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Particulate matter and CO_2eq. emissions from three Euro 6d bi-fuel LPG passenger cars, fed by an innovative LPG/DME blend

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Goals of the work: towards decarbonization and sustainability

Italian Scenario [1]

- # of LPG cars still increasing (+32.7% Jan-May 2023 VS Jan-May 2022, largest increase in the ICE vehicles registrations), nowadays 2.9 million circulating LPG cars over 40.2 million total (7.2%)[2]
- # of BEV and PHEV not growing as fast as expected

Need to investigate how to decarbonize the LPG sector and how to make it more sustainable

Potentially renewable fuels:

- Bio-LPG: byproduct from HVO process[3]
- rDME: included in «Renewable Energy Directive II (RED)»[4] by EU, bio-DME and eDME[5]

Goals of the work

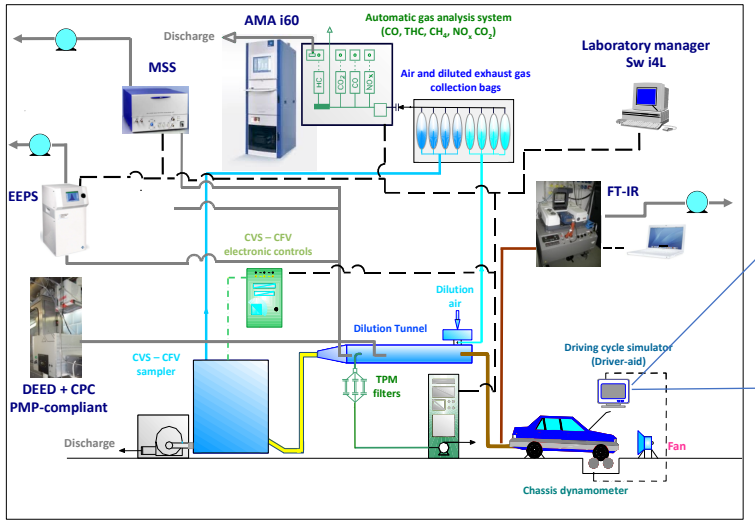
- Measure regulated and unregulated pollutants emissions from ICE vehicles, fed by an innovative and potentially renewable fuel blend, fully compliant with the EN589: LPG/DME 80/20 (% m/m)
- Calculate and compare the emission factors: Gasoline VS LPG/DME

[1] UNRAE
[2]: ACI, 2022
[3]: E. Johnson, *Energies* **2019**, 12, 250
[4]: Directive (EU) 2018/2001, pag 63
[5]: M. A. Charalambous, V. Tulus, M. W. Ryberg, J. Pérez-Ramirez, G. Guillén-Gosàlbez, *Suistanable Energy Fuels*, **2023**, 7, 1930-1941

Materials and Methods

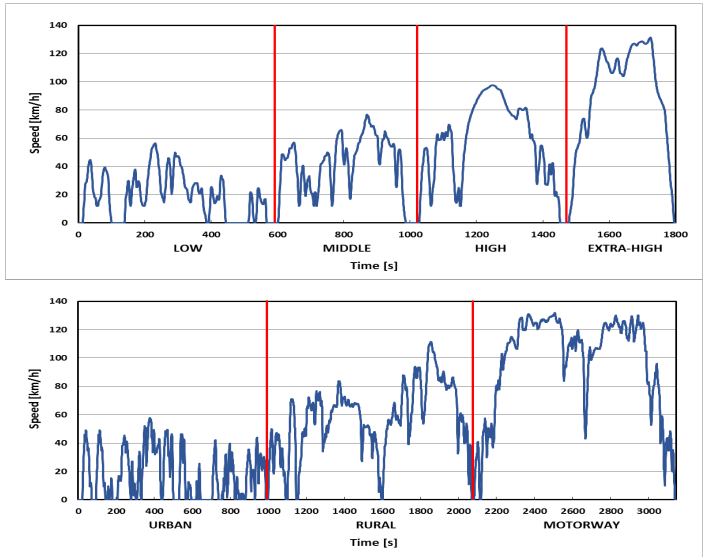
Laboratory and on-road tests on three EURO 6d bi-fuel vehicles (two small and one medium segment)

Laboratory tests:



WLTC: cold start homologation driving cycle

CADC: hot start driving cycle



On-road tests: real driving emissions (RDE)

	Vehicle 1	Vehicle 2	Vehicle 3
Homologation Emission Standard	Euro 6d	Euro 6d	Euro 6d
Mileage at test start (km)	8715	982	4952
Enigne displacement (cm^3)	1197	999	1598
COPERT segment	small	small	Medium
Injection type	Positive Ignition - PFI	Positive Ignition - PFI	Turbo Positive Ignition - TGDI
LPG powertrain	Retrofit	OEM	Retrofit
Emission treatment technology	TWC	TWC	TWC + GPF

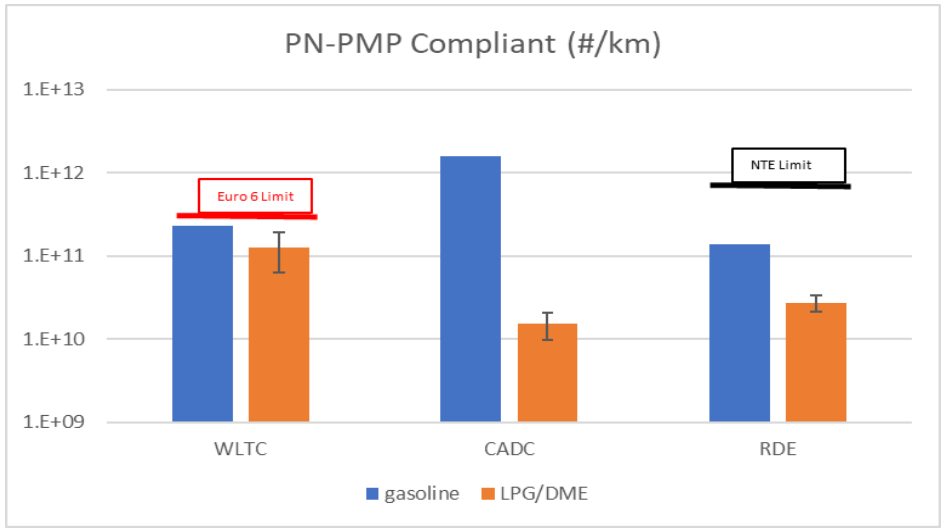
Results: PN and CO_2eq. emissions

Emission Factors of PN and CO_2eq: Gasoline VS LPG/DME

		WLTC (homologation)				CADC (hot start)			RDE (on-road)		
		Gasoline	LPG/DME			Gasoline	LPG/DME		Gasoline	LPG/DME	
		1	Average	EURO 6 LIMIT	Δ, %	1	Average	Δ, %	1	Average	Δ, %
PM	mg/km	0.002	0.007	5.00		0.014	0.026		-	-	-
PN_PMP Compliant	#/km	2.28E+11	1.27E+11	6.00E+11	-44.2	1.56E+12	1.51E+10	-99.0	1.38E+11	2.74E+10	-80.1
CO_2eq.	g/km	136.67	120.82	-	-11.6	146.75	132.98	-9.4	150.60	127.90	-15.1

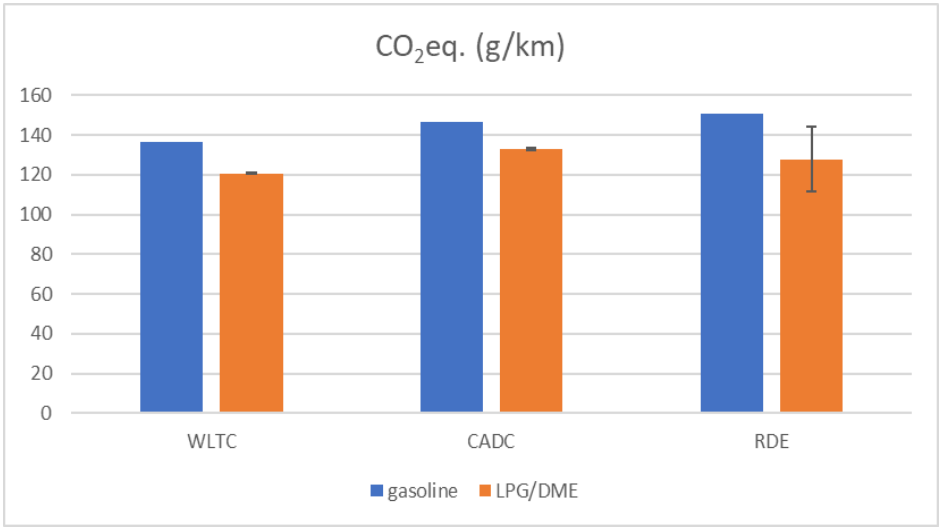
PN-PMP Compliant (regulated)

Decrease in solid particles emissions (23 nm – 2.5 µm) when fed by LPG/DME both in laboratory and on road



CO_2eq. (CO_2, CH_4, N_2O)

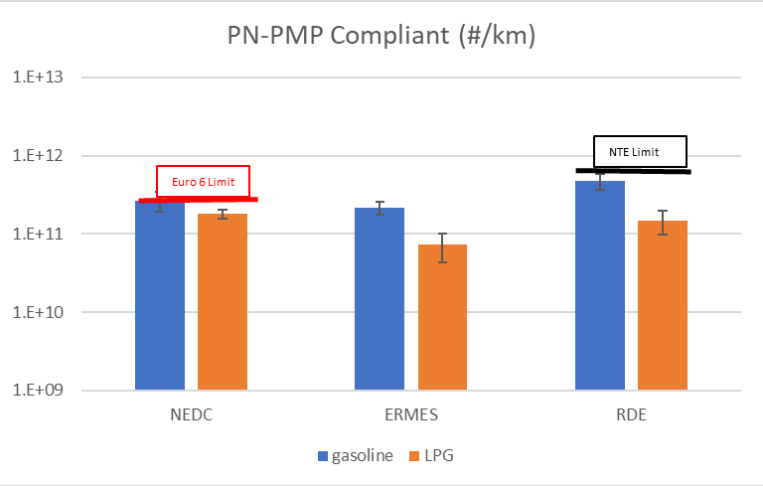
Decrease in CO_2eq. emissions when fed by LPG/DME both in laboratory and on road

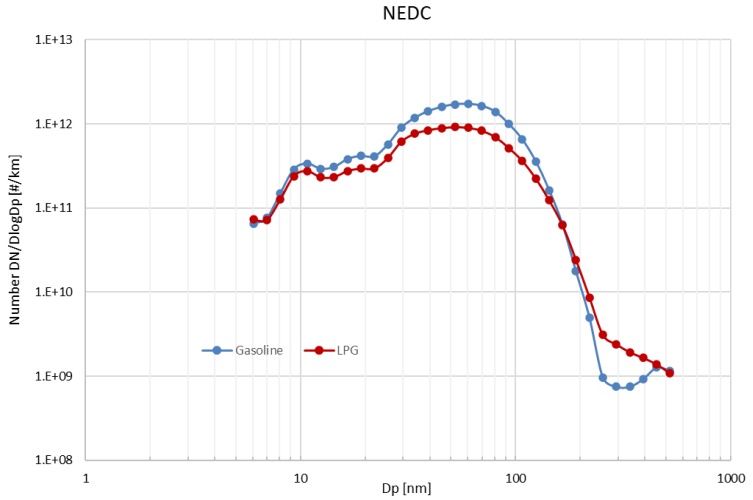


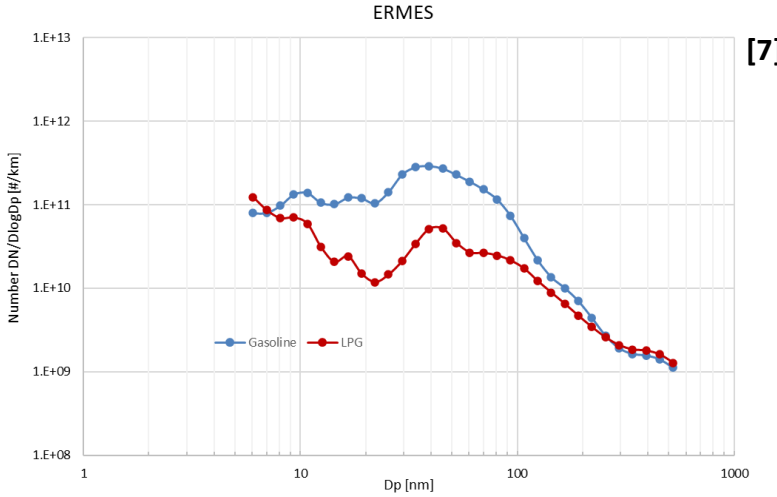
Results: starting from previous work (2017-2018)

Emission Factors: Gasoline VS LPG[6]

- **Laboratory and on-road tests to measure the exhaust emissions of five Euro 6b/c bi-fuel vehicles**
- **NEDC (cold-start homologation cycle), ERMES (hot-start cycle) in lab. and RDE; emission factors for LPG calculated and made available at Italian and International level for updating EFs databases of emission models**







[7]

PN-PMP Compliant

Decrease in PN emissions when fed by LPG both in laboratory and on road

PN-EEPS

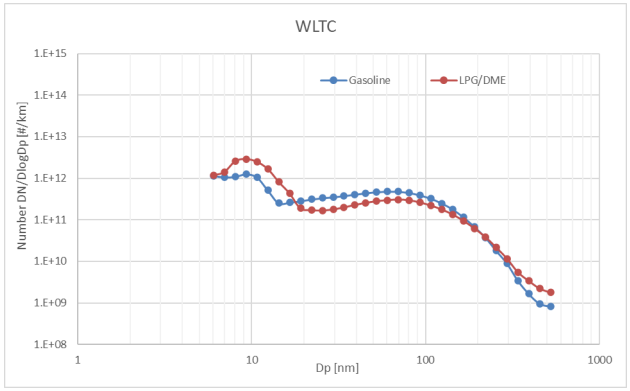
- **Similar particle size distributions in the NEDC for both Gasoline and LPG**
- **Decrease in PN emissions in the hot-start cycle (ERMES) when fed by LPG**

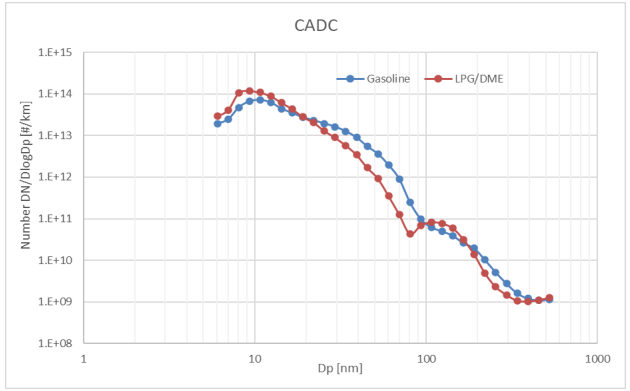
[6] T. Bellin, S. Casadei, T. Rossi, A. Bernetti, R. De Laurentis, G. Lonati, *Atmospheric Environment: X*, 15, **2022**, 100186
[7] G. Lonati, T. Bellin, T. Rossi, S. Casadei, EFCA Ultrafine particles symposium, **2022**

Results: EEPS measurement (laboratory)

PN-EEPS (unregulated)

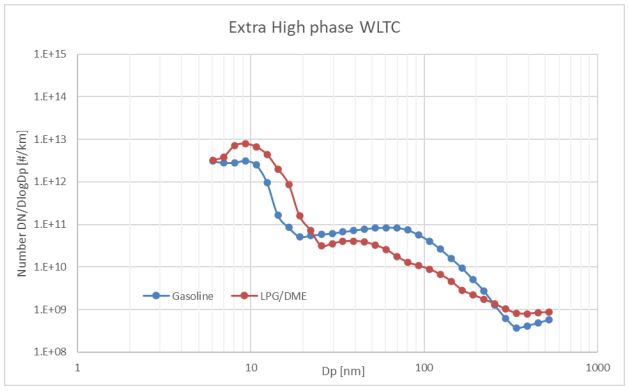
- **Similar solid and volatile particles emissions (5.6 nm – 560 nm) in the overall cycles for both Gasoline and LPG/DME**

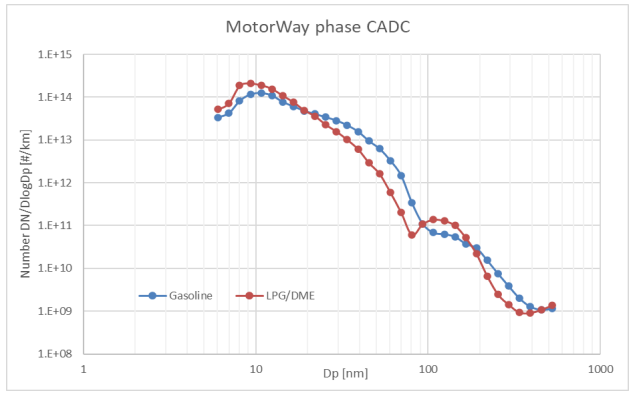


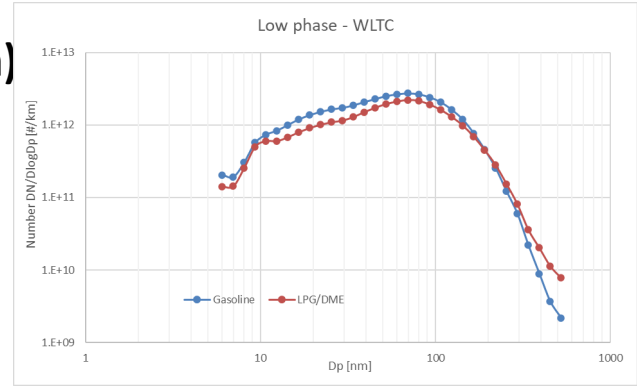


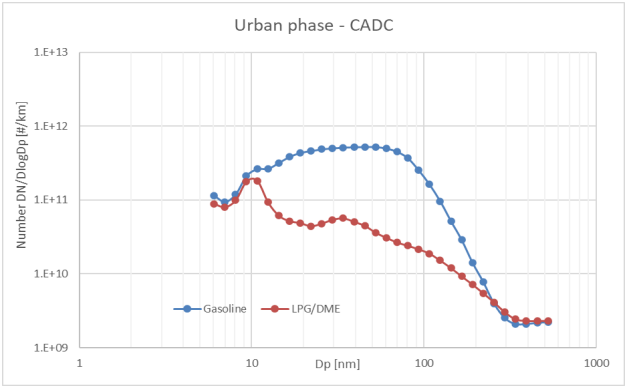
- **Low speeds ----> production of slighlty bigger particles (> 30 nm) in the WLTC cycle for both Gasoline and LPG/DME**
- **Decrease in PN emissions during the Urban phase of the hot-start cycle (CADC) when fed by LPG/DME**

- **High speeds -----> production of ultrafine particles (< 10 nm) in both cycles and for both Gasoline and LPG/DME**









Conclusions and next steps

LPG/DME 80/20 (m/m) blend was tested for Euro 6d passenger cars

- **the pollutants emissions of both regulated and unregulated species were measured;**
- **their emissions factors were calculated and compared with those of gasoline fuelling.**

- **Fully compliant with EN589**
- **Fully compliant with EURO 6 Exhaust Emission Standards, with interesting perspectives towards the EURO 7 ones**

- **Lower PN emissions**
- **Lower GHG emissions**

} **than gasoline**

		LPG/DME	EURO 7 LIMIT (LABORATORY)
NH_3	mg/km	8.5	20
CO	mg/km	223.1	500
THC	mg/km	25.1	100
NMHC	mg/km	21.0	68
NO_x	mg/km	13.7	60

Next step: LCA analysis currently under development (LPG/DME VS BEV)

LPG/DME blend as innovative and potentially renewable fuel towards decarbonization and sustainability

THANK YOU FOR YOUR ATTENTION

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