Biofiltration of low levels of landfill gas: Human Health Risk Assessment of volatile and malodorous compounds emissions

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RE Mida

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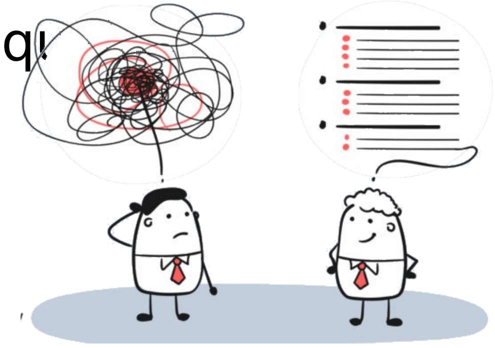
Waste Valorization Group (WVG)

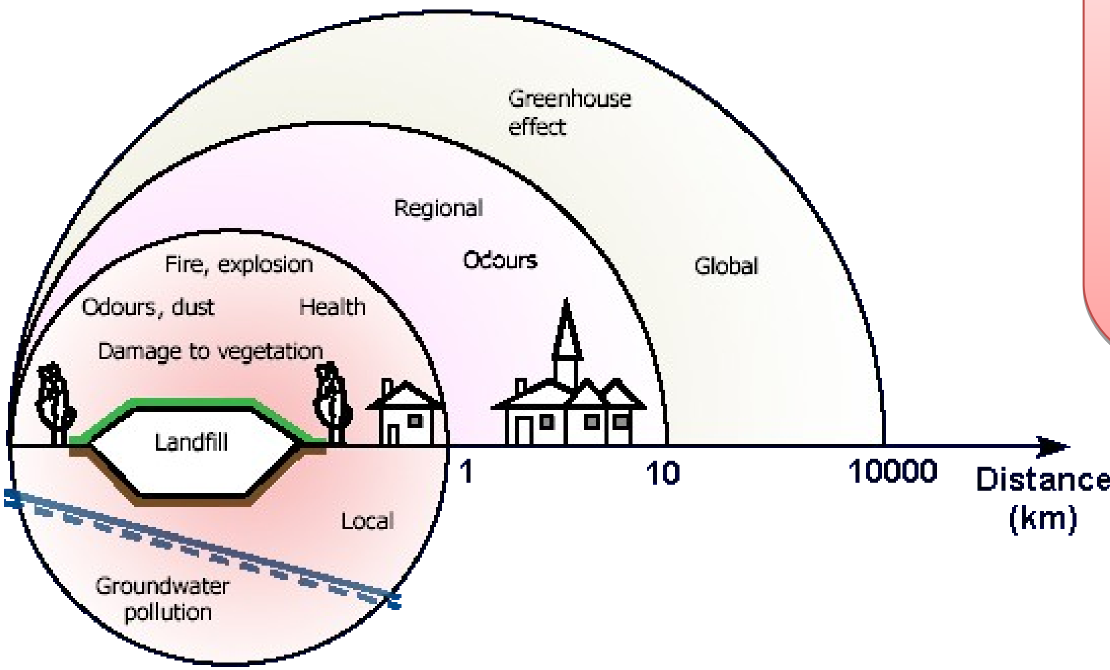
Outline

1. Introduction
   - Background and motivation
   - Management of low calorific value landfill gas (LFG)
   - Research question
2. Materials and methods
   - Site characterization
   - Investigated LFG management scenarios
   - Emissive sources
   - Dispersion modelling
   - Assessment of toxicological risk and air q
3. Results
4. Conclusion and future works



Introduction

Background and motivation



Impacts of landfill gas emissions (Kjeldsen, 1996)

Landfill gas emissions

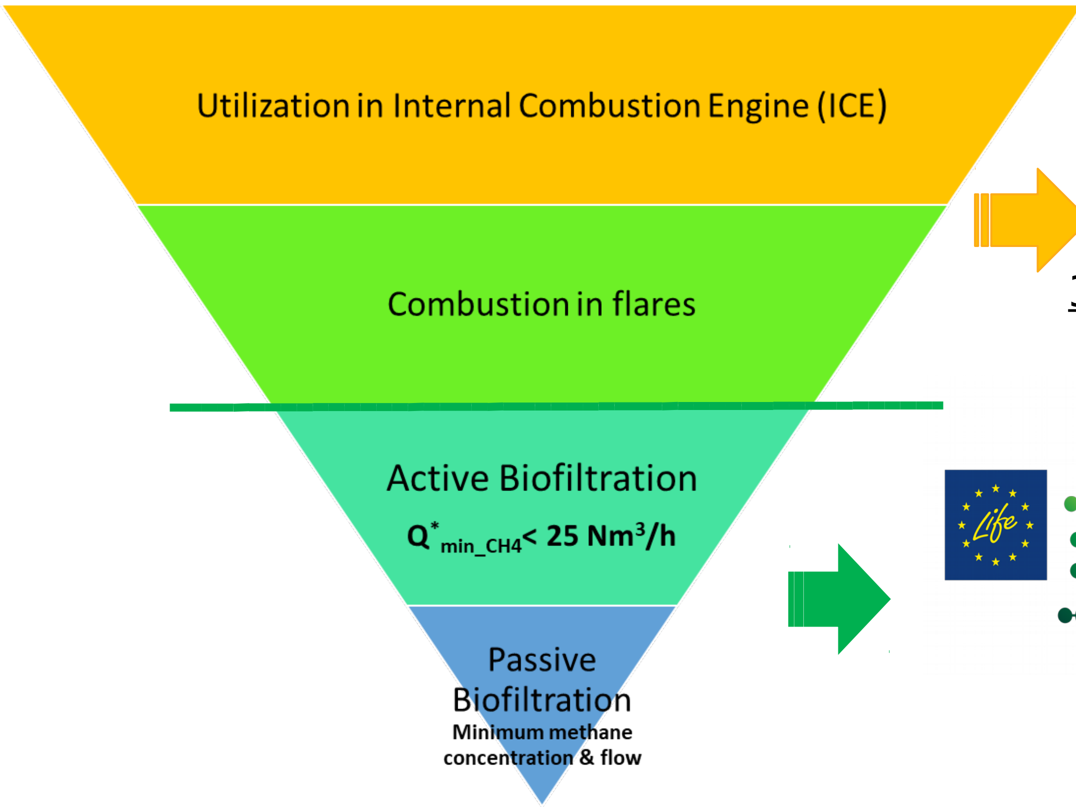
NMVOCs
Aliphatic, aromatic, organ-halogen, sulphur compounds
acknowledge toxicological, cancerogenic
m

Odour compounds
Nuisance effects complaints and concern of the

CH_4
GWP 28 times higher than CO_2

Introduction

Management of low calorific value landfill gas (LFG)



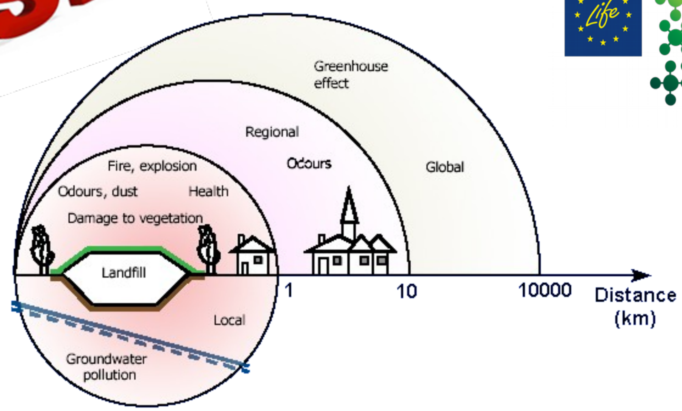
LFG management strategies (LIFE RE Mida, 2017)

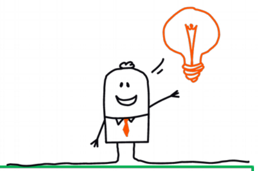
Landfill Directive 31/1999/CE

Introduction

Research question

"Can the application of an active biofilter mitigate the risk from exposure to NMVOCs and malodorous compounds emissions from old landfill sites?"





RE Mida **Active biofilter**

Material and methods

Site characterization

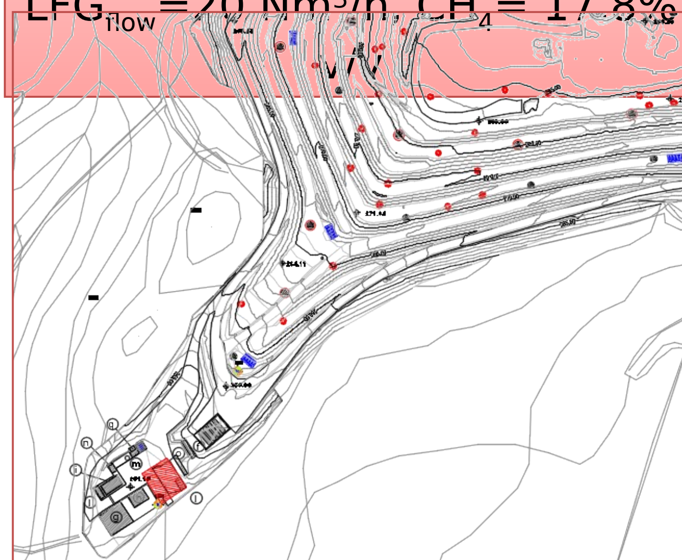
Podere il Pero Landfill (Tuscany – IT)
Post-closure stage (2015)
Non hazarodous waste disposal site
Active LFG extraction system
Average LFG_{prod}= 90 Nm^3/h, Average CH_4 =33.9% v/v

Material and methods

Site characterization

Podere il Pero Landfill
Post-closure stage (2015)
Non hazarodous waste disposal site
Active LFG extraction system
Average LFG_{prod}= 90 Nm^3/h, Average CH_4 =33.9% v/v

Active Biofilter
H: 1.5 m, B: 15 m, L:18 m
Filter media: compost and sand (5:1)
Irrigation system
LFG_{flow} =20 Nm^3/h, CH_4 = 17.8% v/v

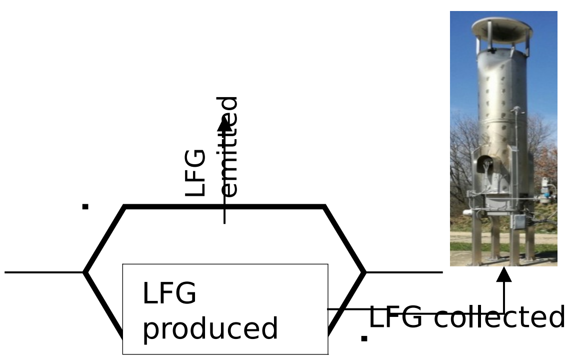


Material and methods

Investigated LFG management scenarios

Scenario 0 - *Reference Scenario*

LFG treatment
Flare
Assumptions
CH_4 oxidation process and NMVOCs abatement due to the final capping layer was not considered



Alternative Scenarios

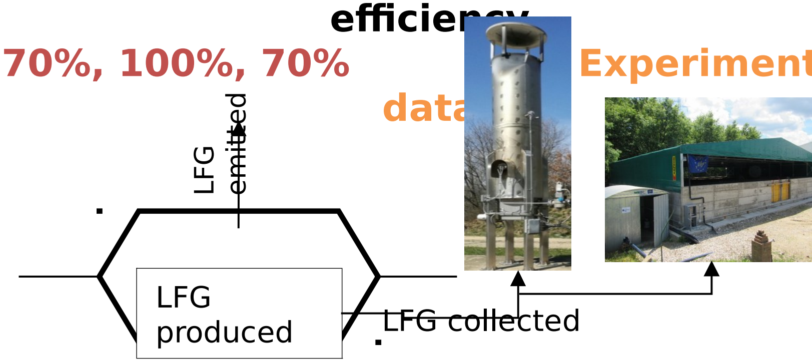
Scenario 1
IPPC
70%, 100%, 70%

Scenario 2
Experimental data

G treatmen
Flare and active biofilter
Assumptions
CH_4 oxidation process and NMVOCs abatement due to the final capping layer was not considered
NMVOCs, H_2S and odour reduction efficien

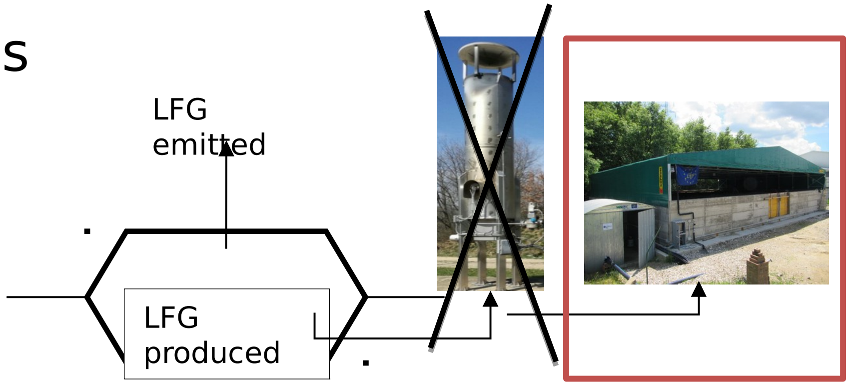
70%, 100%, 70%

Experimental data



Material and methods

Emissive Sources



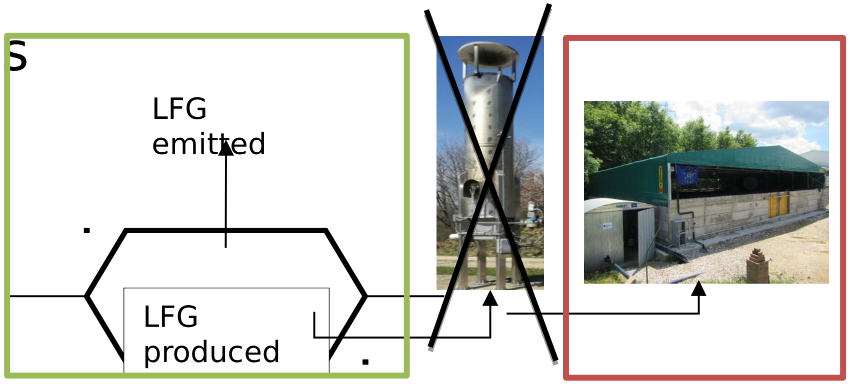
Diffusive emission Passive sources

Analyte	Method
NMVOCs	US EPA 1995, US EPA TO-15
Hydrigen Sylphide (H_2S)	NIOSH 6013:1994
Odour Compound	UNI EN 13725:2003

Emissive Rate	
NMVOCs	*Liu et al., 2015* $\frac{Q_{air}\cdot[NMVOCs]}{A_{chamber}}\ [g\cdot m^{-2}\cdot s^{-1}]$
Odour Compounds	*Lucernoni et al., 2017* $SOER = \frac{c_{od}\cdot Q_{air}}{A_{chamber}}\ [\frac{OU}{m^2/s}]$

Material and methods

Emissive Sources



Diffusive emission Passive sources

Analyte	Method
NMVOCs	Raw landfill gas US EPA TO-15
Hydrigen Sylphide (H_2S)	NIOSH 6013:1994
Odour Compounds (ethlymercaptan, dimethyl sulphur, ethanol, limonene and H_2S)	*Capelli et al., 2013*
Emissive Rate	
NMVOCs	Q_{LFG} [m^3/h] Static accumulation chamber, *Pecorini 2010* $NMVOCs\ [\mu g/m^3]$
Odour Compounds	$SOER = \frac{\mathrm{SOAV} \cdot Q_{\mathrm{LFG}}}{A_{\mathrm{landfill}}} [\frac{OU_E}{m^2/s}]$

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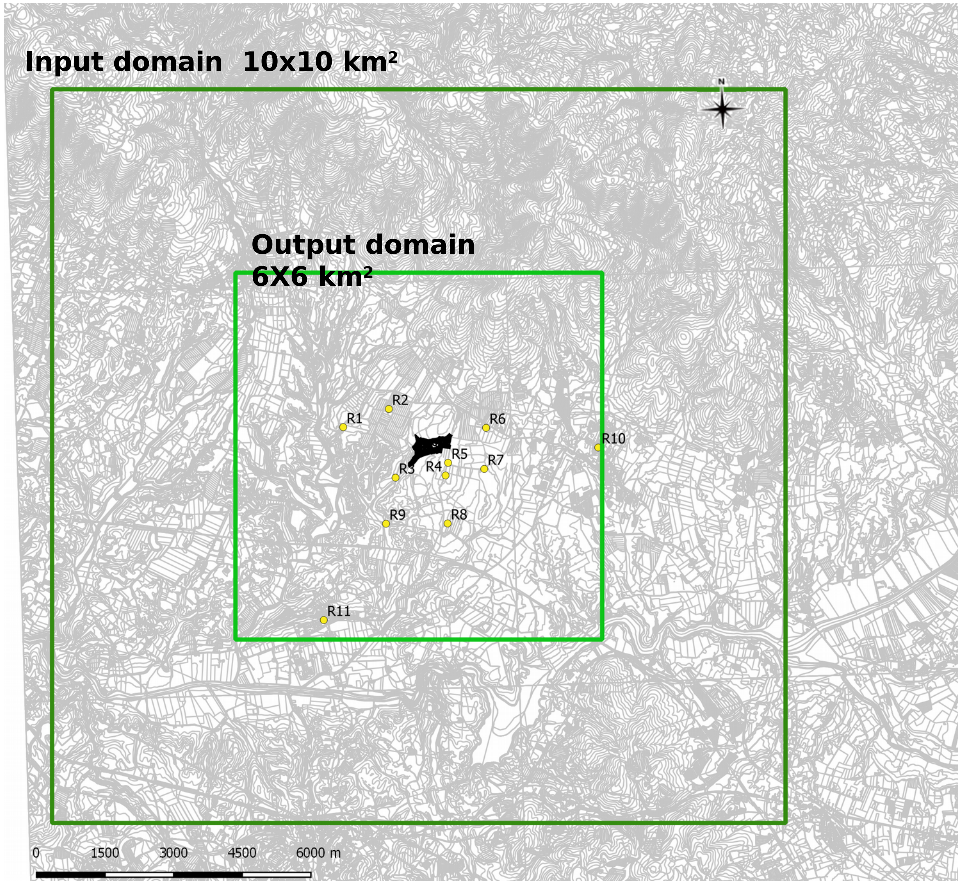
Material and methods

Dispersion modelling



CALPUFF model

Horizontal input resolution of 200 m

Output resolution 100 m

Vertical resolution of 8 layers (0-20-50-100-200-500-1000-2000-4000 m)

Meteorological data

Meteorological station located at the plant

Emission data

9 NMVOCs

cyclohexane, n-hexane, 2-methylpentane, 3-methylpentanE, benzene, xylenes, toluene, dichlorodifluoromethane, vinyl chloride

H_2S

CH_4

Odour compounds

Material and methods

Assessment of the toxicological risk and air quality – APAT, 2005 - D.G.R. 15 febbraio 2012 & n. IX/3018

Risk = Hazard x Exposure

Pollutant Source

Emissions of LFG

Exposure Pathway

Inhalation

Receptors

Children breathing outdoor

11 Sensitive Receptors (9 single-detached houses 2 small city centres)

Non-cancerogenic compounds

Hazard Index (HI) $= EE/RfC$

$$EE = \frac{CR \cdot EF \cdot ED}{BW \cdot AT}$$

$HQ_T < 1$

Cancerogenic compounds (benzene)

$$R = EE_{adj} \cdot SF$$

$$EE_{adj} = EE_{ch} + EE_{adj}$$

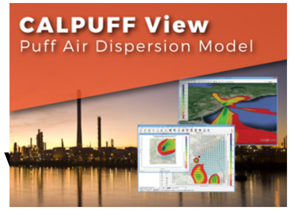
$$= \frac{B_{OBch} \cdot EF_{go} \cdot ED_{ch} \cdot \mathrm{EF}}{BW_{ch} \cdot AT_C} + \frac{B_{OAd} \cdot EF_{go} \cdot ED_{ad} \cdot \mathrm{EF}}{BW_{ad} \cdot AT_C}$$

$R<10^{-6}$

Odour compounds

Three odour threshold: **1, 3 e 5 OU_E/m^3** accounting for the **50%, 85%** and **90-95%** of the population that detects the odour

Results



Dispersion modelling – Annual average concentration of the NM modelled

	Scenario 0		Scenario 1		Scenario 2	
C_{air} [mg/m³]	Max	Average	Max	Average	Max	Average
Cyclohexane	3.18E-06	9.39E-07	9.43E-07	2.96E-07	1.16E-06	4.32E-07
n-hexane	4.13E-07	1.22E-07	1.22E-07	3.84E-08	1.16E-07	3.42E-08
2-metylpentane	9.02E-07	2.67E-07	2.68E-07	8.40E-08	2.88E-07	9.67E-08
3-metylpentane	8.13E-07	2.40E-07	2.42E-07	7.58E-08	2.61E-07	8.78E-08
Benzene	7.96E-09	2.97E-09	2.53E-09	1.00E-09	2.24E-09	8.35E-10
Xylenes*	4.41E-06	1.30E-06	1.31E-06	4.12E-07	1.33E-06	4.25E-07
Toluene	2.76E-06	8.17E-07	8.21E-07	2.58E-07	7.75E-07	2.29E-07
Dichlorodifluoromethane	3.88E-06	1.15E-06	1.15E-06	3.61E-07	1.09E-06	3.21E-07
Vinyl chloride	5.09E-06	1.50E-06	1.17E-06	3.74E-07	1.09E-06	3.21E-07
H_2S	2.08E-05	6.16E-06	1.43E-06	4.23E-07	1.43E-06	4.23E-07

- Scenario 0 shows the highest value of C_{air}, Scenario 1 and 2 showed similar concentration values, H_2S resulted the compound with the maximum value of C_{air}
- Benzene is ten times less than the limit value (5µg/m³)
- R5 resulted the receptor at which were estimated the highest C_{air}

Results

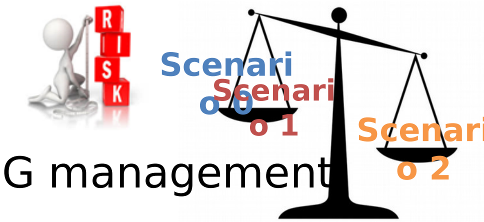
Human Health Risk Assessment – Cumulative risk at each rece

	Scenario 0		Scenario 1		Scenario 2	
Receptor	**HQ_T [-]**	**R benzene [-]**	**HQ_T [-]**	**R benzene [-]**	**HQ_T [-]**	**R benzene [-]**
R1	2.33E-03	1.75E-11	2.23E-04	5.73E-12	2.15E-04	4.91E-12
R2	3.20E-03	1.57E-11	3.09E-04	4.90E-12	2.95E-04	4.42E-12
R3	5.57E-03	2.43E-11	6.10E-04	9.84E-12	5.22E-04	6.82E-12
R4	8.33E-03	2.21E-11	7.93E-04	7.70E-12	7.68E-04	6.23E-12
R5	1.32E-02	4.21E-11	1.25E-03	[illegible]	[illegible]	1.18E-11
R6	2.16E-03	1.59E-11	2.03E-04	[illegible]	[illegible]	4.48E-12
R7	3.26E-03	1.65E-11	3.08E-04	[illegible]	[illegible]	4.64E-12
R8	1.89E-03	5.09E-12	1.85E-04	[illegible]	[illegible]	1.43E-12
R9	1.57E-03	5.91E-12	1.56E-04	[illegible]	[illegible]	1.66E-12
R10	9.27E-04	5.07E-12	8.81E-05	1.65E-12	8.54E-05	1.42E-12
R11	5.06E-04	2.44E-12	5.13E-05	8.59E-13	4.69E-05	6.87E-13

Acceptable Levels of Cumulative Risk!
$HQ_T \leq 5\ 10^{-5}$
$R < 7\ 10^{-13}$

- HQ_T and R are always many orders of magnitude lower than the maximum acceptable value ($HQ_T \leq 1$ e $R<10^{-6}$)
- Scenario 0 is the worst-case scenario (1.32E-02 for HQ_T and 4.21E-11 for R)
- HQ_T and R are one order of magnitude lower for Scenario 1 and 2 than Scenario 0
- Scenario 2 is the best-case scenario

Results



Human Health Risk Assessment – Comparison of LFG management strategies

	Scenario 1vs 0		Scenario 2 vs 0		Scenario 2 vs 1	
Receptor	NC	C	NC	C	NC	C
R1	-90.4%	-67.2%	-90.8%	-71.9%	-3.8%	-14.4%
R2	-90.3%	-68.8%	-90.8%	-71.9%	-4.4%	-9.8%
R3	-89.1%	-59.5%	-90.6%	-71.9%	-14.4%	-30.7%
R4	-90.5%	-65.2%	[illegible]	[illegible]	-3.1%	-19.1%
R5	-90.6%	-68.2%	[illegible]	[illegible]	-2.4%	-11.6%
R6	-90.6%	-69.1%	[illegible]	[illegible]	-2.3%	-9.1%
R7	-90.6%	-67.5%	-90.8%	-71.9%	-2.5%	-13.4%
R8	-90.2%	-64.2%	-90.8%	-71.9%	-5.8%	-21.6%
R9	-90.0%	-64.2%	-90.7%	[illegible]	[illegible]	[illegible]
R10	-90.5%	-67.5%	-90.8%	[illegible]	[illegible]	[illegible]
R11	-89.8%	-64.8%	-90.7%	[illegible]	[illegible]	[illegible]

NC
-91%

C
-72%

Field data give higher reduction efficiency than those indicated by IPPC Directive!!

- Scenario 1 and Scenario 2 show the maximum reduction of the cumulative and cancer risk
- Scenario 2 is better than Scenario 1:
  - The maximum **percentage decrease for Non-Cancerogenic compounds (NC) is 90.8% in Scenario 2 vs 0**
  - The **maximum percentage decrease for benzene is 71.9% in Scenario 2 vs 0**
- R3 show the highest percentage decrease for NC and benzene (14.4% and 30.7%)

Results

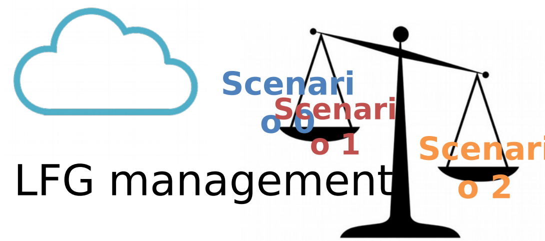
Assessment of the air quality - Peak hourly odour c

Odour concentration ≤ 1 OU_E/m^3

	Odour concentration [OU_E/m^3]		
Receptor	**Scenario 0**	**Scenario 1**	**Scenario 2**
R1	1.02E-02	2.84E-03	3.28E-03
R2	1.49E-02	4.28E-03	4.92E-03
R3	2.56E-02	7.43E-03	1.10E-02
R4	3.76E-02	1.05E-02	1.19E-02
R5	5.62E-02	1.57E-02	1.69E-02
R6	9.88E-03	2.76E-03	3.04E-03
R7	1.35E-02	3.99E-03	4.42E-03
R8	7.33E-03	2.13E-03	2.63E-03
R9	6.50E-03	1.94E-03	2.42E-03
R10	3.19E-03	9.47E-04	1.13E-03
R11	2.17E-03	6.32E-04	8.20E-04

- The odour concentration levels are up to three orders lower than the limit value of 1 OU_E/m^3
- Scenario 0 shows the highest peak hourly odour concentration
- Scenario 1 and Scenario 2 show that the peak hourly odour concentration are one order of magnitude less than Scenario 0
- R5 shows the highest value of odour concentration (1.57E-02 and 1.69E-02)
- Scenario 1 is the best case scenario

Results



Assessment of the air quality - Comparison of the LFG management strategies

Receptors	Scenario 1 vs 0	Scenario 2 vs 0	Scenario 2 vs 1
R1	-72.05%	-67.71%	15.51%
R2	-71.22%	-66.94%	14.86%
R3	-71.01%	-57.10%	47.99%
R4	-72.05%	-68.46%	12.86%
R5	-72.06%	-70.00%	7.38%
R6	-72.05%	-69.25%	10.03%
R7	-70.49%	-67.33%	10.71%
R8	-70.99%	-64.04%	23.96%
R9	-70.15%	-62.76%	24.77%
R10	-70.33%	-64.71%	18.94%
R11	-70.82%	-62.17%	29.64%

Odour Reduction **72%**

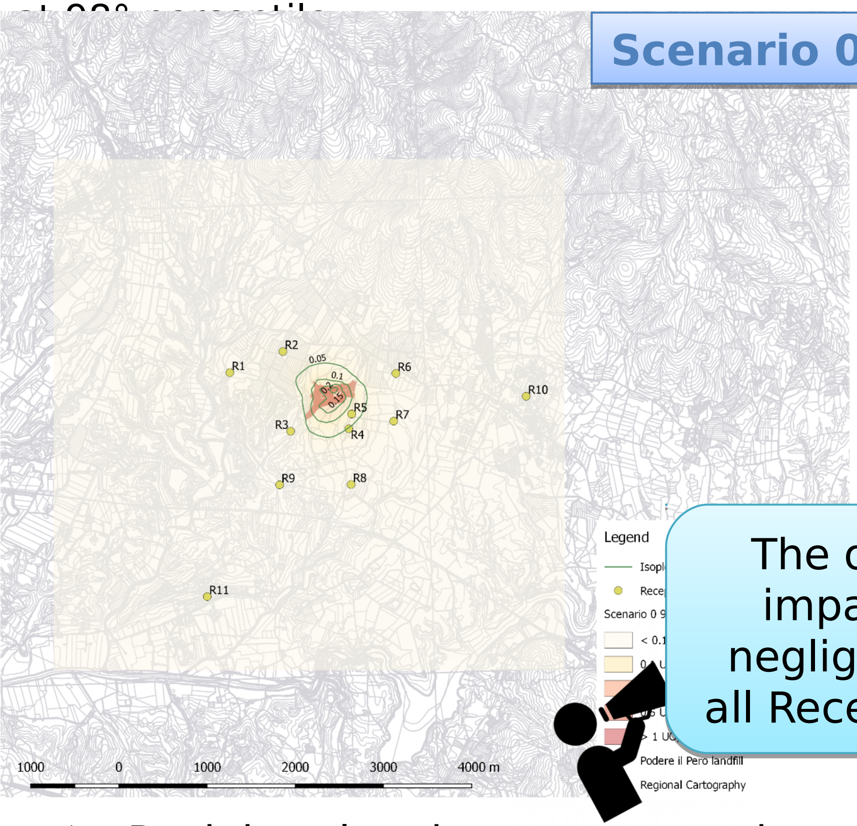
Odour Reduction Efficiency **< 70%**

- Scenario 1 reduce odour impact on average by 72% than Scenario 0
- Scenario 2 reduce odour impact on average by 65.5% than Scenario 0
- The odour impact for Scenario 2 (Reduction efficiency is evaluated using experimental data) is higher than Scenario 1 (Reduction efficiency is assumed to be 70%)
- The assumption of a odour reduction efficiency of 70% should be revised in light of the results obtained

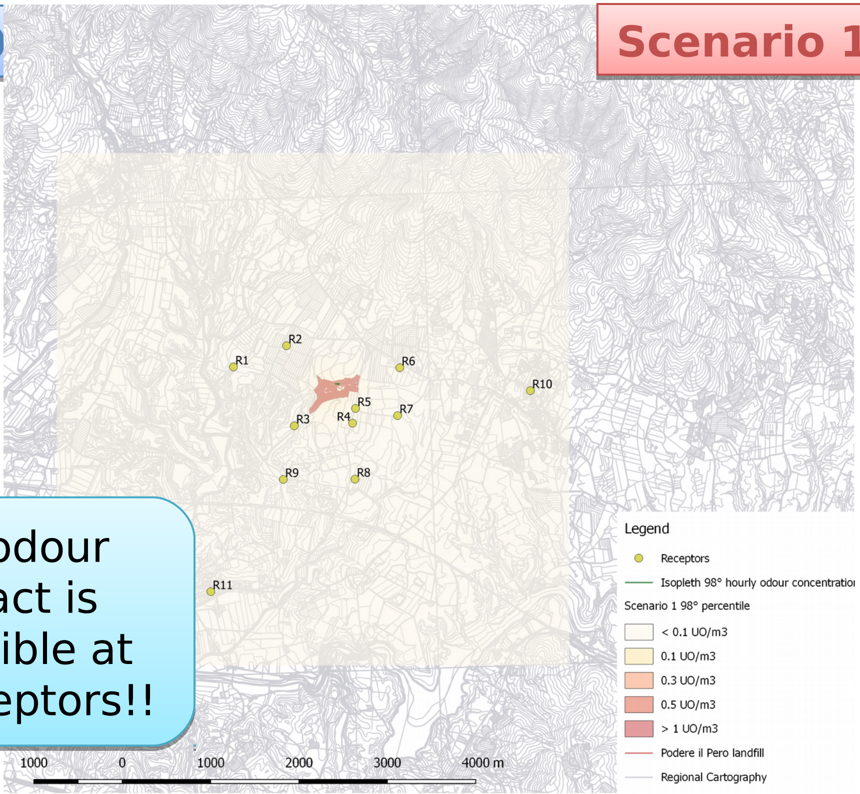
Results

Assessment of the air quality - Isopleth of peak hourly odour concentration at 98° percentile

Scenario 0



Scenario 1



The odour impact is negligible at all Receptors!!

- Peak hourly odour concentration < 1 OU_E/m^3 at any receptors
- R4 and R5 show the maximum peak hourly concentration between 0.05 and 0.1 OU_E/m^3

Conclusion and future works

Research question

"Can the application of an active biofilter mitigate the risk from exposure to NMVOCs and malodorous compounds emissions from old landfill sites?"

Human health risk assessment

- In **Scenario 2** the active **biofilter reduce** the risk on average **by 91% for non-cancerogenic** compounds and **72% for cancerogenic** compounds

Air quality assessment

- In **Scenario 1** the active biofilter **reduce** the **odour impact** on average by **72%**
- The assumption of an odour abatement of **70%** due to the biofilter is higher than the real reduction efficiency

Future Works

- Revision of the preliminary assumptions on:
  - the abatement of NMVOCs and odour compounds due to the final landfill capping layer
- To perform sampling campaigns on the landfill surface to directly assess odour concentration
- Dispersion modelling considering the roof of the active biofilter

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Thanks for the Attention!

Any questions?

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