evs 27

The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION.

Barcelona, Spain
17th-20th November 2013

Energy and environmental characterization of operational modes of plug-in vehicles

Gonçalo Duarte, Ricardo Lopes, Gonçalo Gonçalves, Tiago Farias

IDMEC - Instituto Superior Técnico, Universidade de Lisboa,

Av. Rovisco Pais, 1 - 1049-001 Lisboa – Portugal

Organized by Fira Barcelona avele

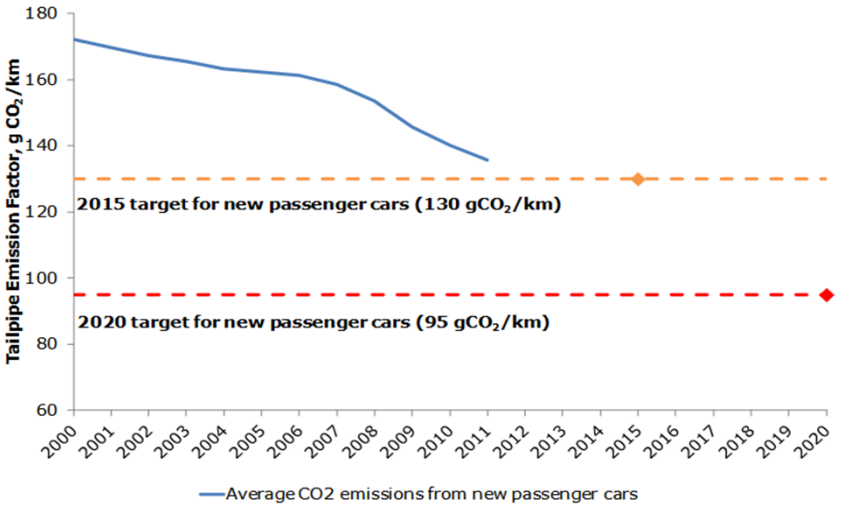
Hosted by AVERE mea Ajuntament de Barcelona

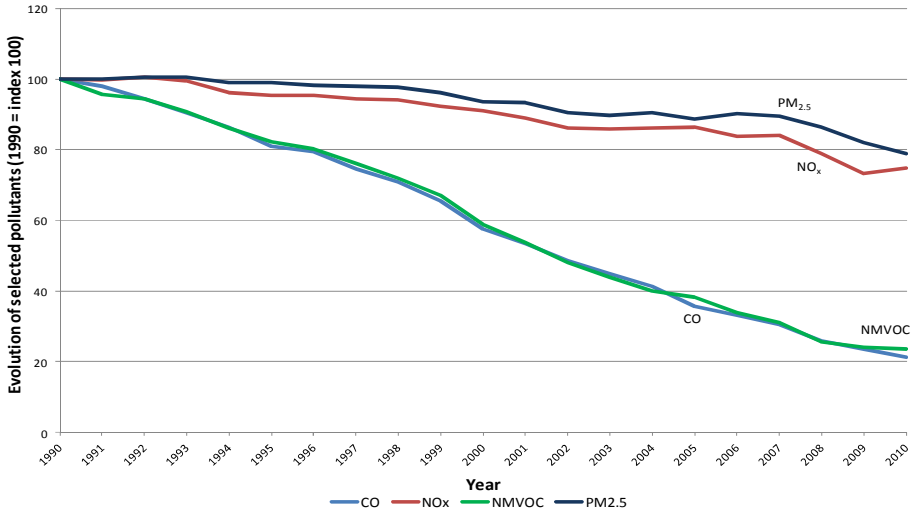
In collaboration with EVAAP EDTA

Supported by European Commission

Introduction

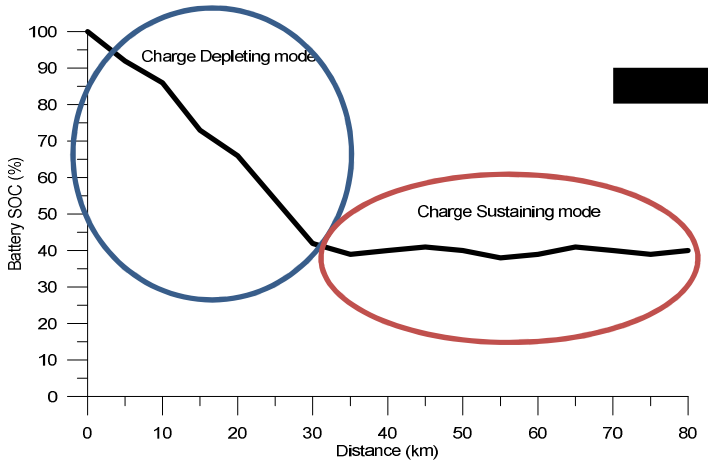
- Mobility of people and goods is responsible for 30% of world's total energy delivered
- NO_x and CO emission is mostly provided by tailpipe exhaust
- Global impacts and local health problems
- Regulations to reduce CO_2 and pollutant emissions

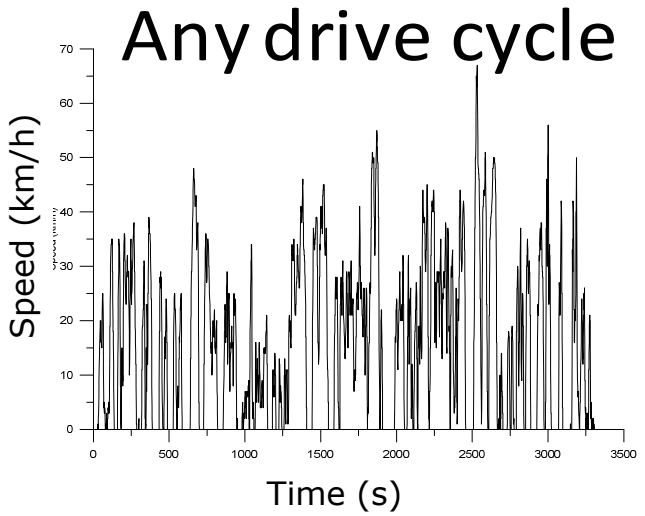




Introduction

- Plug-in hybrid electric vehicles are perceived as a mobility solution
- Vehicle use is of extreme importance to quantify PHEV impacts:
  - Driving mode (CD and CS)
  - Driving cycle





Energy

Pollutants

- How to estimate energy use and pollutant outcomes?

Objectives and Methodology

- Objectives:
  - Perform an energy and environmental characterization of the two most sold Plug-in vehicles (Toyota Prius Plug-in and Opel Ampera) in CD and CS modes
  - Estimate their impacts on energy use and pollutant emissions, for any desired drive cycle according with initial battery SOC conditions.

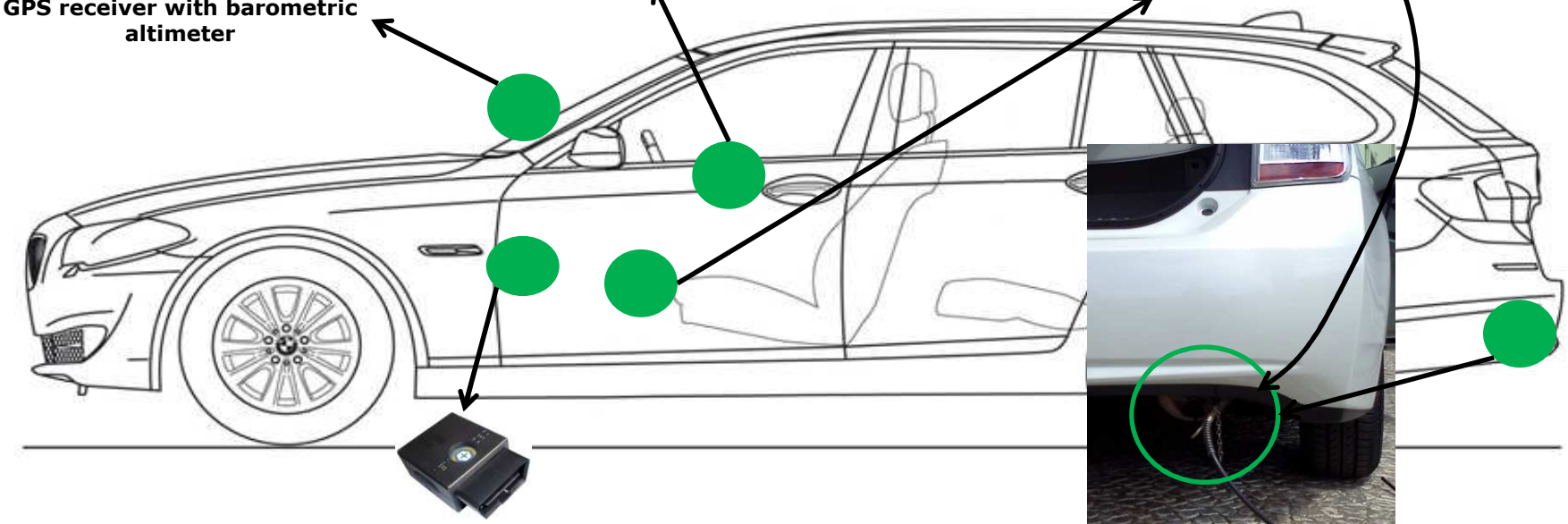
- Methodology
  - On-road measurements under real-world driving
  - Portable Laboratory
  - Vehicle Specific Power (VSP) methodology for data analysis

Portable Laboratory

GPS receiver with barometric altimeter

Laptop running LabView

Gas analyzer



OBD2 reader

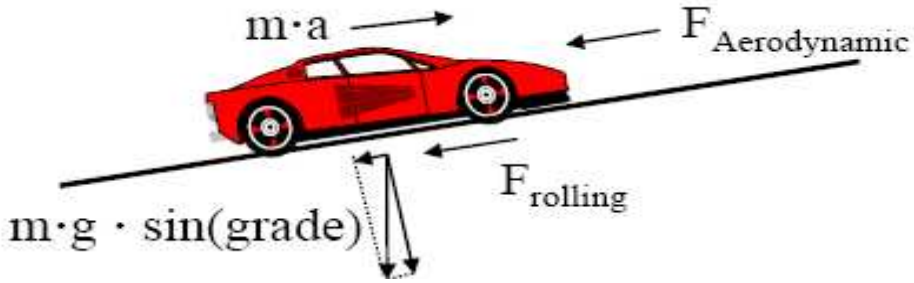
Organized by Hosted by In collaboration with Supported by

Methodology

- On-road Vehicle Measurement
- Portable Laboratory for monitoring of SI, CI, HEV and PHEV
- Equipment used:
  - OBD reader
  - Gas analyzer (O_2, CO_2, CO, HC, NO_x)
  - GPS with barometric altimeter
- Data collected at 1 Hz for development of fuel and pollutant models
- Several driving conditions (~ 11 hours/+500 km of driving)

Methodology

- Vehicle Specific Power (VSP) methodology
- Main Indicator for data analysis
- Based on vehicle dynamics and road topography



$$VSP = \frac{\frac{d}{dt}(E_{Kinetic} + E_{Potential}) + F_{Rolling} \cdot v + F_{Aerodynamic} \cdot v}{m}$$

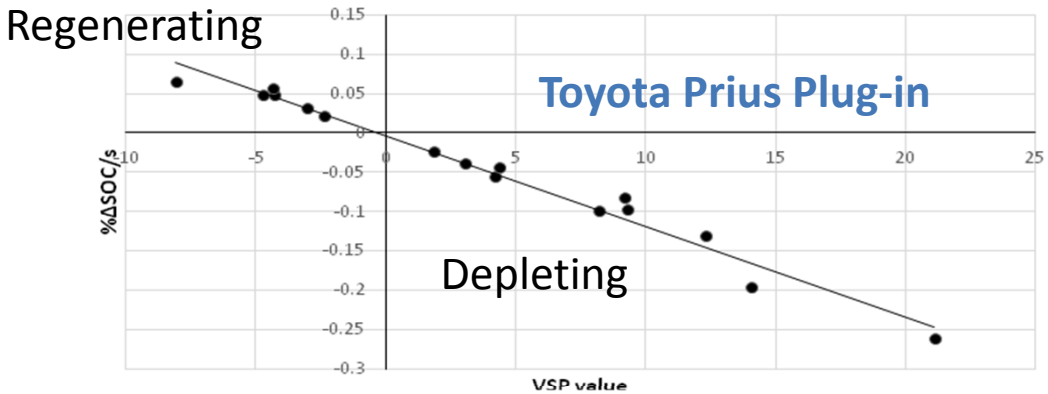
$$VSP = v \cdot (1.1 \cdot a + 9.81 \cdot grade + 0.132) + 3.02 \cdot 10^{-4} \cdot v^3$$

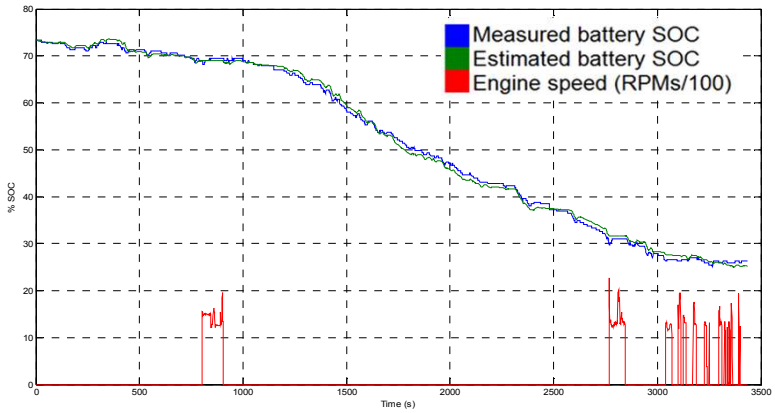
- VSP Modal analysis divided in 14 Modes

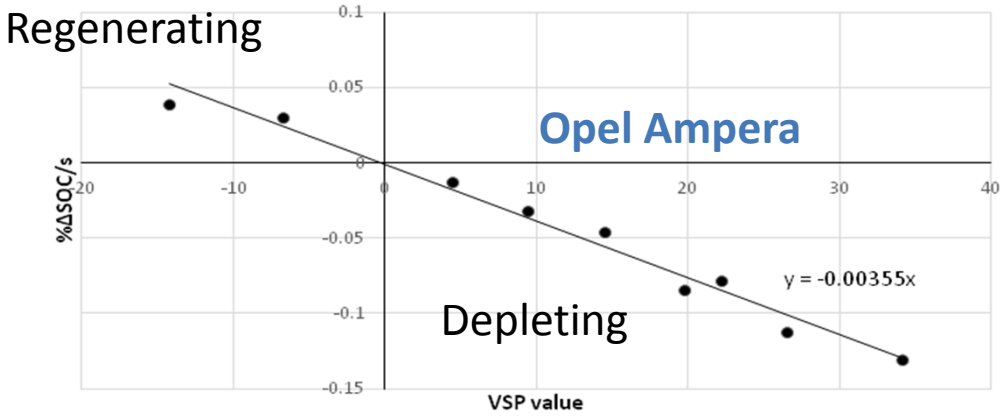
Results

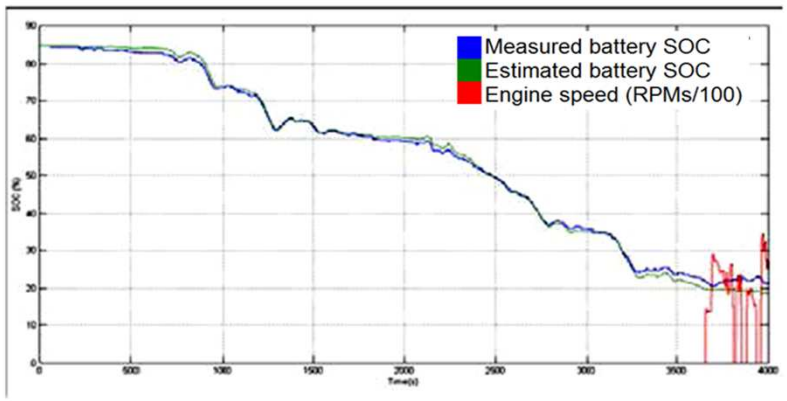
Estimate of electric consumption

- Using OBD Battery SOC information, was possible to assess its variation with power









evs 27

TÉCNICO LISBOA

idmec

Organized by

Fira Barcelona

avele

Hosted by

AVERE

mea

Ajuntament de Barcelona

In collaboration with

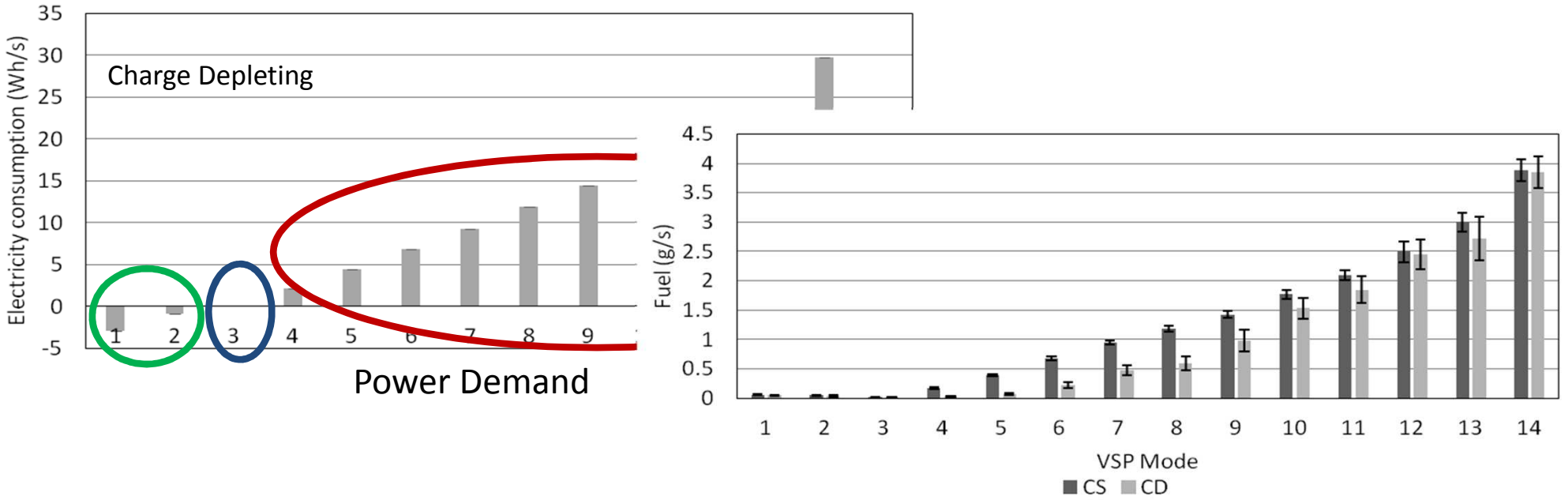
EVAAP

EDTA

Supported by

European Commission

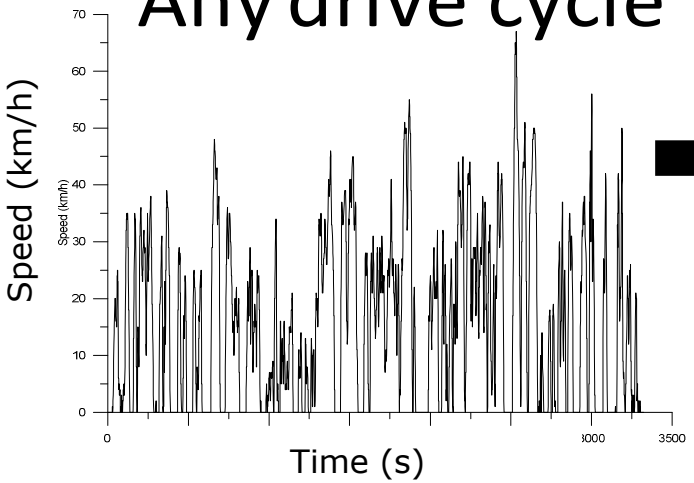
Results



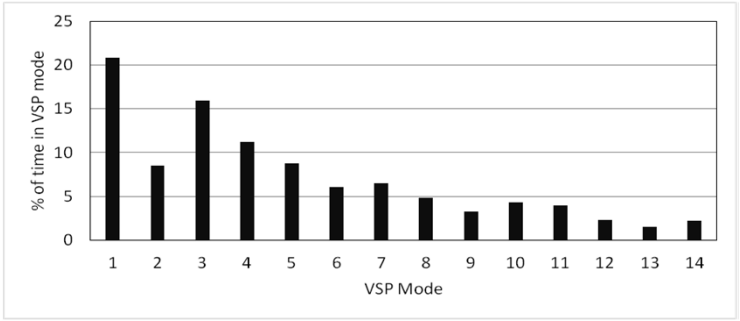
- Electricity consumption calculated from battery SOC (only for CD)
- Regeneration under braking and deceleration

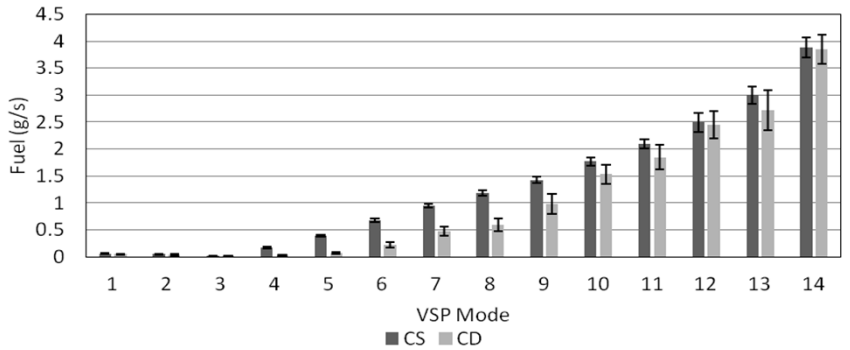
Applications

Any drive cycle



Power demand time distribution



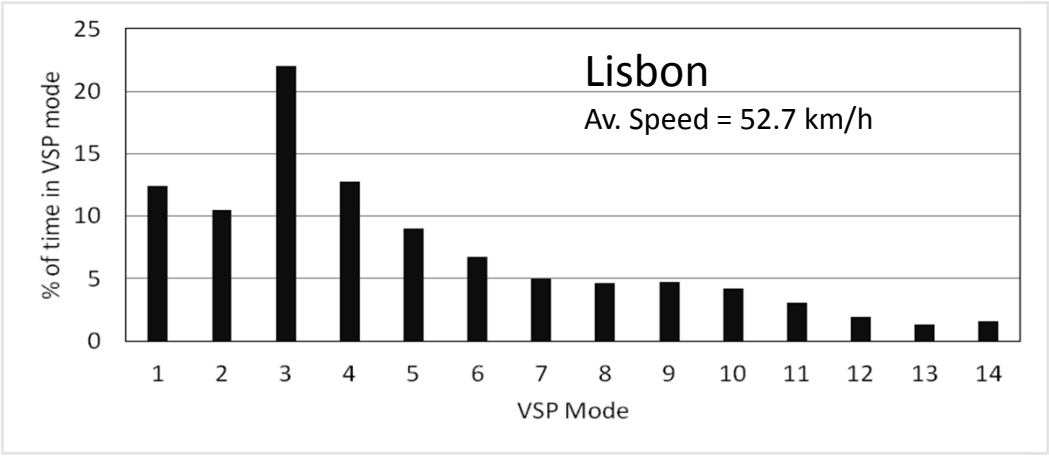


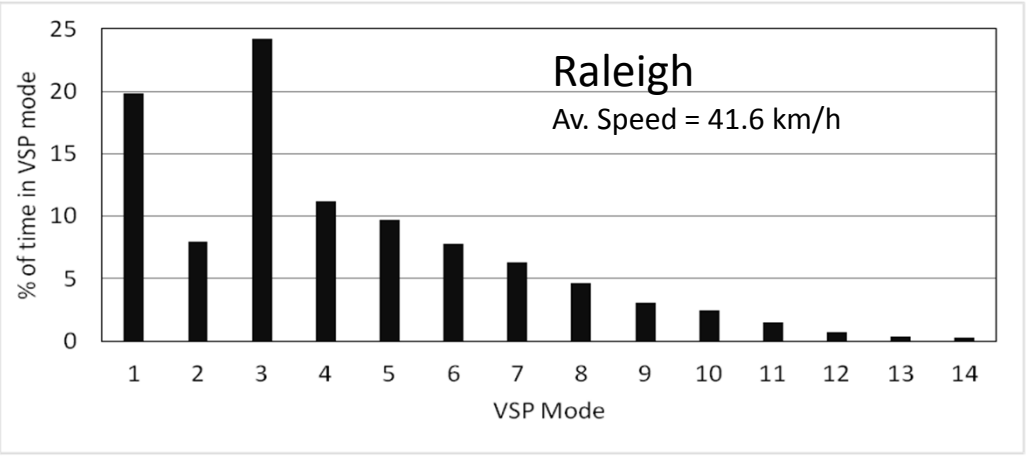
Energy and pollutant maps

- Fuel use per km
- Pollutant emission per km
- Electricity use per km
- CD autonomy

Applications

- Two typical driving profiles:
  - Lisbon metropolitanean area (Portugal)
  - Raleigh, North Carolina (United States)





High power demand
High speed

Low power demand
More than 25% under regeneration modes

Results

Lisbon Metropolitanean Area

Toyota Prius Plug-in

	Charge Depleting					Charge Sustaining
Initial State of charge (%)	100	75	50	20	10	0
CD driving (km)	27.0	20.2	13.5	5.4	2.7	---
Electricity consumption (kWh/km)			0.125			---
Fuel consumption (l/100km)			3.8			5.4
TTW CO_2 emissions (g/km)			100			136
TTW CO emissions (g/km)			0.130			0.300
TTW HC emissions (g/km)			0.016			0.010
TTW NO_x emissions (g/km)			0.004			0.002

Opel Ampera

	Charge Depleting					Charge Sustaining
Initial State of charge (%)	100	75	50	20	10	0
CD driving (km)	44.2	33.1	22.1	8.8	4.4	---
Electricity consumption (kWh/km)			0.306			---
Fuel Consumption (l/100km)			---			5.8
TTW CO_2 emissions (g/km)			0			154
TTW CO emissions (g/km)			0			3.100
TTW HC emissions (g/km)			0			0.030
TTW NO_x emissions (g/km)			0			0.004

- Charge depleting mode autonomy is higher in Opel Ampera
- During CD, both electricity and liquid fuel were measured in Toyota Prius Plug-in

Results

Raleigh, North Carolina

Toyota Prius Plug-in

	Charge Depleting					Charge Sustaining
Initial State of charge (%)	100	75	50	20	10	0
CD driving (km)	27.9	20.9	13.9	5.6	2.7	---
Electricity consumption (kWh/km)	0.121					---
Fuel consumption (l/100km)	2.0					4.0
TTW CO_2 emissions (g/km)	50					100
TTW CO emissions (g/km)	0.10					0.300
TTW HC emissions (g/km)	0.012					0.008
TTW NO_x emissions (g/km)	0.003					0.001

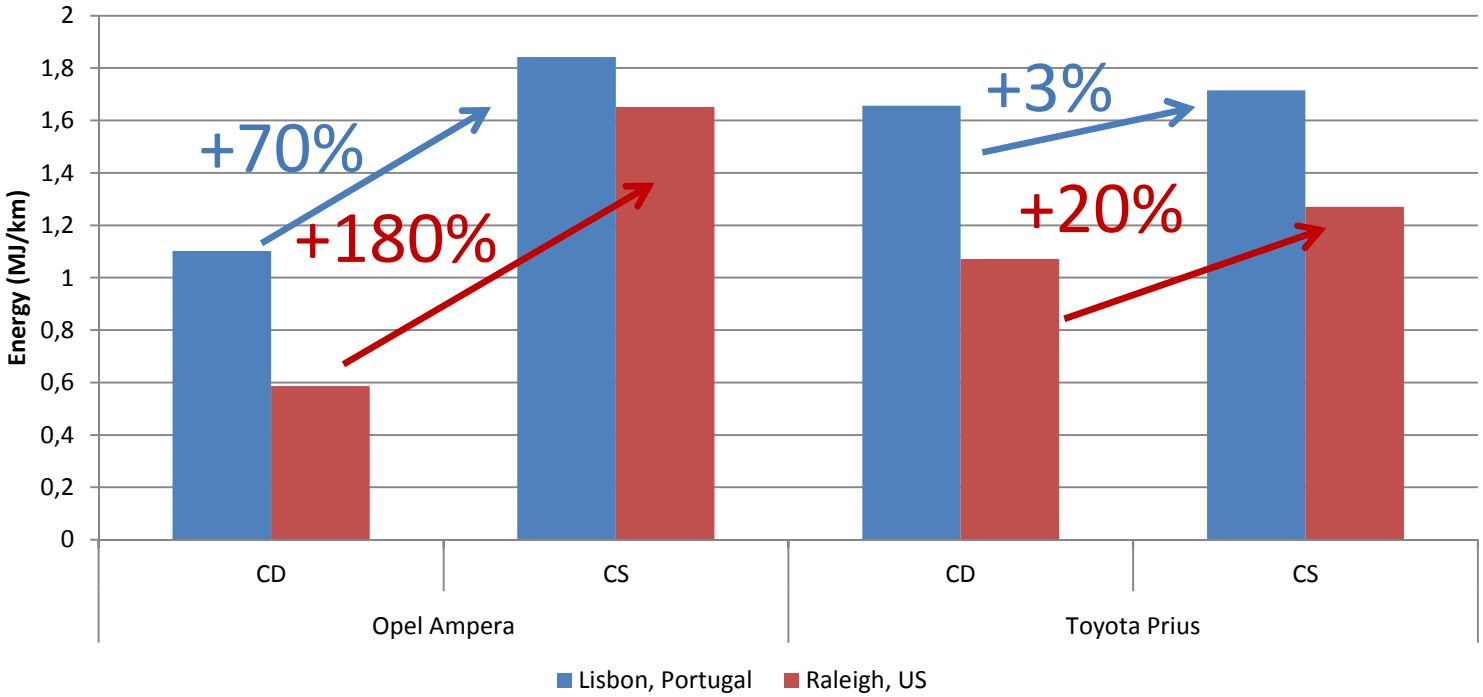
Opel Ampera

	Charge Depleting					Charge Sustaining
Initial State of charge (%)	100	75	50	20	10	0
CD driving (km)	82.9	62.2	41.4	16.6	8.3	---
Electricity consumption (kWh/km)	0.163					---
Fuel Consumption (l/100km)	---					5.2
TTW CO_2 emissions (g/km)	0					139
TTW CO emissions (g/km)	0					2.2
TTW HC emissions (g/km)	0					0.030
TTW NO_x emissions (g/km)	0					0.003

- Charge depleting mode autonomy increases in a less agressive driving profile
- Total energy consumption is lower for both vehicles

Results

Comparison



- CD mode always presents lower energy consumption
- Energy consumption from CD to CS is very dependent on driving profile

Conclusions

- **Energy and environmental characterization** of the most sold plug-in vehicles
- **Vehicle monitoring using on-road, real-world data** and VSP methodology was used for data analysis
- **Indirect method to estimate electricity consumption** in CD mode using battery SOC reading from OBD
- Energy and emission mass rates can be used to assess different driving profiles
- Aggressive driving presents more energy consumption
  - Toyota Prius Plug-in blended CD mode is highly affected by high power conditions
- **Opel Ampera is highly penalized in CS mode**
- **Toyota Prius Plug-in is balanced between CD and CS mode**

Acknowledgments

- The authors would like to acknowledge the sponsors of the research: **Toyota Caetano Portugal and Opel Portugal**.

- Thanks are also due to Fundação para a Ciência e Tecnologia for the PhD and Post-Doctoral financial support (SFRH / BPD / 62985 / 2009, SFRH / BD / 61109 / 2009).