Life cycle assessment of autonomous mobility: scope(s) of assessment

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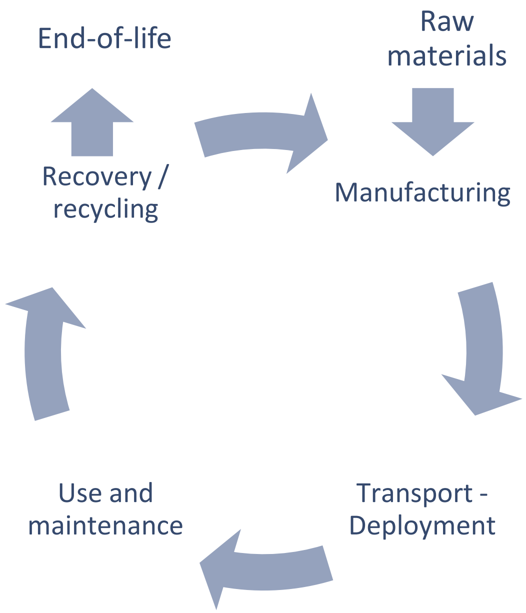
- Context -

- Work presented here is part of the SAM (Safety and Acceptability of driving and Autonomous Mobility) project (for full presentation refer to Ph. Dunez’s presentation in the morning session)
- 6 evaluation themes covering acceptability, safety, socio-economic impacts,...
- Among which environmental impacts including life cycle assessment

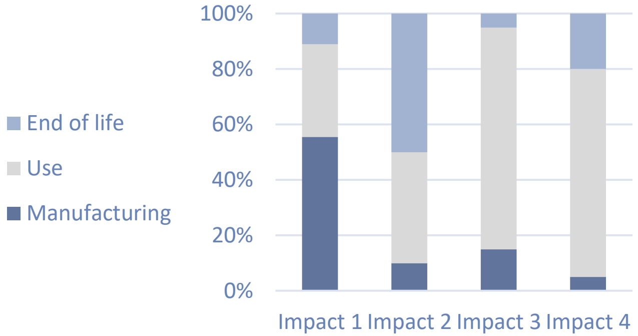
- Life Cycle Assessment -

- **LCA:**
  - **Allows to evaluate potential environmental impacts of the entire life cycle (from manufacturing to the end-of-life)**
  - **Multi-criteria method including, but not restricted to, carbon footprint (other indicators: resources depletion, aquatic eutrophication, ...)**
  - **Uses primary data (from field measurements) and secondary data (from generic databases, reference values and scenarios) concerning material use, transformation processes, and logistics.**



- Application in the SAM project -

- « Mode » LCA
  - Characterise autonomous modes through typical environmental impacts to understand relative burden of different systems and life cycle phases (comprehensive study needed to characterise these NEW modes)



- « Service » LCA
  - Contextualised assessment of an autonomous service's avoided and produced impacts: there is a high variability of estimated potential consequences -> can we identify environmental relevance of autonomous services by reducing this variability on specific case studies?

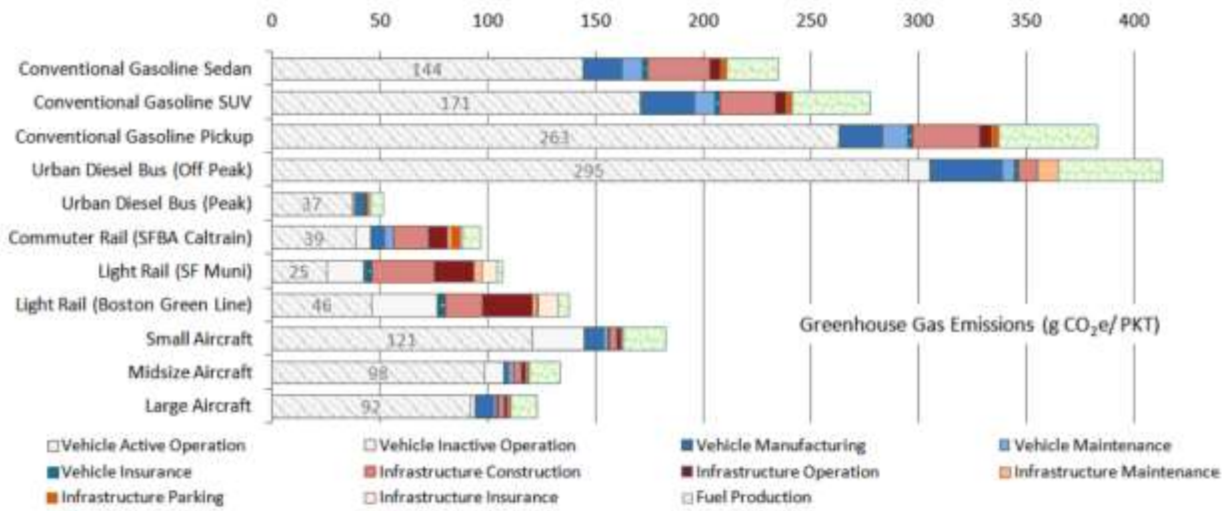
- Service's potential avoided impacts	+ Service's potential produced impacts
-/+ modal shift - Cruise for parking - /+ Congestion mitigation - Shared vehicles + Ridership …	+ Vehicle/ sensors/ infrastructure/ connectivity manufacture + Their use phase: energy consumption,… + Data transfers …

- Aim of the presentation -

- Present evaluation framework and scope
- Discuss uncertainties on a « what-if » scenario : potential impacts, technological choices
  - What could be the main contributors?
  - What are the main parameters at play and how they influence the results?
  - What are the associated technological and context uncertainties ?
  - How can we handle these uncertainties through relevant scenarios ?

- Mode LCA -

- LCA of transport modes -



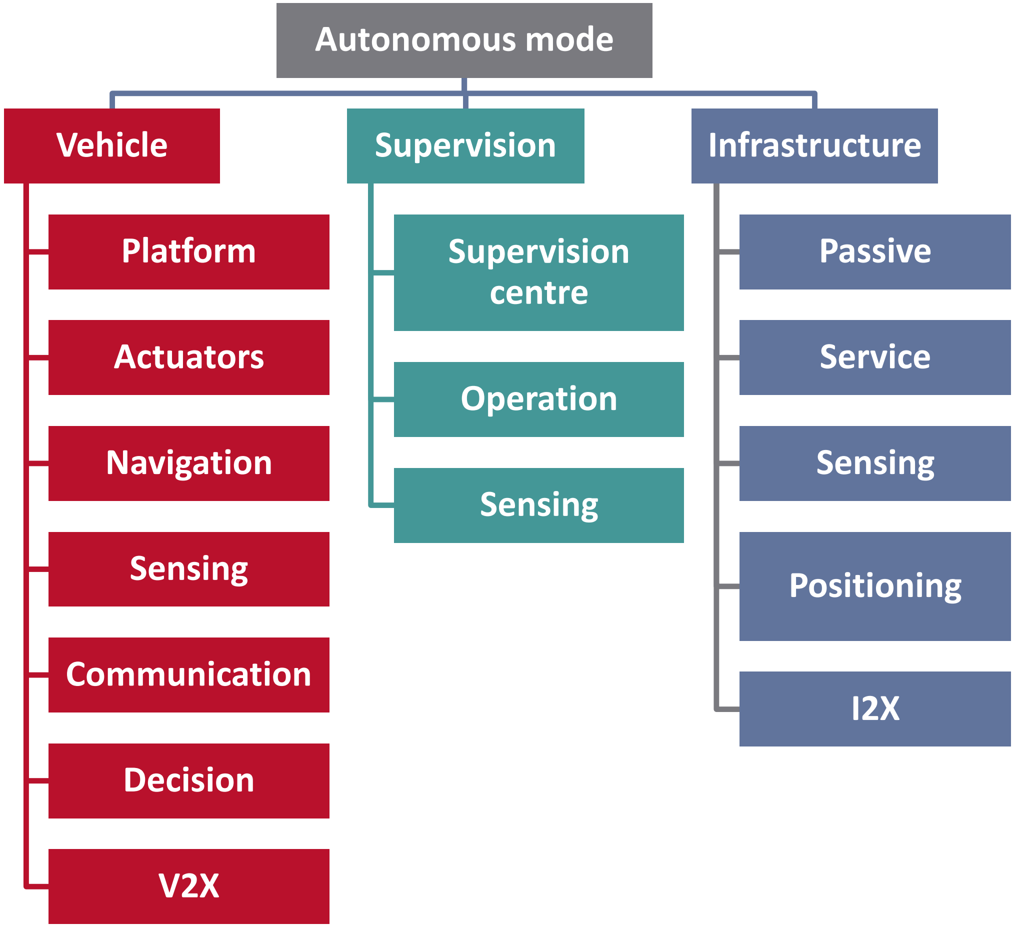
Reference: Chester et al. « Environmental assessment of passenger transportation should include infrastructure and supply chains », Environmental Research Letters, 4, 2009

Be aware: these results are normalized per passenger.km (service) and climate change indicator (CO2 emissions) is used (context)

- **Question: how automation changes the perimeter of systems involved and how will it translate into potential impacts?**

- Evaluation scope -

- Mode LCA results are normalized per vehicle.kilometer and aim at covering the systems involved in mature (as opposed to prototype) autonomous driving « regardless of the service »
- Life cycle phases :
  - Manufacturing, Deployment and End-of-life are included when relevant
  - The Use phase includes, among others, data transfers and maintenance
- The vehicle, the infrastructure and the supervision centre exchange data, often in both directions, an allocation choice needed to be specified
  - Data impacts are allocated to the sub-system that receives and uses the data for its operation



- « What if ? » -

- « What if » approach -

- Results presented here are theoretical and provide exclusively orders of magnitude
- Modelling of the intended scope is incomplete at this stage, providing preliminary results : end-of-life and maintenance are not represented
- Total energy consumption indicator is used to present the results
- As global data were systematically used in the simulations, the results are therefore not specific to local production or operation contexts
- Ecoinvent 3.6[1] database was used to provide data for this case study
- Sensing and computing systems modelling is based on the literature[2]

[1] https://www.ecoinvent.org/

[2] Gawron et al. « Life Cycle Assessment of Connected and Automated Vehicles: Sensing and Computing Subsystem and Vehicle Level Effects », Environmental Science & Technology, 52, 2018

- Exploratory « What if » scenario -

Vehicle

- Light electric vehicle 1180 kg, of which 260 kg battery
- The vehicle totals 150 000 driven km over its 12-years lifespan
- 290h annual use, driving in average at 15 km/h
- Typical energy consumption of the platform of 19.9 kWh/100 km
- Sensing – navigation – V2X – decision architecture : 7 cameras, 2 computers, 1 DSRC, 1 GNSS, 2 Radars, 2 LiDARs, 8 Sonars
- Lifespan if these equipment : 5 years

Infrastructure

- Infrastructure connected equipment : 2 RSU/km (50% connected traffic lights, 25% GNSS relays, 12,5% Cameras, 12,5% LiDARs) half of which are connected to the supervision centre through cable/fibre, others – trough cellular wireless connection
- Lifespan of these equipment : 5 years

Supervision

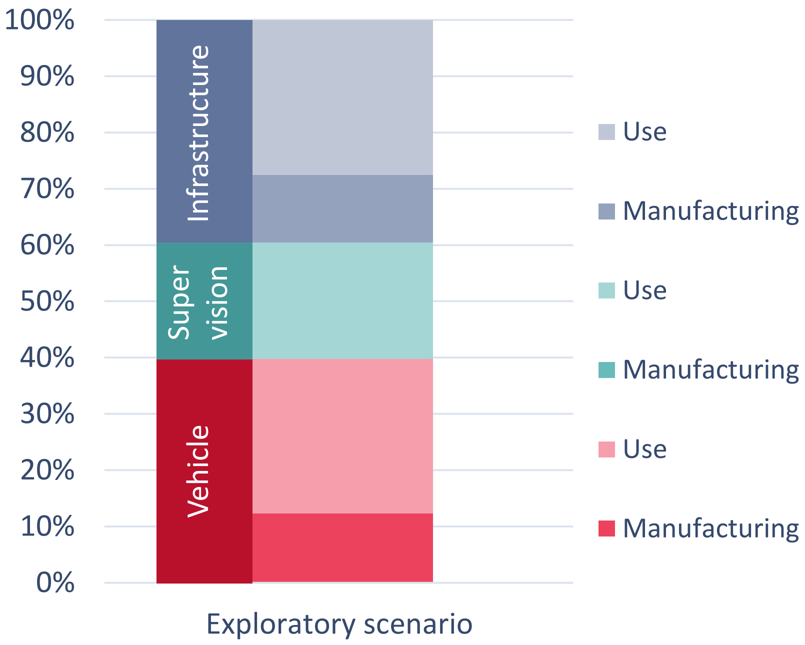
- Total vehicle log represents 4 Go/min, 10% of which is wirelessly transmitted to the supervision centre
- Supervision « sensing » comes from vehicle's cameras as well as cameras encountered on the route + operational and statistical data

Context

- Average traffic speed of 50km/h, average vehicle flow rate of 100 veh/h
- 0.1% of traffic flow are connected vehicles

- Main changes brought by automation -

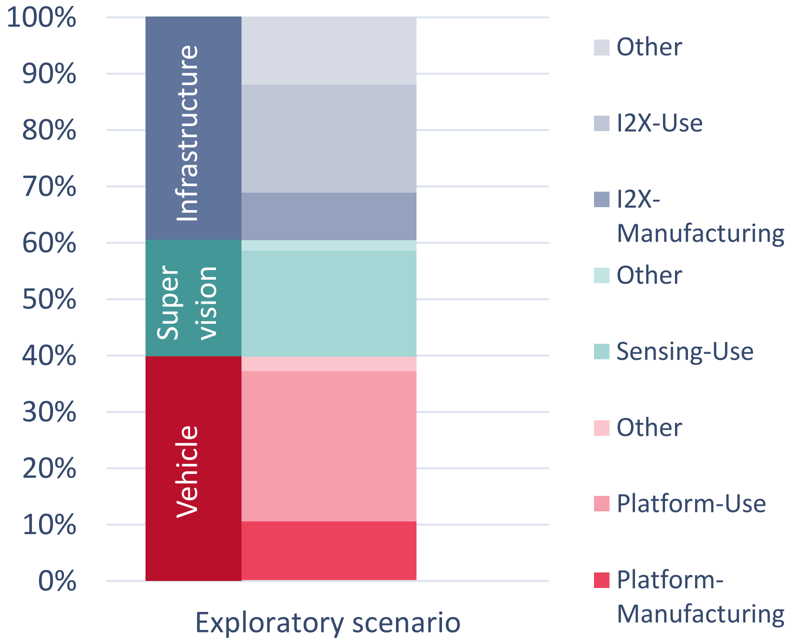
- **An additional system, additional equipments**
  - Vehicle – Infrastructure -> Vehicle – Infrastructure – Supervision (regardless of the use case)
  - Vehicle +7% (compared to bare platform impacts)
  - Infrastructure x 9 (compared to passive infrastructure alone)
- **Breakdown of impacts among systems**
  - 90 (vehicle) / 10 (infrastructure) -> 40 (vehicle) / 40 (infrastructure) / 20 (supervision)
- **Breakdown between use phase and manufacture phase**
  - 66 (use) / 33 (manufacture) -> 75 (use) / 25 (manufacture)
  - Additional equipment exclusive of those on the vehicle itself are shared, therefore their manufacture phase weighs less and their relative contribution is more substantial on the use phase



Primary energy breakdown, normalized by veh.km

- Exploration of potential main contributors -

- **On the vehicle side:**
  - The increase of impacts is mainly due to on-board equipment (mainly computers)
- **On the infrastructure side: connectivity is a major contributor**
  - In the manufacturing phase (RSUs)
  - And their energy consumption during the use phase
  - Main parameters : infrastructure equipment density (per km) and the degree to which they are shared
- **On the supervision side: log transmission and remote supervision are major contributors**
  - Log transmission is predominating in the supervision impacts (80% in the exploratory scenario vs 20% for video streaming)
  - Cellular transmission is itself dominated by the wireless access technology
  - Main parameters: log size, the log's share actually transmitted, data transfer technology' energy efficiency



Primary energy breakdown, normalized by veh.km

- Discussion and future work -

- Discussion of uncertainties and variabilities

Technological variabilities:

- **Vehicle sensing architecture <-> Density of infrastructure equipment**
  - How much of the sensing will rely on the vehicle and how much will be provided by the infrastructure ?

Use case variabilities:

- **Density of infrastructure equipment <-> Mutualisation of these equipment**
  - Fixed route service with dedicated infrastructure
  - Diffuse service with dedicated infrastructure in critical areas
  - Publicly accessible shared infrastructure equipment
- **Time spent in autonomous mode for level 3 and 4 vehicles:**
  - Diffuse or mixed-trafic uses where trafic situations may vary greatly
  - Fixed route(s) service on dedicated lanes, encoutering lower variability in trafic situations

Context uncertainties:

- **Telecommunication technologies <-> Supervision data transfer needs + Penetration level of connected and autonomous vehicles**
  - Will autonomous driving « push » the development of data transfer capacity? -> with associated deployment and potential rebound effects burden? Or, inversely will developed data transfer capacity « push » higher data transfer volumes for autonomous driving?
  - What will be the minimal data transfer needs to ensure proper remote supervision and comply with safety-related legal obligations?
  - Will autonomous driving be limited to certain types of uses restraining global data transfers related to autonomous driving ? Or will it be widespread?

- Future work -

- The three major systems – vehicle, infrastructure and supervision – as well as the context are inter-dependent -> need to build coherent variants for future deployment of autonomous mobility
- Strong variability and uncertainties on future technological choices -> simulate contrasting scenarios to build potential impact ranges (rather than a single value)
- Sensitivity analysis on different parameters to cover uncertainties, for example, on future performances

- Thank you for your attention ! -