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Evaluation of E-Mobility benefits in Klagenfurt Air pollutant and GHG reduction

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Abstract

Promoting E-mobility in Klagenfurt and realizing environmental co-benefits are major objectives of CEMOBIL. In Klagenfurt, there is a high share of light diesel vehicles (> 60 % VKT) and NO_2 levels at air quality stations have remained high near major roads within the last couple of years. Due to Klagenfurt's location in a sheltered alpine basin, there is a strong sensitivity of air quality towards emissions released close to the ground. The impact of increased E-mobility (20 % electric light vehicles, 25 % electric buses) in the Klagenfurt area was assessed for 2025 and compared with a BAU 2025 reference scenario. Additional electricity related emissions were estimated.

Emission reductions were computed for CO_2 (-14 %), NO_x (-8.8 %) and PM10 (-0.6 %). An area-wide reduction potential of -0.8 µg/m³ annual mean NO_2 was computed for the city center and up to -1.5 µg/m³ at kerbside locations compared to the BAU scenario 2025. For PM2.5 and PM10 the computed improvements are up to -0.1 µg/m³ at busy roads. The comparison BAU 2025 versus Base 2014 revealed that the reduction potential of improved exhaust aftertreatment technologies along with fleet renewal is larger than the E-mobility reduction potential for NO_2 and PM.

Keywords: E-mobility, air pollution, GHG reduction, co-benefits

1 Introduction and Background

Depending on its market penetration as well as electricity mix, E-mobility technologies have a great potential in reducing greenhouse gases (GHG) and air

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pollutant emissions such as nitrogen oxides (NO_x) or particulate matter (PM). In addition, urban noise levels can be reduced. Demonstrating and facilitating E-mobility in order to realize future environmental co-benefits in Klagenfurt are major objectives of the EU-Life+ project CEMOBIL (CO_2 neutral Electro-MOBILity for the reduction of air pollutants and noise in European cities, for example Klagenfurt; http://www.cemobil.eu/).

In the sheltered Klagenfurt basin (population ~100 000) located south of the Alpine bow, air quality problems (PM10, NO_2) have occurred frequently over the last years (see Figure 1). There, frequently low wind speeds and inversions are encountered. Eastward of Klagenfurt, 67 % of the recorded winds were below 1.5 m/s in 2010 [1]. In Klagenfurt there is not much industry and the city is not located close to area-wide extensive sources of high pollution. Therefore, a strong sensitivity of air quality particularly towards emissions released close to the ground results. Traffic is the main NO_x source and a major PM source in Klagenfurt [1][2]. A specific aspect of E-mobility is that almost no harmful air pollutants are emitted close to the ground. Their most promising application is urban transport and commuting. Due to the high share of diesel light vehicles in Austria, which is over 60 % on vehicle kilometers travelled (VKT), the reduction potential of electric vehicles on NO_x and PM exhaust emissions is high. Within the framework of CEMOBIL future E-mobility scenarios and a business as usual scenario (BAU) have been developed to evaluate the potential impact of electric vehicles on air quality in Klagenfurt in the near future.

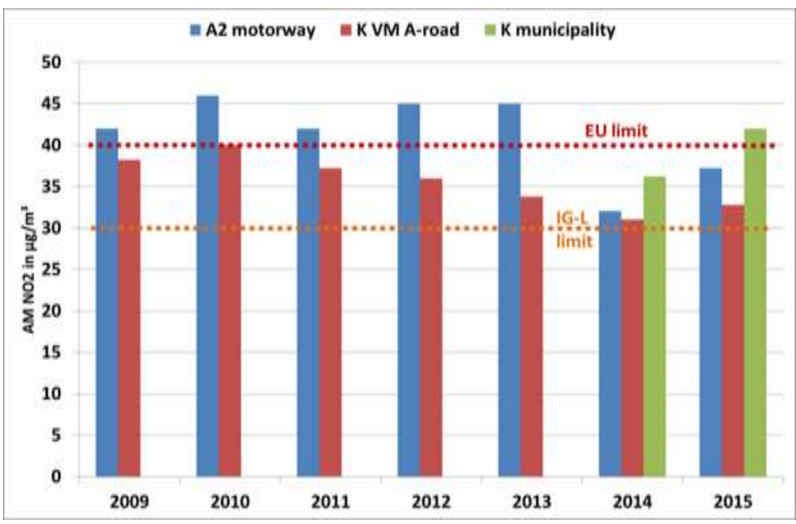

Figure 1: Monitored AM NO_2 at stations located near busy roads. The red dotted line indicates the EU limit of 40 µg/m³, the orange one the Austrian limit (IG-L).

2 Objectives

Within this work the emission reduction potential of one E-mobility scenario as well as improved engine and exhaust aftertreatment technologies along with fleet renewal will be evaluated and discussed. The additional electricity demand for electric light vehicles and busses is computed and resulting power generation related emissions were estimated for CO_2, NO_x and PM10. Annual mean (AM) NO_x, NO_2, PM2.5 and PM10 concentrations were computed to assess the impact on air quality of these three cases. A further objective was to estimate the E-mobility reduction potential on air quality in case the emission reductions related to improved engine exhaust technologies are delayed or their effect significantly lessened in extent.

3 Methodology

Traffic data and emissions: Traffic model results using the VISUM [3] traffic model containing traffic densities for light vehicles (LV) (mostly cars and vans), heavy duty vehicles (HDV) and buses on the Klagenfurt road network, as well as average speeds were provided by Klagenfurt municipality for 2014 and form the basis of this work. These traffic count data, together with vehicle speed data, were used as an input to compute traffic related air pollutant emissions for the road network. For this purpose the vehicle emission prediction model (NEMO 3.7 [4]), which contains the Austrian vehicle registration data along with future fleet projections, was used. The computed emissions were allocated in space to approx. 34 000 road sections. Tunnel emissions were integrated over the tunnel length and calculated as portal area sources.

Scenarios: Based on the experiences in Klagenfurt and latest traffic numbers, no further increase in traffic volume for 2025 was assumed in the BAU 2025 scenario and E-mobility scenario. The aim of the Klagenfurt BAU scenario was twofold: 1) to assess the impact of technological progress in exhaust after-treatment, driven by more stringent emission standards until 2025 in combination with the ongoing fleet renewal; 2) to provide a basis to evaluate the E-Mobility Scenario of a 20 % share of electrically driven LV (cars, vans) in Klagenfurt, 10 % share of electrically driven LV at the motorways around Klagenfurt and 25 % share of electrically driven city buses in 2025. Emissions from both scenarios were computed using NEMO and allocated in space to road sections.

Dispersion: In order to compute dispersion of NO_x, PM2.5 and PM10 the GRAMM (GRAz Mesoscale Model [5]) and GRAL (GRAz Lagrangian model [6]) models were used. For the flow field computations, digital elevation model data and land use data [7] were processed on 250 m x 250 m grids. Meteorological data from a meteorological station located eastward of Klagenfurt were classified into different prevailing flow conditions (wind speed classes, 10° wind sectors and 7 stability classes [1]). Finally, CPU intensive dispersion computations were carried out for the selected area around Klagenfurt, 16.5 km by 16 km in size, using a counting grid resolution of (10 m x 10 m) to compute dispersion. AM NO_x, PM2.5, PM10 concentrations were modelled. NO_x to NO_2 conversion was computed using a Romberg type empirical conversion formula [8][9]. Residential heating, in particular wood burning is a major PM source within the area of interest. Within the PMinter project [1] emissions from residential heating have been assessed bottom-up and validated. In order to represent the strong contributions and concentration gradients resulting from residential heating the PMinter data have been used. Homogeneous constant background values for NO_x, PM2.5 and PM10 were used to compensate for neglected sources and regional transport towards the model domain. Air quality monitoring data from 5 to 6 stations were used to adjust NO_x, PM2.5 and PM10 background values and for validation of the modelling approach.

4 Main Results

4.1 Emissions

Internal combustion engine (ICE) related traffic emissions were computed for all road sections of the modelling domain using the model NEMO. NO_x, PM2.5, PM10 exhaust and non-exhaust emissions were allocated to respective road sections for light vehicles, buses and heavy duty vehicles for all three cases respectively. Figure 2 shows the dispersion modelling domain and results from traffic emission modelling for NO_x using NEMO for the Klagenfurt road network. Maximum emissions are found near the motorway, the main arterial roads and within the city center.

In total 1003 million vehicle kilometers travelled per annum were computed for all three cases. Table 1 summarizes the ICE related CO_2, NO_x, PM2.5 and PM10 exhaust as well as non-exhaust traffic emissions. For the scenarios the required electricity consumption was computed using NEMO. For the base case 2014 and the BAU 2025 scenario the actual CEMOBIL fleet was taken into account. The E-mobility power production related NO_x, PM10 and CO_2 emissions were computed based on the Austrian 2013 power mix [10]. In addition, for the E-mobility scenario 2025 the power production related emissions were computed based on the continental Europe ENTSO-E (European Network of Transmission Systems Operators) power mix, see Table 2 and Figure 3. The Austrian power mix comprises electricity from 68.1 % hydro power, 10.5 % other renewables, 18.7 % fossil fuels and 2.6 % nuclear power. In contrast, the ENTSO-E 2014 power mix contains less hydro power but large shares of fossil fuel and nuclear power produced electricity (18.5 % hydro power, 10.5 % other renewables, 40.5 % fossil fuels and 26.4 % nuclear power). Electrical power consumption related emission factors (in g/kWh el) from ÖKO (2010) [11], GEMIS 4.6 [12] and PROBAS [13] data bases were used to estimate the power production related emissions for both power mixes (Table 2).

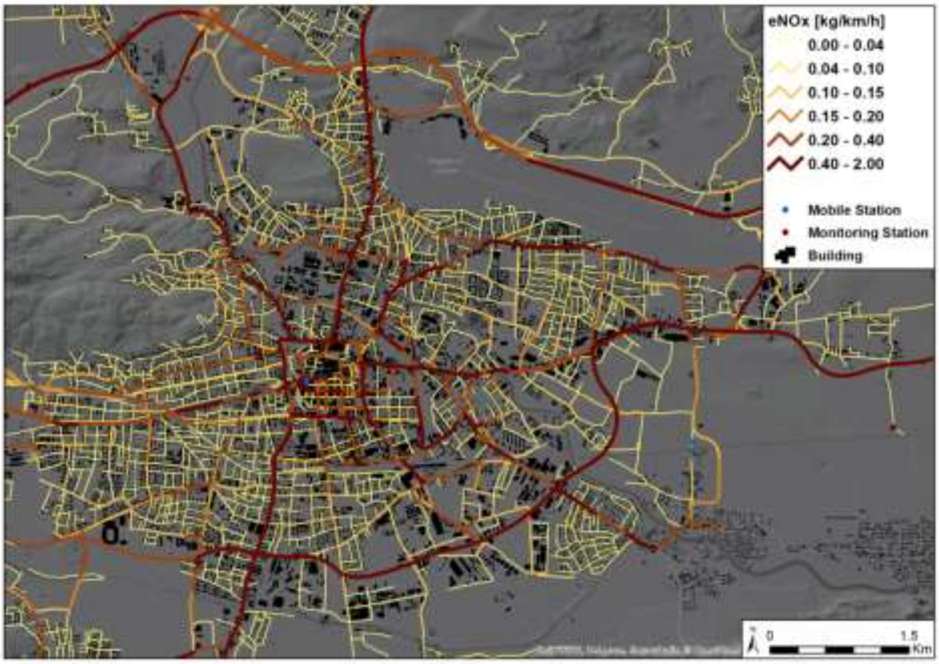

Figure 2: Dispersion modelling domain and location of air quality monitoring stations comprising Klagenfurt municipality and modelled line source emissions for NO_x, base case 2014.

Table 1: Total traffic internal combustion engine related emissions per annum (t/a) for the Klagenfurt area. Exh/Nexh denotes exhaust/non-exhaust PM emissions.

Scenario	CO_2 [t/a]	NO_x [t/a]	PM2.5 Exh [t/a]	PM2.5 NonExh [t/a]	PM10 NonExh [t/a]
Base 2014	205024	743.55	19.95	24.25	44.75
BAU 2025	176283	251.39	5.02	24.26	44.76
Emob 2025	144624	216.46	4.12	24.26	44.76

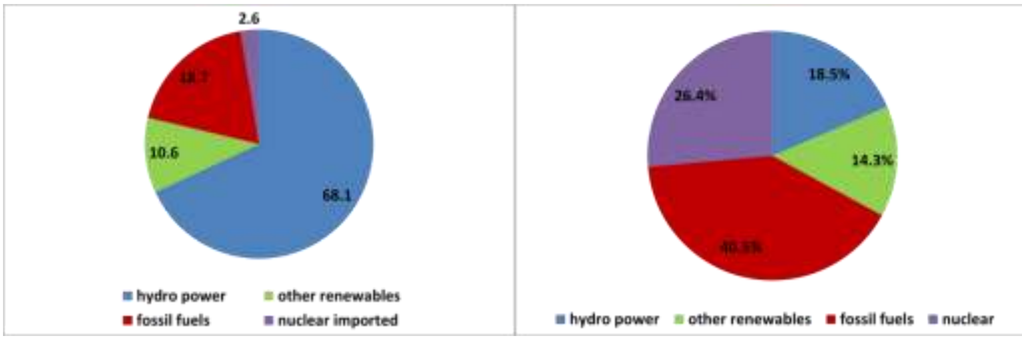

Figure 3: Austrian power mix (left) and ENTSO-E power mix (right).

Table 2: Total E-mobility related power consumption and related indirect emissions according to the Austrian power mix and additionally ENTSO-E.

Scenario	E-mob power consumption [GWh/a]	CO_2 [t/a]	NO_x [t/a]	PM2.5 Exh [t/a]
Base 2014 A-mix	19.95	27	0.05	0.00
BAU 2025 A-mix	5.02	27	0.05	0.00
Emob 2025 A-mix	4.12	6631	12.85	0.62
Emob 2025 ENTSO-E	4.12	13528	31.05	0.89

BAU 2025 CO_2 emissions from internal combustion engines (ICE) driven vehicles are reduced by -28 741 t/a (- 14 %) compared to the base case 2014. E-mobility 2025 CO_2 ICE emissions are reduced by -31 659 t/a (-18 %) compared to the BAU 2025 scenario (Table 1). 49.3 GWh/a electricity are required for the electric vehicles (from the plug-in, without production and line losses). If the required electricity is produced according to the Austrian 2013 power mix, 6 631 t/a power production related CO_2 emissions would result (Table 2), assuming 5 % line losses. With the ENTSO-E 2014 power mix (40.5 % fossil fuels) the positive impact of E-mobility on CO_2 declines, but is still positive (Table 2 and Figure 4).
BAU 2025 ICE NO_x emissions are reduced by -492 t/a (-66 %) compared to the base case 2014. E-mobility 2025 NO_x ICE emissions are further reduced by -34.9 t/a (-14 %) compared to the BAU 2025 scenario (Table 1). The substantial NO_x reductions of both 2025 scenarios compared to the base case 2014 are mainly attributable to improved exhaust aftertreatment technologies driven by emission legislation (Euro 6) and fleet renewal. It should be noted that the computed substantial NO_x exhaust emission reductions (BAU 2025 – Base 2014) include NO_x reductions of HDV as well. With the Austrian power mix, 12.9 t/a electricity production related NO_x emissions would result (Table 2). With the ENTSO-E

2014 power mix the positive impact of E-mobility on NO_x emissions is almost counter balanced, see Figure 4.
BAU 2025 PM2.5 ICE related exhaust emissions (ICE) are reduced by -14.9 t/a (-75 %) compared to the base case 2014. E-mobility 2025 PM2.5 ICE emissions are reduced by -0.9 t/a (-17 %) compared to the BAU 2025 scenario. PM2.5 exhaust emissions comprise 45 % of the total PM2.5 emissions and PM10 exhaust emissions comprise 31 % in the base case. With the BAU 2025 scenario the share of PM2.5/PM10 exhaust emission is reduced to 17 % and 10 %. The E-mobility related reductions are limited to exhaust PM, consequently the total reduced PM mass is low, i.e. -0.9 t/a ICE related, and counterbalanced by 0.62 t/a with the Austrian power mix and 0.89 t/a with the ENTSO-E power mix, see Figure 4.

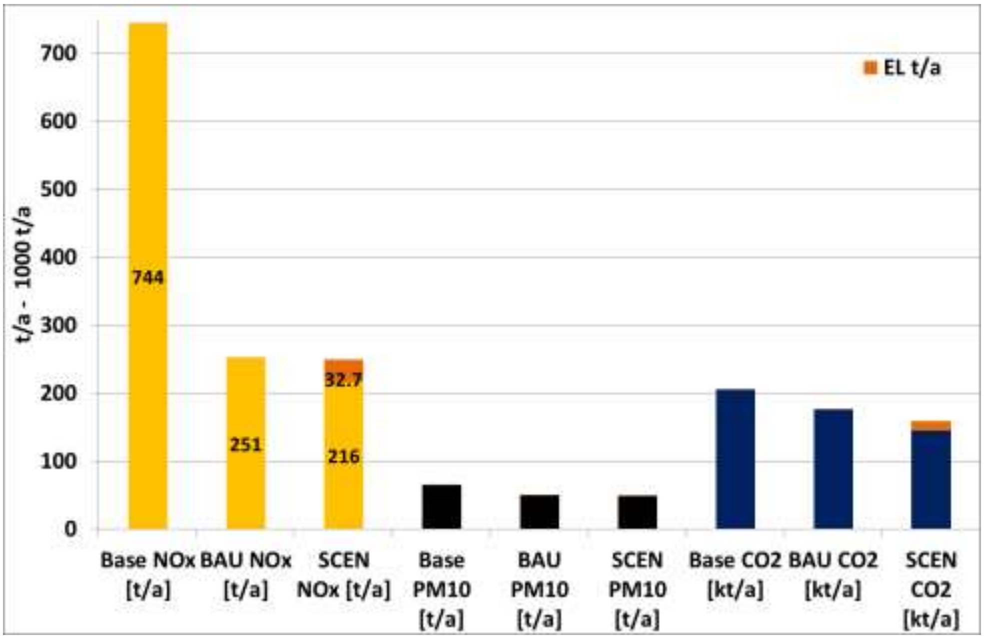

Figure 4: Total traffic NO_x, PM10 (t/a) and CO_2 (in 1000t/a) emissions from internal combustion engines (ICE) and power production related emissions according to ENTSO-E mix.

The computed substantial NO_x exhaust emission reductions (BAU 2025 – Base 2014) are only realistic if future real world emissions will not deviate significantly from the upcoming “Real Driving Emission” RDE legislation (September 2017 Step 1, September 2019 Step 2). The representation of dynamic driving behavior impacting on NO emissions is expected to be well represented by the NEMO model. However deactivation of exhaust aftertreatment components at low temperatures or malfunctioning of complex exhaust aftertreatment components is currently not represented. For future PM exhaust emission computations leaking of old regenerating particle may pose as well a major uncertainty of emission computations.

3.2 Air Quality

3.2.1 Base case 2014

Figure 5 shows the result for the AM NO_2 for the base case 2014 for the entire domain. The locations of the monitoring sites are indicated. Results of the comparison monitoring results versus simulations are shown in Figure 6. For NO_2 the agreement is good, for PM2.5 and PM10 (not shown, $R^2 = 0.74$) the agreement is fair. The measurements have been used for the evaluation of background values which were also used in both scenarios:

- 7 µg/m³ for NO_x (as NO_2 mass equivalent)
- 8 µg/m³ for PM2.5
- 10 µg/m³ for PM10

Generally, within the inner city of Klagenfurt elevated NO_2 levels of up to 30 µg/m³ are computed. At some locations near the ring road and inner city the Austrian (IG-L) air quality standard is exceeded; close to busy roads even the EU air quality standard. Generally, the AM NO_2 is low around the city center, i.e. less than 20 µg/m³. However, near main arterial roads, near the motorway and the tunnel portals, very high elevated AM NO_2 concentration levels above the air quality standards (IG-L/EU) of 30/40 µg/m³ were computed. Generally AM PM2.5 and AM PM10 levels are low in Klagenfurt, near major roads AM PM2.5 up to 19 µg/m³ and PM10 levels up to 25 µg/m³ are computed (not shown). However, particularly during winter time, high PM2.5 and PM10 levels are monitored exceeding frequently the daily mean limit of 50 µg/m³, dominated by PM attributable to secondary inorganics, solid fuels used in residential heating and traffic non-exhaust [1].

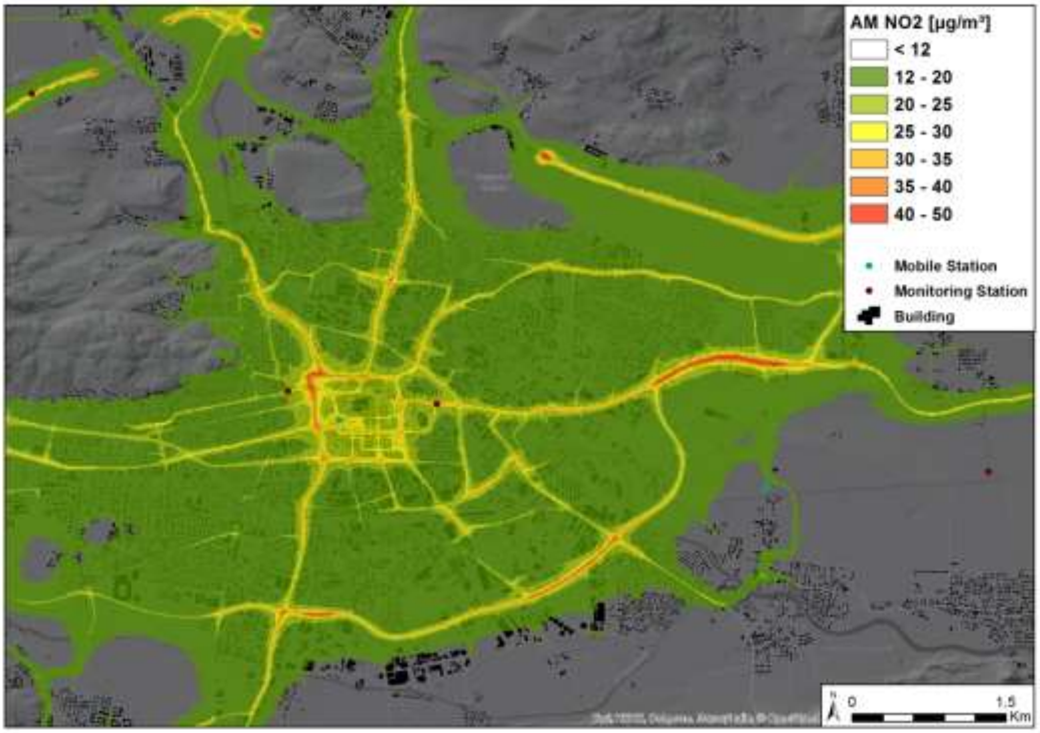

Figure 5: Simulated AM NO_2 concentration for Klagenfurt base case 2014, and locations of air quality monitoring.

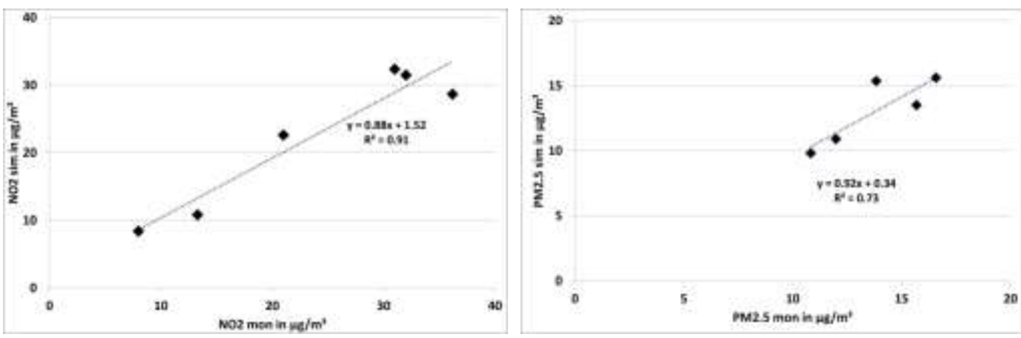

Figure 6: Comparison of monitored versus simulated base case AM NO_2 and AM PM2.5, 2014.

3.2.2 BAU 2025 Scenario

After verification of the model approach on the basis of the 2014 simulations, the impact of technological progress in exhaust aftertreatment in combination with ongoing fleet renewal until 2025 was analyzed. AM NO_2 concentration levels are significantly decreased, values above the IG-L limit of 30 µg/m³ result only near major roads and the tunnel portals (Figure 7, left). Levels above 40 µg/m³ were only computed at the tunnel portal locations. The reduction of BAU 2025 NO_x emissions results in substantial area-wide NO_2 concentration reductions. AM NO_2

is reduced area-wide by up to –11 µg/m³ in the city center and in the vicinity of busy roads. Maximum reductions amount up to –14 µg/m³ close to busy roads (Figure 8, left). Figure 7 shows the simulated AM PM2.5 which is dominated by PM2.5 from solid fuels used in residential heating; concentration gradients are even at major roads low. According to the definition of the scenario, PM Reductions are limited to exhaust emissions. The share of exhaust particle emissions has been significantly reduced since the introduction of the Diesel particle filters (in most cases together with the introduction of the Euro 4 emission standard in 2006). In 2014, 53 % of the diesel LV in Austria were equipped with regenerating particle traps. Consequently, the future impact on PM exhaust emissions can be expected to be moderate as long as pre-Euro 4 diesel vehicles are not replaced in large quantities. BAU 2025 simulations for PM2.5 yield area-wide reductions of about –0.7 µg/m³ and up to –1.5 µg/m³ in the vicinity of busy roads (Figure 8).

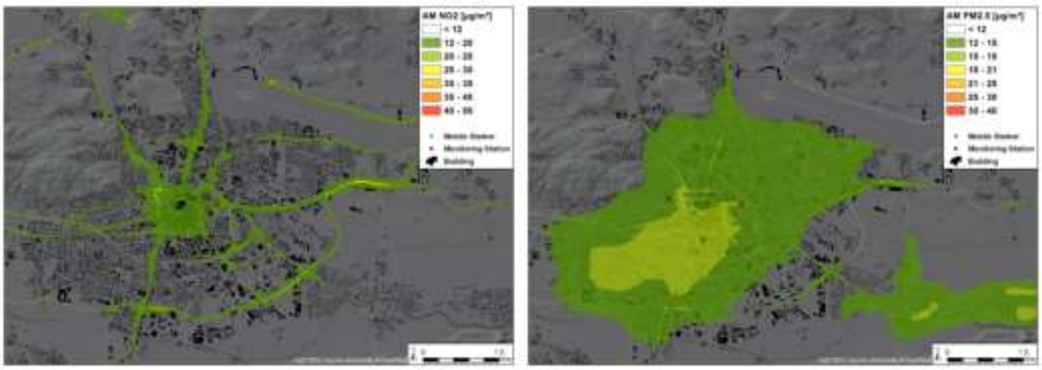

Figure 7: Simulated AM NO_2 concentration (left) and simulated AM PM2.5 concentration for Klagenfurt BAU 2025.

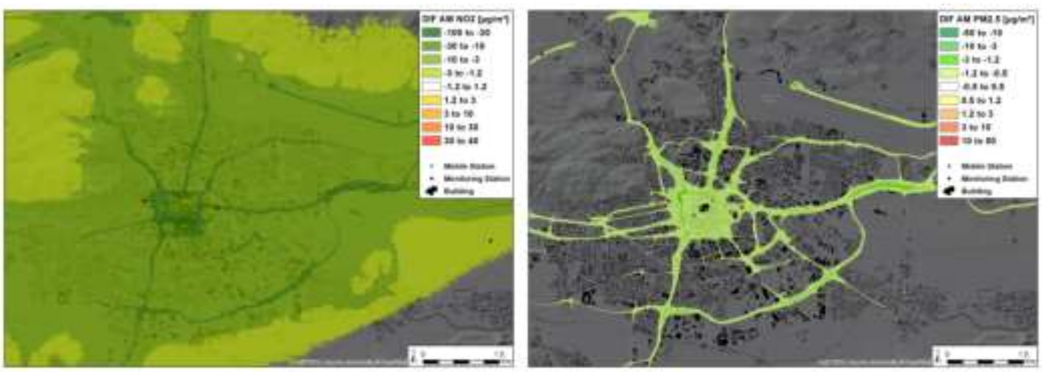

Figure 8: Difference AM NO_2 (left) and difference AM PM2.5 (right) BAU 2025 vs. Base 2014.

3.2.2 E-Mobility 2025 Scenario

Compared to the BAU 2025 scenario AM NO2 concentration levels are significantly decreased (Figure 9). Within the city center and the main roads air quality may improve by -0.5 to -1.5 µg/m³ at major road kerbside locations. Compared to the BAU 2025 scenario, computed PM2.5 reductions are very small, up to -0.1 µg/m³ at busy roads (Figure 8). These improvements (Emob 2025 – BAU 2025) are small compared with BAU 2025 – Base 2014. However, the reductions compared to the base case are large, i.e. in principal the superposition of the differences in NO_2 and PM2.5 of Figure 8 (BAU 2025 - Base 2014) and Figure 9 (Emob 2025 – BAU 2025). The reduction potential of improved exhaust aftertreatment along with fleet renewal is larger than the E-mobility reduction potential. However, in case the expected impact of technological progress is delayed or considerably lessened, the E-mobility reduction potential is increased. Figure 9 shows the results for the E-mobility reduction potential for the extreme scenario of stagnating conditions in NO_x and PM exhaust emissions related to the base case 2014. The E-mobility reduction potential is improved by up to 2.4 µg/m³ for AM NO_2 and up to 0.4 µg/m³ for AM PM2.5 at city center kerbside locations. It should be noted that the air pollution reduction potential of E-Mobility can be maximized, if ICE vehicles with extremely high NO_x and/or PM exhaust emissions are replaced. Finally, considering the event of reduced or delayed future exhaust aftertreatment the reduction potential of electric vehicles may range between the two cases illustrated in Figure 9 and Figure 10, given a high share of electric light vehicles and electric buses in 2025.

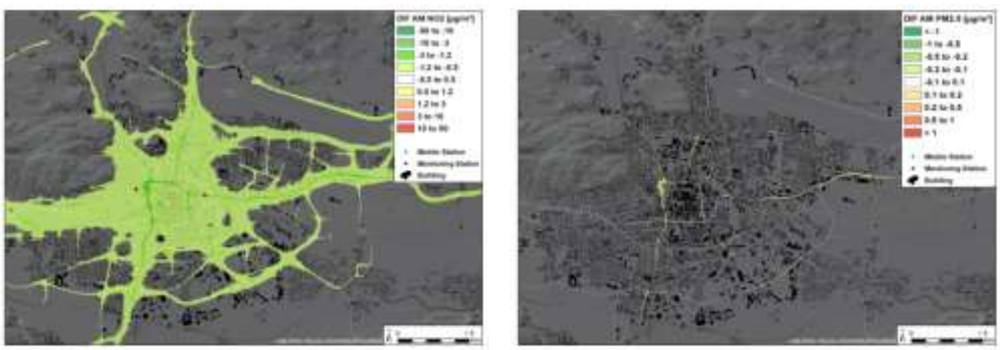

Figure 9: Difference AM NO_2 E-mobility Scen 2025 vs. BAU 2025 (left), Difference AM PM2.5 E-mobility Scen 2025 vs. BAU 2025 (right).

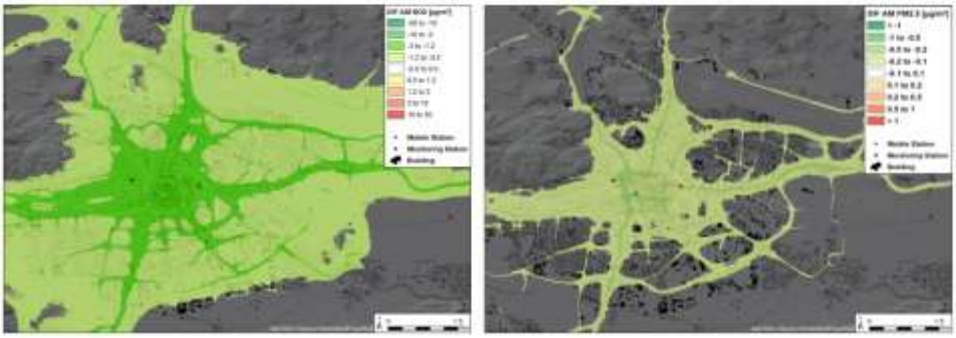

Figure 10: Maximum reduction potential of E-mobility on AM NO2 (left) and AM PM2.5 for the extreme case of absent advances in future exhaust aftertreatment related to the base case 2014.

5 Conclusion

The impact of increased E-mobility on CO_2, NO_x and PM2.5 emissions and air quality (annual mean NO_2, PM2.5 and PM10) was studied for the Klagenfurt municipality (~100 000 pop.) for 2025. The E-mobility scenario comprised a replacement of light vehicle ICE traffic by 20 % VKT in Klagenfurt municipality and 10 % replacement at the surrounding motorways, city buses were replaced by 25 % electric busses until 2025. A business as usual (BAU) scenario for 2025 was used as a reference case, to account for technological advances in exhaust after-treatment driven by more stringent emission standards and ongoing fleet renewal until 2025.

Substantial ICE related emission reductions were computed for CO_2 by -28 741 t/a (-18 %) as well as NO_x -34.9 t/a (-14 %) compared to the BAU 2025 scenario. PM exhaust emissions were reduced by -0.90 t/a (-3.1 % of total PM2.5 and -1.8 % of total PM10 vehicle emissions) indicating that the future reduction potential for PM is exhausted due to the prognosed high share of vehicles with efficient state of the art or future exhaust aftertreatment technologies, e.g. regenerating particle traps. A power demand of 49.3 GWh/a was computed to run the electric vehicles. Additional power generation related emissions were estimated using the Austrian power mix which is characterized by a high share of hydro power (68 %). CO_2 emissions increase by 6 631 t/a (+3.8 %), NO_x by 12.9 t/a (+5.1 %) and PM10 by 0.62 t/a (+1.2 %). A comparison with the continental European ENTSO-E power mix (41 % fossil fuels) revealed power generation related CO_2 emissions of 13 528 t/a (+7.7 %) and NO_x emissions of +31.1 t/a (+12.3%). Here, NO_x emission reductions due to replacement of ICE vehicles are almost counter balanced by high NO_x emissions emitted by power plants using fossil fuels for power and heat generation.

However, a specific aspect of E-mobility is that almost no harmful air pollutants are emitted close to the ground. This effect was studied in detail by running flow field and dispersion simulations to compute annual means (AM) for NO_2, PM2.5 and PM10. An area-wide reduction potential of -0.8 µg/m³ AM NO_2 was computed for the city center and up to -1.5 µg/m³ at kerbside locations of major roads, compared to the BAU scenario 2025. For PM2.5 and PM10 the computed improvements are very small, only up to -0.1 µg/m³ at busy roads. The comparison BAU 2025 versus Base 2014 revealed that the reduction potential of improved exhaust aftertreatment technologies along with fleet renewal is larger than the E-mobility reduction potential. In case, the expected impact of technological progress is delayed or considerably lessened, the E-mobility reduction potential as evaluated by the difference "Scenario 2025 – BAU 2025" would be increased. It should be noted that the air pollution reduction potential of E-Mobility can be maximized, if ICE vehicles with extremely high NO_x and/or PM exhaust emissions are replaced.

ACKNOWLEDGEMENTS
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