IGN[4] (see the annex for more details and an example).

*[2] Centre for Research in Thermal Machines, www.crmt.fr*

*[3] Fleet Management Solution, www. truckonline.pro*

*[4] French National Institute of Geographic Information, www.ign.fr*

# METHODOLOGY (REST)

## MAIN INFLUENCING FACTORS

The main factors influencing the vehicles' fuel consumption and pollutant emissions are speed, acceleration, weather conditions, gross vehicle weight, driver, road type, ascent/descent, and traffic conditions.

Initial statistical analysis of the data by IFSTTAR[5] indicated that the vehicles could be compared on the basis of three of these factors:

The road type (e.g. motorway, country road, urban road) which is characterized by the frequency of acceleration (variations in speed).

the total ascent over the journey


the gross vehicle weight

[5] *French Institute of Science and Technology for Transport, Development and Networks, www.ifsttar.fr*

# METHODOLOGY (REST)

## DESCRIPTION OF SELECTED INFLUENCING FACTORS

### Road type

IFSTTAR used data supplied by IGN and INSEE[6] to place each section of the road network in one of five road categories:

- » **Category 1 :** Motorway-type roads (motorways, dual carriageways)
- » **Category 2 :** 'Country' roads (non-motorway, non-urban)
- » **Category 3 :** Urban expressways
- » **Category 4 :** Roads crossing small towns
- » **Category 5 :** Roads in highly built-up urban areas (lots of stopping and starting)

98% of the journeys undertaken by the vehicles were covered by the road categories listed above. The remaining journeys corresponded to manoeuvres, loading/unloading operations, coupling/uncoupling operations, or journeys on roads for which there was insufficient data on IGN maps.

### Ascent/descent

An average ascent/descent was calculated for each road section. Only ascent was considered to be an influencing factor, given its significant impact on fuel consumption and pollutant emissions.


### Gross vehicle weight

The gross vehicle weight and variations therein over the course of an assignment were determined based on statements from the hauliers. Consistency checks were carried out by weighing the vehicles to ensure that the data were reliable.

*[6] French National Institute of Statistics and Economic Studies*

# INITIAL RAW RESULTS

Testing was carried out, under actual operating conditions, for six months. Since it is not this study's intention to compare different vehicle makes, the results were made anonymous by assigning a number to each vehicle (1 to 3 for the natural gas vehicles, and 4 to 6 for the diesel vehicles).

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.

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

| | Vehicle | | | | | |
|---|---|---|---|---|---|---|
| **Road categories** | 1 | 2 | 3 | 4 | 5 | 6 |
| Category 1 **Motorway** | 4469 | 2248 | 14614 | 50513 | 18064 | 36271 |
| Category 2 **Country road** | 3998 | 10444 | 1540 | 4620 | 620 | 5504 |
| Category 3 **Urban expressway** | 13 | 79 | 1416 | 1875 | 19 | 4966 |
| Category 4 **Road crossing a small town** | 20050 | 10673 | 452 | 7979 | 3044 | 1145 |
| Category 5 **Road in a highly built-up urban area** | 1348 | 1631 | 1051 | 524 | 68 | 3983 |

Where a value is shown in red, this indicates that the distance covered at this stage in the study 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.

# INITIAL RAW RESULTS (REST)


*Data inconsistent at this stage – further study required. Vehicle excluded from analysis until additional information becomes available*

# INITIAL RAW RESULTS (REST)

It is important to remember that these results do not include manoeuvring, or loading and unloading operations. This may explain the differences between the values shown here and commonly observed consumption figures, especially in urban areas. For instance, over the course of a 100-km journey with lots of stops, a natural gas vehicle may consume 3 to 4 kg of fuel while manoeuvring, loading and unloading. Diesel vehicles behave similarly.

## NATURAL GAS CONSUMPTION – RAW DATA

| Typical Route | Consumption while maneuvring (kg) | Total consumption (kg) | Consumption while maneuvring (%) |
|---|---|---|---|
| Savoie | 906 | 12262 | 7.4 |
| Ain & Lyon | 1093 | 9116 | 11.6 |
| Auvergne-Rhône-Alpes | 199 | 6612 | 3.0 |

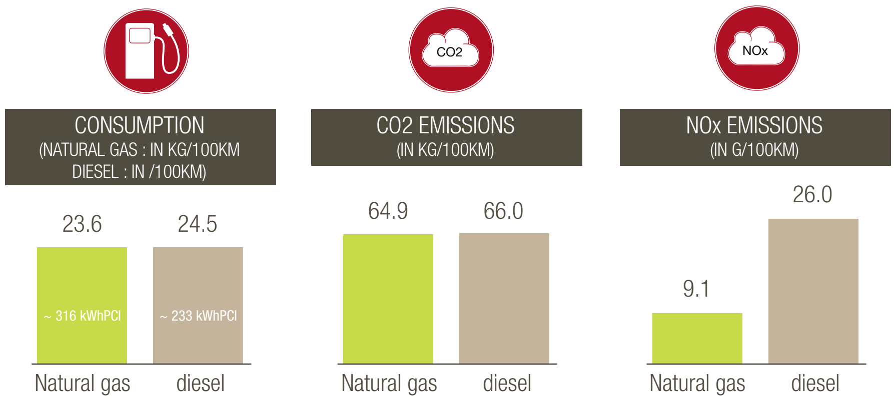
It is also worth noting that, under actual operating conditions, the five vehicles that have delivered usable data so far all have NOx emission values that come in below the limit value set by the Euro VI ISC (In-Service Conformity) standard.

# COMPARISON OF NATURAL GAS / DIESEL VEHICLES ON SIMILAR ROAD CATEGORIES

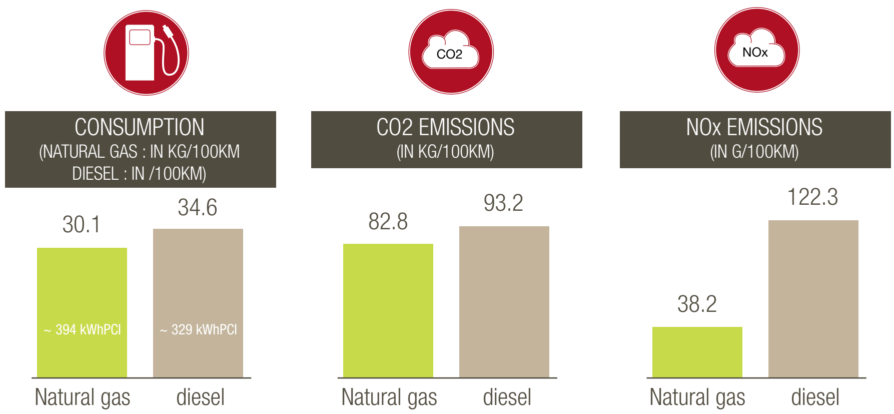
In order to compare results for the two engine types (diesel and natural gas), average results need to be calculated for the diesel vehicles and for the natural gas vehicles.

The initial results presented here refer to flat sections of motorways or roads crossing small towns, as focusing on these sections limits the influence of the gross vehicle weight (see the annex for more details). A more detailed, more exhaustive analysis of all road types will be presented at a later stage, when enough data has been gathered to arrive at a reliable conclusion.

The figures shown below are averages for the engine type in question, each vehicle's consumption having been recalculated by road category for the selected sections.




Average observed for sections classed as motorways




Average observed for sections classed as roads crossing small towns

# CONCLUSION AND OUTLOOK

The preliminary results for this first part of the Equilibre project, which relate to 6 of the 15 vehicles being studied, confirm what was already known about fuel consumption and pollutant emissions: diesel vehicles and natural gas vehicles perform similarly (**or natural gas vehicles perform slightly better**) in terms of fuel consumption and CO2 emissions when driving on motorways or roads crossing small towns. However, **natural gas vehicles emit far less NOx** than diesel vehicles (around three times less on motorways, and almost four times less on roads crossing small towns).

It should be noted that the average values produced above refer to the operational performance of the audited truck fleet and do not claim to be statistically representative of all forms of use.

A more detailed study on fuel consumption and emissions now needs to be conducted to flesh out this initial analysis. This study should take account of the main observable variables (road type, ascent/descent, and gross vehicle weight), as well as the specific characteristics of the journeys undertaken (e.g. average speed, traffic conditions, number of stops and starts) and the impact of other influencing factors.

This analysis will be based on more data collected from 44-tonne semi-trailer trucks. It will also provide more information about vehicle no. 6, which was temporarily excluded from the analysis. The study will also be supplemented with data from 19-tonne diesel and natural gas straight-body trucks.

Taken together, these results will feed into the development of models to predict vehicles' fuel consumption based on their gross weight and the journey they are undertaking. Ultimately, this will make it possible to compare vehicles under similar conditions of use, and thus determine which engine type would be most appropriate for which type of assignment.

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# ANNEX

**Distance travelled :** This is calculated based on GPS readings, then cross-checked against road databases and the vehicle's odometer. The degree of uncertainty is less than 1%.

**Fuel consumption and CO2 emissions :** For diesel vehicles, data on fuel consumption are retrieved from the vehicle computer (through the CAN bus). The CO2 emissions are calculated on the basis of standard diesel composition. After verification and calibration, the degree of uncertainty for these data is less than 2%.

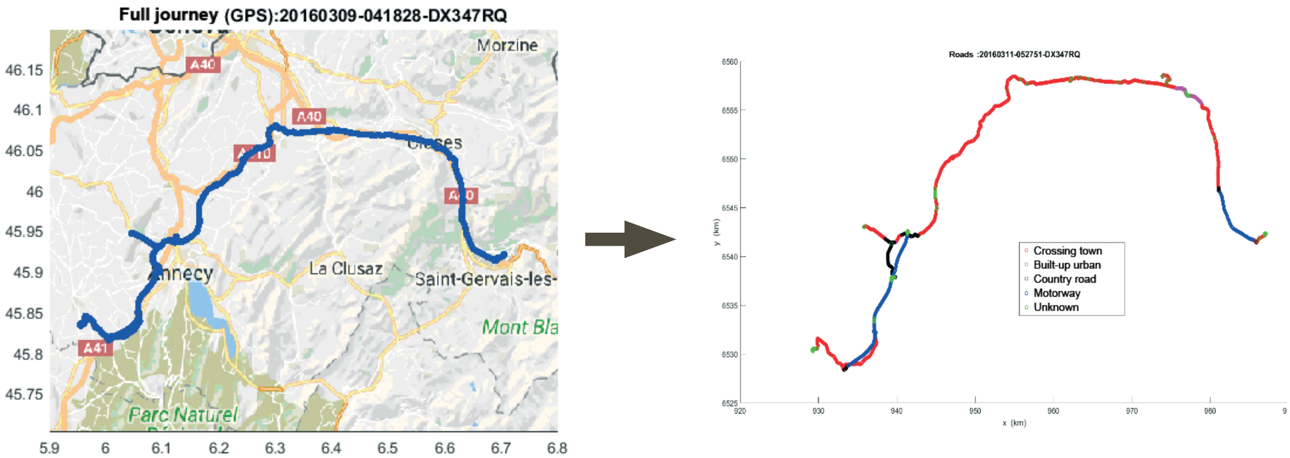
For gas vehicles, the engine's fuel consumption and CO2 emissions must be mapped for each vehicle in the study before testing begins. This entails carefully measuring the fuel consumption and CO2 output for all possible combinations of torque and power setting using a heavy-duty device (PEMS). Once this information is mapped, the fuel consumption and CO2 output can be reconstructed based on the power settings and engine load. Corrections are then performed to take account of variations in gas quality when the vehicle is refuelled. Finally, checks are performed to make sure the calculations match up with the operators' statements regarding refuelling. The degree of uncertainty is less than 3%.

**NOx :** Data are measured by a probe fitted to the exhaust system for the purpose of the test. This probe was calibrated and verified during testing to prevent any drift. The degree of uncertainty is less than 3%.

**IFSTTAR's substantial work on categorising the journeys :** The entire study is based on post-hoc reconstruction of a vehicle's path, so that variations in fuel consumption and emissions can be assigned to a journey.

**Segmentation :** A section is considered to be flat if it has a gradient of 1% or less. By only taking these sections into account, IFSTTAR has ensured that the gross vehicle weight will not influence the fuel consumption or emissions. This allows vehicles' fuel consumption and emission levels to be compared in similar situations (e.g. gradient of no more than 1%). However, these comparisons cannot be extended to other situations.

Below us a purely indicative example of how a journey has been divided into sections belonging to different categories.




Note that some sections have not been categorised (marked in green in the diagram on the right). These are sections in which the vehicle was manoeuvring or sections affected by mapping problems. These sections were not included in the analysis.

### Analysis of sections classed as roads in highly built-up areas:

The diesel vehicles did not travel a sufficient distance on roads of this type to allow a reliable comparison. Additional data are currently being gathered, which will allow results to be presented in future.

### Analysis of sections classed as country roads:

Analysis of the results showed that the topology of these ‘country roads’ is highly diverse (from long, straight roads to roads with heavy traffic and numerous intersections, requiring the vehicle to stop and start multiple times). Unlike for other types of road (motorway or urban), placing very different ‘basic sections’ (road sections with similar characteristics) into a single category, namely ‘country roads’, does not allow comparison of vehicles that made different journeys.  The road’s configuration has a considerable influence here.

This serves to highlight the complexity of the factors influencing fuel consumption and emissions. Beyond the three main factors (weight, ascent/descent, and road type), the frequency with which a vehicle stops and starts on a journey will have a substantial impact. As such, the urban environment (e.g. roundabouts, reduced-speed areas) has a major influence on vehicles’ fuel consumption and pollutant emissions. A more detailed analysis must be conducted if a conclusion is to be reached about journeys of this type.

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## PARTICIPANTS

## PARTNERS

## MEMBERS OF THE ASSOCIATION EQUILIBRE

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