Connecting electrification with eco-driving: using real-world driving data for assessing potential energy savings

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Session B3: Electric vehicle energy consumption optimization in real world driving conditions

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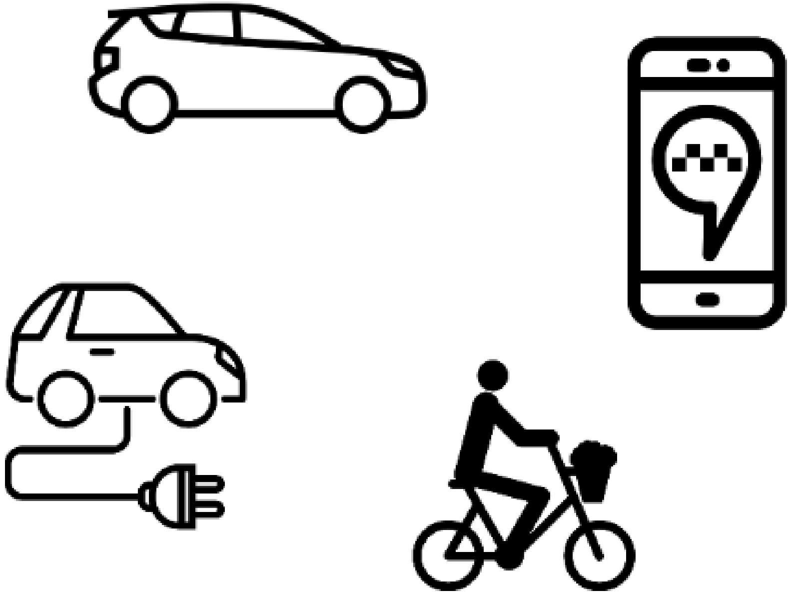
- PhD in Sustainable Energy Systems in 2011
- Research topics:
  - Real world monitoring, energy and environmental impact quantification, life-cycle assessment
  - Sustainable urban mobility, electric mobility, shared mobility, policy design

1. Introduction - Motivation



- **Significant impacts of transport sector:**
  - Energy consumption (→ security of supply)
  - GHG emissions (→ global warming)
  - Local pollutants (→ air quality, health)
  - Accidents (→ injuries, fatalities)
  - Etc.
- **Alternative options on urban mobility:**
  - Cross-modal electrification coupled with user behavior
  - Transport system integration coupled with Mobility-as-a-Service (MaaS) to promote modal shift
  - Redesign of transport infrastructure (urban plazas, reduction of speed limits, etc.)
  - Etc.

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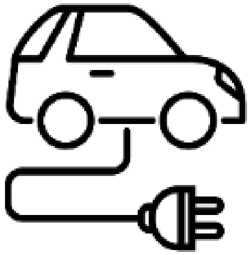
    - **Adequacy of technology to mobility patterns**
    - **Adaptation of user to driving and recharging habits**
    - **Influence of driver performance in energy impacts**
    - **...**



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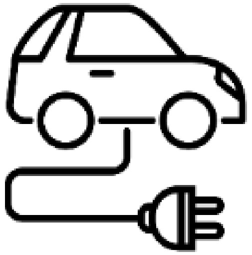

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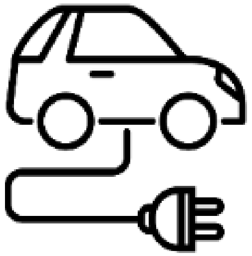
1. Introduction - Objective

- Penetration of electric vehicles is rising
- Continuous need to promote eco-driving

→ This work proposes a **combined approach to quantify the impact on driving behavior of shifting to electric vehicles and of promoting eco-driving**, based on real world measured data



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2. Data and Methods – Data sample

- 4 drivers, monitored in Lisbon, Portugal (mostly on urban and sub-urban roads), for a period of 2 to 3 weeks, in both vehicle technologies
- The conventional and electric models of the Renault Kangoo van were monitored
- On-board monitoring unit connected to the OBD port collected 1 Hz driving data (speed, acceleration, engine data (if applicable), road topography and GPS location

2. Data and Methods – Data sample

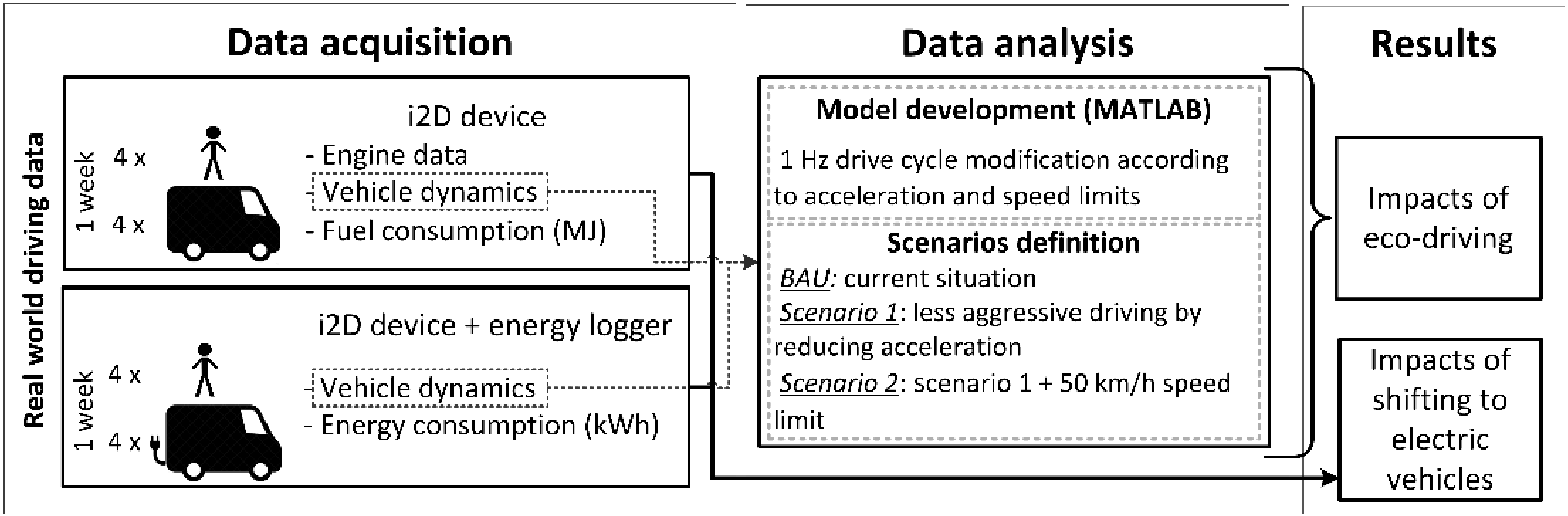
- Employees of a distribution company, thus most of the monitored data was acquired during daytime, under regular operation
- 1st period - conventional internal combustion engine light-duty vehicle (ICEV), while during the 2nd period they used an electric vehicle (EV)

Table 1. Characterization of the mobility patterns for ICEV and EV

Type of vehicle	Driver	Number of days	Number of trips	Distance travelled (km)
ICEV	1	14	265	337
	2	12	269	502
	3	14	534	619
	4	15	487	740
EV	1	15	93	302
	2	15	138	395
	3	14	209	357
	4	15	231	732

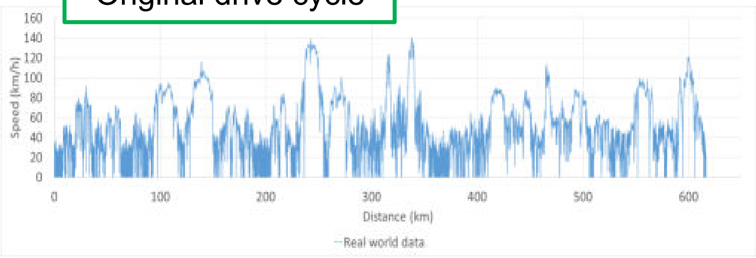
2. Data and Methods - Approach

Combined approach of real-world data with eco-driving modeling



2. Data and Methods – Model development

Original drive cycle



Original driving data (speed, altitude)

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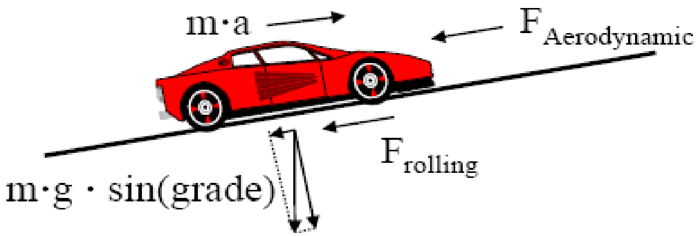
Road load model:
Second-by-second power requirement (VSP)

Road load model – vehicle specific power (VSP)



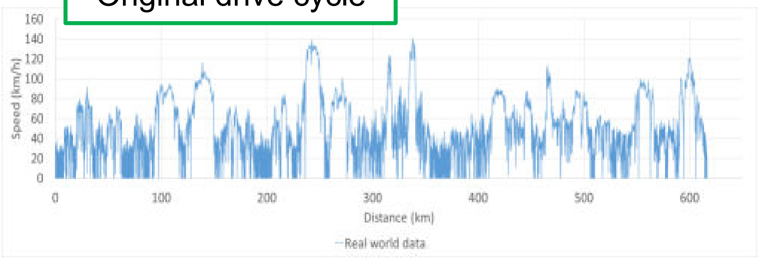
$$VSP = \frac{\frac{d}{dt}(E_{Kinetic} + E_{Potential}) + F_{Rolling} \cdot v + F_{Aerodynamic} \cdot v}{m} =$$

$$= v \cdot [a \cdot (1 + \varepsilon_i) + g \cdot sen(\theta) + C_{Roll}] + C_{Aero} \cdot v^3$$

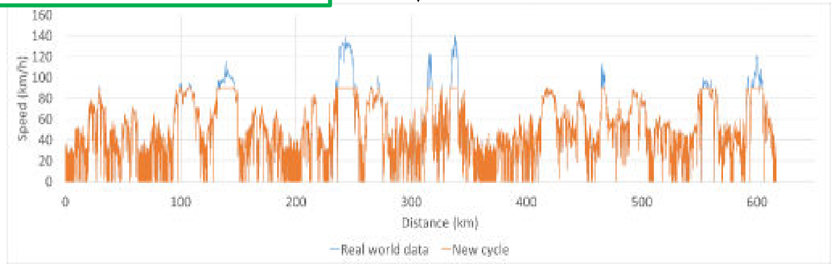
Per driver

2. Data and Methods – Model development

Original drive cycle



New drive cycle with modified limits



Per driver

Original driving data (speed, altitude)

↓

Road load model:
Second-by-second power requirement (VSP)

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Verification of the **eco-driving principles** (namely in terms of speed and acceleration), implemented in MATLAB.

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Adjustment of speed and acceleration to fulfill criteria by maintaining:
- Total distance
- Stops along road infrastructure
- Power requirements

2. Data and Methods – Scenario definition

- **Business-as-usual (BAU)** – Current situation enabling the quantification of the impacts of the mobility patterns and shift to EV;

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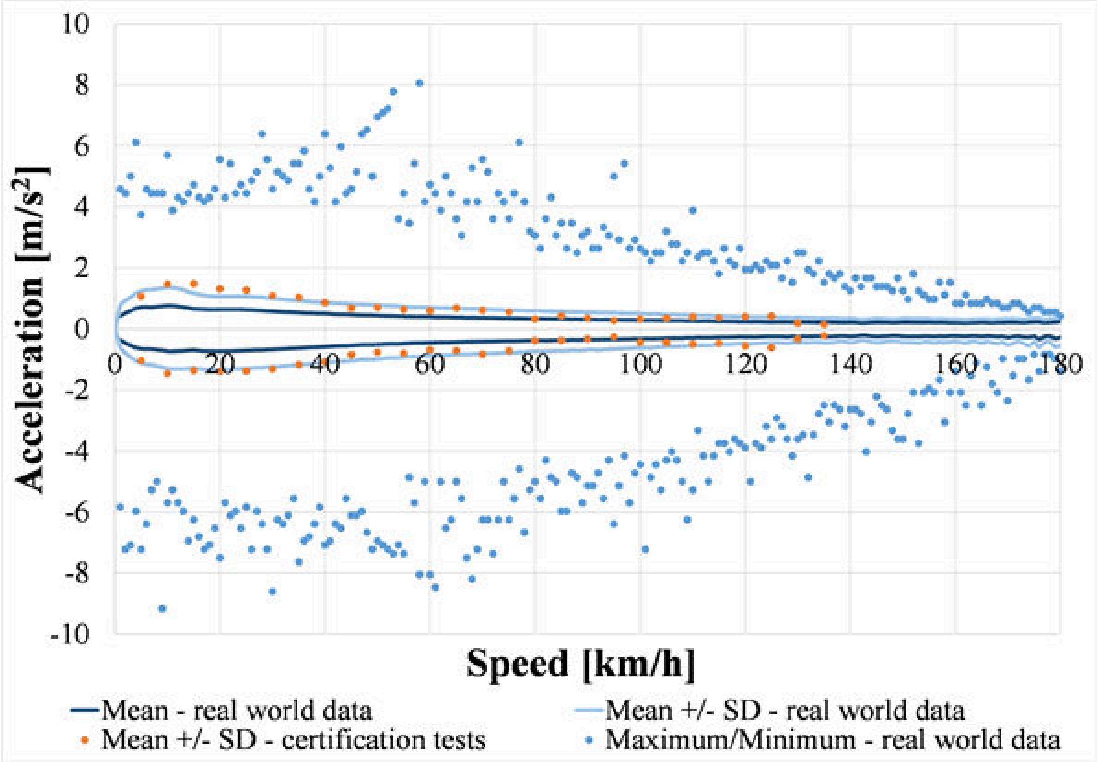
- **Scenario 1** – Promoting a more eco-driving behavior by imposing a less aggressive driving by using an acceleration threshold. This threshold is variable according with speed and was defined based on real world driving data from 47 drivers (Faria et al.); and



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- **Scenario 1** – Promoting a more eco-driving behavior by imposing a less aggressive driving by using an acceleration threshold. This threshold is variable according with speed and was defined based on real world driving data from 47 drivers (Faria et al.); and
- **Scenario 2** – This scenario combines scenario 1 with a speed limit of 50 km/h. This corresponds to a more restrictive scenario by imposing less aggressive driving coupled with a maximum speed of 50 km/h.

3. Results – Mobility patterns

- Slight differences in mobility patterns indicators justified by differences in the type of service performed in each period
- Drivers considered that **EV technologies** were **suited to perform this type of service** and few operational constraints were observed (e.g. mostly recharging but not to the driving experience itself)

Table 2: Mobility patterns characterization for the selected sample

Type of vehicle	Driver	Trips per day (avg.)	Trip distance (km)	Distance per day (km)	Average speed (km/h)
ICEV	1	18.9	1.3	24	29
	2	22.4	1.9	42	32
	3	38.1	1.2	43	20
	4	32.5	1.5	49	32
EV	1	6.2	3.2	20	29
	2	9.2	2.9	26	27
	3	14.9	1.7	26	27
	4	15.4	3.2	49	20

3. Results – Energy consumption

- EV are 3 to 4 times more efficient in energy consumption, independently of the driver
- Substantial reductions in most events: 67% on the high-speed road, 62% for traffic lights, 59% on roundabouts, 60% on a steep uphill and 158% on steep downhills

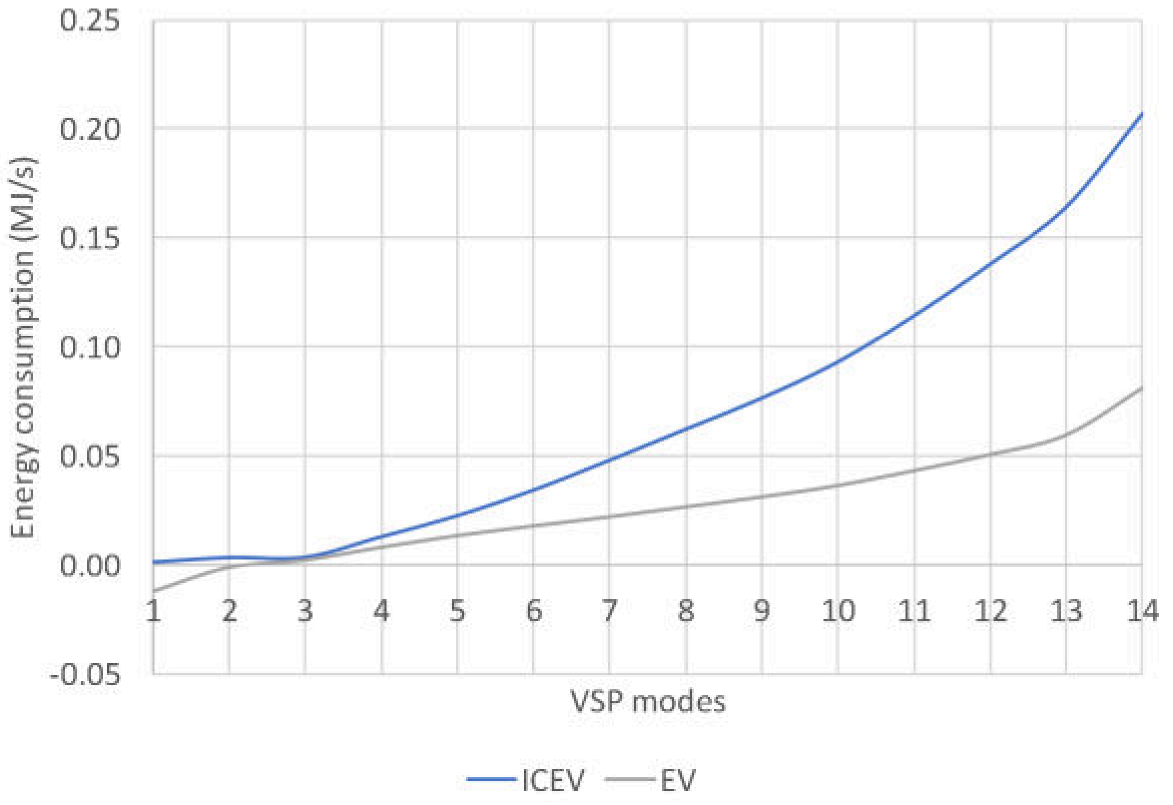


Figure 2: Energy consumption per VSP mode for both technologies

3. Results – Scenarios

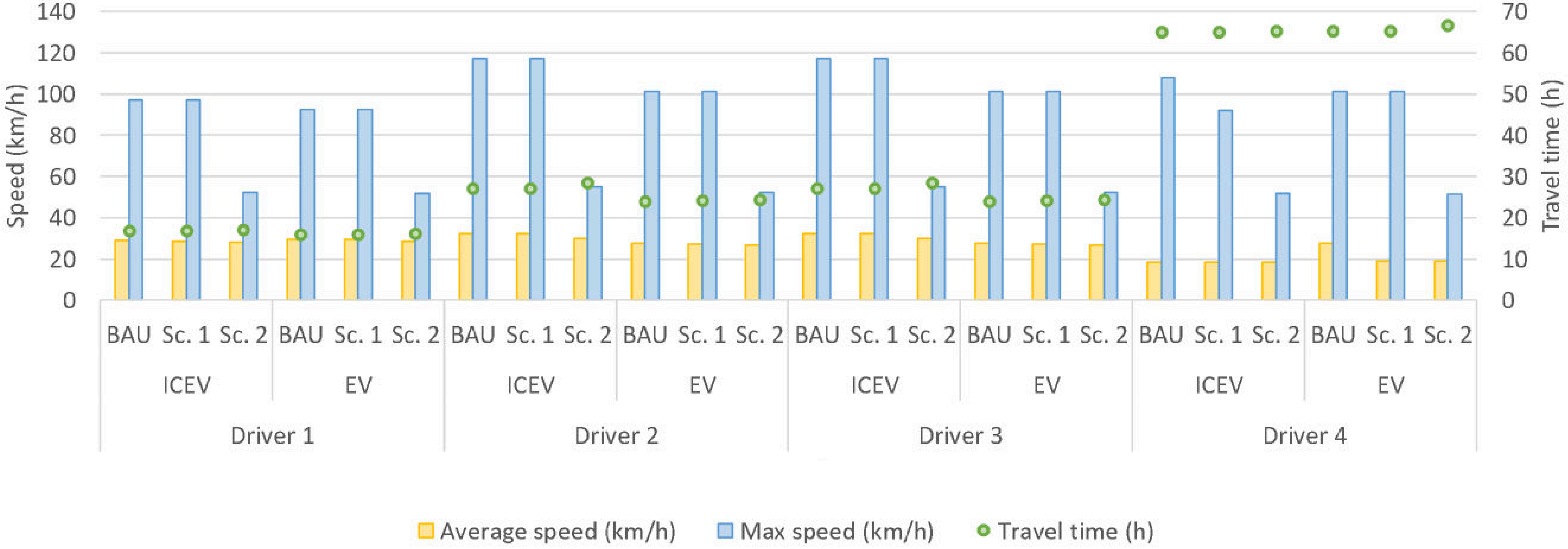


Figure 3: Scenario results considering travel time and speed variables

- Scenario 1 resulted in a 0.1% increase in travel time for ICEV and 0.3% for EV (max. of 6 minutes increase in total travel time)

3. Results – Scenarios

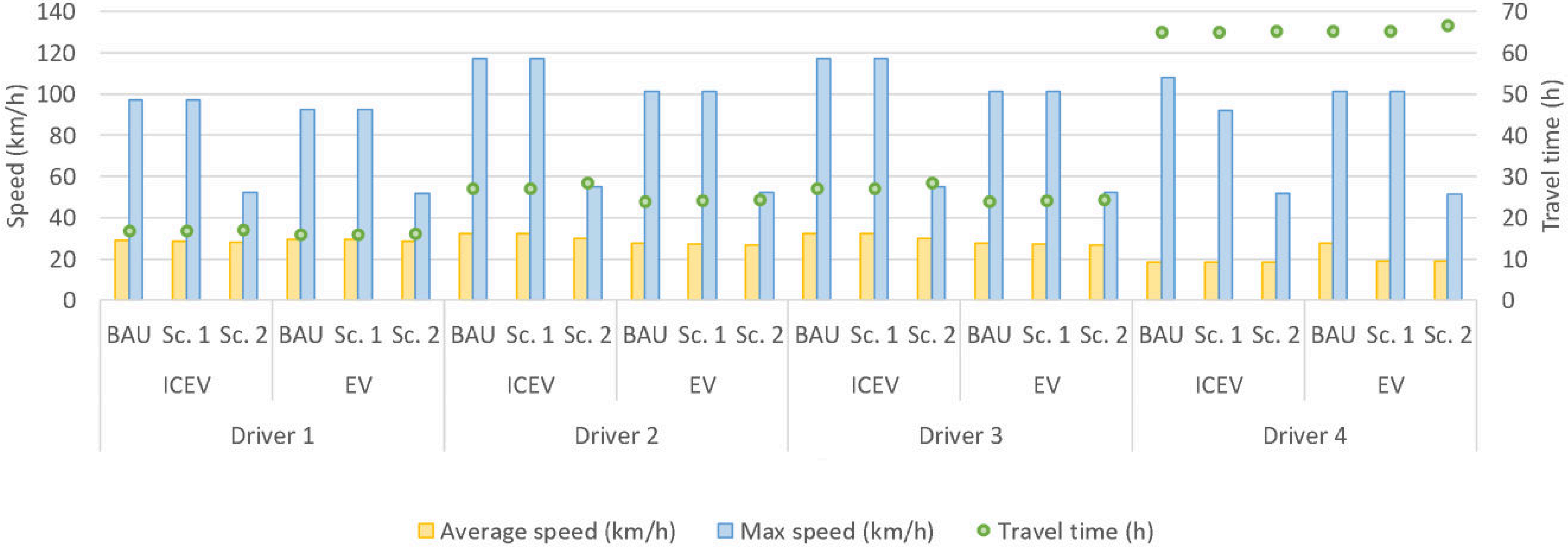


Figure 3: Scenario results considering travel time and speed variables

- Scenario 2 results in a 3.2% increase in travel time for ICEV and 1.8% for EV, (avg 47 minutes increase in total travel time)

3. Results – Scenarios

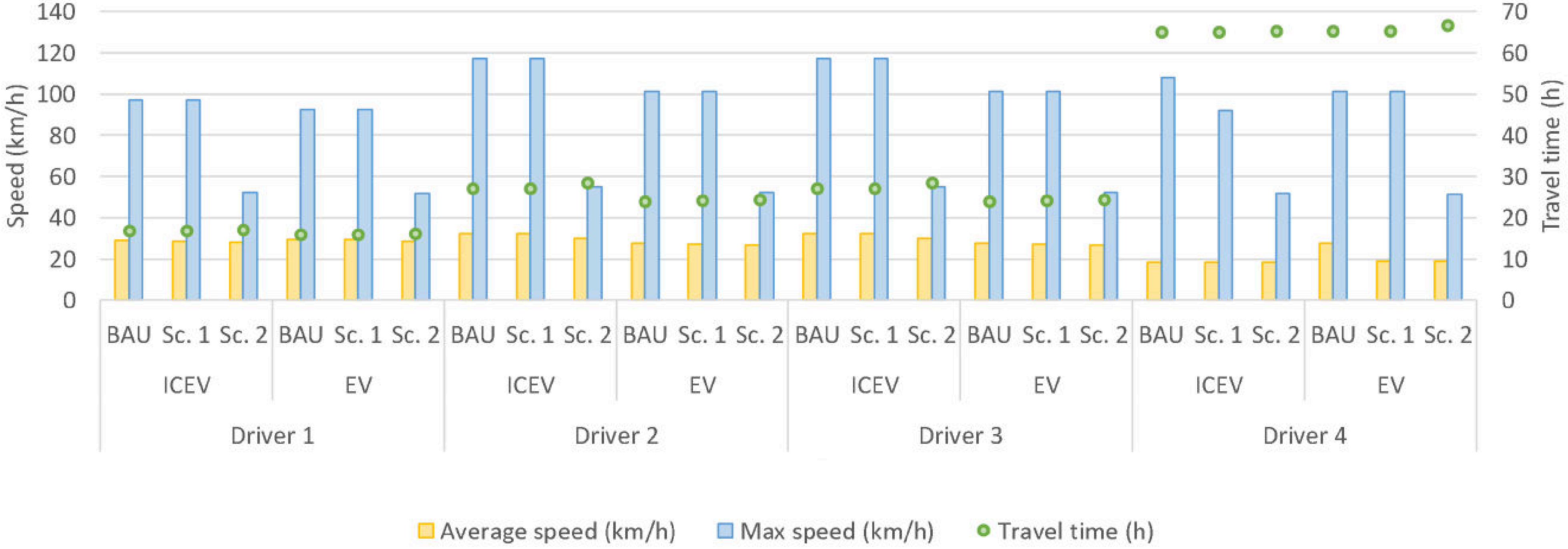
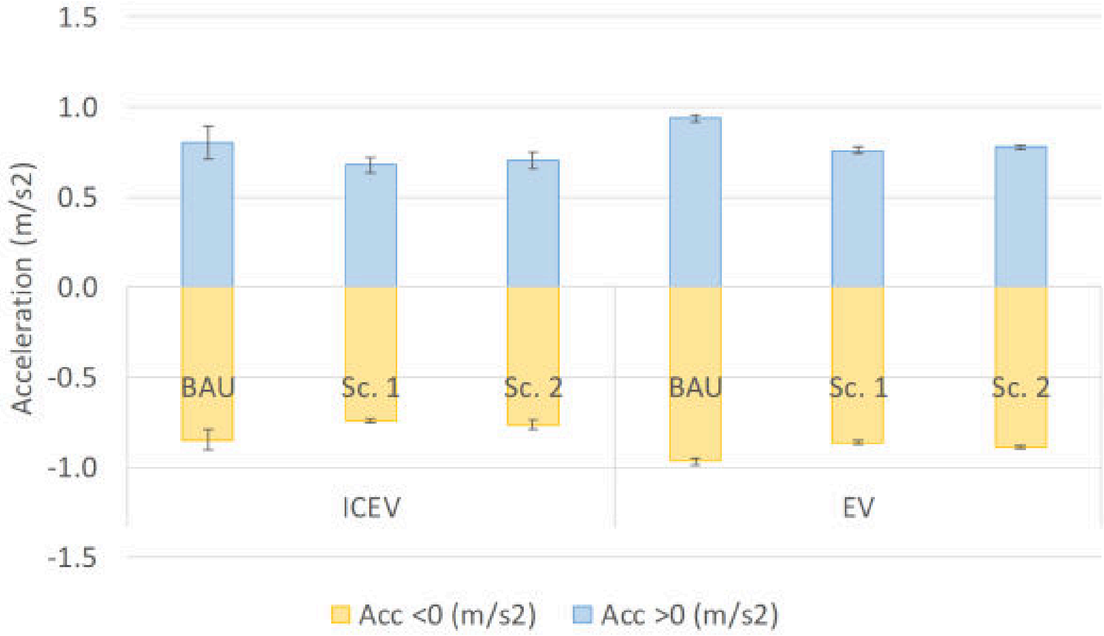


Figure 3: Scenario results considering travel time and speed variables

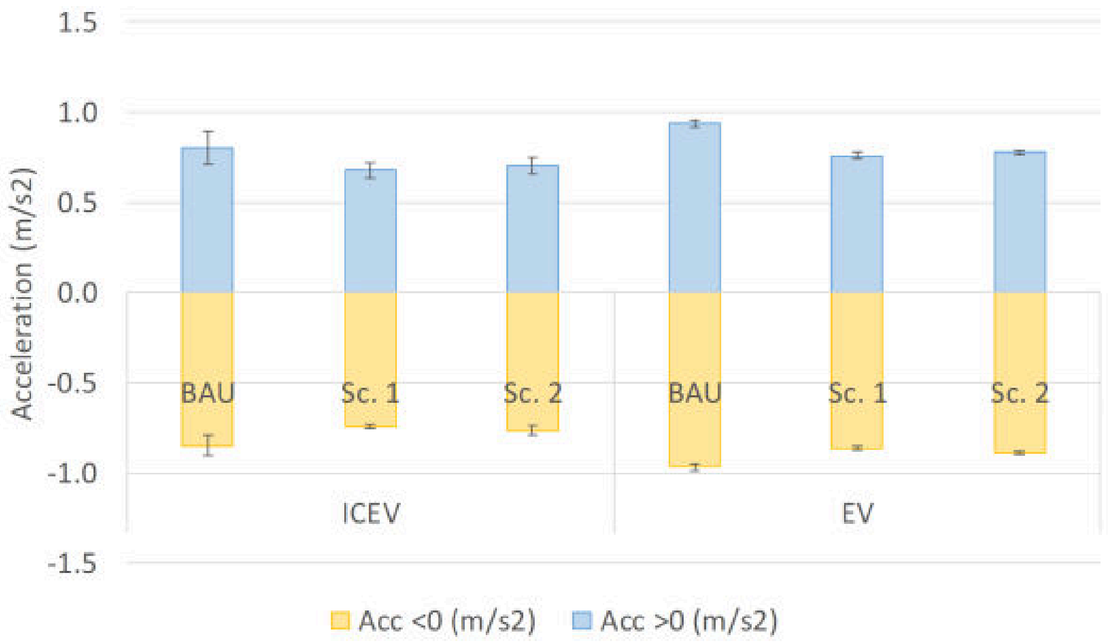
- Opposite for average speed, with a 0.1% and 0.4% decrease in average speed in Scenario 1 for ICEV and EV respectively, while for Scenario 2 these reductions are of 3.1% and 1.6% for ICEV and EV respectively.

3. Results – Scenarios



- Average 13% reduction in aggressiveness, both for accelerating and braking

3. Results – Scenarios



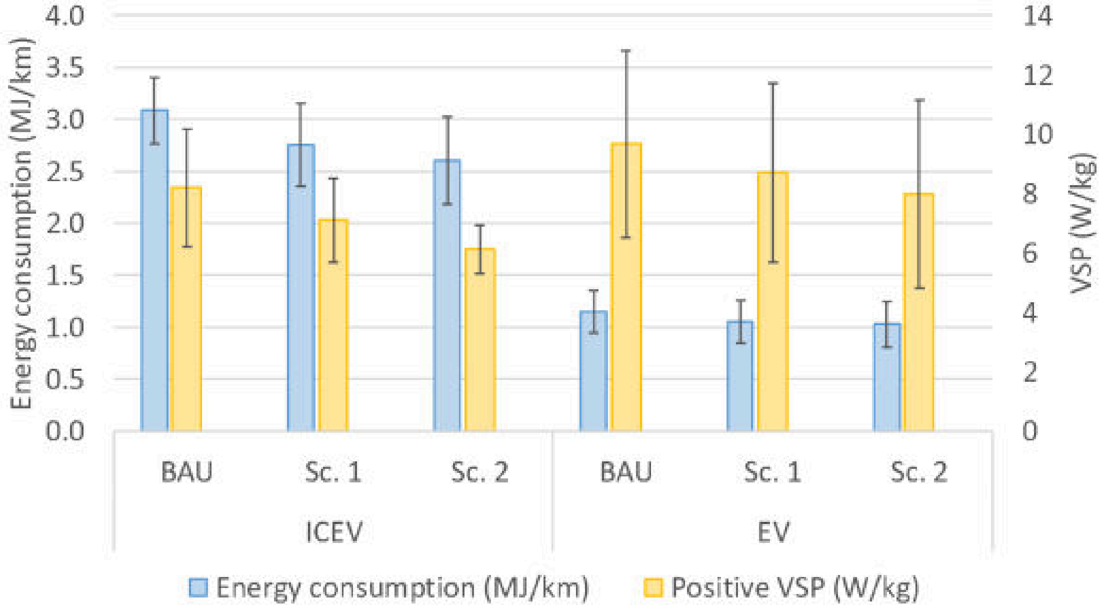
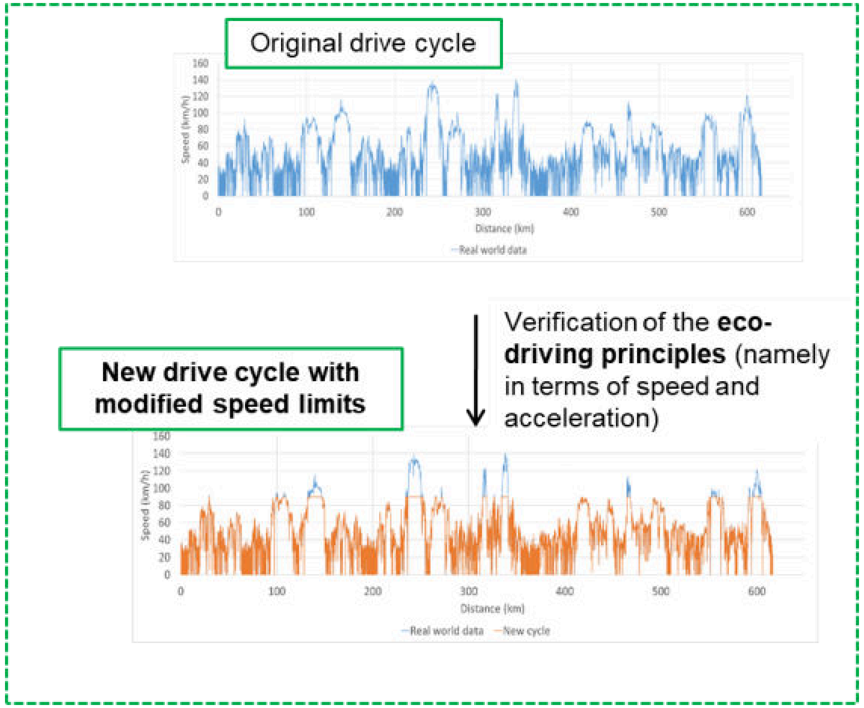


Figure 5: Energy consumption per VSP mode for both technologies

- Implementation of the scenarios: less power required to the vehicle (-12% for Scenario 1 and -21% for Scenario 2)
- Impacts of shifting technology: 2.8 MJ/km to 1.1 MJ/km

4. Conclusions

- Preliminary work on the combination of real-word data with a numerical simulation to assess the individual and combined impacts of shifting to electric mobility and of inducing changes in driving behavior.



- The potential of reduction associated only to eco-driving (Scenario 1) is slightly higher for ICEV than for EV, without sacrificing travel time → **Opens the opportunity for definition of eco-driving in EV**

4. Conclusions

- The combination of both measures proves to be a good approach to reduce the impacts associated to this sector in a sustained manner, but the question of how to promote/deploy behavioral change still remains (e.g. real-time versus delayed **driver feedback**)

- The topic of eco-driving will continue to be relevant while the **driver has an active role within the vehicle**. When autonomous driving gains terrain, eco-driving information may also be relevant in drive cycle algorithm design for road network efficiency optimization.

Acknowledgments

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Thank you!

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