Road traffic emissions calculation and analysis

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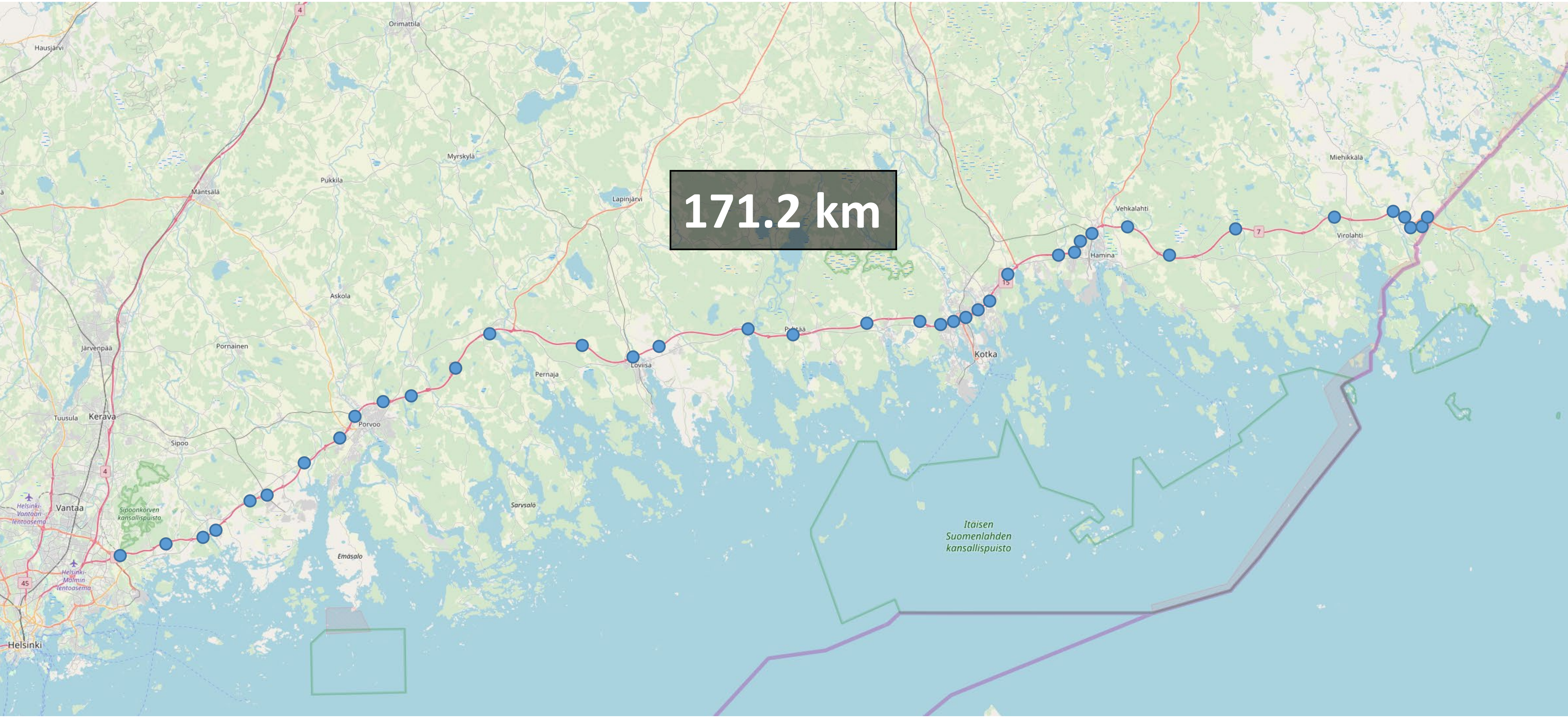
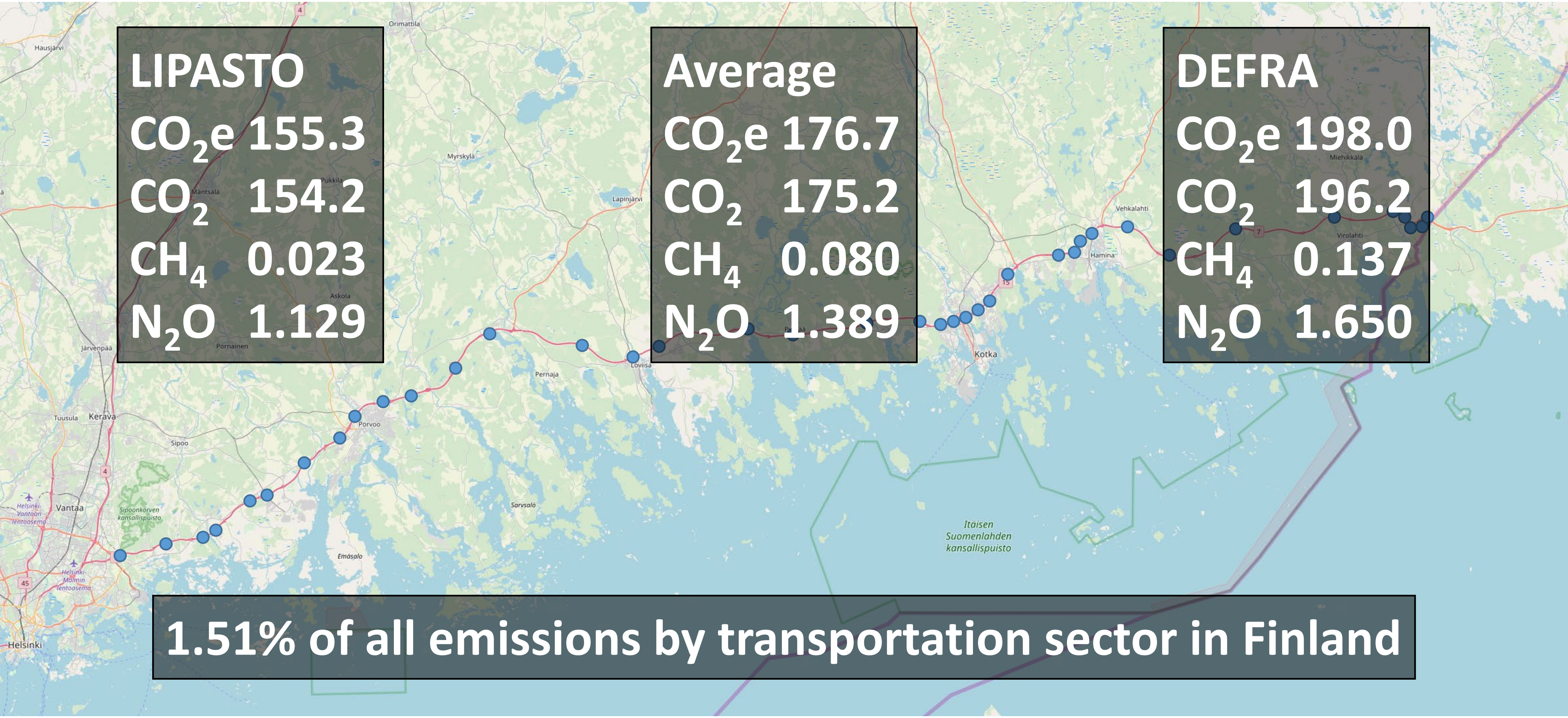
Automatic measurement stations for traffic volumes on E-18 road in 2018 (Helsinki – Vaalimaa border zone)



References:
Väylävirasto (2019). Liikennemääräkartat. Available at URL: https://vayla.fi/kartat/liikennemaarakartat/ Retrieved 18.Apr.2019
OpenStreetMap contributors (2019). OpenStreetMap. Available at URL: https://www.openstreetmap.org/ Retrieved 18.Apr.2019

Amount of GHG emissions on E-18 road in 2018 (CO2 equivalent units, thousand tons)

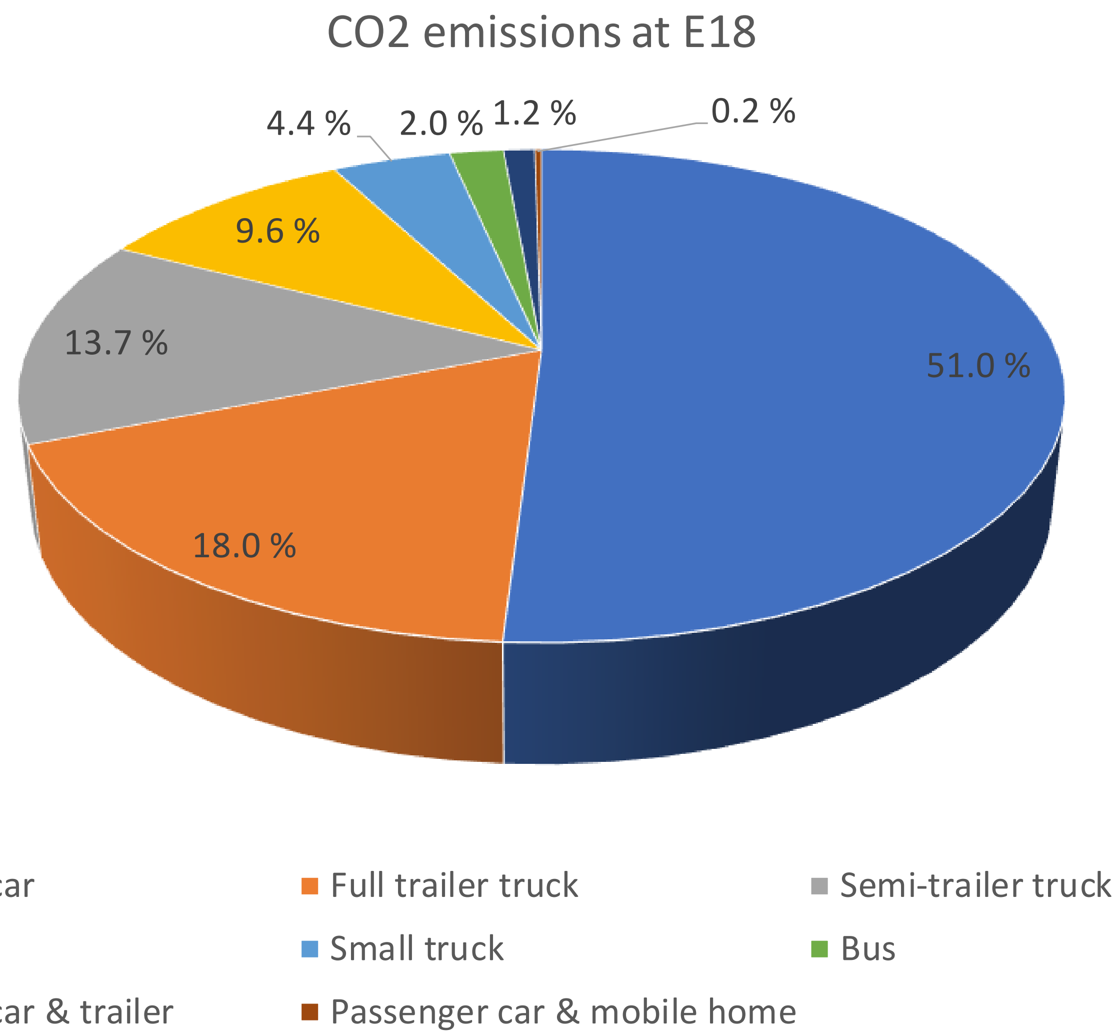


References:
Väylävirasto (2019). Liikennemääräkartat. Available at URL: https://vayla.fi/kartat/liikennemaarakartat/ Retrieved 18.Apr.2019
OpenStreetMap contributors (2019). OpenStreetMap. Available at URL: https://www.openstreetmap.org/ Retrieved 18.Apr.2019

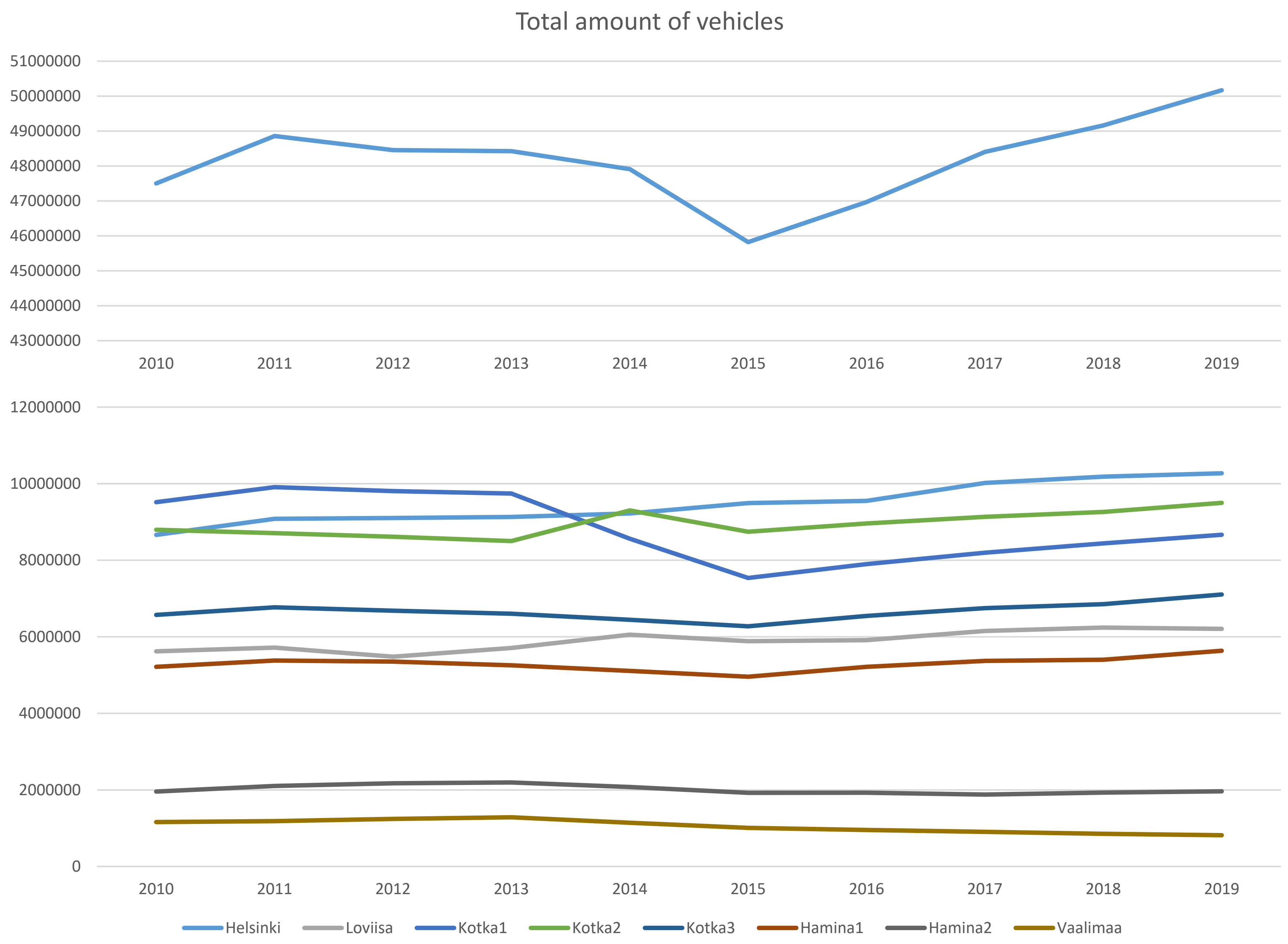
Why only so ”small” part out of CO_2 emissions?

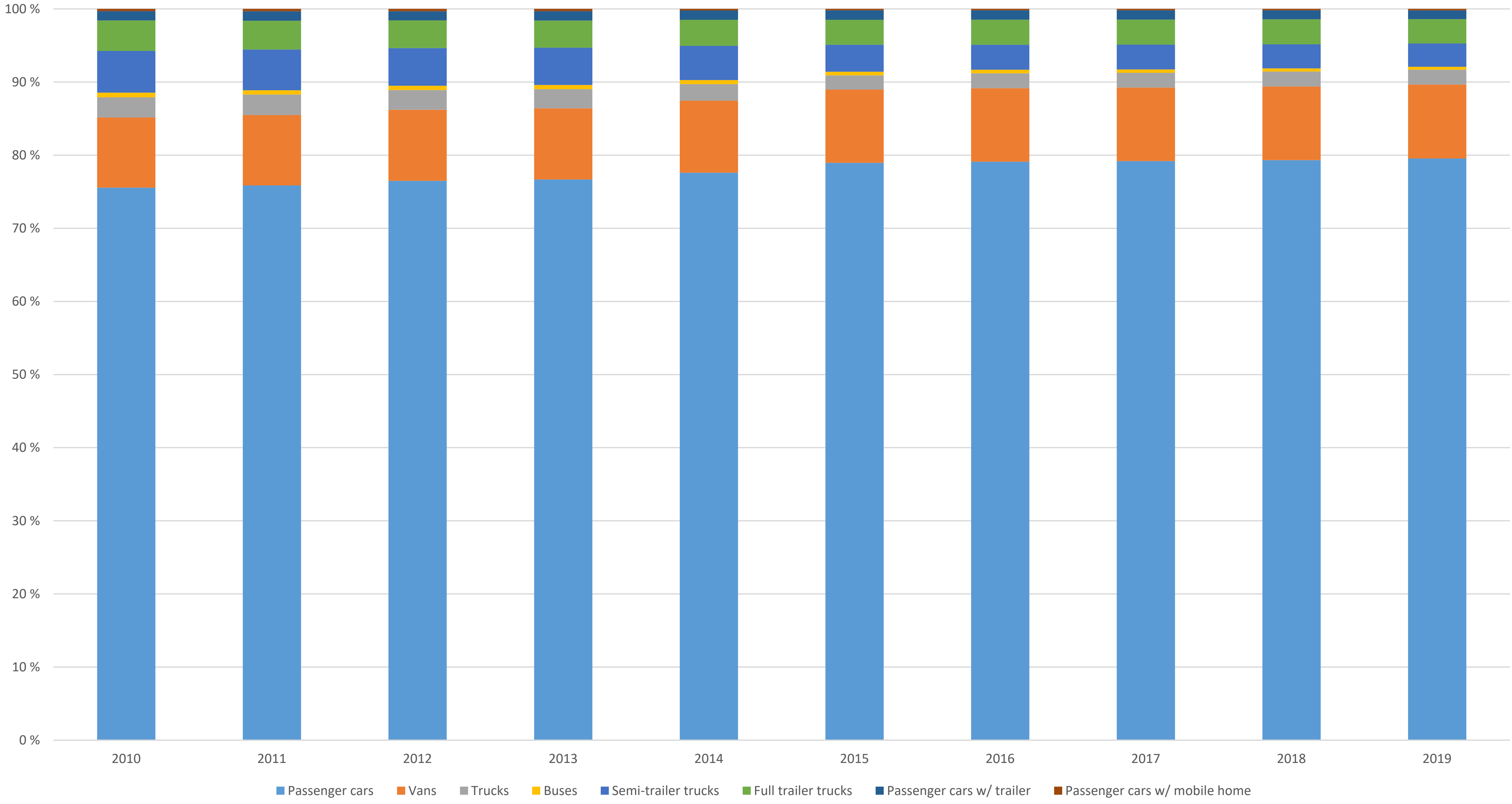
- Transportation sector pollution is mostly located, where people are living and building their homes
- Based on VTT Liisa database in 2012 city traffic (in streets) accounted 37 % from overall road transport CO_2 emissions
- Based on VTT Liisa database in 2017 city traffic (in streets) accounted 26 % from overall road transport CO_2 emissions
- Difference in year 2012 and 2017 is just measurement based, not that much has changed in the transportation system itself – also measurement of traffic is still troublesome for cities
- Based on VTT Liisa database in 2017 private passenger cars, motorcycles (incl. small ones) and small vans accounted in total 64.1 % from CO_2 emissions out of road transport
- E18 is important road section in Finland, and there exist numerous higher used roads (from Helsinki to north, north-west and west)

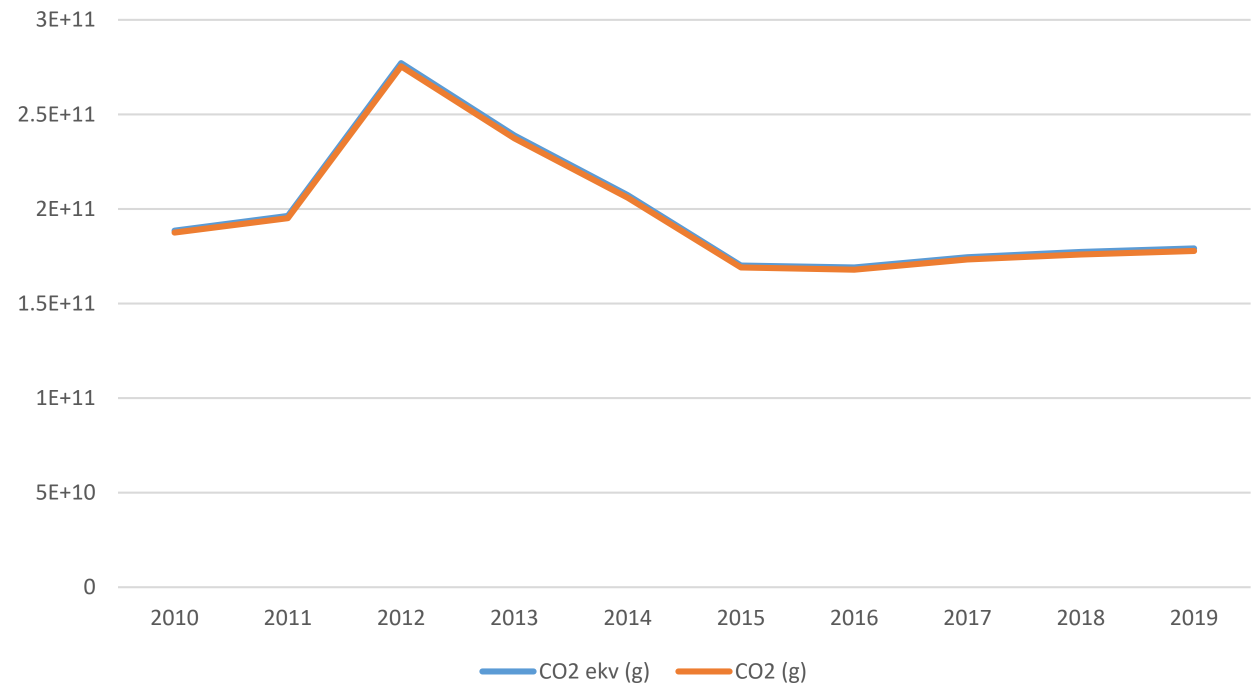
E18 is not an exception to overall situation

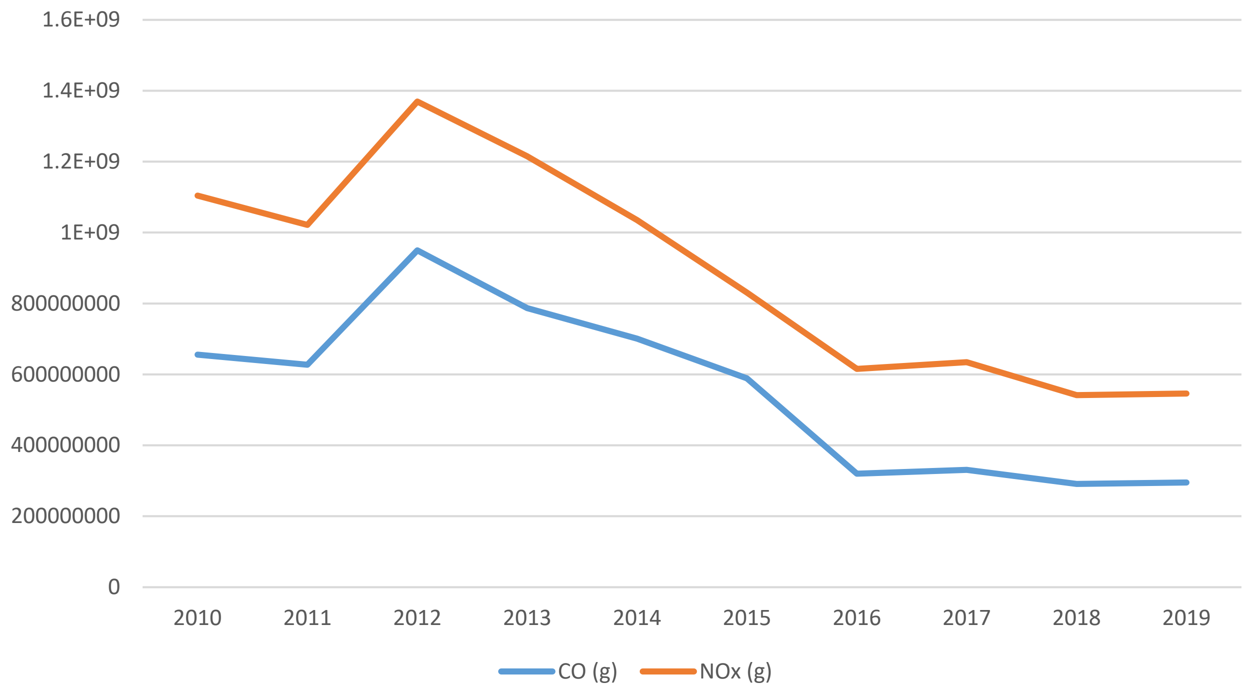


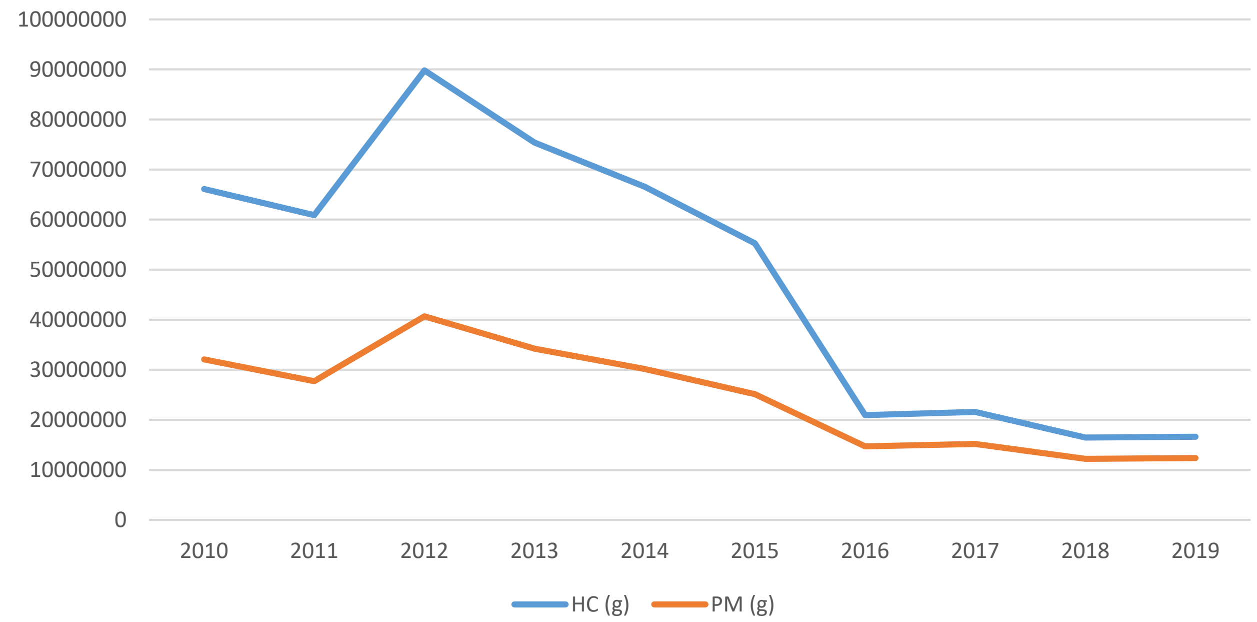
Highway E18 during the period of 2010 - 2019

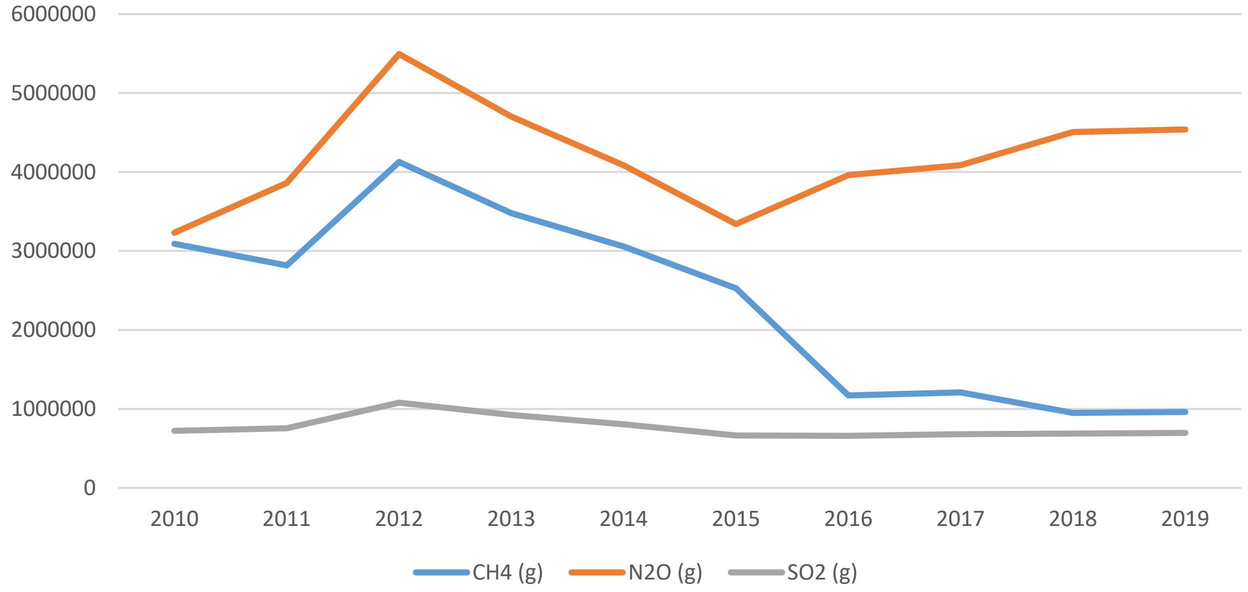

Total amount of vehicles
51000000
50000000
49000000
48000000
47000000
46000000
45000000
44000000
43000000
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
12000000
10000000
8000000
6000000
4000000
2000000
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Helsinki
Loviisa
Kotka1
Kotka2
Kotka3
Hamina1
Hamina2
Vaalimaa


100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Passenger cars
Vans
Trucks
Buses
Semi-trailer trucks
Full trailer trucks
Passenger cars w/ trailer
Passenger cars w/ mobile home


3E+11
2.5E+11
2E+11
1.5E+11
1E+11
5E+10
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
CO2 ekv (g)
CO2 (g)


1.6E+09
1.4E+09
1.2E+09
1E+09
800000000
600000000
400000000
200000000
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
CO (g)
NOx (g)

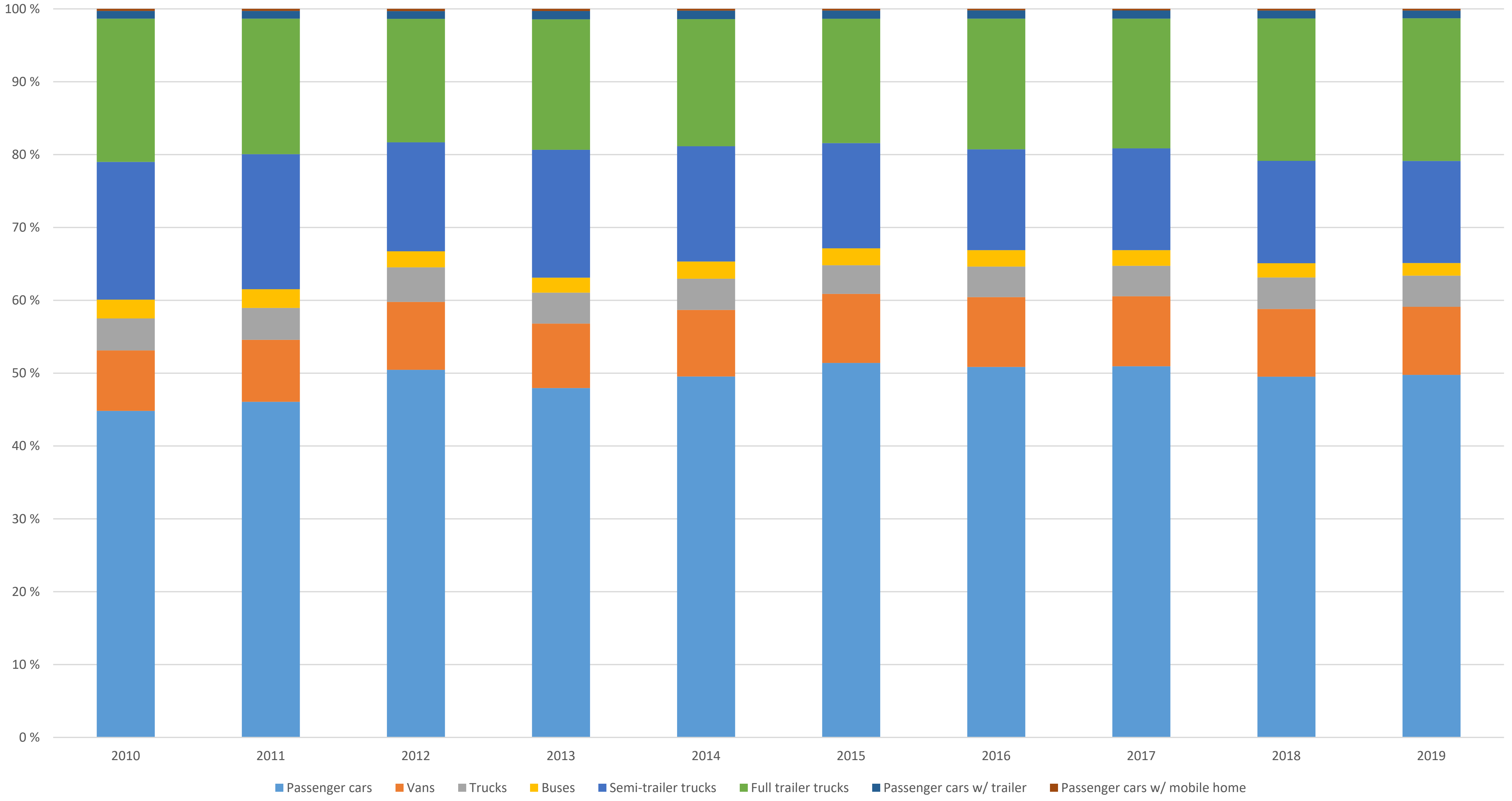

100000000
90000000
80000000
70000000
60000000
50000000
40000000
30000000
20000000
10000000
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
HC (g)
PM (g)

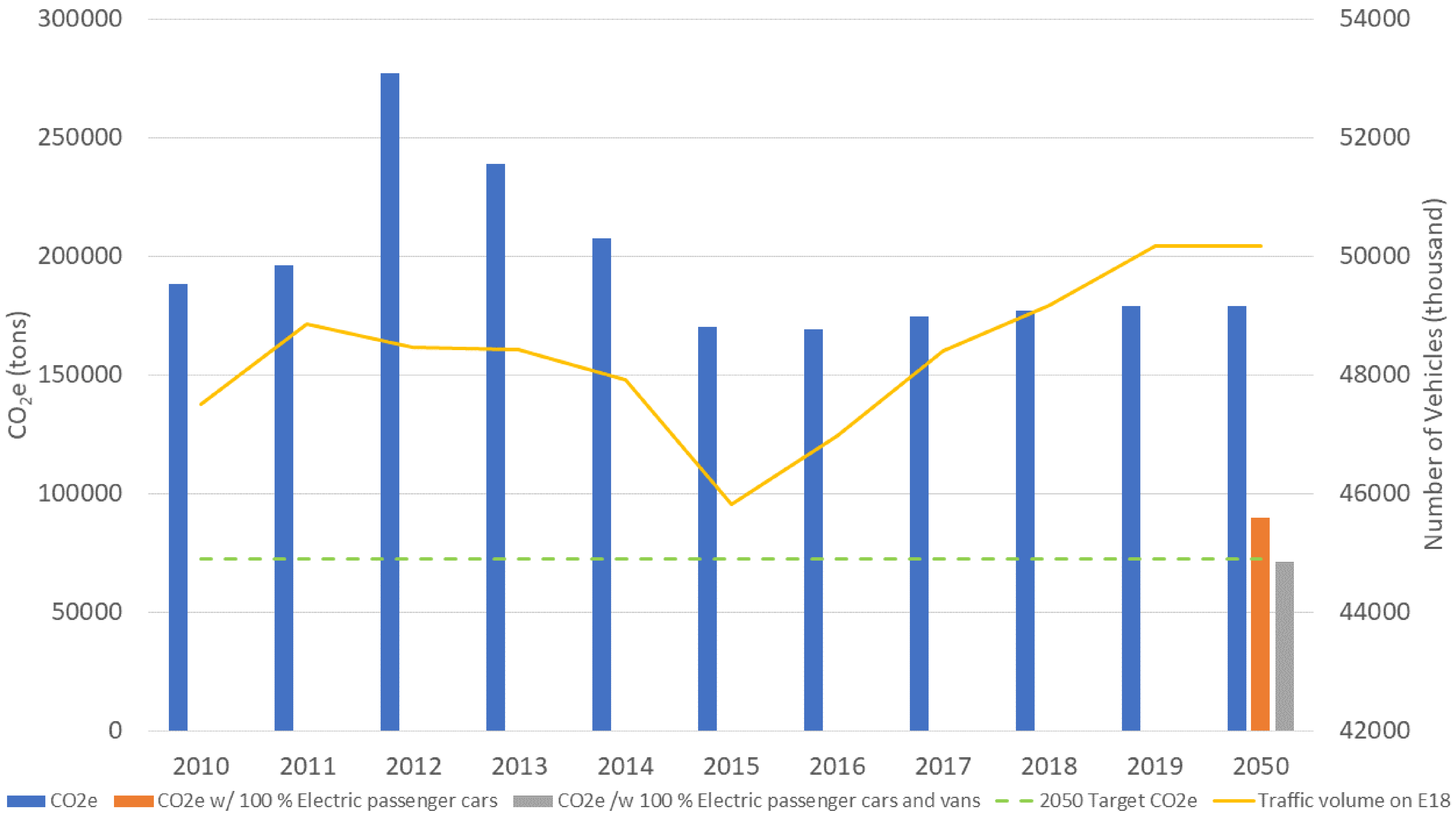

6000000
5000000
4000000
3000000
2000000
1000000
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
CH4 (g)
N2O (g)
SO2 (g)

Emission of N_2O

- Levels are rising due to the emission of N_2O as a by-product from NO_x conversion in diesel engines

Reference: Cho, C. P., Pyo, Y. D., Jang, J. Y., Kim, G. C., & Shin, Y. J. (2017). NOx reduction and N2O emissions in a diesel engine exhaust using Fe-zeolite and vanadium based SCR catalysts. *Applied Thermal Engineering*, *110*(2), 18–24.


100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Passenger cars
Vans
Trucks
Buses
Semi-trailer trucks
Full trailer trucks
Passenger cars w/ trailer
Passenger cars w/ mobile home


300000
250000
200000
150000
100000
50000
0
CO_2e (tons)
54000
52000
50000
48000
46000
44000
42000
Number of Vehicles (thousand)
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2050
CO2e
CO2e w/ 100 % Electric passenger cars
CO2e /w 100 % Electric passenger cars and vans
2050 Target CO2e
Traffic volume on E18

Could LNG be a reliable option for road freight transport?

- European transport sector accounts to 24.4% of all produced GHGs
- H_2 is too costly investment as it is to be widely implemented in road transport
- Electric cars currently have low autonomy and high production costs
- **LNG** is dense in energy which serves the needs of long-distance transportation
  - Autonomy, infrastructure obstacles, viable and mature enough substitute for diesel
  - Does not produce N_2O emissions

References:
Osorio-Tejada, J. L., Llera-Sastresa, E., & Scarpellini, S. (2017). Liquefied natural gas: Could it be a reliable option for road freight transport in the EU?. *Renewable and Sustainable Energy Reviews*, *71*, 785-795.
Zhiyi, Y., & Xunmin, O. (2019). Life cycle analysis on liquefied natural gas and compressed natural gas in heavy-duty trucks with methane leakage emphasized. *Energy Procedia*, *158*, 3652–3657.

Thank you!

- Questions?

Environmental aspects

- Environmental sustainability of LNG
  - **80% less CO; 70% less NO_x; 45% less NMVOCs; >97% less SO_x and PM**
  - **20% less CO_2; 80%-90% less NO_x; close to 100% less SO_x and PM** (Pfoser et al., 2016, for comparison)
  - **80% less NO_x; close to 100% less SO_x; 99% less PM; 70% less GHG** (Kumar et al., 2011, for comparison)
  - ➢ LNG truck can fulfil **EURO VI standard** without exhaust treatment (as is needed in diesel trucks)
- Tank-To-Wheel analysis suggests that LNG generates 24% less overall GHG compared to Diesel
  - Well-To-Tank part of LNG lifecycle has higher environmental impact due to the production and distribution processes required
  - ➢ Well-To-Wheel analysis suggests that **LNG has 16% less emissions than diesel**
- LNG is less energy efficient than diesel, i.e., LNG truck consumes more energy per kilometer in comparison to diesel truck
- Liquefied synthetic methane could decrease GHG emissions by up to 92%
- Liquefied biomethane could decrease GHG emissions by up to 62%

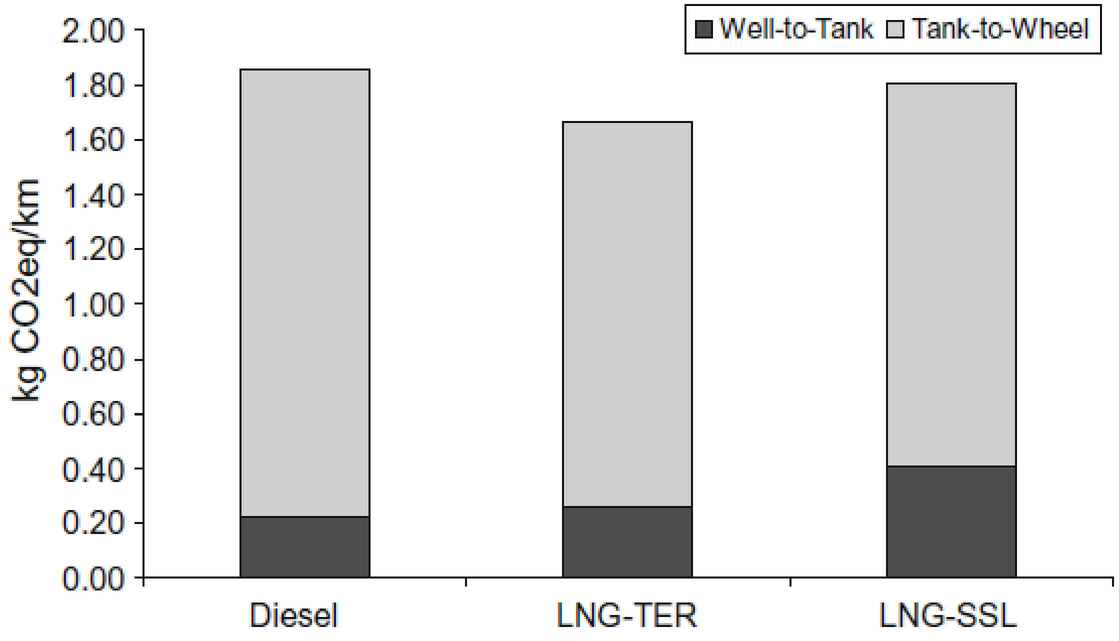
References:
Osorio-Tejada, J. L., Llera-Sastresa, E., & Scarpellini, S. (2017). Liquefied natural gas: Could it be a reliable option for road freight transport in the EU?. *Renewable and Sustainable Energy Reviews*, *71*, 785-795.
Pfoser, S., Aschauer, G., Simmer, L., & Schauer, O. (2016). Facilitating the implementation of LNG as an alternative fuel technology in landlocked Europe: A study from Austria. *Research in transportation business & management*, *18*, 77-84.
Kumar, S., Kwon, H. T., Choi, K. H., Lim, W., Cho, J. H., Tak, K., & Moon, I. (2011). LNG: An eco-friendly cryogenic fuel for sustainable development. *Applied energy*, *88*(12), 4264-4273.

Comparison of LNG and diesel truck emissions

Total lifecycle emission (Well-To-Wheel) for LNG truck:
0.2188 kg CO2-eq/km

Greenhouse gas emissions, in grams per kilometer, for a class 8 truck fuelled by diesel or by LNG with diesel pilot [17].

Emissions	Diesel	LNG with diesel pilot
CO_2 (g/km)	1631	1355
CH_4 (g/km)	Not measurable	2.62
N_2O (g/km)	0.0144	0.0204



Life-cycle emissions, in total and by category of the cycles analyzed.

	Production	Distribution	Combustion	Diesel pilot	Total emission
	kg CO_2-eq/km$_{truck}$	kg CO_2-eq/km$_{truck}$	kg CO_2-eq/km$_{truck}$	kg CO_2-eq/km$_{truck}$	kg CO_2-eq/km$_{truck}$
Diesel	0.2003	0.0208	1.6353	–	1.8563
LNG-TER	0.1600	0.0879	1.4013	0.0150	1.6642
LNG-SSL	0.3887	0.0006	1.4013	0.0150	1.8055

Reference: Arteconi, A., Brandoni, C., Evangelista, D., & Polonara, F. (2010). Life-cycle greenhouse gas analysis of LNG as a heavy vehicle fuel in Europe. *Applied Energy*, *87*(6), 2005-2013.

Technical aspects

- Current studies suggest that LNG truck could perform on par with a diesel truck
- Modern LNG truck manufacturers promise up to 1100 km autonomy
- The lack of efficiency compared to state-of-the-art diesel engines are compensated by lower technology and fuel costs
- High pressure direct injection (HDPI) engine by Westport Power, inc.
  - In tests, drivers report that HDPI engine performs as well or better than diesel engines
  - State of the art engine uses 95% LNG (5% diesel) and can produce the same torque and fuel efficiency as diesel engine, while reducing GHG emission by 20-25%
- In a Heavy-duty Urban Driving Dynamometer Schedule test cycle (HD-UDDS), LNG trucks performed poorly in terms of energy efficiency
  - Slower average speeds, increased idling

Reference: Osorio-Tejada, J. L., Llera-Sastresa, E., & Scarpellini, S. (2017). Liquefied natural gas: Could it be a reliable option for road freight transport in the EU?. *Renewable and Sustainable Energy Reviews*, *71*, 785-795.

Socio-economic aspects

- LNG use can diversify the currently 100% diesel dependent road transport industry
- LNG as a fuel is cheaper than diesel → potential higher competitiveness
- Lower amount of air and noise pollution
- Numerous studies suggest that the LNG truck investment payback time in comparison to using diesel truck is somewhere between 1 to 3 years
- Infrastructure is still inadequate, i.e., only a small share of service stations offer LNG
  - Country and EU level initiatives to stimulate development of the LNG infrastructure
  - Extensive development in the maritime industry to approach LNG could spillover to road transport industry also
- While LNG is a substitute for diesel, it shouldn't be viewed as a competitor for conventional fuel traders, but as an product to extend the product portfolio
- Urban freight transport
  - 10% of the traffic volume is HDVs, whereas 40% of the emissions produced are from HDVs
  - Air pollutants and noise pollution
  - LNG trucks produce lower amount of both of these emission types

Reference: Osorio-Tejada, J. L., Llera-Sastresa, E., & Scarpellini, S. (2017). Liquefied natural gas: Could it be a reliable option for road freight transport in the EU?. *Renewable and Sustainable Energy Reviews*, *71*, 785-795.

Methane slip

- Unburned methane slips from tank and it is emitted to the atmosphere
  - Methane has 25 times higher global warming potential than CO_2
- An analysis of data from the DtT-sponsored Low Carbon Truck Trial by Imperial College London, the University of Cambridge and Minnesota State University has found that greenhouse gas emissions from the 217 dual-fuel gas trucks sampled rose between 50% and 127%
  - Occurs mostly in dual-fuel trucks
- Methane slip has also been found in LNG ships (Anderson et al., 2015; Baresic et al., 2018)

References:
Anderson, M., Salo, K. and Fridell, E. (2015). Particle- and gaseous emissions from an LNG powered ship. *Environmental Science & Technology*, 49:20, pp. 12568-12575.
Baresic, D., Smith, T., Raucci, C., Rehmatulla, N., Narula, K. & Rojon, I. (2018). *LNG as a marine fuel in the EU. Market, bunkering infrastructure investments and risks in the context of GHG reductions*. UMAS, London.
Millett, C. (2017). Two's better? *Commercial Motor, 227*(5721), 12-13.
Department for Transport. (2016). Low Carbon Truck and Refuelling Infrastructure Demonstration Trial Evaluation - Final Report to the DfT
Low Carbon Vehicle Partnership. (2017). Emissions Testing of Gas-Powered Commercial Vehicles

Calculation method

- Traffic volumes
- Emission factors
- Distances

Example case:

- Semi-trailer truck, EURO III, 16.05t load, Highway driving
  - CO_2 (g/km): $e_{partial} = e_{empty} + (e_{full} – e_{empty})$ / max load * partial load
  - http://lipasto.vtt.fi/en/index.htm
  - CO_2 (g/km): $e_{16.05t}$ = 627 + (974 – 627) / 25 * 16.05 = **849.77**

- Semi-trailer truck (EURO III) carrying transito from HaminaKotka harbor to Russian border (69.6 km):
  - Arrival without cargo: 627 g/km * 69.6 km = 43 639.2 g (CO_2)
  - Carrying a sea container to border: 849.77 g/km * 69.6 km = 59 144 g (CO_2)
  - Total CO_2 emission: 43 639.2 + 59 144 g = **102 783.19 g**
  - CO_2 emission per ton-kilometers: **92.01 g/tkm**

NOTE: approximated values used