In-situ effect of pervious concrete slabs doped with activated carbon on NO2 adsorption and mineralization process

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INTRODUCTION
FROM CLIMATE CHANGE TO AIR QUALITY

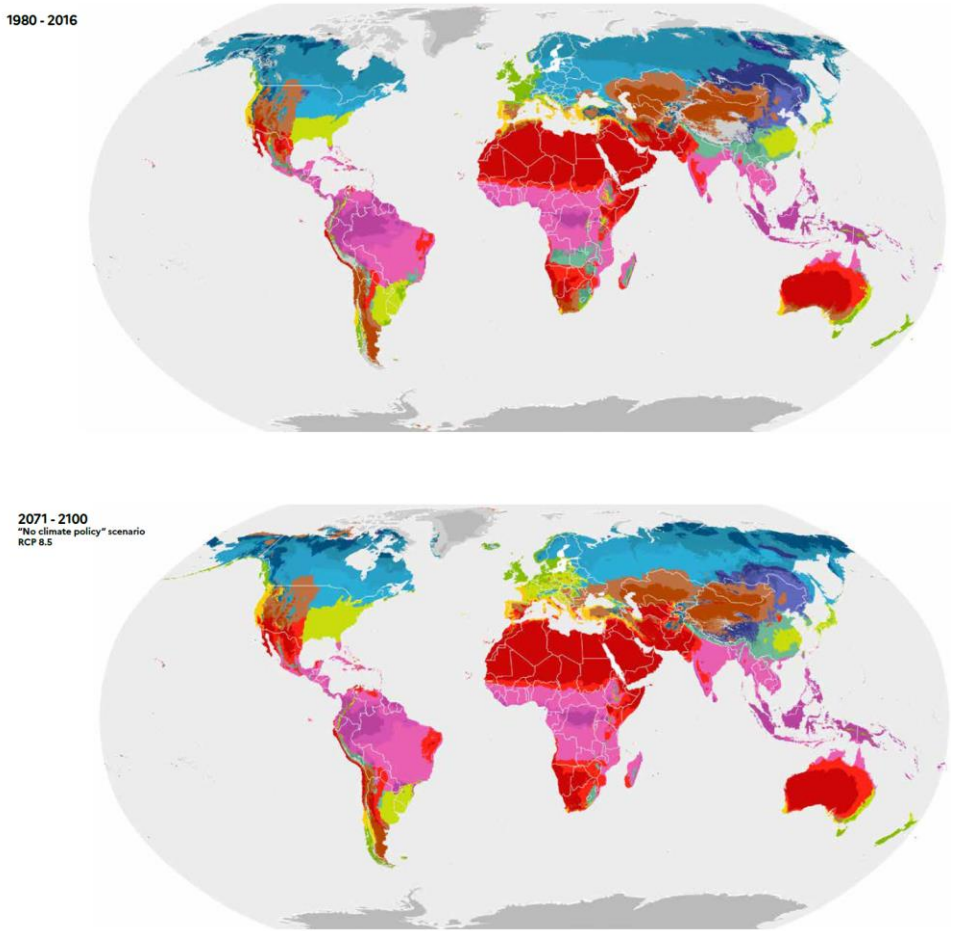
Urban Heat Island (UHI) is the temperature difference observed between an urban area and nearby rural area (2 to 3°C)

Urban Overheating encompasses both UHI and the thermal discomfort (affect the health) experienced by city people on hot days

EUROPE IS MORE CONCERNED

"According to the European Commission, 78% of European citizens now live in cities, and the UN predicts a worldwide increase of 13% of the population living in cities by 2050. ***Developing a more sustainable compact urban form and limiting soil sealing is an important step*** *in a city's development as they anticipate this growth, and plan for related future changes" (EU Commission, 2021) -*

SOLUTIONS: Depolluting solutions to improve Air quality and reduce UHI



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OUTLINES

- Air pollution versus World Health Organization guidelines
- Pervious concrete technology
- Methodology: demonstrators' implementation and tests
- German demonstrator analysis and first conclusions drawings
- Comparison with other solutions
- Conclusion

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AIR POLLUTION
HEALTH ISSUE OF CONCENTRATION TRESHOLD

Pollutants most detrimental:

- **Nitrogen Oxydes (NO/NO2)**
- **Ozone (O3)**
- **Fine Particles (PM 2.5/10)…**

World Health Organization guidelines

averaging time	2021 New Air Quality Recommendations *NO2 (µg/m³)*
1-hour	200*
24-hour	45**
annual	10

*should not be exceeded more than 18 times a year (18h / year)

**should not be exceeded 3-4 days year (72h - 96h / year)

i.e. NO2 concentration can reach 200µg/m3 only if it doesn't persist at this level more than 1h

https://apps.who.int/iris/handle/10665/345329

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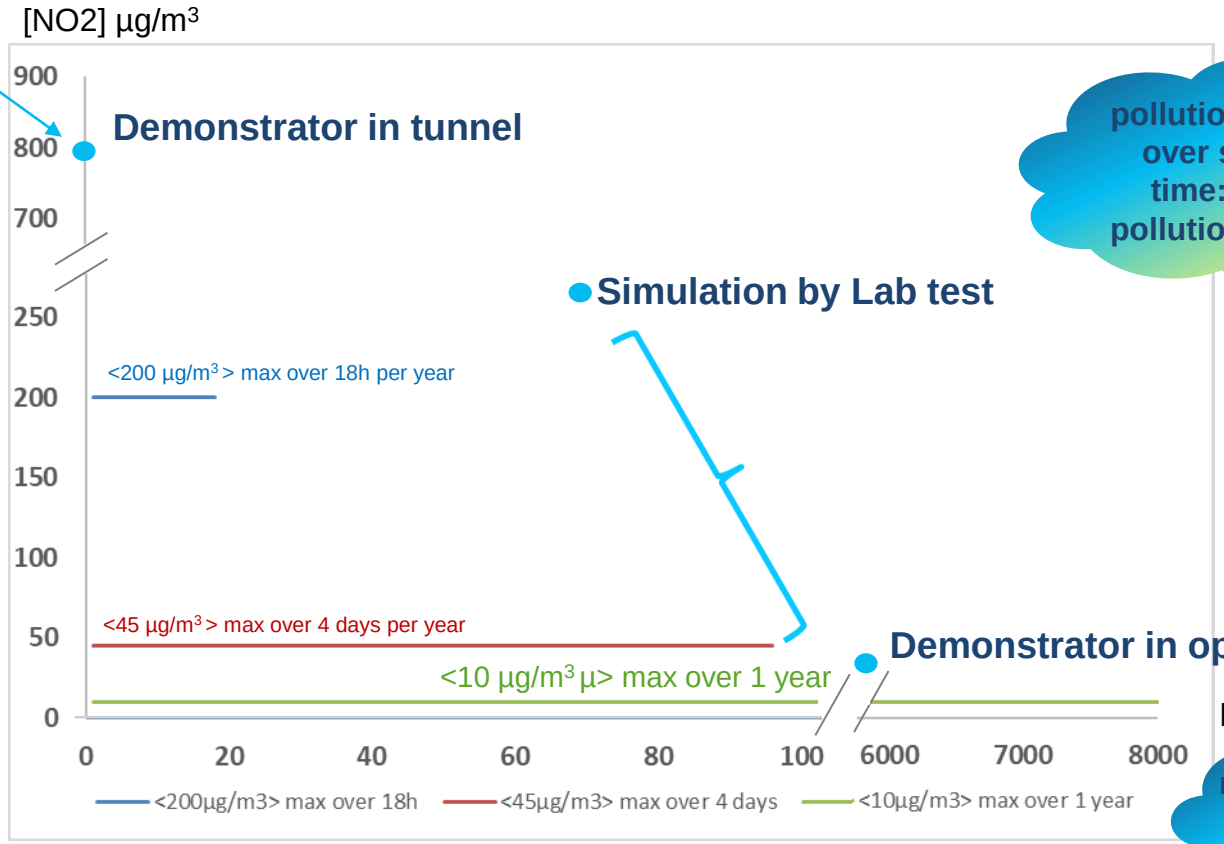
CHOICE OF THE APPROPRIATE POLLUTION CONDITIONS FOR THIS STUDY (VERSUS WHO GUIDELINES)

confined space: very high pollution level 800µg/m³



pollution peak episodes over short period of time: medium/high pollution level 478µg/m³

real everyday life pollution: low level 10-45µg/m³

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PERVIOUS CONCRETE TECHNOLOGY
ACTIVATED CARBON SOLUTION

high porosity concrete (>20%)

Water management

high drainage capacity (600L/m2)

Roads concrete
Parking slabs
Cycle paths
Roof-top

Activated charcoal
→ works without
solar or UV light

POLLUTION CONDITIONS FOR HOLCIM FIELD TESTS

2 types of **field** pollution conditions:

- **Demonstrator in Germany Dortmund Plant** (Parking near high traffic road: 80 cars & 400 trucks per day)

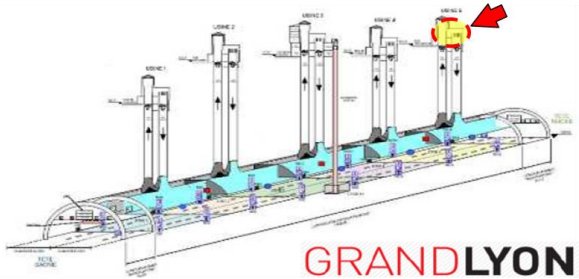
Focus today

Pollution level in the realistic average 10-45 µg/m^3

- **Demonstrator in Tunnel Croix Rousse Lyon (2017) (47000 cars per day)** (Samples exposed to the gas evacuation chimney)

2017 results will be used for comparison

Very high pollution level 800 µg/m^3 in confined space



GERMAN DEMONSTRATOR: DORTMUND PLANT

Small samples for regular testing

4 slabs of 12 m^2 each were casted

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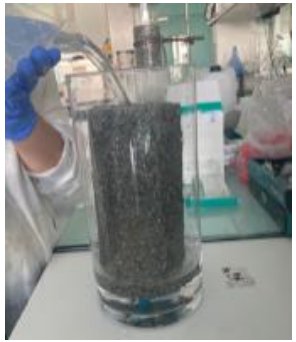
METHODOLOGY USED FOR GERMAN DEMONSTRATOR FIELD TESTS (1/3)

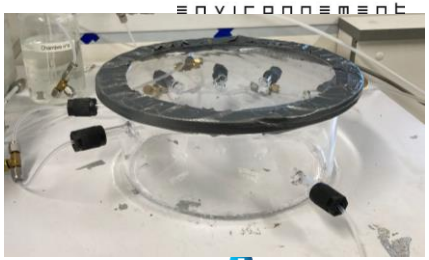
Conditions:

- **Samples exposed to the same pollution level as the parking slabs, removed at regular deadlines**
  (1 month, 3 months, 6 months, 1 year, 18 months)
- **Half of the samples are covered**
  (to measure the maximum of performance & to follow the effect of natural rainfall leaching on performance)

Tests:

- **Direct performance measurement: Gas adsorption With Lab reactor test: remaining pollutant adsorption capacity after a shorter or longer period exposure**
  (high/medium pollution 478µg/m3)
- **Indirect performance measurement: Leaching test**
  (1 month, 3 months, 6 months, 1 year, 18 months)





TERA
environnement

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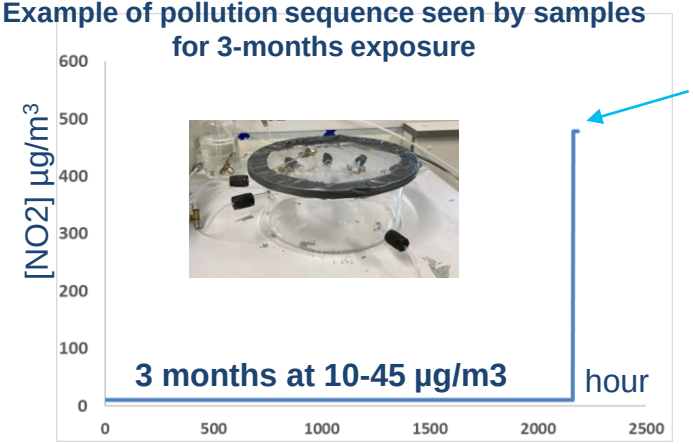
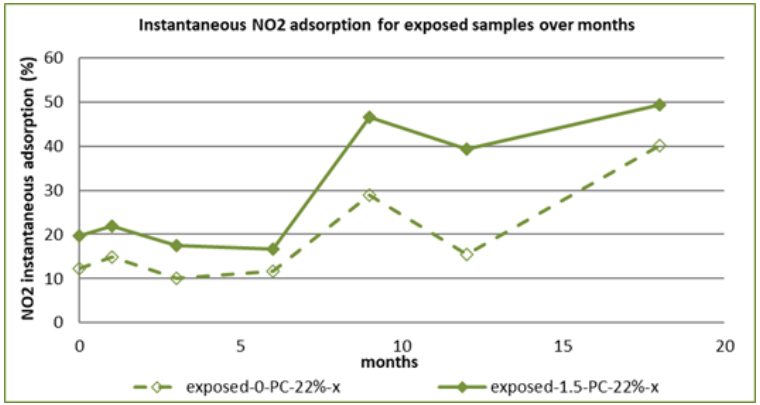
PERFORMANCE EVALUATION WITH DIRECT MEASUREMENT: GAS ADSORPTION

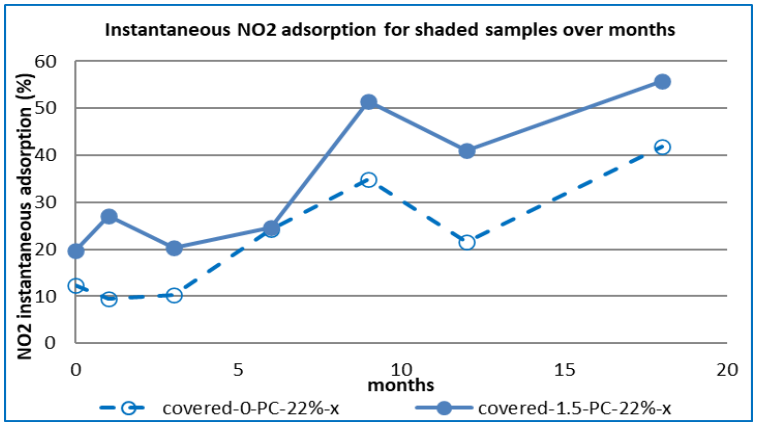
INSTANTANEOUS GAS ADSORPTION:
EVALUATION WITH GERMAN DEMONSTRATOR (1/2)

Example of pollution sequence seen by samples for 3-months exposure



24h at 478µg/m3 (simulation for pollution peak episode)





- **Adsorption increases along the 18 months:**
  up to ~40% for no AC samples
  and up to ~50% for AC samples
- **Adsorption capacity is sustained over 18 months**
- **No huge difference between covered and uncovered samples**

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INSTANTANEOUS GAS ADSORPTION:
EVALUATION WITH GERMAN DEMONSTRATOR - PRELIMINAR CONCLUSION (2/2)

- After 18-months low pollution exposure, NO2 gas adsorption performance ***at high NO2 level (478µg/m3)*** is maintained for pervious concrete (up to 40% for No AC samples and up to 50% for *$AC^{1.5\%}$ doped samples)
- AC improves performance
- No saturation is observed after 18 months: 100% efficiency sustained

**AC=Activated Charcoal or Carbon*

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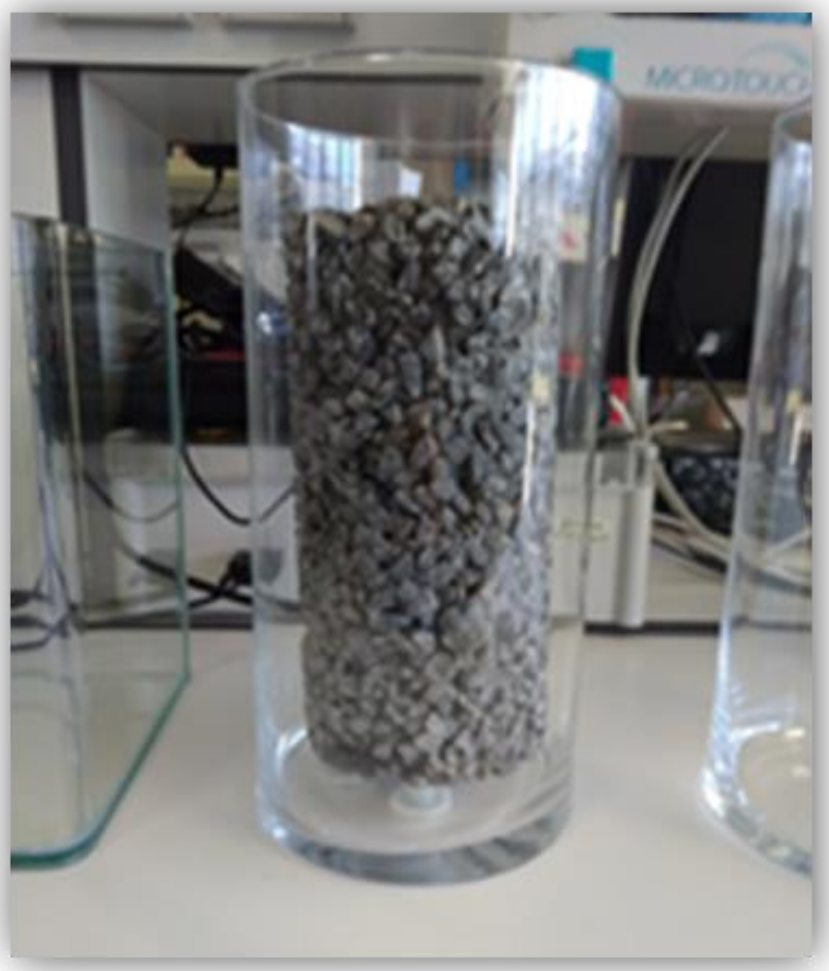
PERFORMANCE EVALUATION WITH INDIRECT MEASUREMENT: LEACHING TEST



INDIRECT MEASUREMENT: LEACHING TEST
EVALUATION WITH GERMAN DEMONSTRATOR (1/6)

Mineralisation process:

$$2\ Ca(OH)_2 + 4NO_2 \rightarrow (Ca^{2+}, 2NO_3^-) + (Ca^{2+}, 2NO_2^-) + 2H_2O$$

- **When adsorbed, transformation of adsorbed NO2 gas in ions NOx-containing cristals occurs: long process**
- **Possibility to dissolve NOx-cristal by (natural) or forced leaching to observe release of NOx ions: the release phenomenon is also a long process**
- **Analysis of possible natural rainfall leaching with the behaviour of non covered samples (to prove the ‘auto-regeneration’ phenomenon)**

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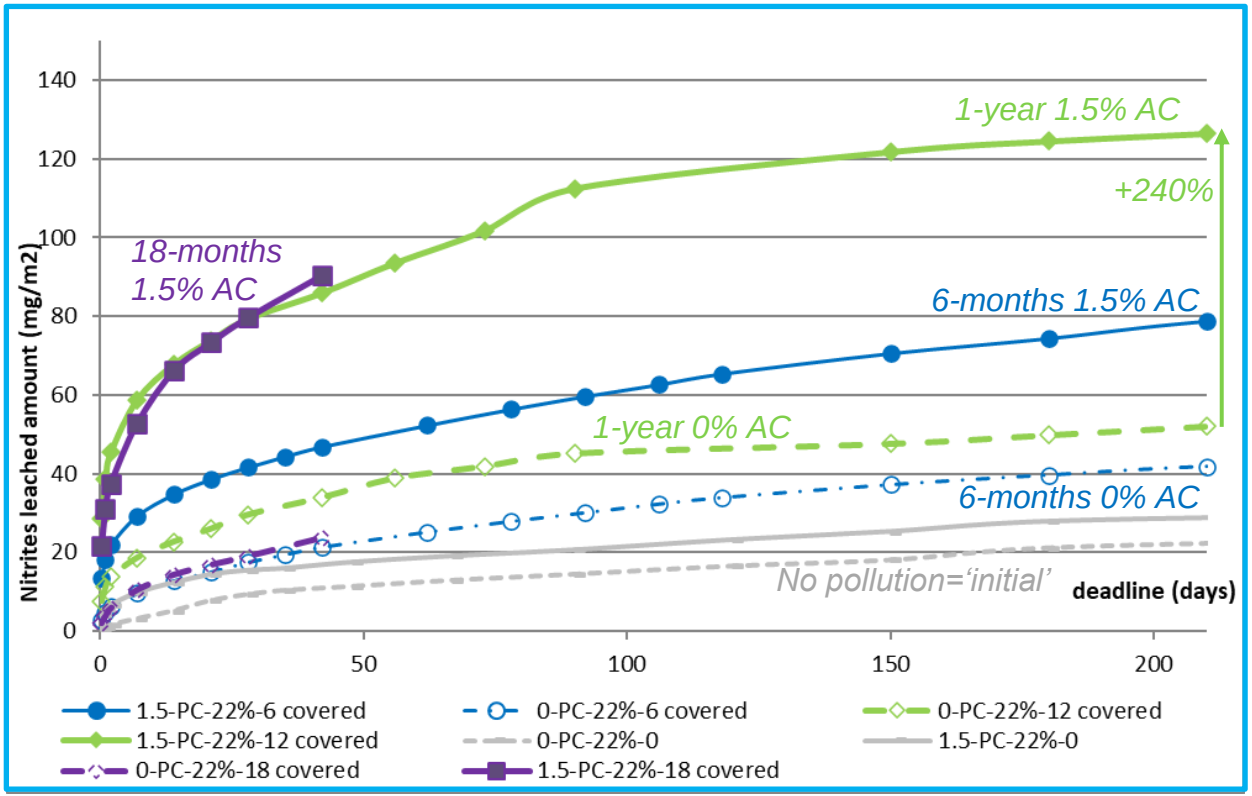
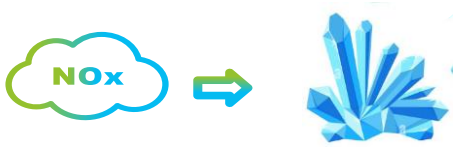
INDIRECT MEASUREMENT: LEACHING TEST
EVALUATION WITH GERMAN DEMONSTRATOR (3/6)



straight line 1.5% AC dotted line 0% AC



- **AC samples present enhanced nitrites release compared to no AC samples** (+240% for 1-year samples)
- **Nitrites release increases over months** (126mg/m2 for 1-year AC-samples versus 80mg/m2 for 6-months AC-samples)

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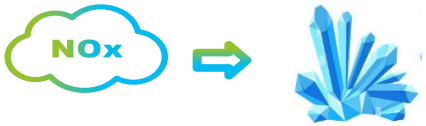
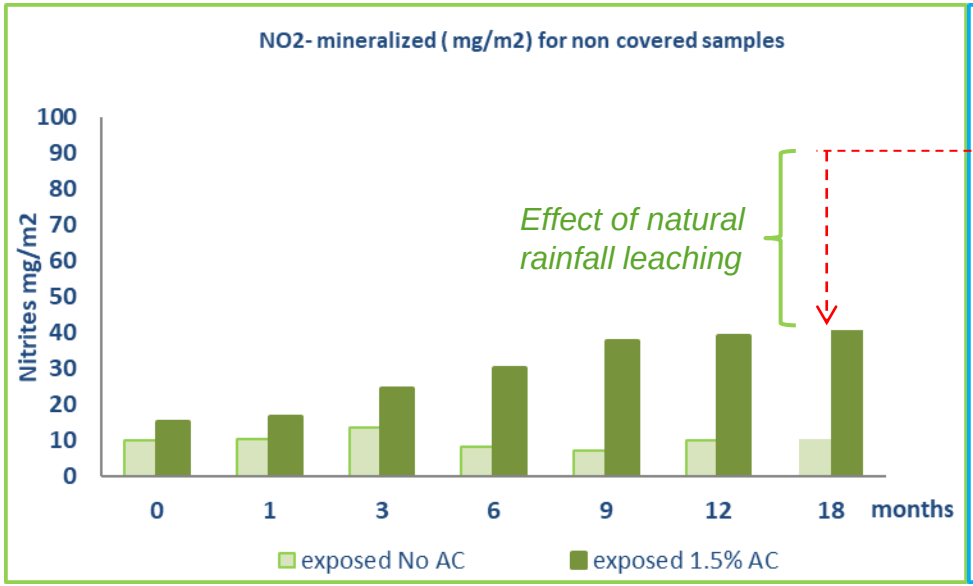
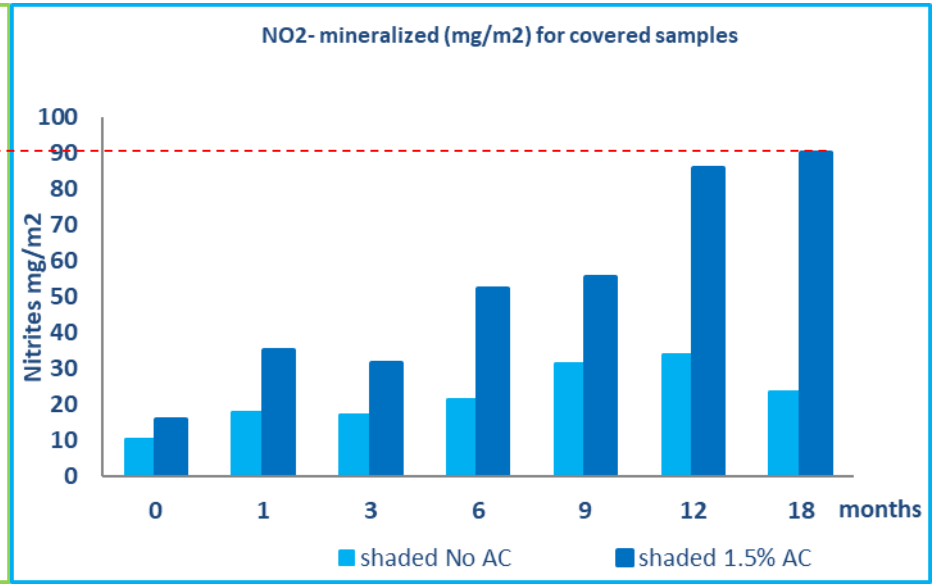
INDIRECT MEASUREMENT: LEACHING TEST
EVALUATION WITH GERMAN DEMONSTRATOR (4/6)







graphs plotted with values obtained at 42 days of leaching

Effect of natural rainfall leaching is evidenced:

- ✓ The rain allows nitrites to release for exposed samples compared to covered ones, this permits to liberate adsorption sites and acts as regeneration for adsorption
- ✓ Natural leaching is 40-50% efficient

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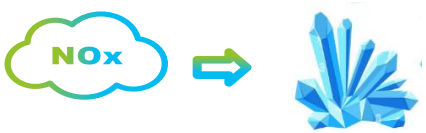
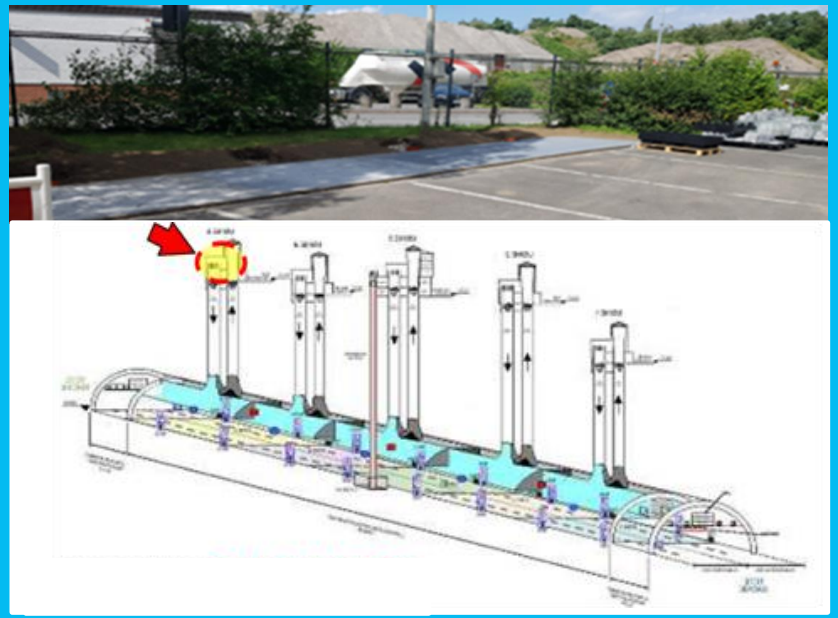
INDIRECT MEASUREMENT: LEACHING TEST
EVALUATION WITH GERMAN DEMONSTRATOR (6/6)



- Mineralization of pollutants is occurring over time and is enhanced with the presence of AC (+180% after 1 year, 200 days leaching) in low pollution conditions
- Rainfall allows natural leaching of nitrites: this regenerates adsorption capacity

COMPARISON TUNNEL/GERMAN DEMONSTRATORS



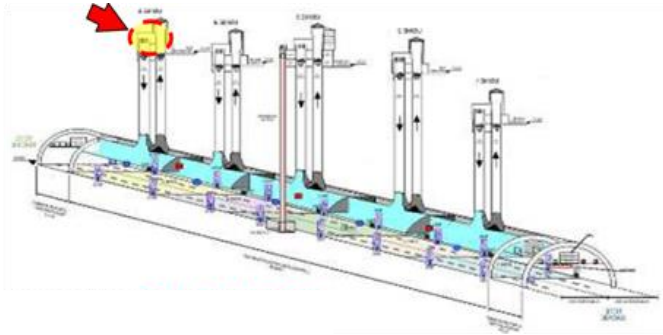
PERFORMANCE COMPARISON BETWEEN TUNNEL/GERMAN DEMONSTRATORS (1/2)

7-months exposure

NOx

confined space: very high pollution level 800µg/m³

0-PC-36%-7
3-PC-36%-7



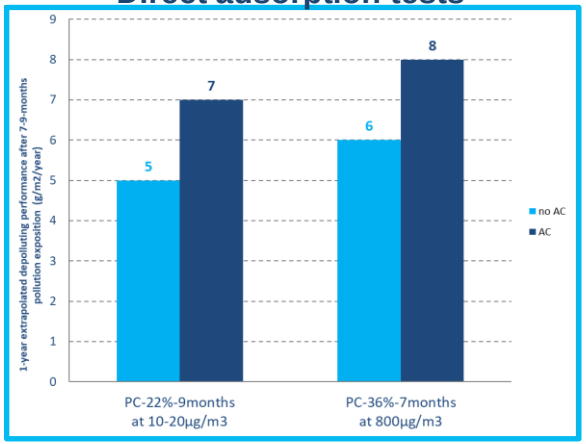
9-months exposure

0-PC-22%-9
1.5-PC-22%-9

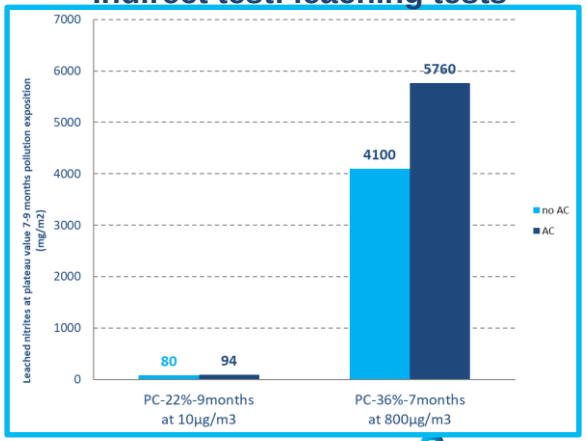
NOx

open air space: low pollution level 10-45µg/m³

Direct adsorption tests



Indirect test: leaching tests



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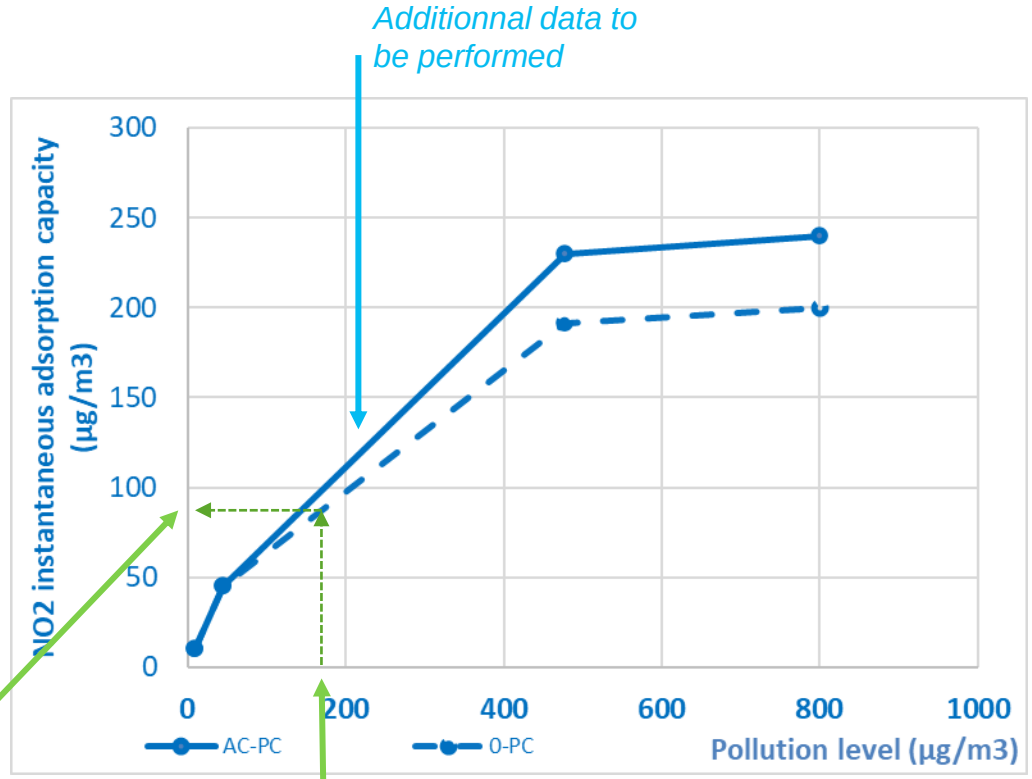
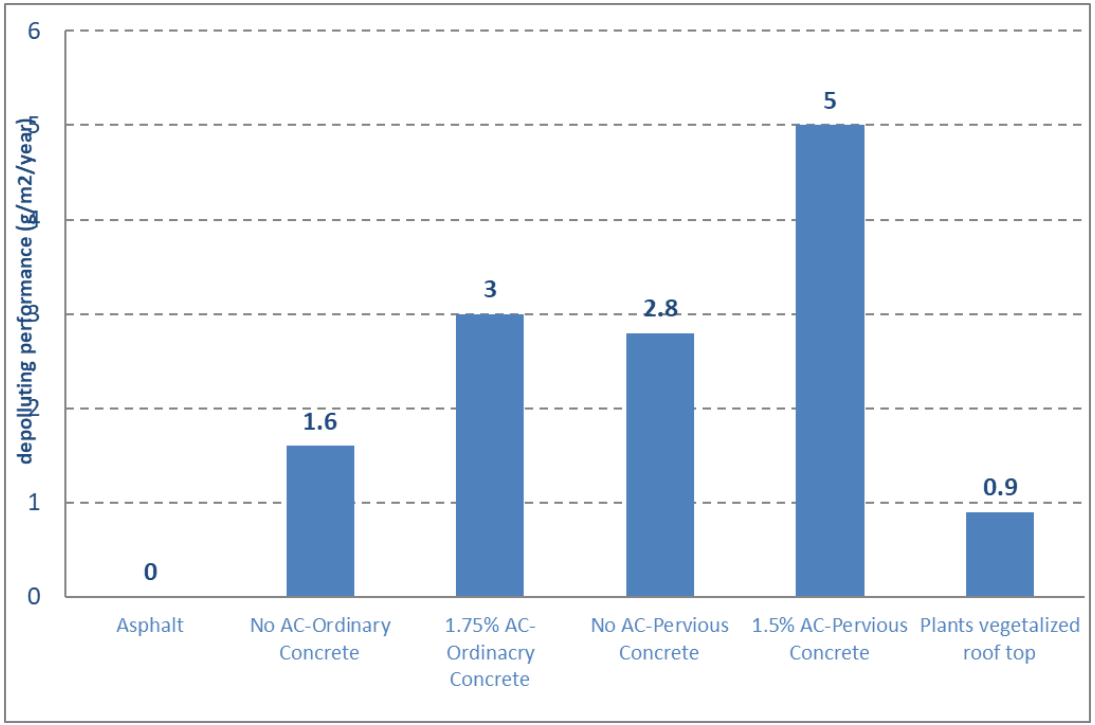
PREDICTION OF PERFFORMANCE (2/2)

- the lower the pollutant concentration, the greater the adsorption is sustained
- the higher the concentration, PC doped with AC still remain above the WHO guidelines for pollution peaks



COMPARISON WITH OTHERS SOLUTIONS:

APPLICATION: COMPARISON WITH ORDINARY CONCRETE AND VEGETALIZED ROOF-TOP



- Pervious Concrete > Ordinary Concrete >> Asphalt
- AC doped pervious concrete is more efficient than AC doped ordinary concrete
- AC pervious concrete is also more sustainable than vegetalized roof concrete (thyme, sedum)

Y. Arbid, C. Richard, M. Sleiman Towards an experimental approach for measuring the removal of urban air pollutants by green roofs Build. & Env. ***205*** *(2021) 108286.*

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CONCLUSION (1/3)

GERMAN DEMONSTRATOR

After 18-months low pollution exposure, NO2 gas adsorption performance is maintained for pervious concrete

Mineralization occurs over times

No saturation observed after 18 months by leaching measurements (efficiency maintained at 100% for 10-20µg/m3 pollution)

Rainfall allows natural leaching of nitrites and regenerates NO2 adsorbing capacity

ACTIVATED CARBON

AC boosts NO2 adsorbing capacity (up to 50% for *AC$^{1.5\%}$ doped samples versus 40% for No AC samples) and mineralization process (+180% after 1 year exposure)

AC 1.5% / cement is a good compromise

CONCLUSION (2/3)

WHO GUIDELINES

World Health Organization guidelines are observed

averaging time	2021 New Air Quality Recommendations NO_2 ($\mu g/m^3$)	
1-hour	200*	✓
24-hour	45**	✓
annual	10	✓

*should not be exceeded more than 18 times a year (18h / year)

**should not be exceeded 3-4 days year (72h - 96h / year)

NOx

⇨ pass for 4 times a year for 24h

⇨ efficiency=100%

⇨ efficiency=100%

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CONCLUSION (3/3)

OTHER BENEFITS

Water purification from heavy metals ions[1] total nitrogen & phosphorus from cattle manure [2, 3]

Particles Maters captation [4, 5] (PM 2.5, PM 10)

Adsorption/decontamination of oil coming from vehicles [6, 7, 8]

1) Xie *& al. Construction and Building Materials* ***285*** (2021) 122767
2) Luck *& al. Construction and Building Materials* ***200*** (2008) 401-408
3) Vasquez Riviera *& al. Construction and Building Materials* ***93*** (2015) 22-28
4) Zanoletti *& al. Sustainable Cities & Society* **53** (2020) 101961
5) Singh *& al.Construction and Building Materials* ***261*** (2020) 120491
6) Xie *& al.Journal of Cleaner Production* ***210*** (2019) 1605-1621
7) Dussassoy PhD *Thesis* (2021)
8) Exbrayat HIC *Intership* (2022)

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