IFP ENERGIES NOUVELLES (IFPEN) IS A MAJOR FRENCH RESEARCH AND TRAINING PLAYER

- Located in Paris and Lyon metropolitan area
- Provides solutions to challenges in energy and climate
- Active role in the context of the EU Horizon Framework Program
- Collaborative environment with academic and industrial partners
- Promoting training in the fields of energy, motor vehicle and environment

4 strategic sectors

- Climate, environment and circular economy
- Renewable energy production
- Sustainable mobility
- Responsible oil and gas

ABOUT IFPEN

Sustainable mobility

3 priority areas in sustainable mobility

- **Electric mobility**:
  - increase energy efficiency via electrification
  - develop devices adapted to the needs such as battery, motors and converters
- **Connected mobility**:
  - reduce the environmental footprint and develop soft mobility
  - measure and treat land transport emissions to improve air quality
- **Mobility with a low environmental impact**:
  - maximize powertrains energy efficiency
  - implement solutions for CO_2 and pollutant emissions reduction

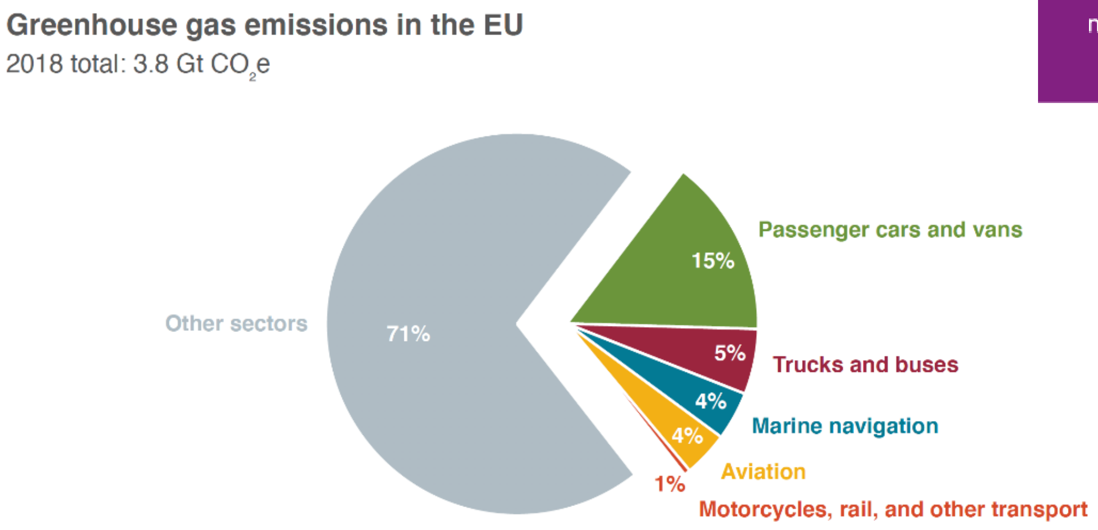
ENERGY-EFFICIENT OPTIMIZATION STRATEGIES FOR ELECTRIC AND CONNECTED MOBILITY

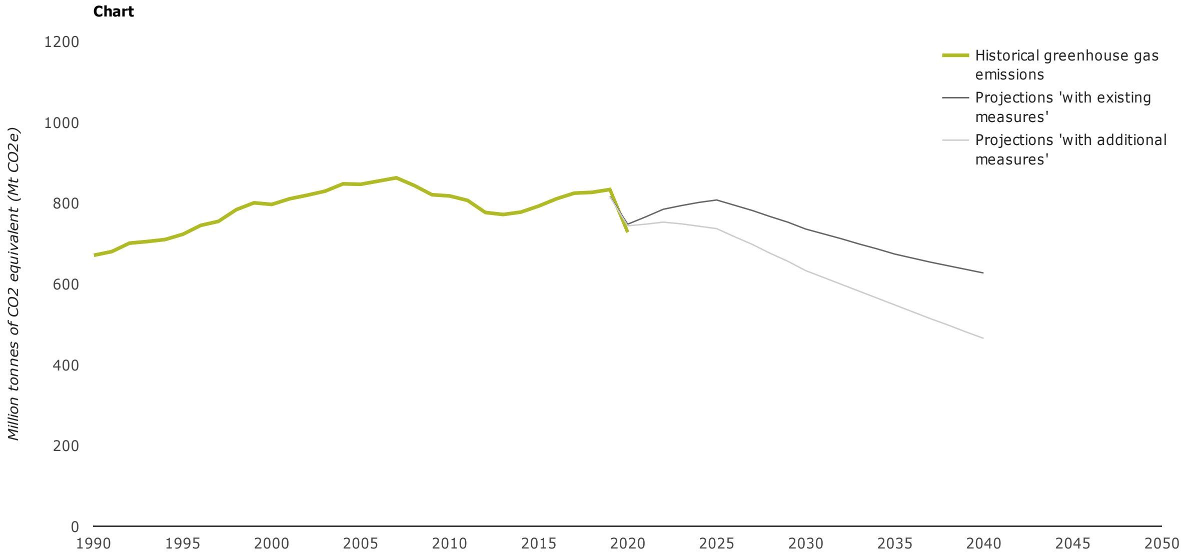
ANTONIO SCIARRETTA

ETH, 6 JUNE 2023

CONTEXT

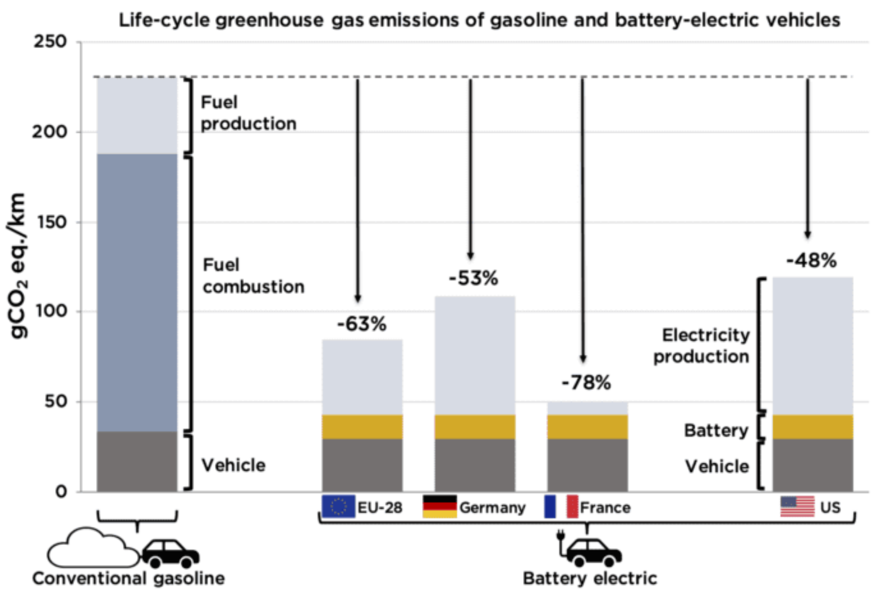
- Goal green deal: climate neutrality by 2050 and a 55% reduction of net GHG emissions by 2030, compared with 1990 levels (FitFor55 Feb 2023)
- Transport is the only sector in which emissions remain higher than 1990 → 90% reduction in transports is required
- Fit for 55: 100% ZEV (new cars and vans) by 2035 (55%-50% by 2030, compared to 1990)



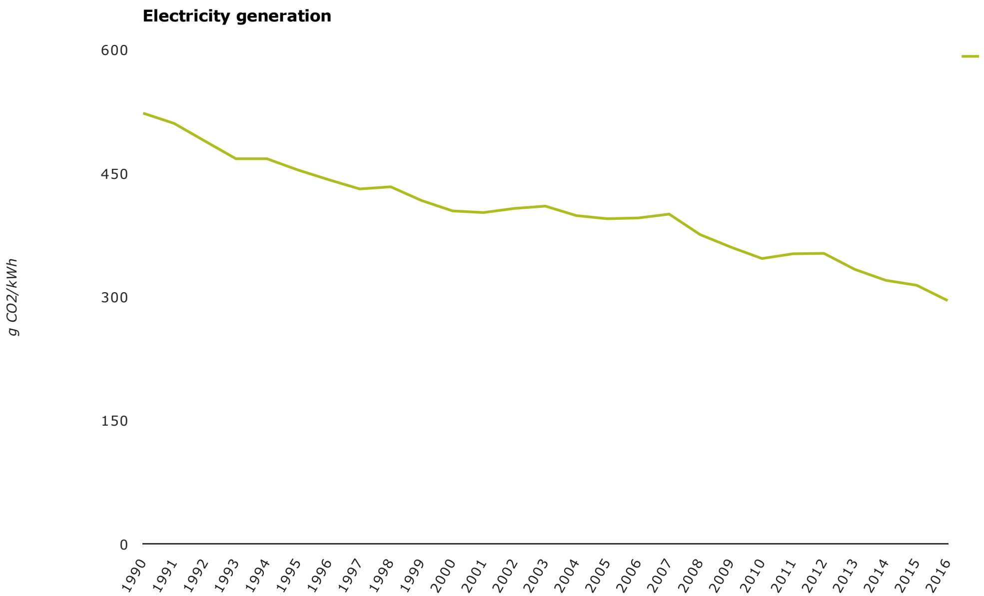


ELECTRIFICATION AND BEYOND

- Electric = 0% « taipipe » CO2 but non-zero upstream processes
- CO2 emissions from electricity generation is decreasing as EU has achieved 10,2% usage of renewables in transport (2021)
- But:
  - Strongly dependent on the country
  - Manufacturing, battery lifecycle must be considered as well
- Electric vehicles alone are not sufficient but require new mobility system and a change of habits

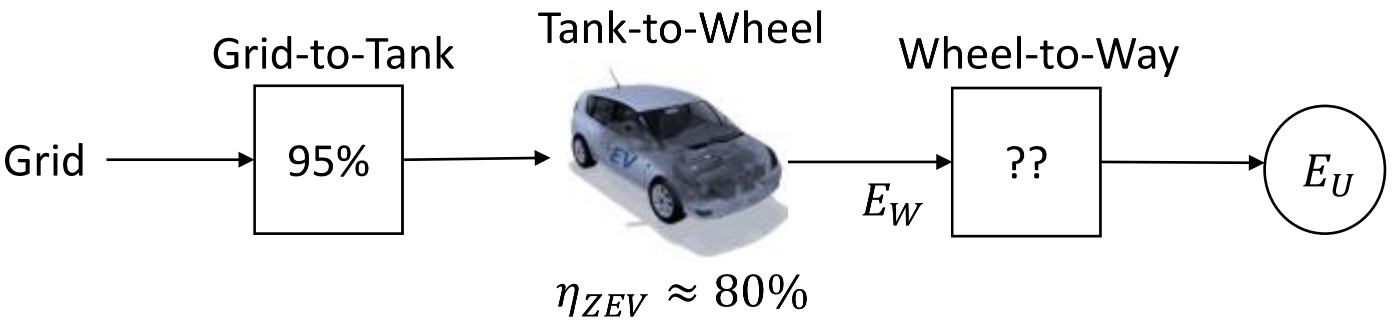


Source: ICCT, 2021



ENERGY MANAGEMENT

In addition to electrification, reducing grid-to-wheel consumption is necessary

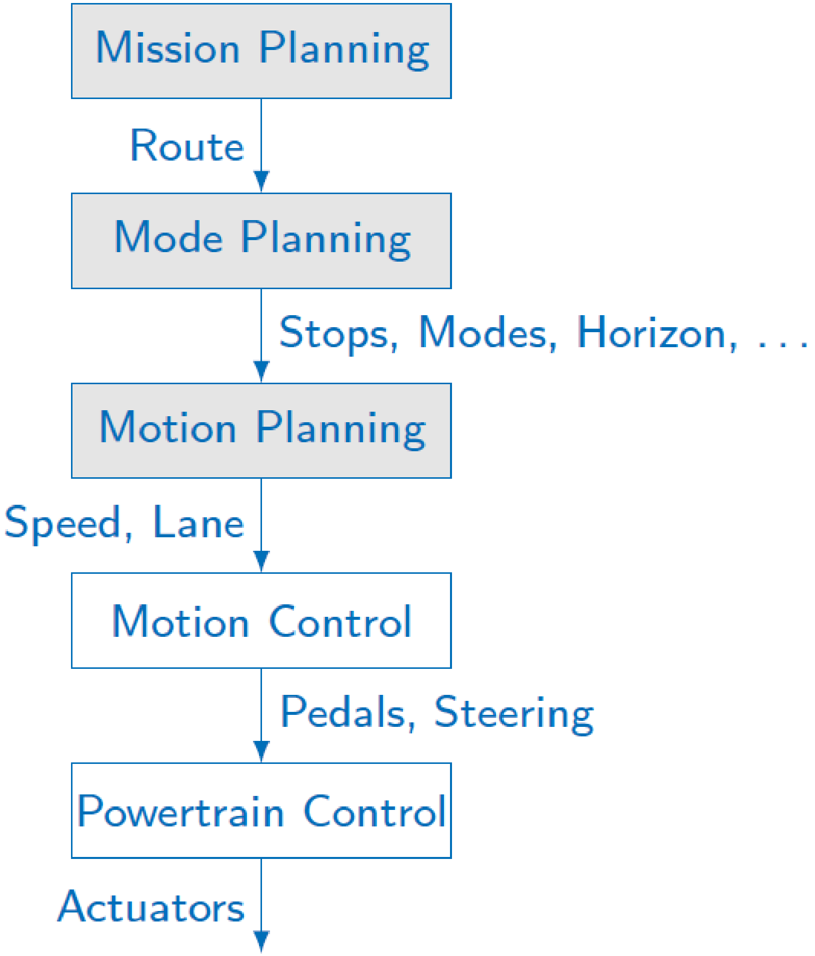


$$E_W = \frac{1}{2} m_v \left(v_f^2 - v_i^2\right) + m_v g \left(z_f - z_i\right) + m_v g C_{rr} \left(x_f - x_i\right) + \frac{1}{2} \rho_a A_{fr} C_D \int_0^{t_f} v^3(t) dt$$

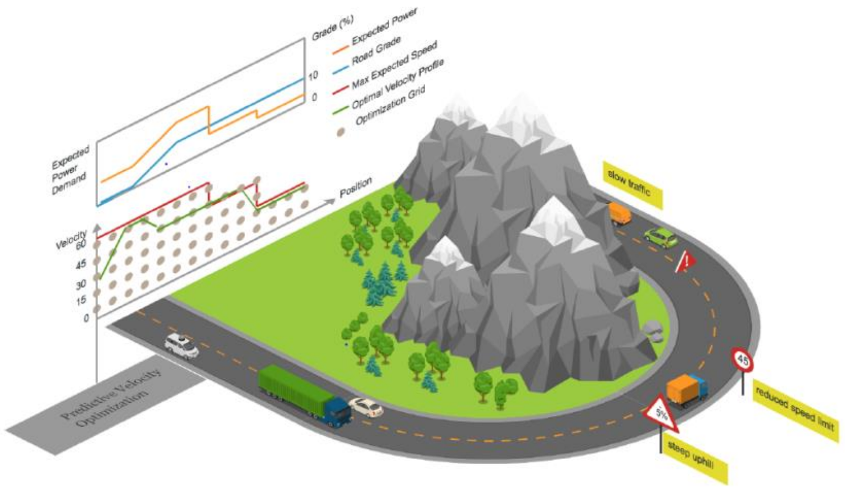
Energy at wheels = « Useful » energy + Design-dependent losses + Driving-dependent losses

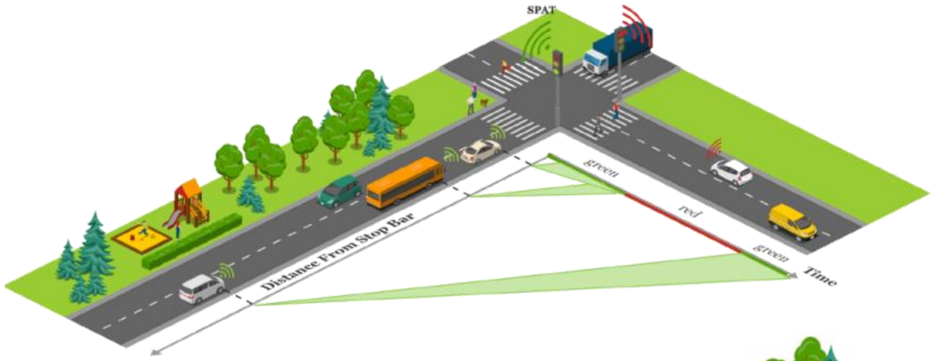
WHEEL TO WAY ENERGY MANAGEMENT AND CONNECTIVITY

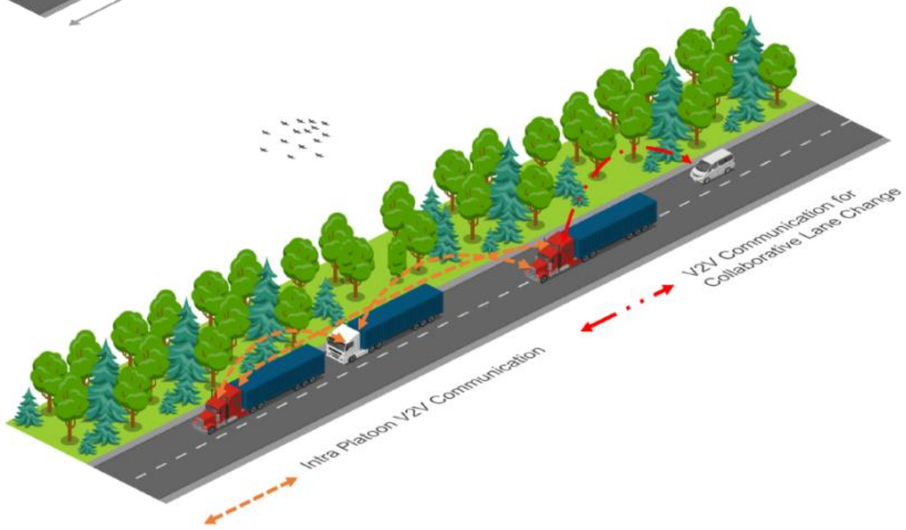
Sustainable mobility



Logical scheme of planning and control layers in CAVs.

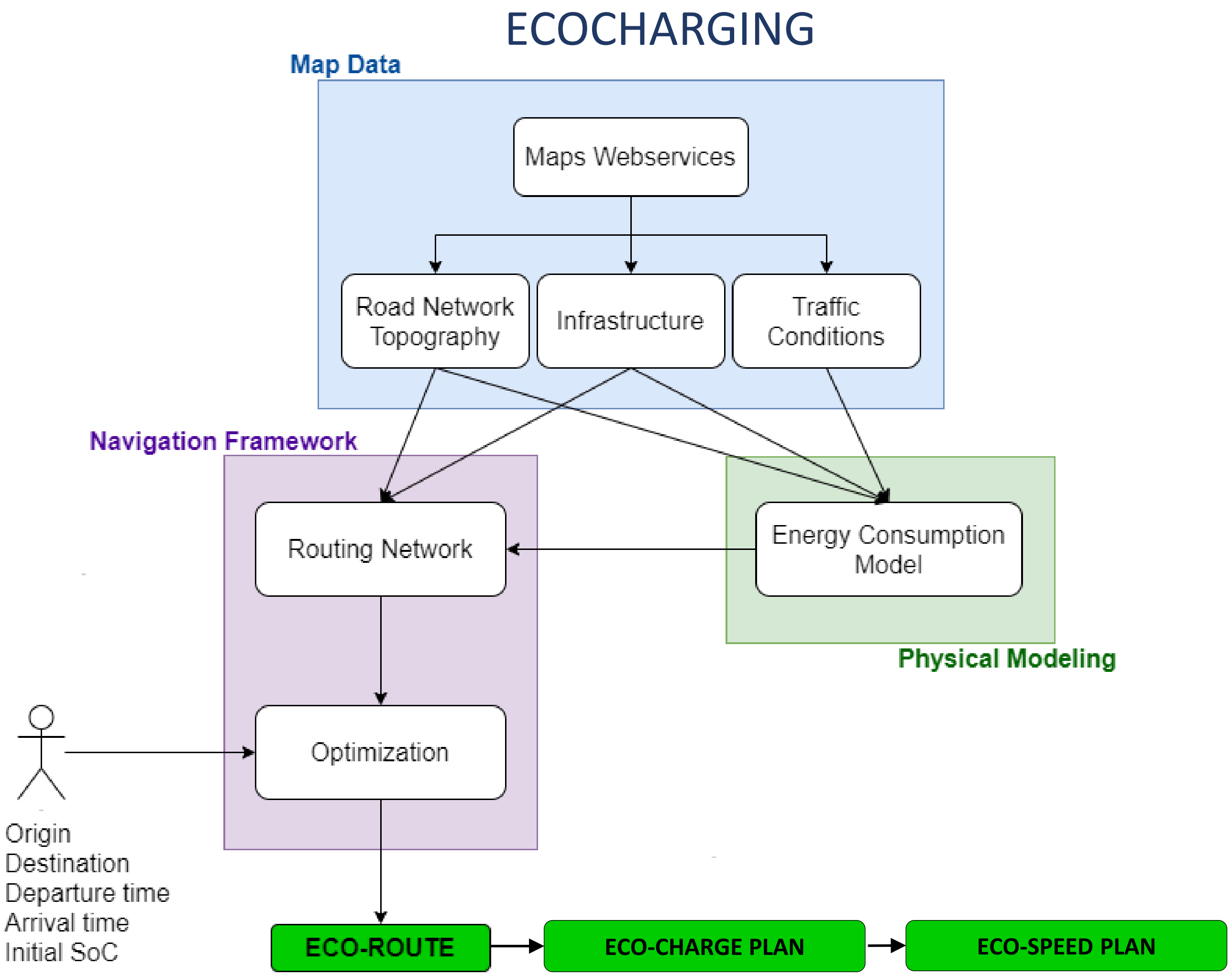


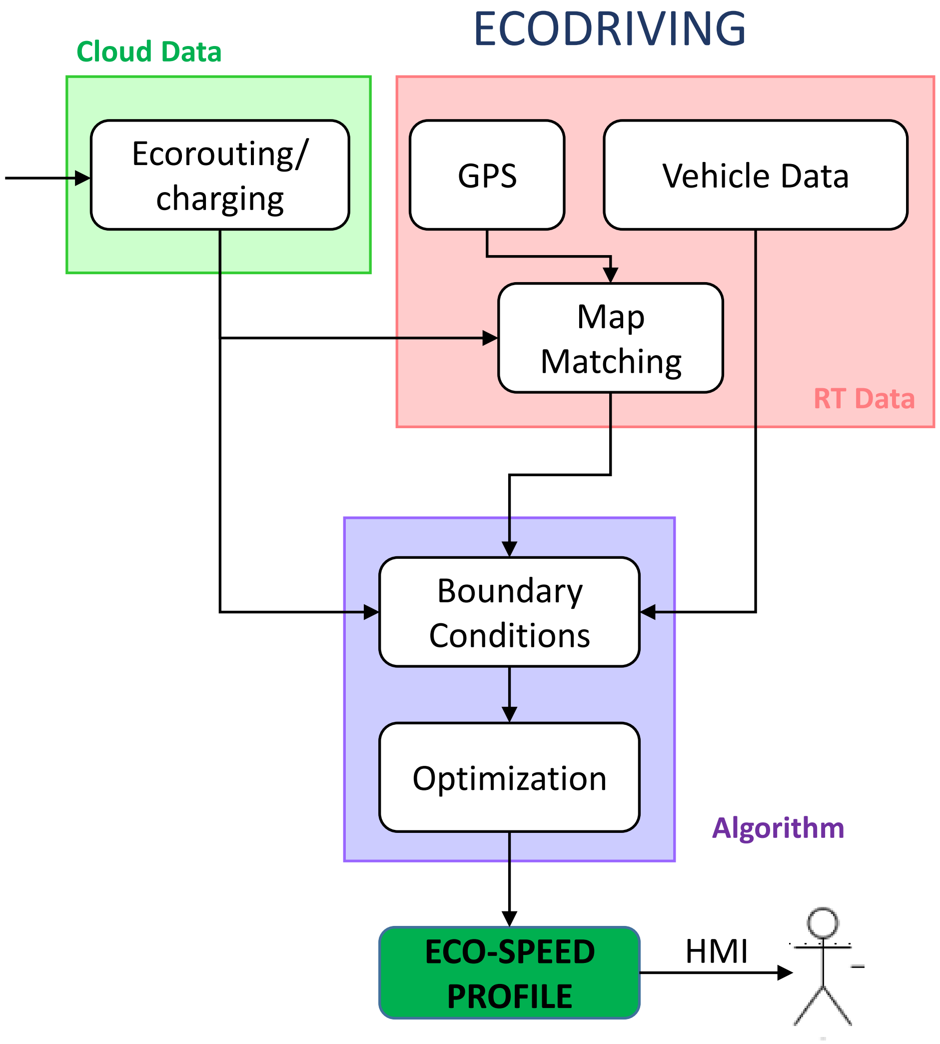




BACKGROUND

FROM ECOROUTING TO ECODRIVING

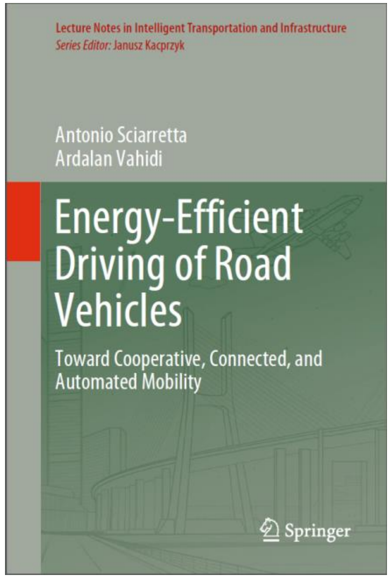




ACADEMIC COLLABORATIONS

Sustainable mobility

- Chair ECAV « Chair on Electric, Connected, and Autonomous Vehicle for Smart Mobility”, IFP School, since 2019
- Monography « Energy-Efficiency Driving of Road Vehicles » (Springer) published in 2020
- Organisation of the workshop e^{3}CAV (2 days, ~20 invited speakers) in 2019
- Collaborations with academic institutions
  - Mines Paritech, CAS (joint publication)
  - Ecole Polytechnique, CMAP (Ph.D. defended, joint publications)
  - INRIA, GIPSA-Lab (ongoing Ph.D., joint publication on traffic eco-management)
  - Clemson Univ. (scientific visitor 4 m, visiting Ph.D. 8 m, several joint publications)
  - Ohio State Univ., CAR (visiting Ph.D., joint publication)
  - Oak Ridge Nat. Lab. (joint publication)



PARTICIPATION IN EU FUNDED PROJECTS

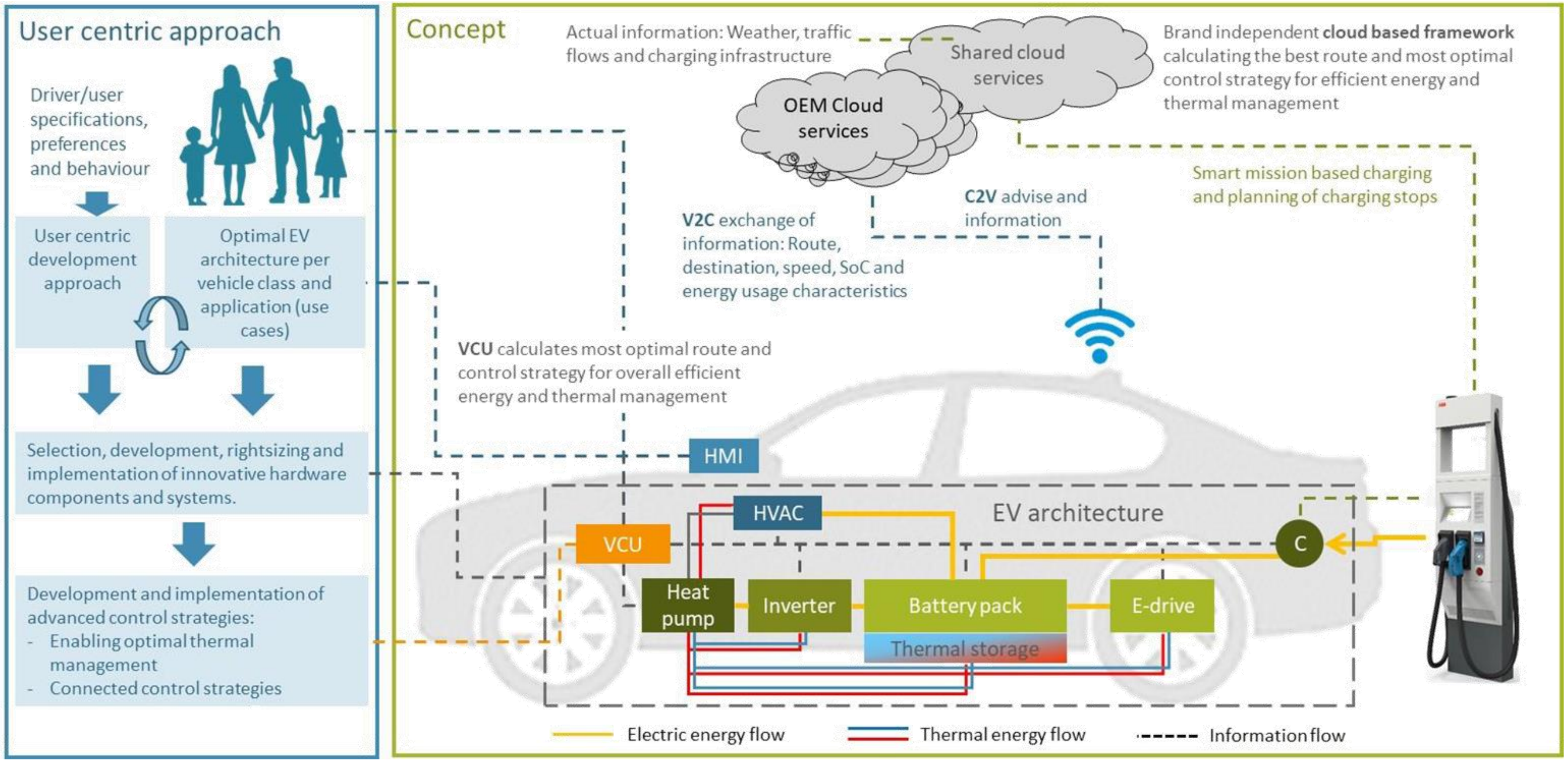
Sustainable mobility

- EMPOWER (Eco-operated, Modular, highly efficient, and flexible multi-POWERtrain for long-haul heavy-duty vehicles), EU HORIZON-CL5-2022-D5-01-08 (WP leader), 2023-present.
- XL-CONNECT (Electric vehicle fleet behavior, interaction with the grid, and digital twin), EU HORIZON-CL5-2021-D5-01, 2023-present.
- LONGRUN (Eco-x strategies for electrified heavy-duty vehicles), EU H2020-LC-GV-2019, 2020-present.
- CEVOLVER (Demonstration of eco-charging and eco-driving concepts for electric vehicles), EU H2020-LC-GV-01-2018, 2018-2022.
- ADVICE (Eco-x strategies for hybrid cars), EU H2020-GV-03-2016 (WP co-leader), 2017-2020.
- OPTEMUS (Eco-routing and thermal management of an electric car), EU H2020-GV-2-2014 (also WP leader), 2014-2019.

CEVOLVER PROJECT

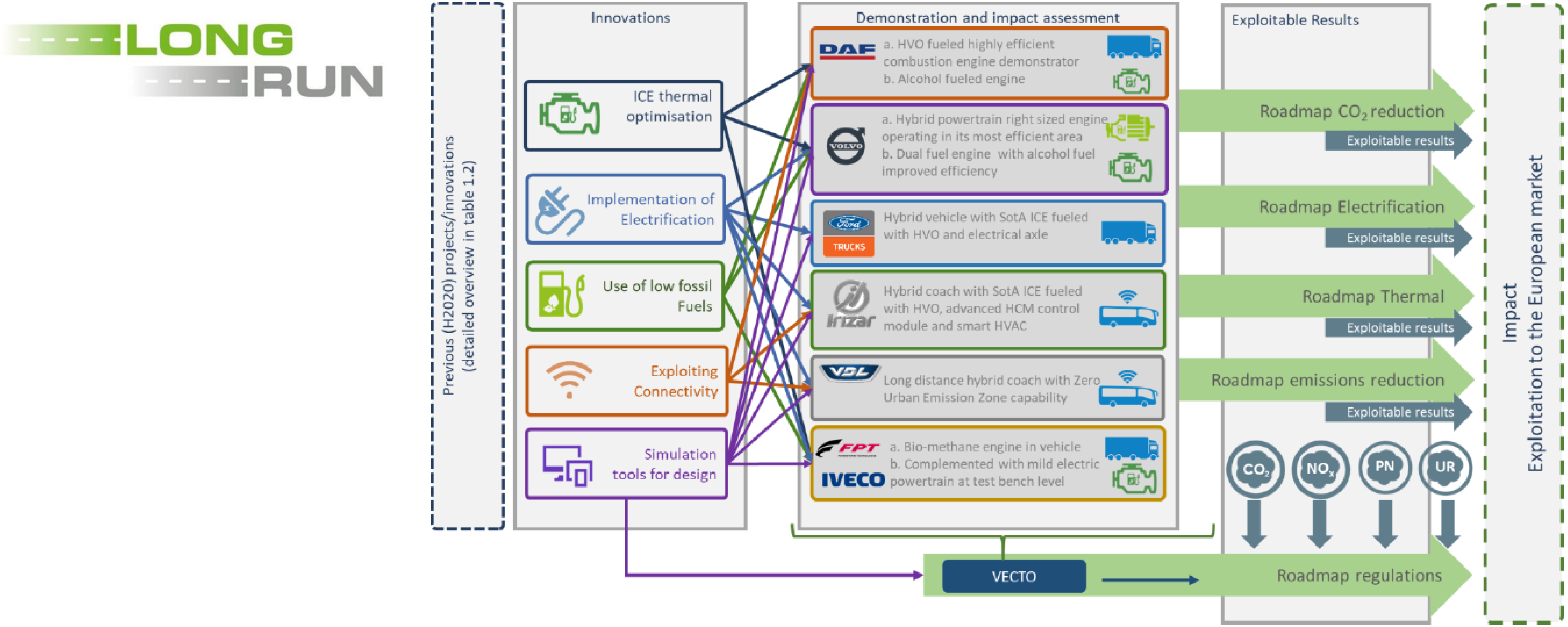
Sustainable mobility

CEVOLVER
Connected Electric Vehicle Optimised for Life, Value, Efficiency and Range



LONGRUN PROJECT

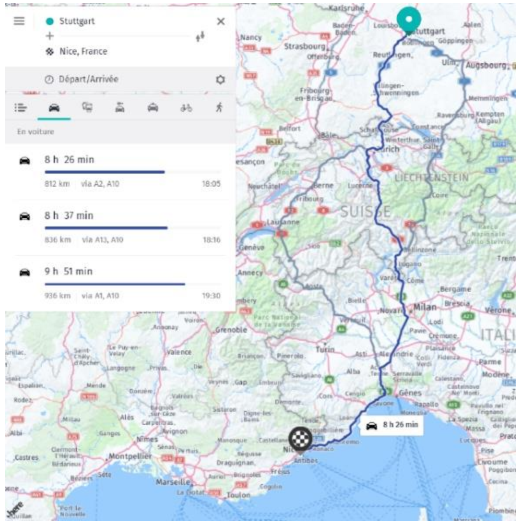
Sustainable mobility

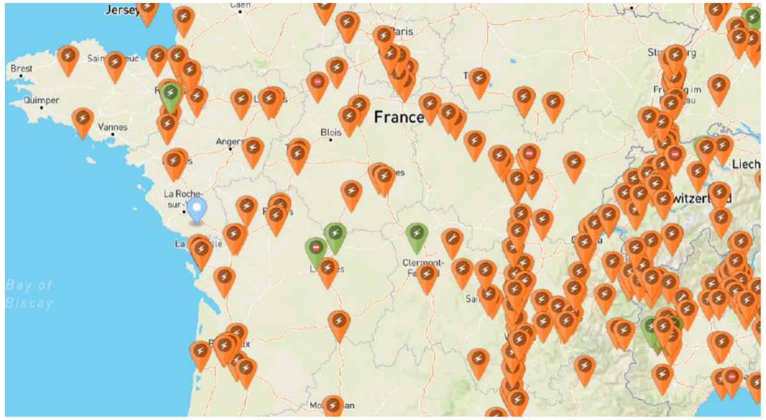


ECOROUTING AND ECOCHARGING

ECOROUTING/CHARGING DATA

- Road topography (offline)
  - Length
  - Importance class
  - Geometry (lat, long, altitude)
  - Signalization
- Charging infrastructure (offline)
  - Location (lat, long)
  - Charger power (DC, ≥ 50kW)
- Traffic data (online)
  - Avg. travel time
  - Avg. traffic speed
- Ambient data (online)
  - Temperature
  - Weather conditions





Source: https://openchargemap.org/site

OPTIMIZATION PROBLEM

Sustainable mobility

Bi-objective eco-routing formulation

$$\min_{x_i} \sum_{i \in A} [\lambda e_i + (1-\lambda) t_i] \cdot x_i$$

Objective function

$$\text{s.t.} \sum_{i \in u^+} x_i - \sum_{i \in u^-} x_i = \begin{cases} 1, & \text{if } u = \text{origin} \\ -1, & \text{if } u = \text{destination} \\ 0, & \text{otherwise} \end{cases} \quad \forall u \in V$$

Flow constraints

$$x_i \in \{0,1\} \quad \forall i \in A$$

Binary variable constraints

$$\lambda \in [0,1]$$

Optimization weight bounds

x_i : binary decision variable

e_i : energy consumption cost on each arc

u^+: set of outgoing arcs of node u

u^-: set of incoming arcs of node u

t_i : travel time cost on each arc

λ : optimization weight

OPTIMIZATION PROBLEM

Sustainable mobility

Bi-objective formulation with speed and charging embedded in the routing graph (eco-charging)

$$\min_{x_i} \sum_{i \in A_{\mathcal{L}}} [\lambda e_i(v_i, \Delta_i) + (1-\lambda) t_i(v_i, \Delta_i)] \cdot x_i$$

Objective function

$$\text{s.t.} \sum_{i \in u^+} x_i - \sum_{i \in u^-} x_i = \begin{cases} 1, & \text{if } u = \text{origin} \\ -1, & \text{if } u = \text{destination} \\ 0, & \text{otherwise} \end{cases} \quad \forall u \in V$$

Flow constraints

$$x_i \in \{0, 1\} \quad \forall i \in A_{\mathcal{L}}$$

Binary variable constraints

$$\lambda \in [0, 1]$$

Optimization weight bounds

x_i : binary decision variable

e_i : energy consumption cost on each arc

u^+: set of outgoing arcs of node u

u^-: set of incoming arcs of node u

t_i : travel time cost on each arc

λ : optimization weight

v_i : travel speed on each arc

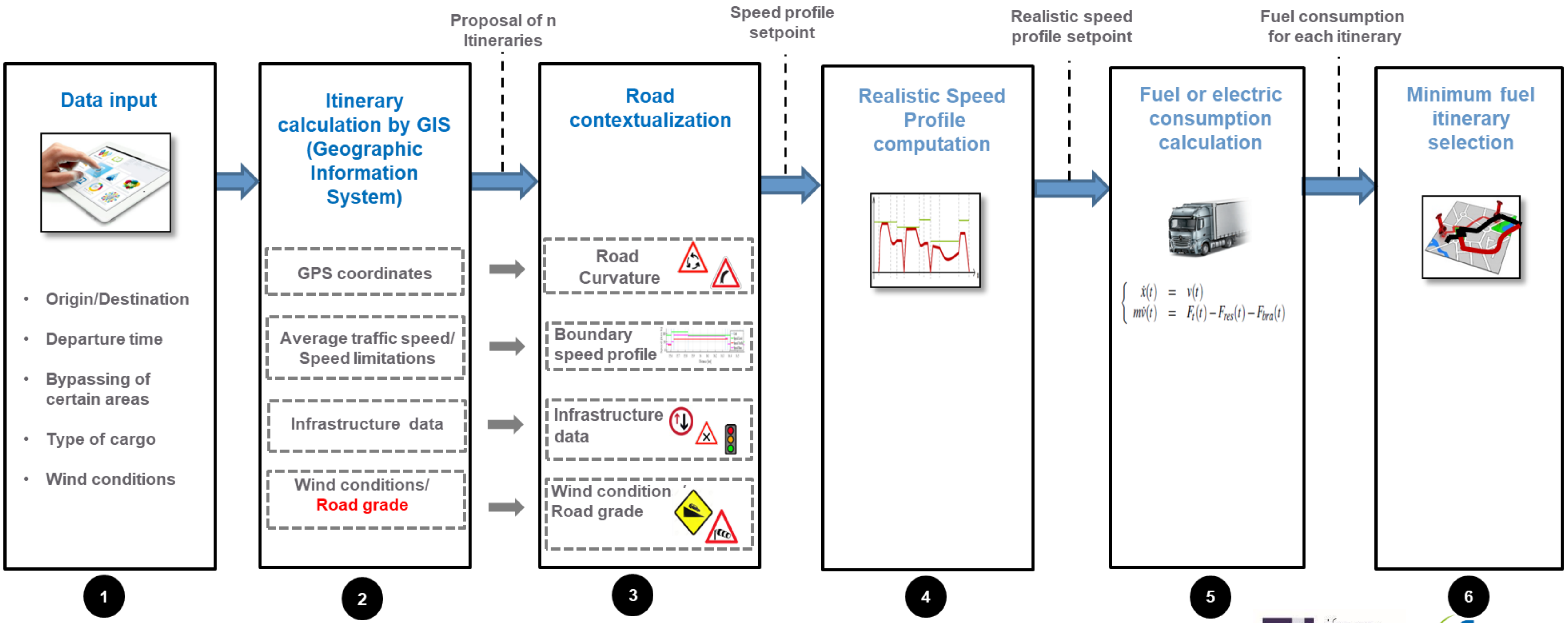
Δ_i: recharged energy on each arc

OPTIMIZATION PROBLEM

LONG RUN

Sustainable mobility

Pragmatic approach for long distance trips



Carnot ifpen Transports Energie

IFP Energies nouvelles

ECOROUTING/CHARGING WEBSERVICE

EVOLVER

Paramètres du véhicule

A | Ford

Itinéraire

Belgium, Maasmechelen, Rijksweg 477

67483 Edesheim, Deutschland

+ Ajouter une destination

Partir Maintenant | 17 oct. 22, 16:17

Calculer l'itinéraire

Résultats

2 itinéraires trouvés | Effacer les résultats

A	Eco Route	338 km	5 h 42 min	99.0 kWh

Fast Route

350 km | 4 h 3 min | 114.4 kWh

Charging points

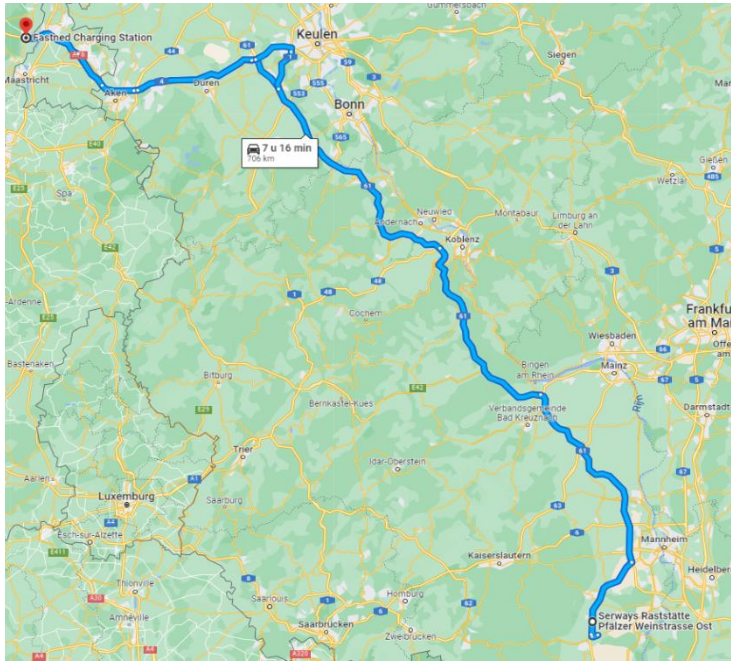
#	Distance (km)	Heure Arrivée	Heure Depart	Durée	SOC Arrivée (%)	SOC Départ (%)	Charge (kWh)
1	150	1 h 29 min	1 h 47 min	18	22	71	33
2	245	2 h 44 min	2 h 58 min	14	28	67	26

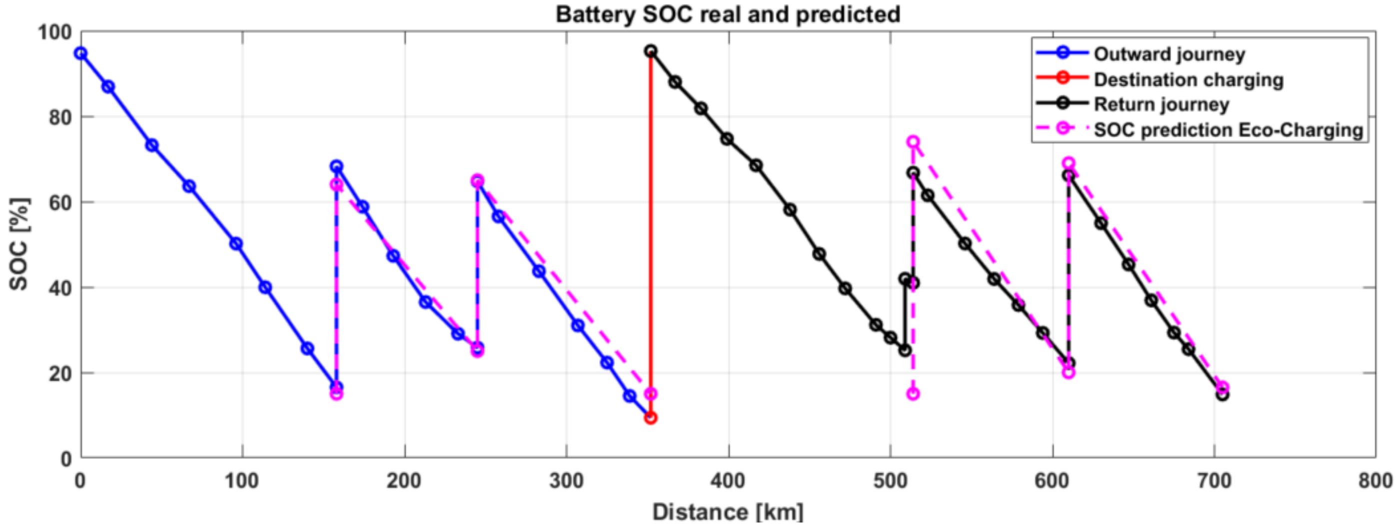
Télécharger gpx

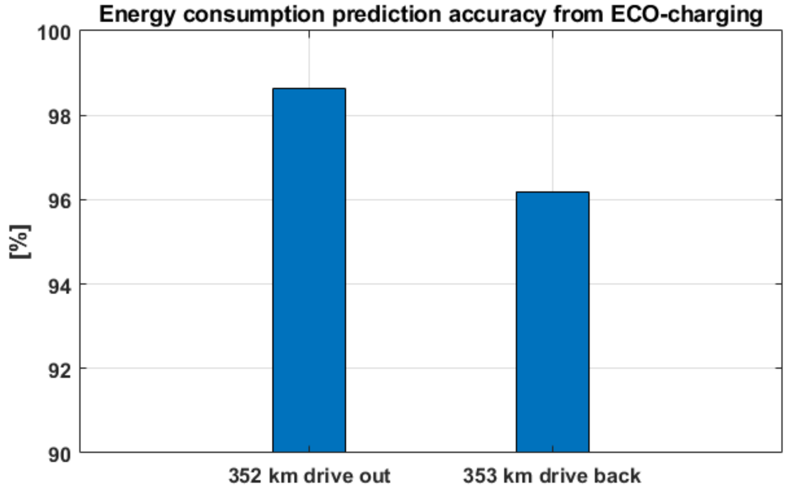
European Commission | Horizon 2020 European Union funding for Research & Innovation

ECOROUTING/CHARGING EXPERIMENTAL RESULTS
FORD CAMPAIGN

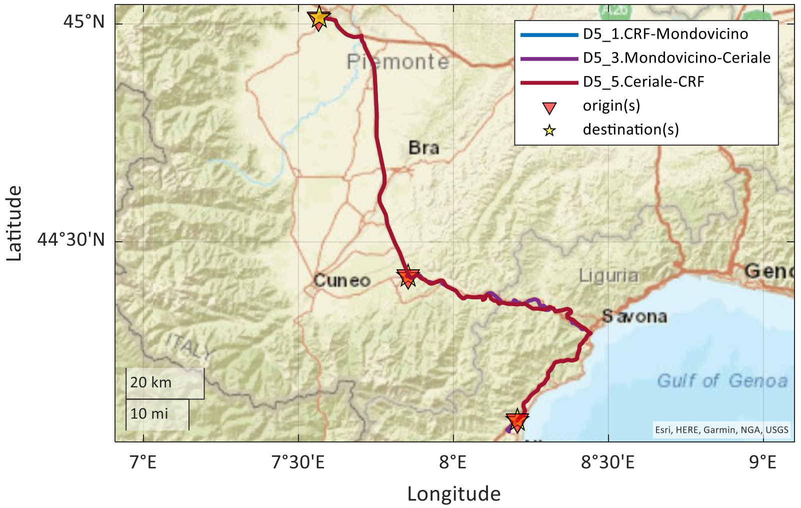
Sustainable mobility







ECOROUTING/CHARGING EXPERIMENTAL RESULTS
FIAT CAMPAIGN



	η_t (Day 7) / %	η_t (Day 8) / %	η_t (average Day 7 & Day8) / %
Day 5	-11.20	-14.24	-12.72
Day 6	-4.91	-8.16	-6.53
Day 9	-10.03	-13.11	-11.57

Table 7: Time gain ηt overview of trips a comparison to baseline (Day 7 and Day 8)

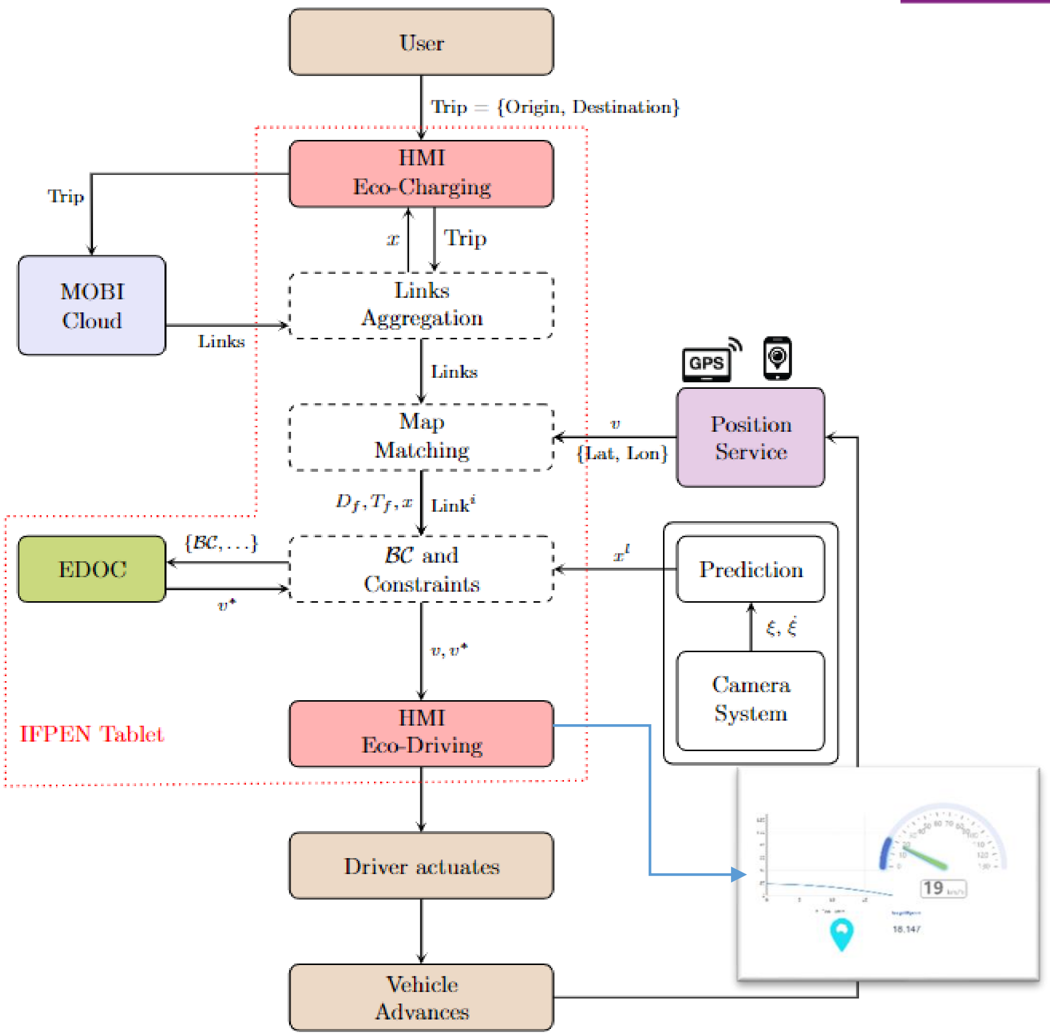
	$\eta_{E,Batt}$ (Day 7) / %	$\eta_{E,Batt}$ (Day 8) / %	$\eta_{E,Batt}$ (average Day 7 & Day8) / %
Day 5	5.01	10.47	7.74
Day 6	4.77	10.24	7.51
Day 9	1.35	7.02	4.18

Table 8: Energy saving $\eta_{E,Batt}$ overview of trips and comparison to baseline (Day 7 and Day 8)

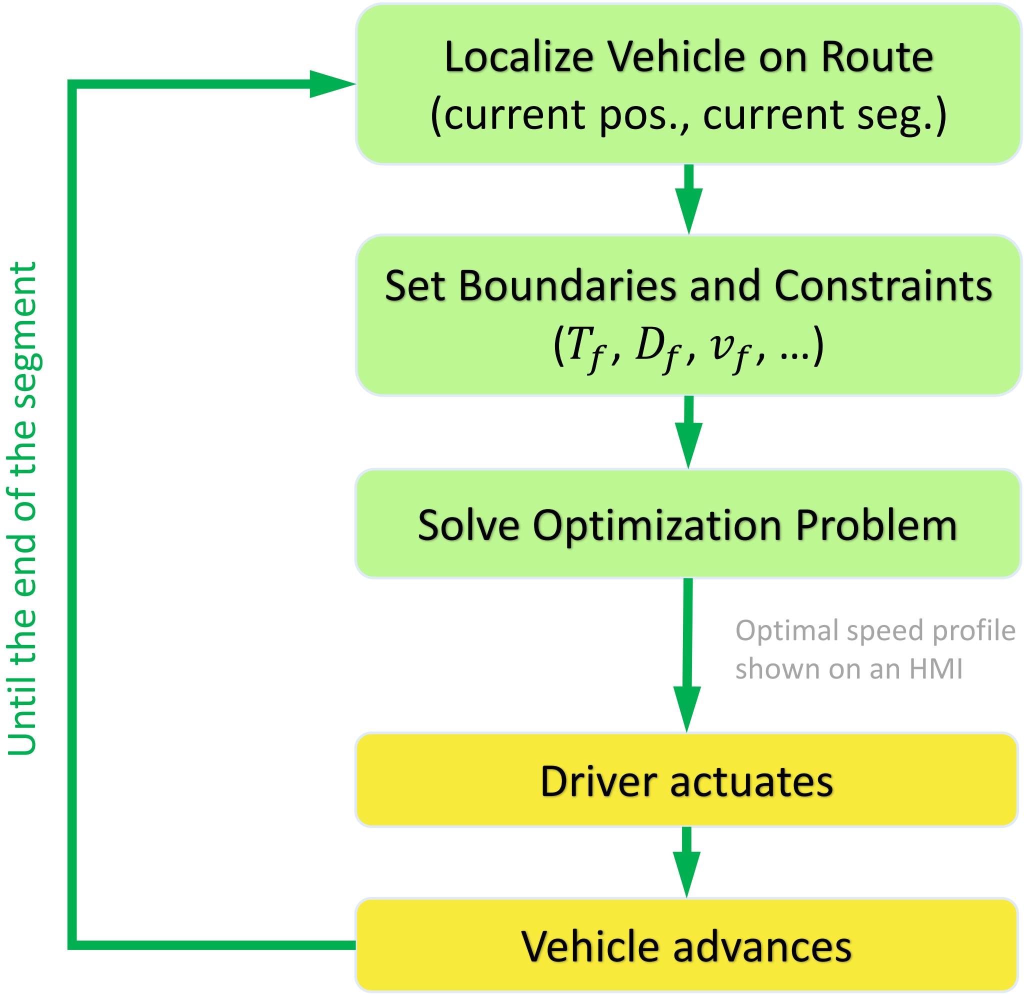
ECODRIVING

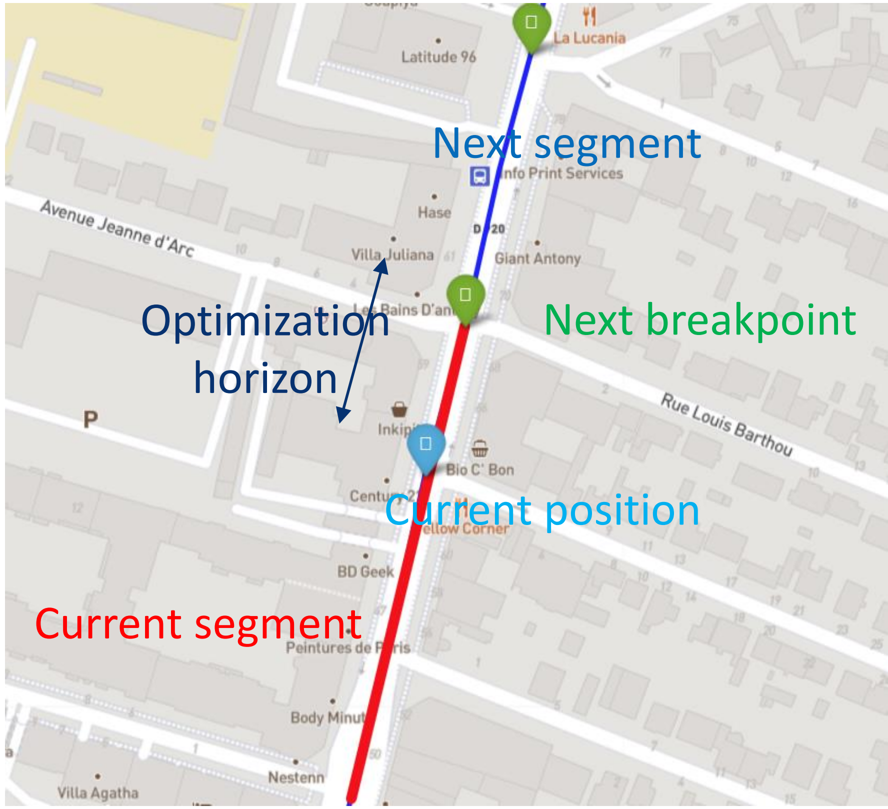
DATA AND ARCHITECTURE

- Cloud Data
  - Ecocharging webservice (ecoroute with all its attributes)
  - External webservices (traffic, weather)
- Real-Time Data
  - ADAS sensors (leading vehicle detection, traffic light) (optional)
  - In-vehicle sensors (SoC, speed, etc.)
  - GPS
- Additional Modules
  - Road links aggregation and breakpoint detection
  - Map Matching (current position, current segment on route)
  - Generation of boundary conditions and constraints for the optimization
  - HMI



ECODRIVING CONCEPT





OPTIMIZATION PROBLEM

Sustainable mobility

An optimal control problem with fixed terminal time and state constraints

Control Inputs: powertrain force, brake force (per unit mass)

Time horizon

Objective Function: energy consumption

Running cost: battery power

$$\underset{u_p(t),u_b(t)}{\text{minimize}} \quad J = \int_0^{t_f} P_b(u_p(t), v(t))dt,$$

$$\text{subject to} \quad \frac{ds(t)}{dt} = v(t),$$

State variables: position, speed

$$\frac{dv(t)}{dt} = u_p(t) - \frac{C_1}{m}v(t) - \frac{C_2}{m}v^2(t) - h(s(t)) - u_b(t),$$

Newton's 2nd law

$$v(0) = v_i, v(t_f) = v_f,$$
$$s(0) = 0, s(t_f) = s_f,$$

Terminal conditions: final speed, distance horizon

$$u_{p,min}(v(t)) \leqslant u_p \leqslant u_{p,max}(v(t)),$$
$$0 \leqslant u_b(t) \leqslant u_{b,max},$$

Control constraints

$$v_{min}(t, s(t)) \leq v(t) \leq v_{max}(t, s(t)),$$

Speed limits (top legal, cornering, traffic…)

$$s_{min}(t) \leq s(t) \leq s_{max}(t),$$

Position constraint induced by a preceding vehicle

ANALYTICAL SOLUTION

Sustainable mobility

Model simplification

$$P_b(t) = bu_p^2(t) + mu_p(t)v(t), \quad \dot{v}(t) = u_p(t) - h$$

Derivation of analytical solutions using PMP

Unconstrained

$$v^*(t) = v_i + \left(-\frac{4v_i}{t_f} - \frac{2v_f}{t_f} + \frac{6s_f}{t_f^2}\right)t + \left(\frac{3v_i}{t_f^2} - \frac{6s_f}{t_f^3} + \frac{3v_f}{t_f^2}\right)t^2$$

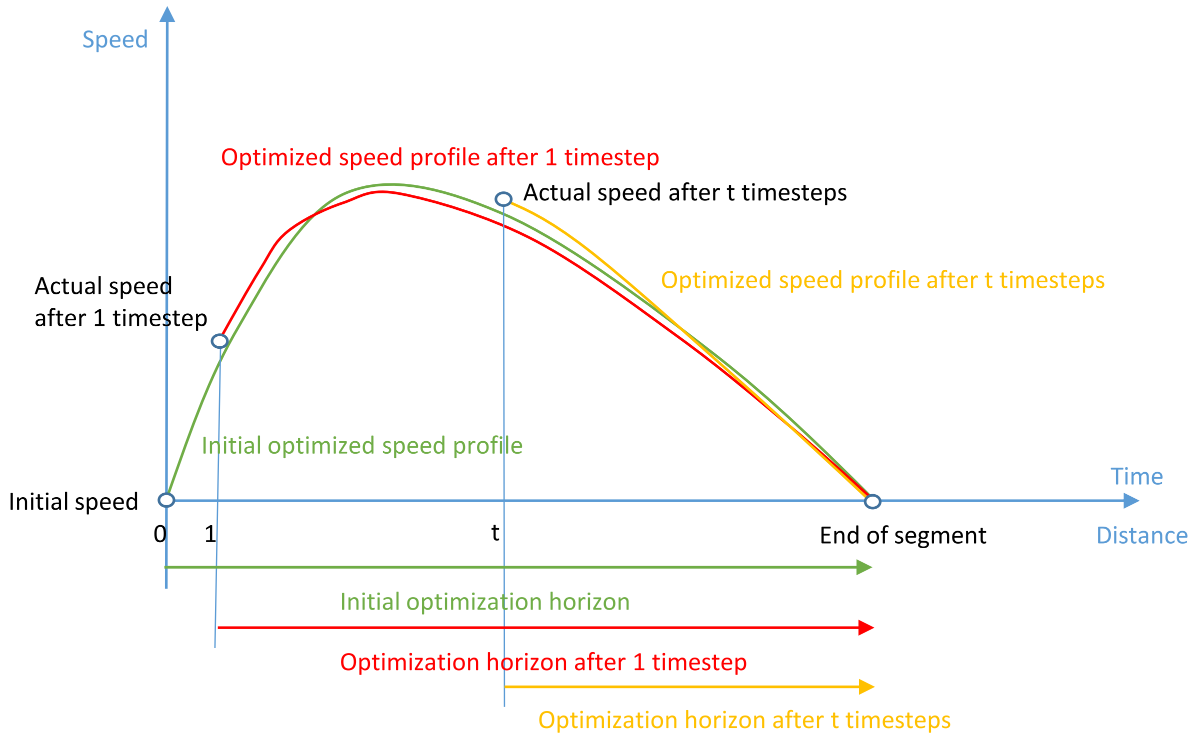
Speed-constrained

$$v^*(t) = \text{Piecewise quadratic function}(t|v_i, v_f, t_f, s_f, v_{max})$$

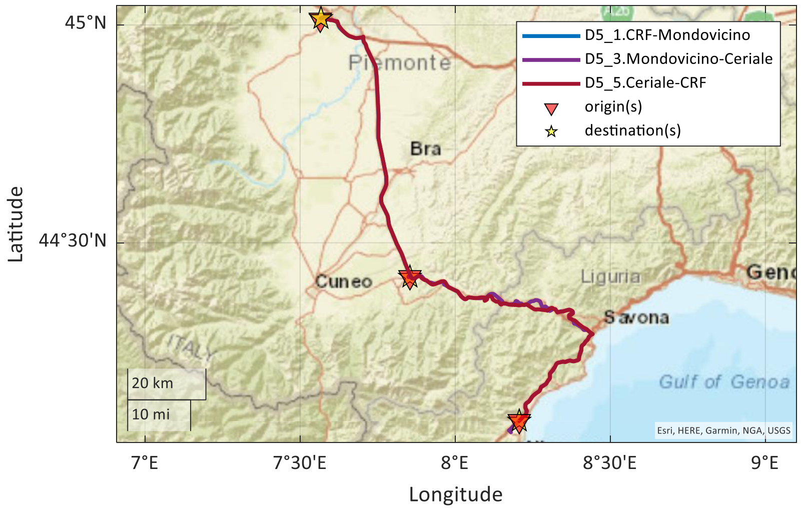
Position-constrained

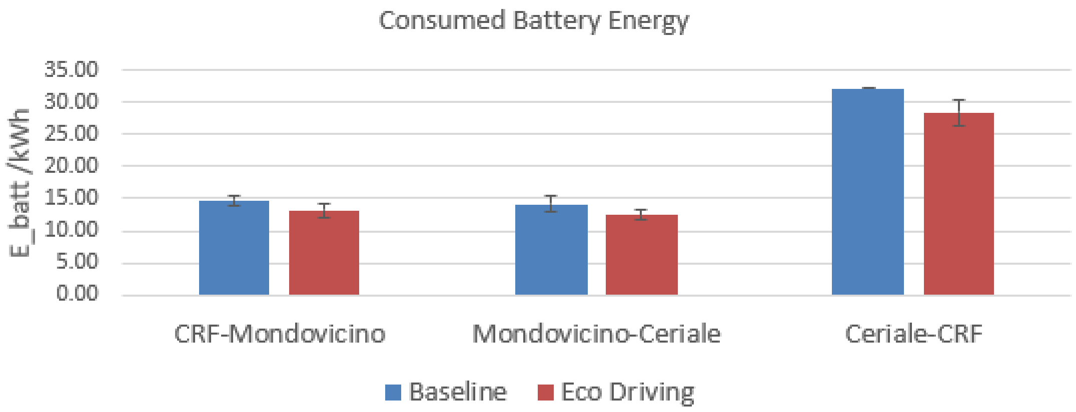
$$v^*(t) = \text{Piecewise quadratic function}(t|v_i, v_f, t_f, s_f, s_{p0}, v_{p0}, a_p)$$

Application in a shrinking-horizon (MPC) framework

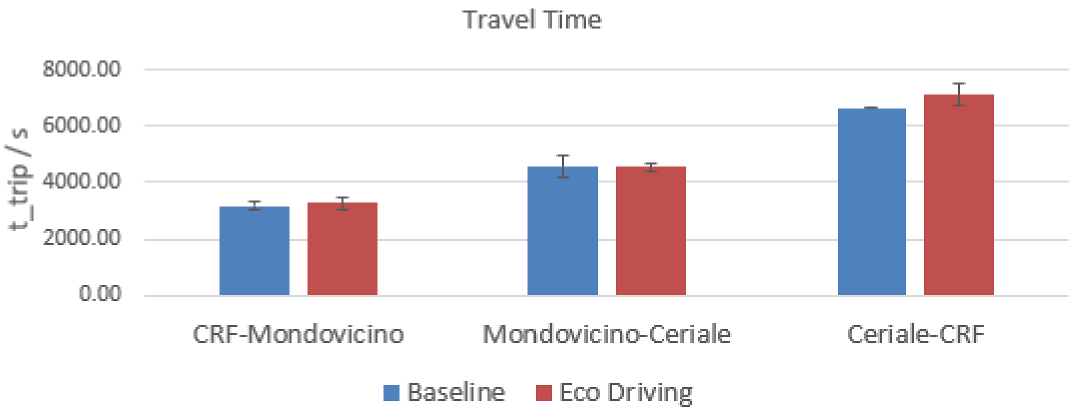


ECODRIVING EXPERIMENTAL RESULTS
FIAT CAMPAIGN





Trip	eta_E_Batt / %	delta_t_trip / s
CRF-Mondovicino	10.8957%	105.48
Mondovicino-Ceriale	11.9844%	-24.78
Ceriale-CRF	11.8032%	451.13
Average	**11.5611%**	**177.27**



ECODRIVING EXPERIMENTAL RESULTS
IFPEN PROPRIETARY SYSTEM

Sustainable mobility

- Perception system by a French start-up company called Visual Behavior
- Stereoscopic camera with ability to detect, identify, and measure
  - Relative speed and distance of the preceding vehicle
  - Traffic light status

ifpen Transports Energie

IFP Energies nouvelles

MOBILITY SYSTEMS

MOBILITY OBSERVATION AND ANALYSIS

Data space

Raw data:
Counting measurement, GPS trace, mobility survey, …

Data handling

Treatment
Diagnostic
Knowledge extraction

Processed and exploitable data

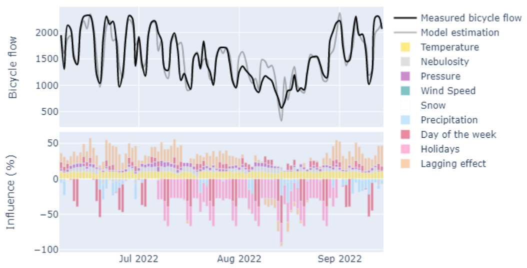
Data enhancement

Fusion
Enrichment
Calibration
Generation

Improved, representative and calibrated data

Estimation of full flow per street by fusion

Model of counting time series for prediction and gap removing

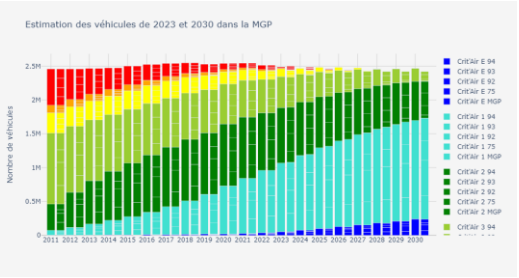


Tuning of bike routing algorithm from user's preferences

eqasim

MATSim Multi-Agent Transport Simulation

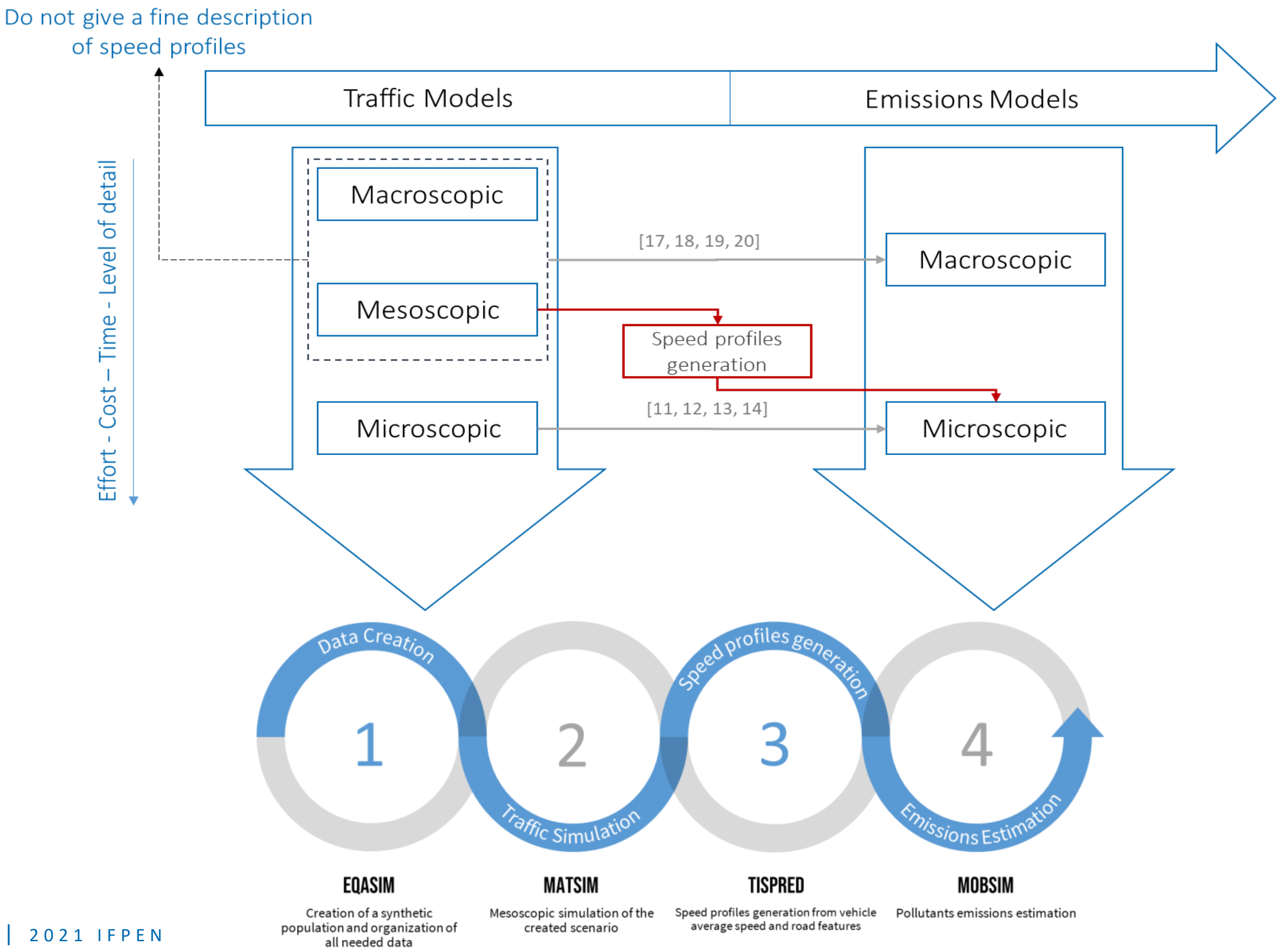
Evaluation of prospective scenarios on territory: bicycle infrastructure, LEZ restriction



MACRO TO MICRO: SPEED PROFILES GENERATION
PHD OF ABDELKADER DIB, CO-SUPERVISED BY MILOŠ BALAĆ

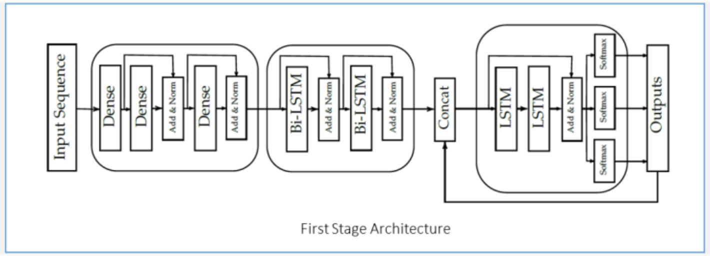
Sustainable mobility

Goal: predict emissions from traffic and air quality

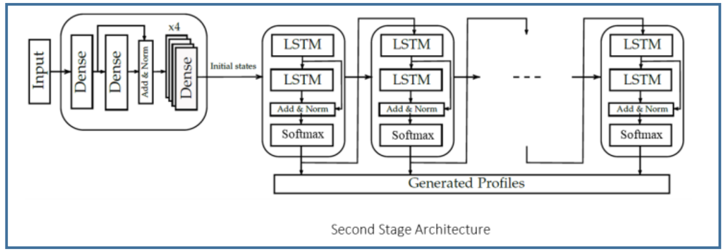


Approach: LSTM-based neural network architecture

Trained through recorded trip profiles



First Stage Architecture

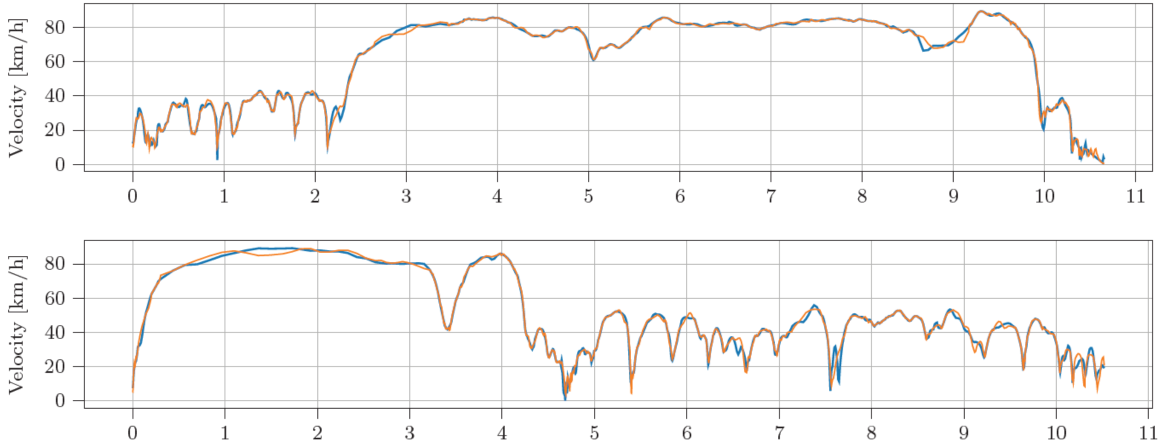


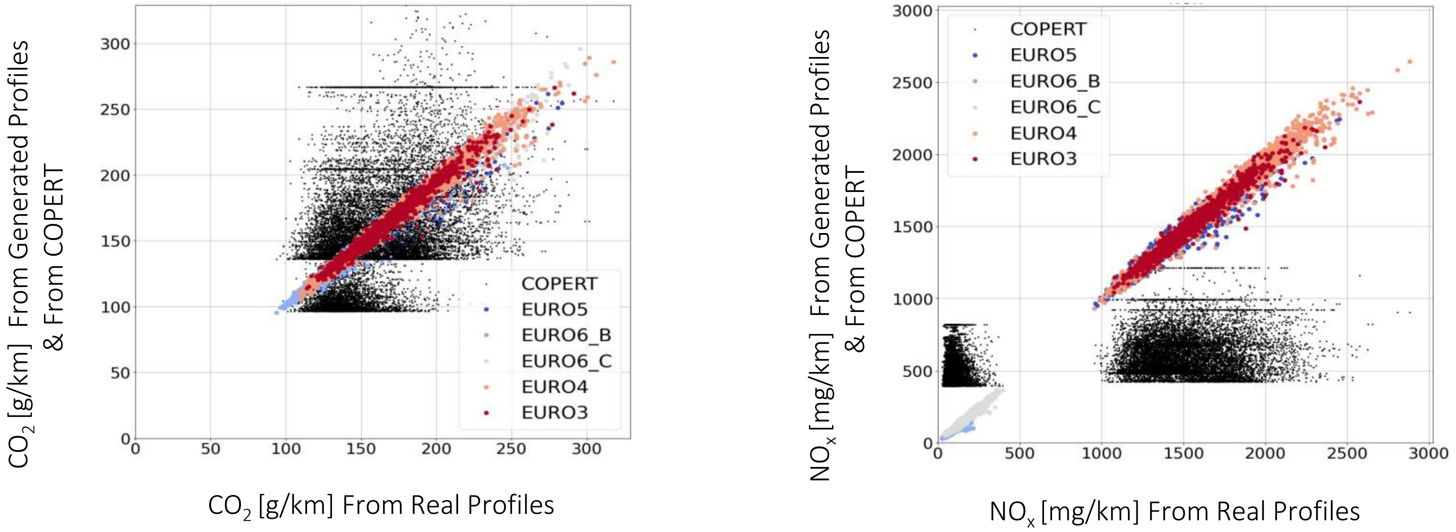
Second Stage Architecture

MACRO TO MICRO: SPEED PROFILES GENERATION
PHD OF ABDELKADER DIB, CO-SUPERVISED BY MILOŠ BALAĆ

Sustainable mobility

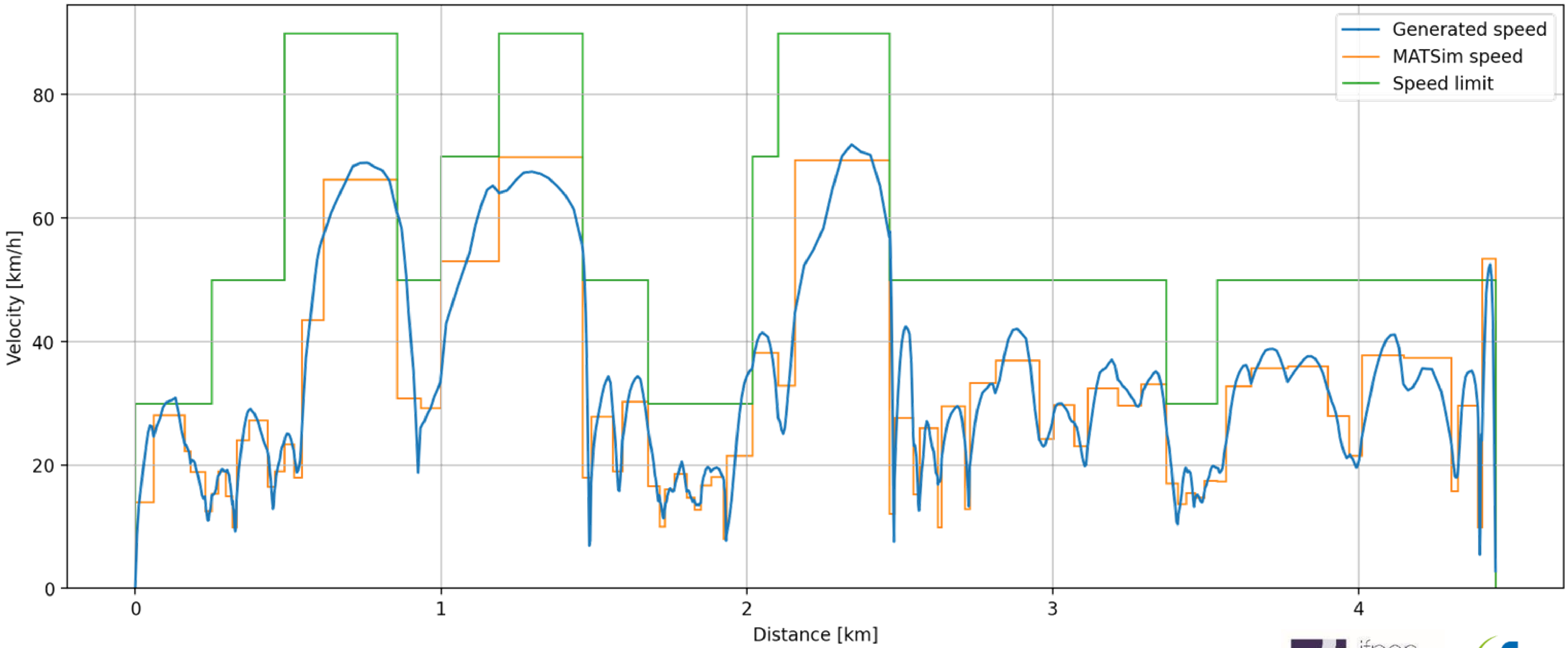
First results: reconstruction of speed profiles + emission estimation





MACRO TO MICRO: SPEED PROFILES GENERATION
PHD OF ABDELKADER DIB, CO-SUPERVISED BY MILOŠ BALAĆ

Sustainable mobility

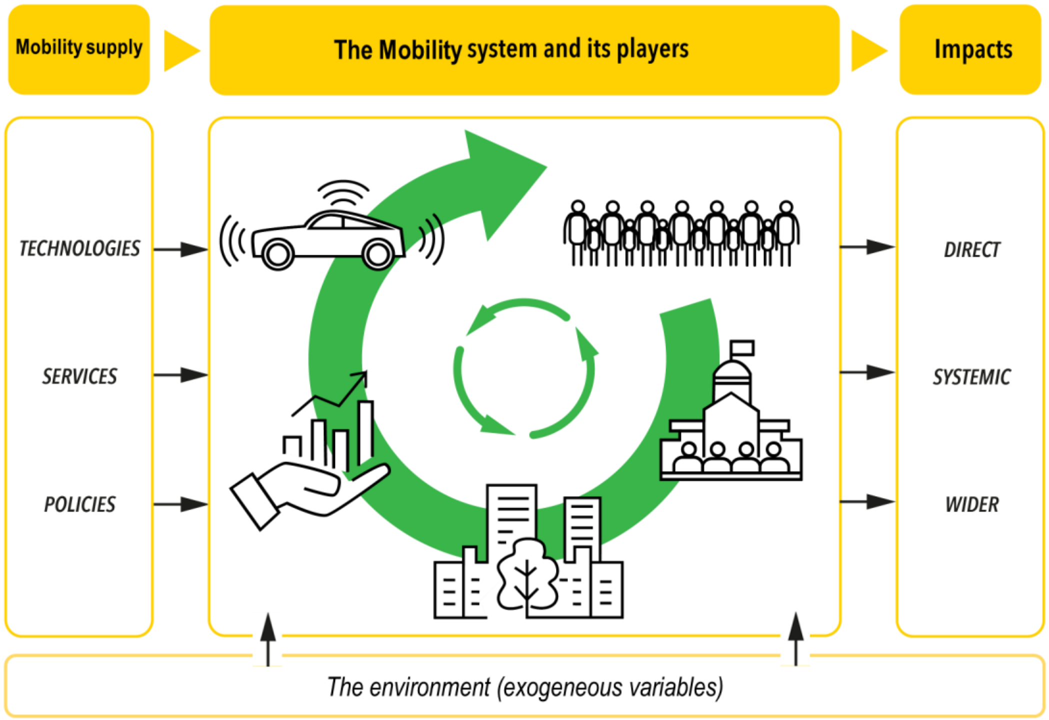


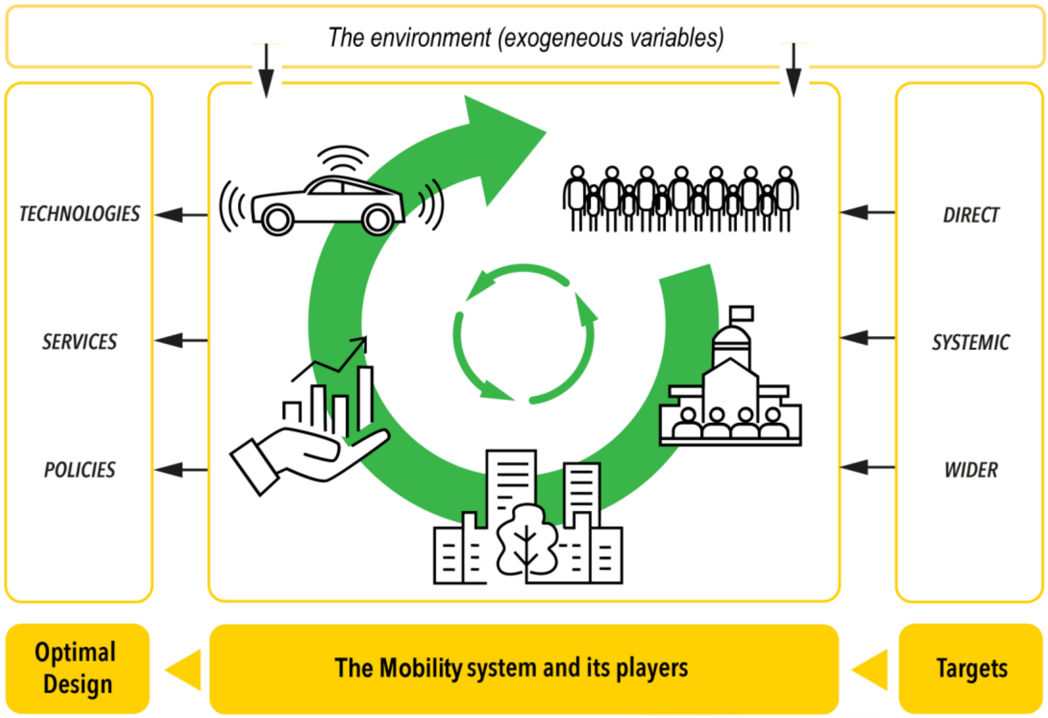
MOBILITY SYSTEMS DYNAMICS AND OPTIMISATION
UPCOMING FRENCH PROJECT « FORBAC »

Sustainable mobility

Goals:

- Mobility system described by system dynamics
- From Forecasting to « backcasting » (optimal control)





Innovating for energy

Find us on:

www.ifpenergiesnouvelles.com

@IFPENinnovation