Efficiency and Environmental Impact Assessment

L3Pilot Final Event

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Research questions

1. What are the impacts of automation on travel times, reliability of travel time and network capacity?
2. What are the impacts of automation on energy demand and CO_2 emissions?
3. What impacts can be expected on the European (EU27+3) level?
   - 27 EU countries + Norway, Switzerland and United Kingdom

Measuring effects: The indicators of interest

Time used for a given distance

Delay indicates congestion

Travel time (s)

Delay (s)

Intersection Throughput

Indicates traffic volume and efficiency

Correlates with fuel consumption

CO_2 Emissions (g)

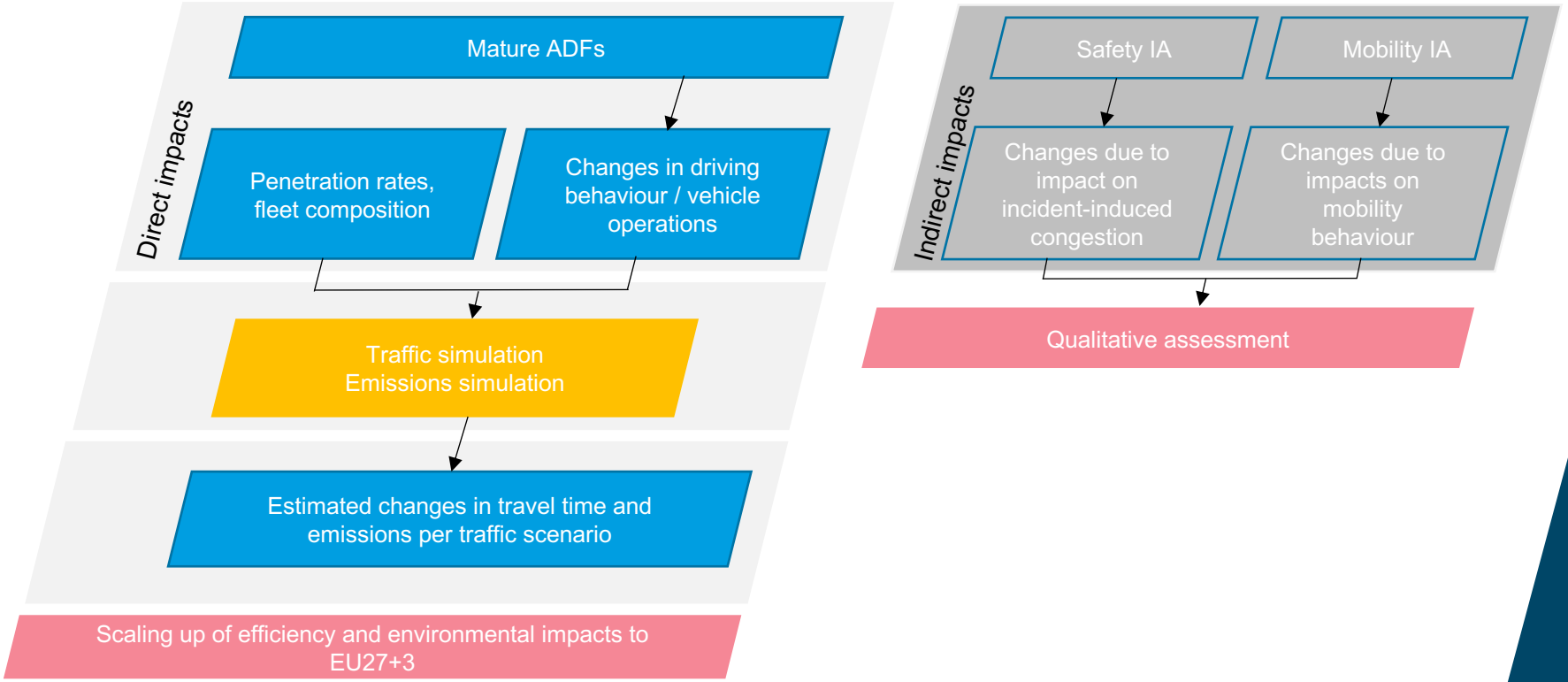
Energy demand (kWh)

Total energy used for moving the vehicles

Main approach

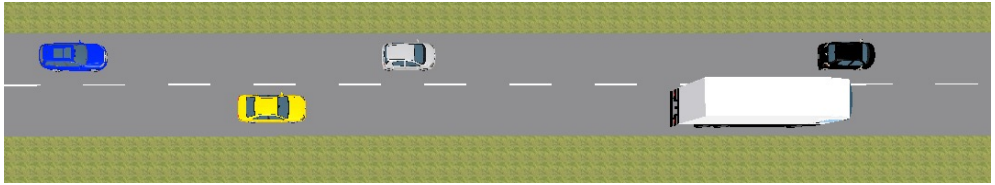
- L3 ADFs (automated driving functions) represented by **L3Pilot Mature ADFs**
  - Represent ADFs mature enough for the usage on public roads by ordinary drivers
  - ADFs do not represent any particular L3Pilot ADF tested at the pilot sites
  - In our simulations, automated vehicles are mainly characterised by longer time headways and more stable acceleration
  - ADFs operate in good weather conditions, heavy rain and snowfall excluded
  - ADFs aim to drive at the speed limit, or up to 130km/h
- Effect estimates from **traffic simulations**
  - Motorway effects scaled up to European level
- **Snapshot approach**: Add L3 ADFs to current traffic system
  - No other differences in automated and manually driven vehicles – capture effect of automation only

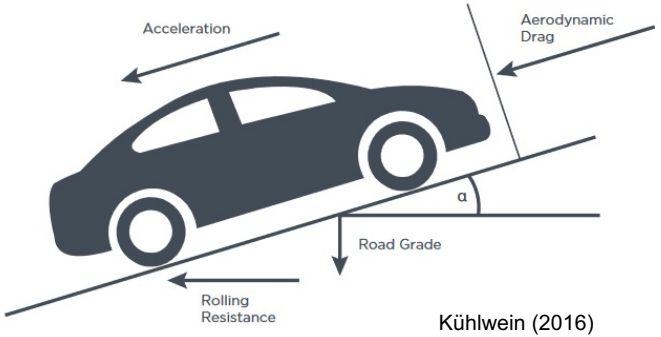
Method for assessing efficiency and environmental impacts



Tools

- Traffic simulations with PTV Vissim
  - Microscopic traffic simulation tool
- CO_2 emissions with EnViVer
  - Calculates emissons from detailed vehicle data from Vissim based on specified fleet composition
  - Uses Versit+ emissions model
- Energy demand
  - Calculated based on driving resistance forces

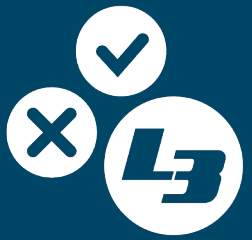




Kühlwein (2016)

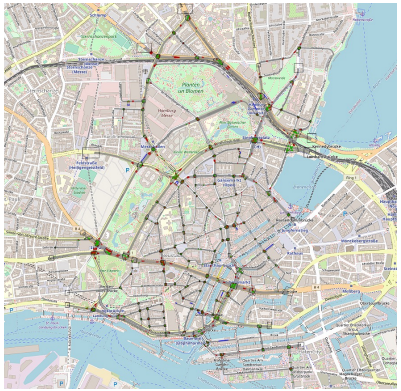
Evaluation

Urban roads – Methodology



Urban Simulations with PTV VISSIM

- Question: How does the rate of L3 ADF-enabled vehicles impact efficiency in urban settings?
- Generic approach proved unfeasible
  - Hamburg and Wolfsburg networks
  - Variable rates of automated vehicles among passenger cars
  - Fixed rate of public transport, pedestrians, cyclists
  - Several traffic volumes and speed limits
- Repeated for 100 40-minute trials per condition (1000 hours of simulated traffic)



Urban Simulations – Scaling Up

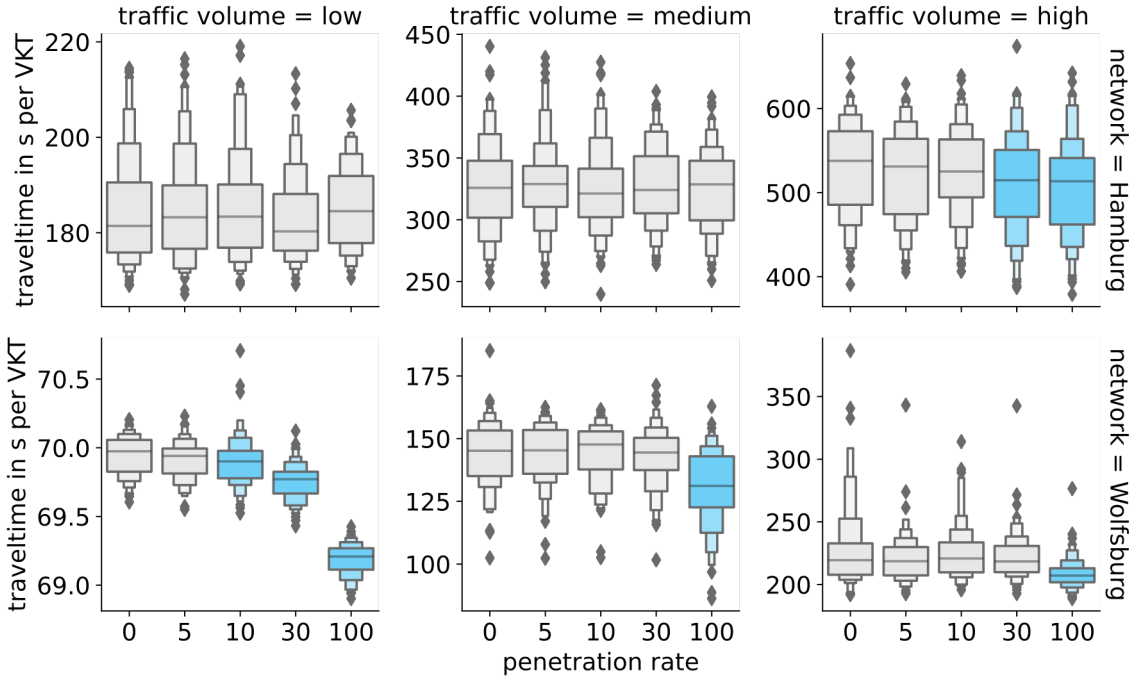
- Urban Area
  - High diversity
  - High complexity
  - → Difficult to form clusters
  - → How to compare cities?
- Limited Data
  - Degree of detail in OpenStreetMap
  - Traffic data
- → Difficult to scale up

Evaluation

Urban roads – Results

Results: Traffic Flow Travel time

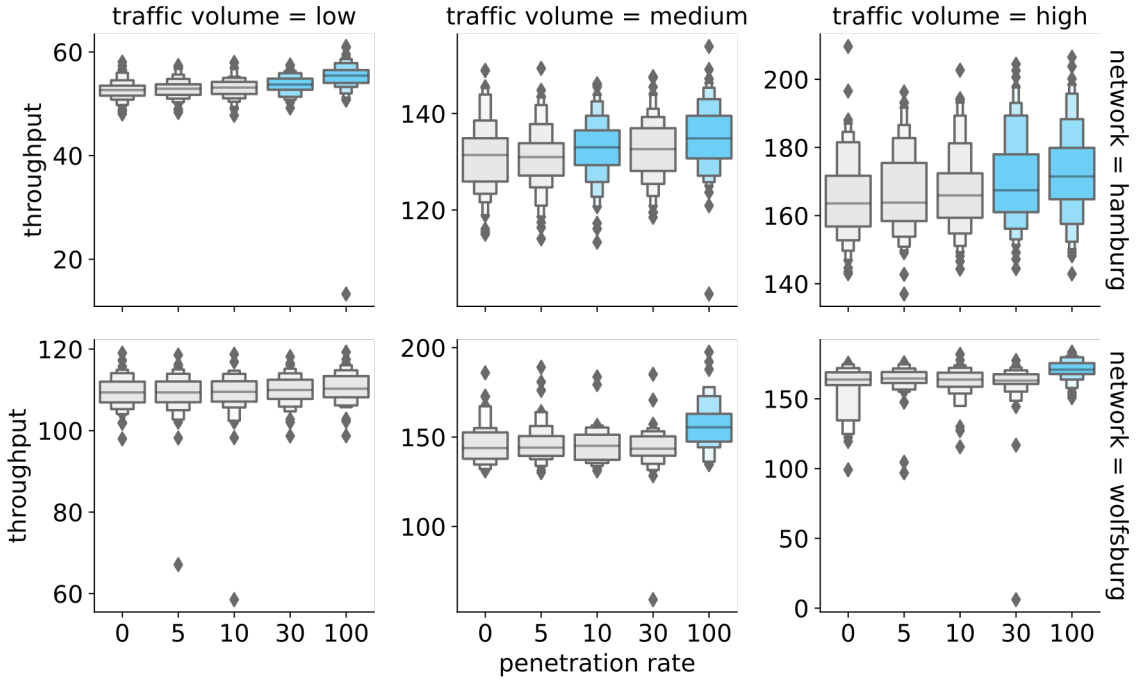
- *Decrease in travel time and delay with high traffic volumes and ADF penetration rates*
- Spread within conditions
- Effect size depends on network



Blue colour indicates significance in difference of means

Results: Traffic Flow
Intersection throughput (vehicles per hour)

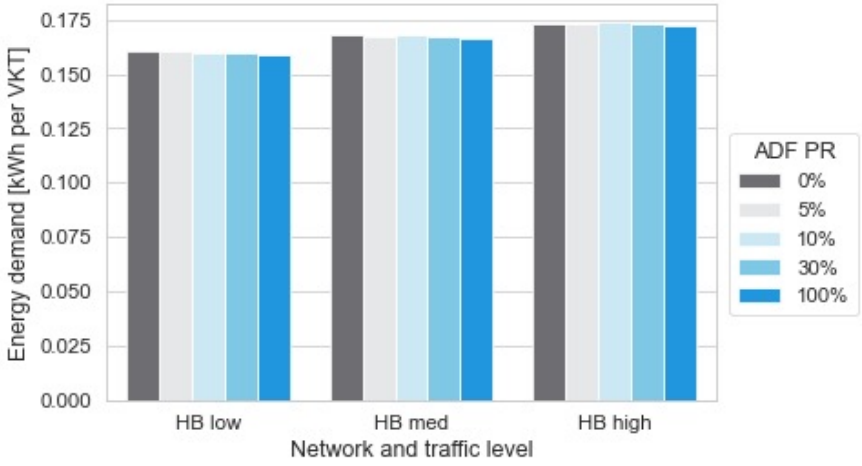
- *Increase in intersection throughput with high ADF penetration rates*
- Spread within conditions
- Effect size depends on network

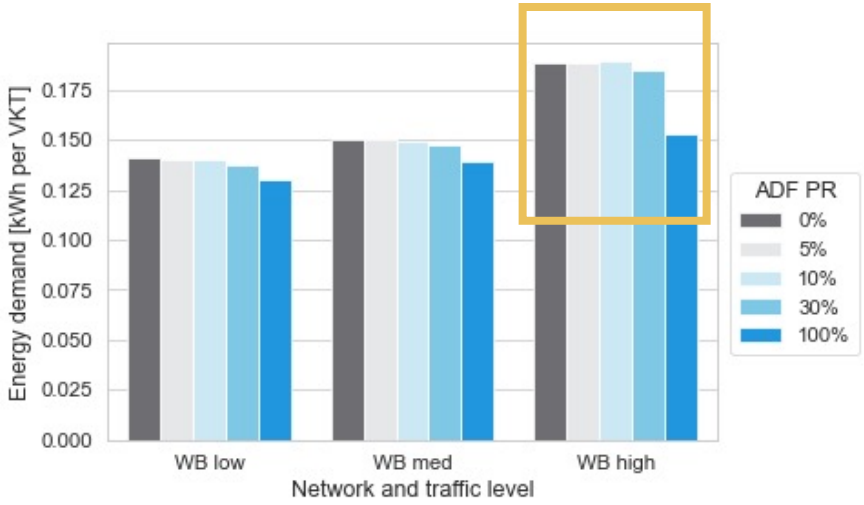


Blue colour indicates significance in difference of means

Results: Environment

- Decrease in CO_2 and energy use with high traffic volumes and ADF penetration rates for Wolfsburg network





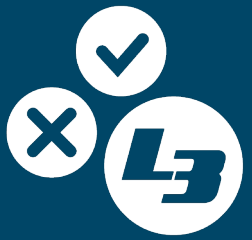
- Effect size not consistent between networks

Summary

- Benefits for both travel time and emissions at highest traffic volumes and high penetration rate
- Effect size dependent on network properties and structure
- Large spread of indicator values per condition
  - Confounding factors influenced the outcome
- Further research needed to allow for generalisation of impact estimates to the European level

Evaluation

Motorway – Simulation methodology



Starting points of motorway simulation

- What is the impact of automation on the efficiency of motorway traffic?
- In order to answer this, representative scenarios were needed
- Traffic volume was considered in five classes
- Road type analysis using OpenStreetMap
  - All combinations of number of lanes and speed limit representing at least 1% of motorway network in EU27+3 were included in the simulation
  - Division into line sections and sections with on- and off-ramps

Volume/h/lane and volume class

500	1000	1500	2000	2500
1	2	3	4	5

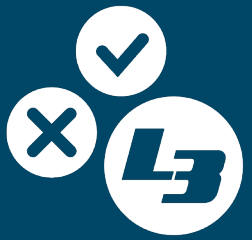
Speed limit	Nr. of lanes	Share
130	2	26.8%
120	2	21.3%
no limit	2	9.2%
110	2	6.5%
130	3	6.4%
100	2	5.6%
120	3	3.9%
110	3	3.7%
no limit	3	3.4%
140	2	3.0%
80	2	2.1%
100	3	2.1%
90	2	1.4%

Motorway simulations with PTV Vissim

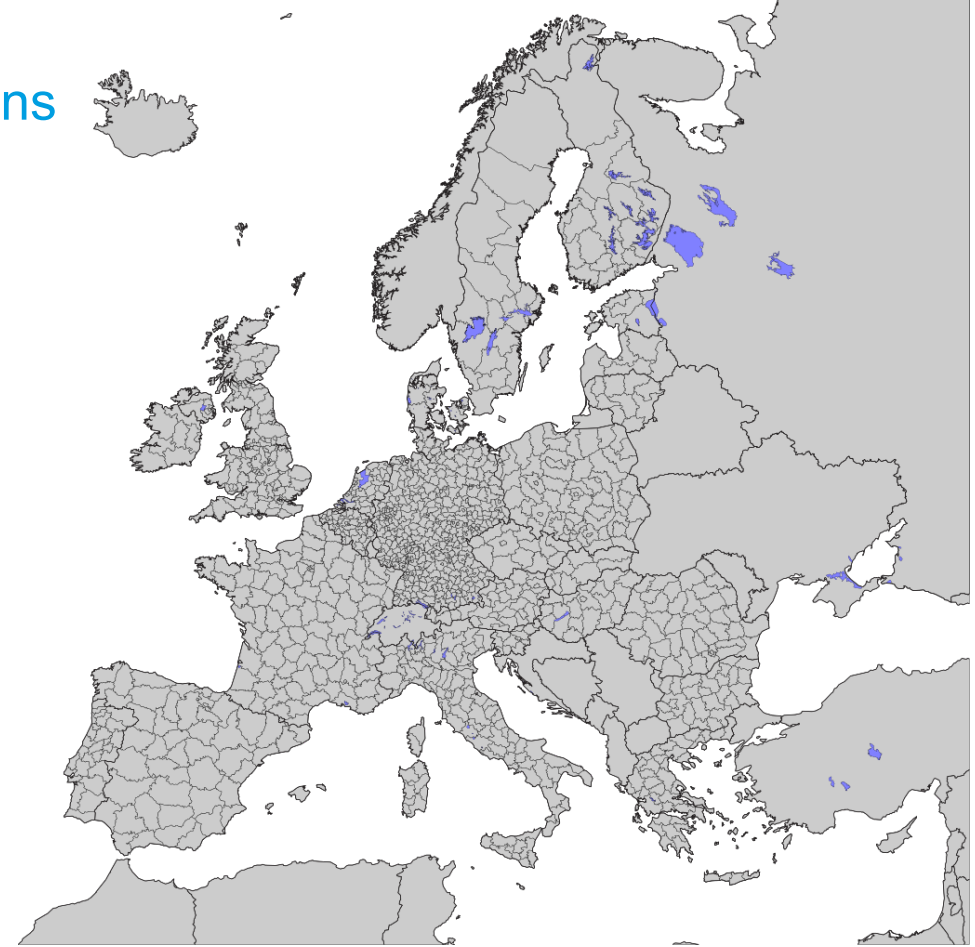
- A “generic” four kilometre motorway section was created
  - Variable penetration rates of automated vehicles among manually driven vehicles (0%, 5%, 10%, 30%, 100%)
    - Rate of (manually driven) heavy duty vehicles fixed to traffic volume (6%–12%)
  - Five traffic volumes and eight speed limits
  - Two or three lanes per direction
  - Ramp sections and line sections
- Resulted in 700 variable combinations (“traffic scenarios”)
- Repeated for twenty 30-minute trials per condition (149 million vehicle km)

Evaluation

Motorway – Scaling up to EU27+3 Methodology

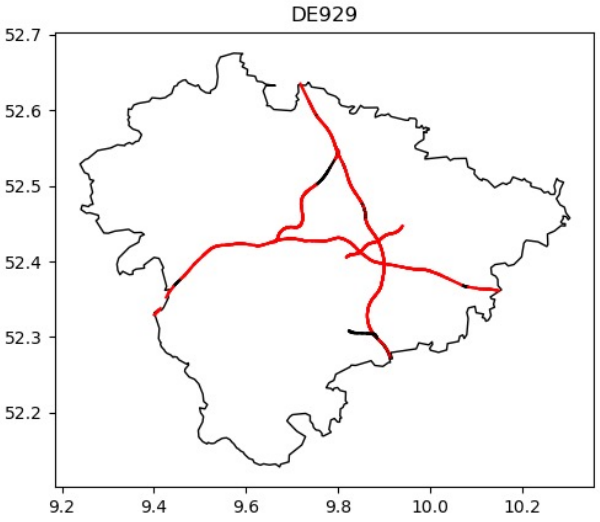


NUTS 3 regions



Scaling up

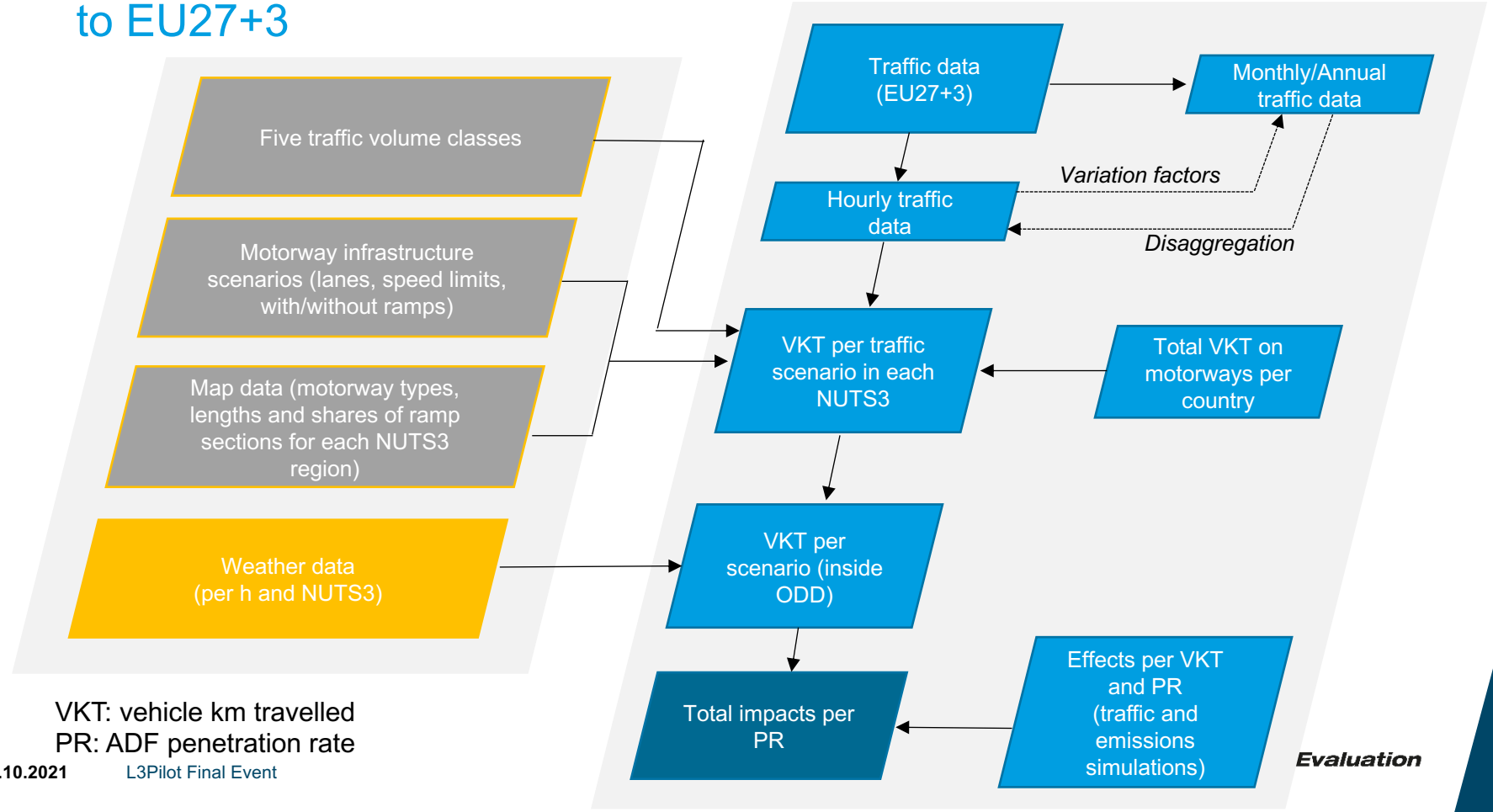
Scaling up was based on collection and classification of traffic volume data from European countries, in combination with geographical data from OpenStreetMap



Example: Hanover region (DE929)

- The vehicle km travelled in each traffic scenario were determined for all NUTS3 regions
- Hour-by-hour weather data was applied to determine whether driving happened within Operational Design Domain (ODD)
- Results from the simulation step were matched to traffic scenarios to provide the total impact for each NUTS3 region

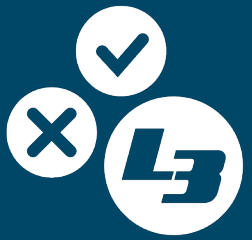
Scaling up process for efficiency & environment motorway impacts to EU27+3



VKT: vehicle km travelled
PR: ADF penetration rate

Evaluation

Motorway – Results



Overall impact on traffic flow efficiency in EU27+3

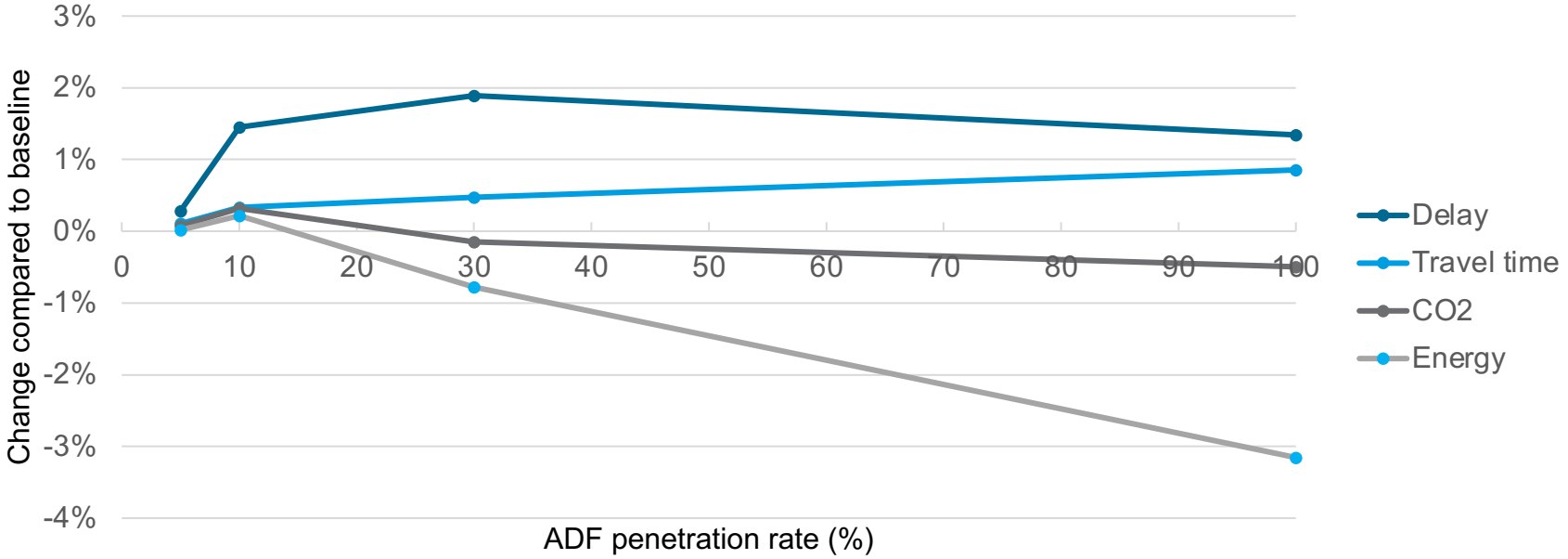


Figure shows the overall impact of ADF penetration rate on the indicators: Change in travel time, delay, CO_2 and energy demand compared to baseline

PR	Travel time	Delay	CO_2	Energy
5%	0.1%	0.3%	0.1%	0.0%
10%	0.3%	1.5%	0.3%	0.2%
30%	0.5%	1.9%	-0.2%	-0.8%
100%	0.9%	1.4%	-0.5%	-3.2%

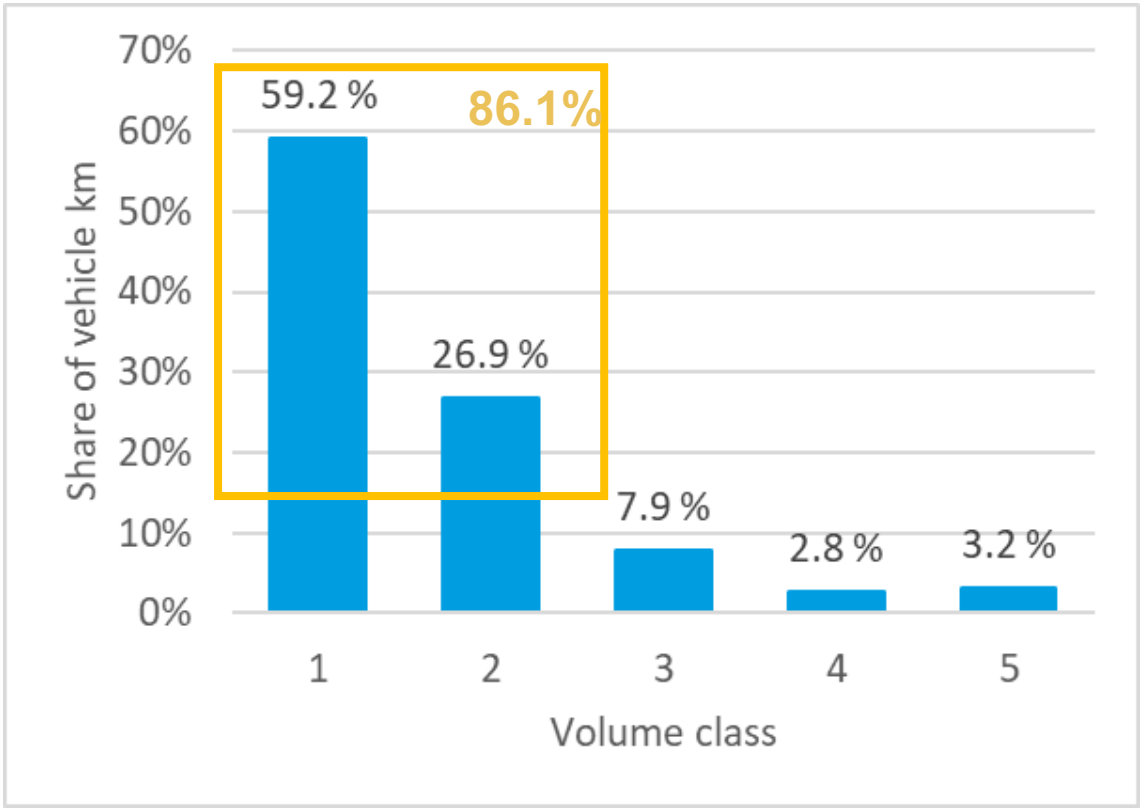
Most common motorway-traffic-combinations

Total: 58% of vehicle km travelled (VKT) in EU27+3

	Share of VKT	Nr. of lanes	Speed limit (km/h)	Veh/h/lane	Traffic volume class
1	12.9%	2	130	Up to 750	1
2	9.7%	2	120	Up to 750	1
3	6.6%	3	130	Up to 750	1
4	5.8%	2	unlimited	Up to 750	1
5	4.2%	2	130	750–1250	2
6	4.1%	3	120	Up to 750	1
7	4.0%	2	120	750–1250	2
8	3.7%	3	110	Up to 750	1
9	3.6%	3	unlimited	Up to 750	1
10	3.5%	3	unlimited	750–1250	1

Total nr of combinations: 70
(combinations of speed limit, number of lanes and traffic volume)

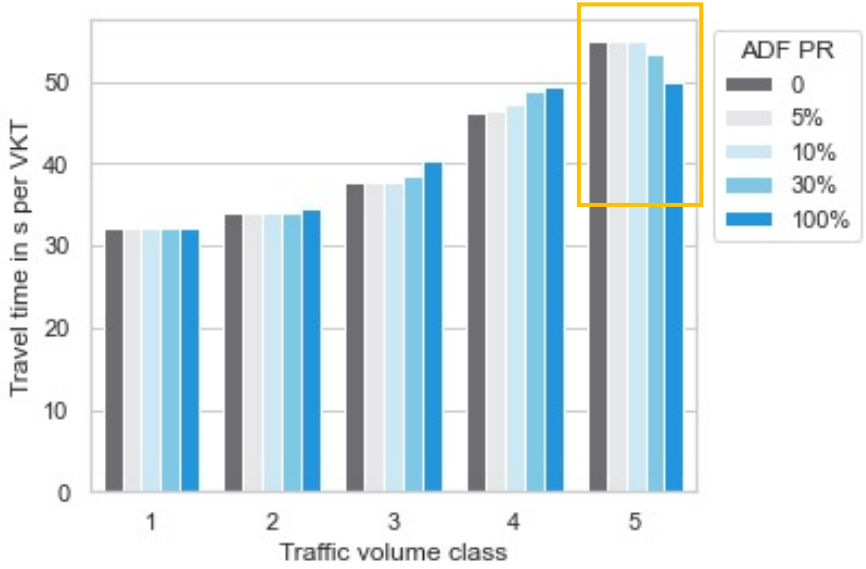
Most vehicle km are driven in low traffic conditions



Volume classes
1: up to 750 veh/h/lane
2: 751 – 1250 veh/h/lane
3: 1251 – 1750 veh/h/lane
4: 1751 – 2250 veh/h/lane
5: over 2250 veh/h/lane

Results: Travel time

- Decrease in travel time with high traffic volumes and ADF penetration rates among passenger cars
- Small effects with lower traffic volumes
- Highest traffic volume:
  - Decrease in travel time **3.0% with 30%** and **9.0% with 100%** penetration rate among passenger cars

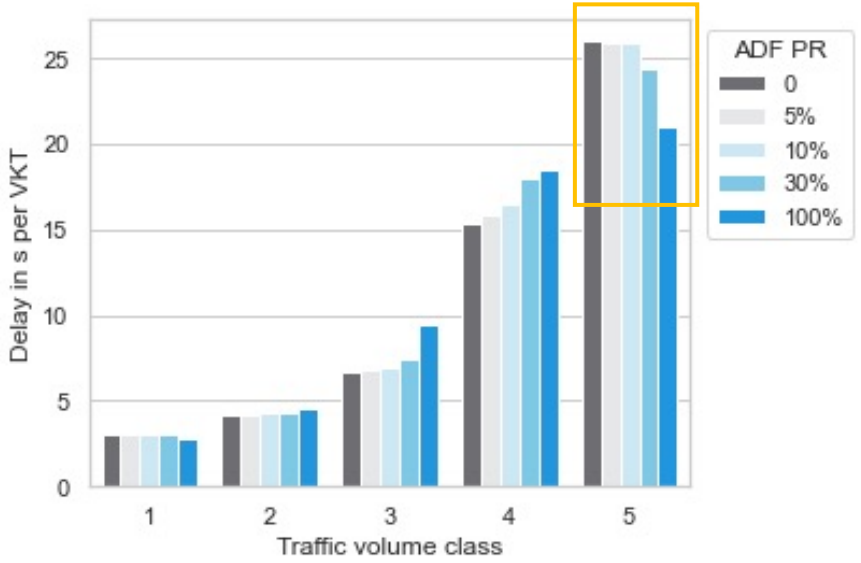


Traffic volume classes
1: <= 750 veh/h/lane
2: 751–1250 veh/h/lane
3: 1251–1750 veh/h/lane
4: 1751–2250 veh/h/lane
5: > 2250 veh/h/lane

Results: Delay

- Decrease in delay with high traffic volumes and ADF penetration rates among passenger cars
- Small effects with lower traffic volumes

- Highest traffic volume:
  - Decrease in delay **6.3% with 30%** and **19.0% with 100%** penetration rate among passenger cars



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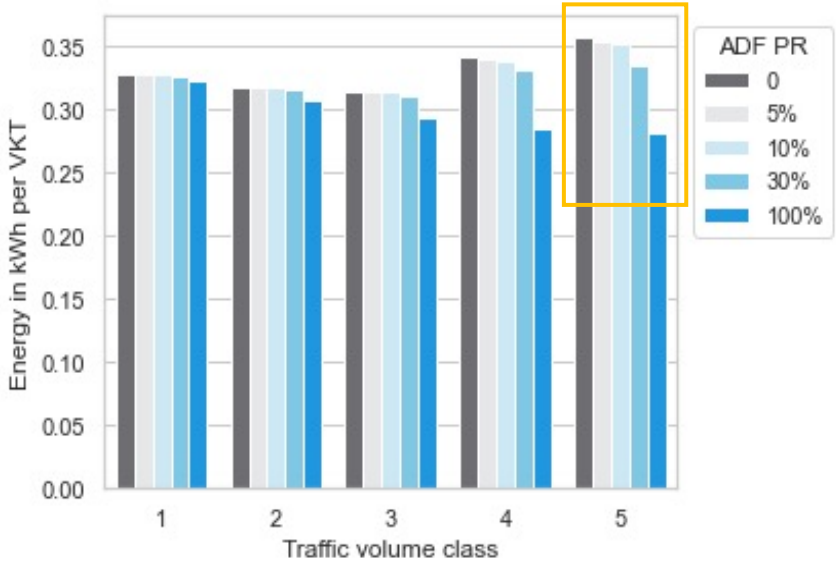
4: 1751–2250 veh/h/lane
5: > 2250 veh/h/lane

Results: Energy demand

- Decrease in energy demand with high traffic volumes and ADF penetration rates among passenger cars
- Small effects with lower traffic volumes

- Highest traffic volume:
  - Decrease in energy consumption **6.0% with 30%** and **21.3% with 100%** penetration rate among passenger cars



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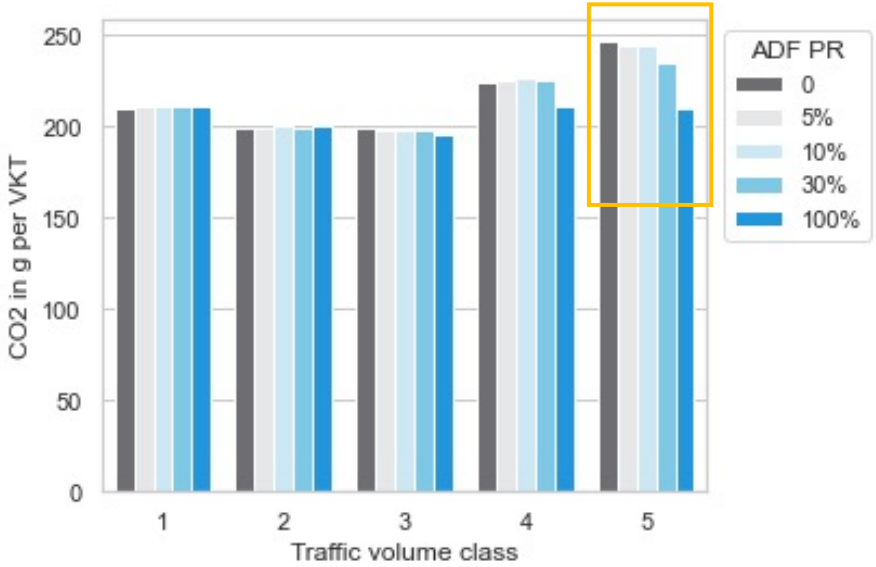
3: 1251–1750 veh/h/lane
4: 1751–2250 veh/h/lane
5: > 2250 veh/h/lane

Results: CO_2 emissions

- Decrease in CO_2 with high traffic volumes and ADF penetration rates among passenger cars
- Small effects with lower traffic volumes

- Highest traffic volume:
  - Decrease in CO_2 **4.8% with 30%** and **14.8% with 100%** penetration rate among passenger cars



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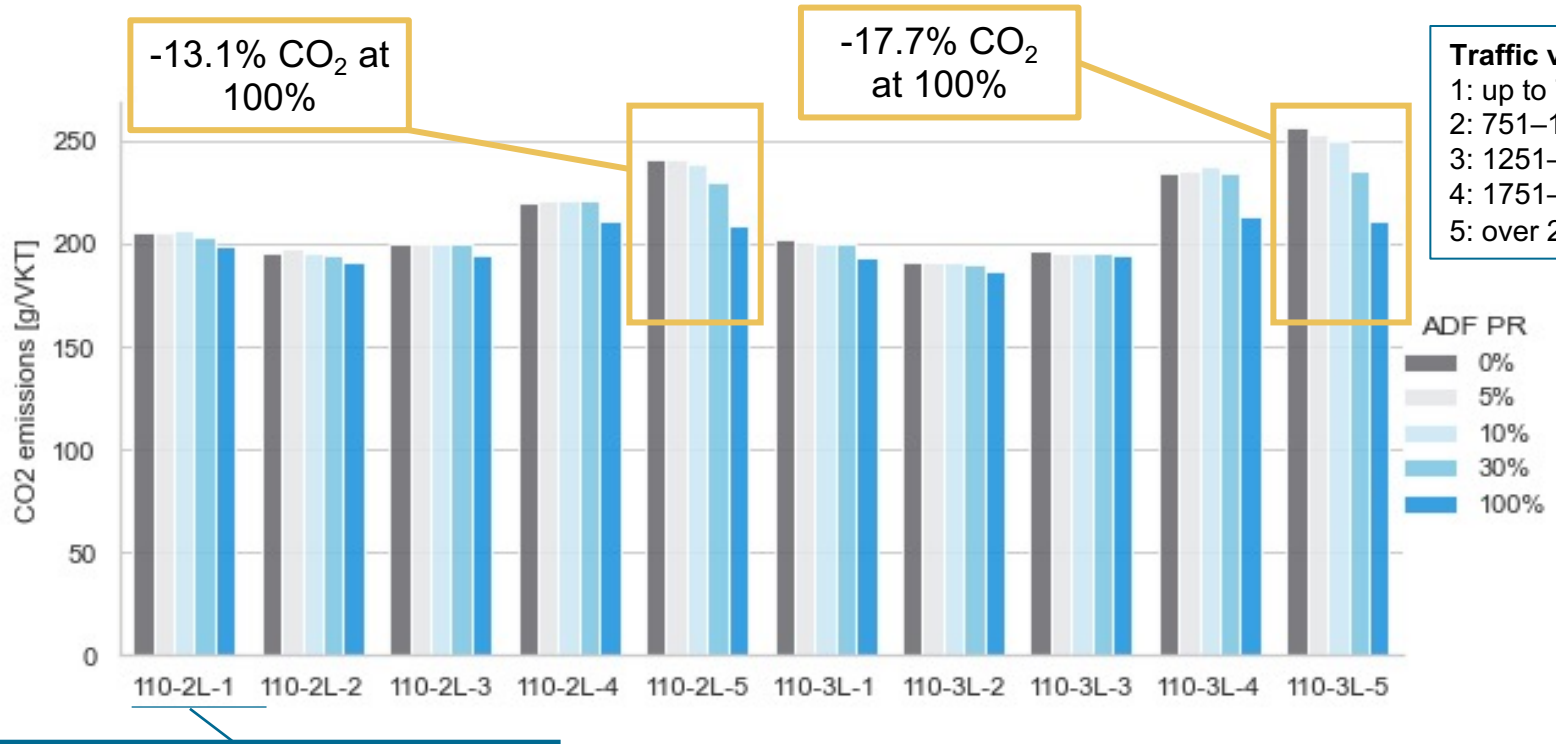
5: > 2250 veh/h/lane

Speed limit 110 km/h with 2 and 3 lanes and different traffic volumes



Traffic volume classes
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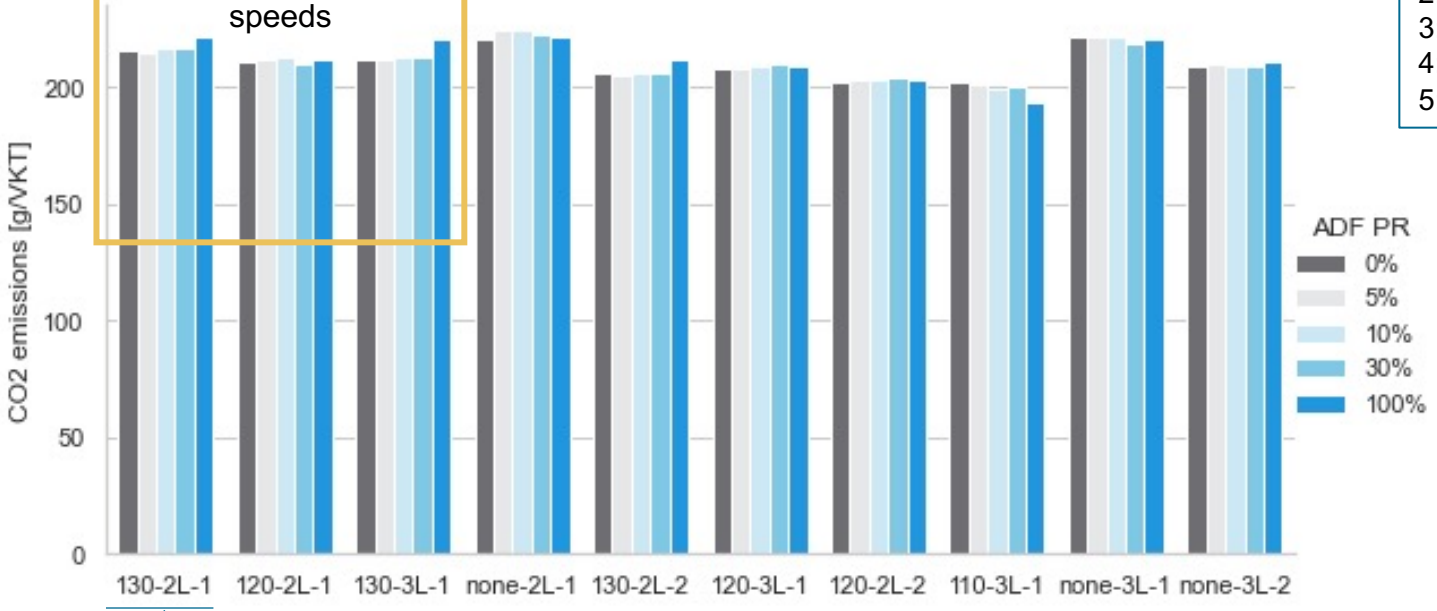
5: over 2250 veh/h/lane

Speed limit – Nr of lanes – Volume class

Ten most common motorway-traffic-combinations in EU27+3

Small increase in emissions at 100% PR due to increase in speeds



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Speed limit – Nr of lanes – Volume class

Indirect impacts

- **Mobility** impact: ~6% increase in vehicle km travelled at 100% penetration rate
  - Results shift towards higher traffic volumes
  - Overall, adverse impacts on emissions and efficiency
- **Safety** impact: Reduction in number of accidents
  - Local effects of accident caused congestion, partly addressed in traffic data
  - Reduction in number of accidents leads to improvement for efficiency, impact for environment is uncertain
- Long-term **behavioural adaptation**, impact on **other road users**
  - Yet unknown, but impact potential is large
- Other factors, e.g. energy consumption of sensors

Contribution to the state of the art

- Automated vehicle behaviour was set up to align with mature functions together with ADF developers
  - Most findings from literature are based on rather different assumptions of automated vehicle behaviour, e.g. very short headways
  - L3Pilot simulation results are in line with those from studies using similar headways
- Holistic methodology created using representative traffic scenarios for simulation
  - Most studies have simulated one network with one speed limit and (high) traffic volume
  - Results have not previously been scaled up to the whole EU motorway network

Conclusions

- Tradeoffs exist between efficiency and environmental impacts
- Urban environment
  - Effect depends on network properties and structure
  - Further research is needed to allow for generalisation of impact estimates to the European level
- Motorways
  - Impacts are largest with high traffic volume and penetration rates
  - Absolute values are lowest with low speed limits and low and moderate traffic volumes
  - Effects of ADF on traffic efficiency and emissions on EU level are rather small
    - Mostly because driving on EU motorways takes place in low traffic conditions
    - However, benefits may be experienced locally, e.g. on urban motorways, by a large number of drivers

Thank you for your kind attention.

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