Annex 1: Economic and environmental benefits of the phase-out of oil heating in Valle d'Aosta

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This annex describes the results of a study conducted by ARPA Valle d'Aosta and Politecnico di Torino on the environmental impacts of oil heating in Valle d'Aosta, identifying possible technical alternatives for the phase out of this old and polluting heating technique.

The work was presented at the conference organized by ARPA in Aosta on November 21st, 2018 and is composed of the following parts:

- Literature review on the issue of leaking Underground Storage Tanks (USTs);
- Assessment of leaking episodes in Valle d'Aosta between 1999 and 2018, based on the review of administrative procedures for contaminated sites;
- Identification of technical alternatives to phase out oil heating, identifying pros and cons from the technical, economic and environmental points of view;
- Demonstration in two benchmark case studies of the techno-economic feasibility of replacing oil heating with different heating techniques, among which geothermal heat pumps turn out to provide the highest overall benefits, i.e. reduction of greenhouse gases, absence of pollutant emissions on site, reduction of global pollutant emissions, possibility to exploit photovoltaic energy, low noise and high efficiency independent of the outdoor air temperature.

No.	Partner	Contact	E-mail
2	ARPA VdA	Pietro Capodaglio Fulvio Simonetto	P.Capodaglio@arpa.vda.it F.Simonetto@arpa.vda.it
6	POLITO	Alessandro Casasso Rajandrea Sethi	alessandro.casasso@polito.it rajandrea.sethi@polito.it

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Economic and environmental benefits of the phase-out of oil heating in Valle d'Aosta

Alessandro Casasso[1], Pietro Capodaglio[2], Fulvio Simonetto[2], Rajandrea Sethi[1]

Politecnico di Torino – DIATI

ARPA Valle d'Aosta

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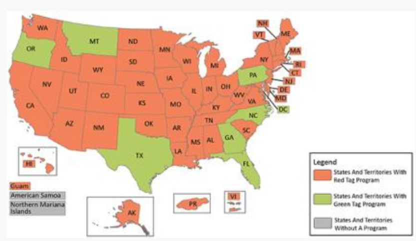
Oil tanks: use and related issues

- Oil heating was massively introduced in Italy since the 60's, replacing coal and wood
- USA pioneer in tackling Underground Storage Tanks (USTs):
  - End of 70's: awareness of the issue
  - 1984: first UST census
  - 1988: first guidelines by the Environmental Protection Agency (EPA)
  - Since 1984: 540000 leakage detected, of which 473000 remediated

1984: an article by the EPA on Environmental Science and Technology https://pubs.acs.org/doi/abs/10.1021/es00128a714



Depending on the state, a sign is required which provides information on whether the tank is unsuitable (red) or suitable (green). Source: EPA, 2018

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Regulation on USTs in Italy

- In Italy, a compulsory registration and monitoring system for all USTs is still missing
- In 1999, the DM 246/99 introduced it, but it was cancelled by the Constitutional Court due to conflict of legislation competence
- Only gasoline stations are regulated and constantly monitored


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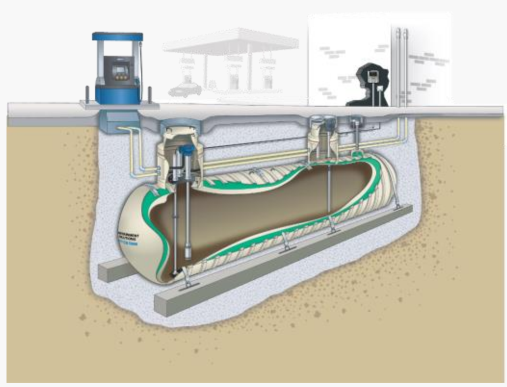
USTs and leakages

- Leakages from USTs mostly depend on the tank type:
  - Steel or other materials?
  - With or without anti-corrosion internal coating?
  - Single or double wall?
  - With or without leakage detection systems?
- Safety measures (double wall etc.) have been introduced recently, so most of USTs are single-wall with reduced opportunities for refurbishment
- Oil release causes:
  - 26% errors in filling operation
  - 74% in the tank and/or the pipes, of which:
    - 46% structural failure
    - 27% corrosion
    - 12% loose fittings



Double-wall UST (source: http://containmentsolutions.com/double-wall-tanks.html**)**

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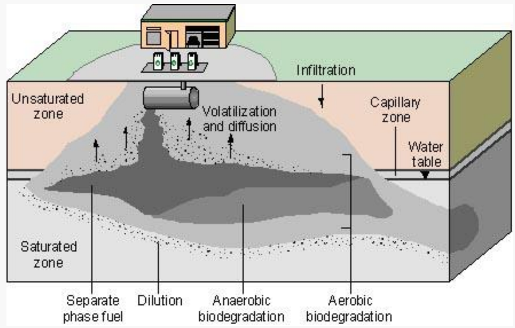
Propagation of hydrocarbons (HCs) from USTs

- USTs are installed in the unsaturated (vadose) zone above the aquifer
- Paths of released HCs:
  - Volatilization: risk of vapor inhalation for people above ground surface
  - Infiltration towards the saturated zone
  - Degradation depending on oxygen and on the HC type
- HC in the saturated zone:
  - Separate phase i.e. Light Non-Aqueous Phase Liquid (LNAPL)
  - Partly dissolved and migrating downstream
- Most dangerous substances:
  - Benzene, Ethylbenzene, Toluene, Xilene (BTEX)
  - Methyl-Ter-Buthyl-Ether (MTBE)
  - Heating oil: molecules with more than 12 atoms of carbon (C>12)



Source: California Environmental Protection Agency

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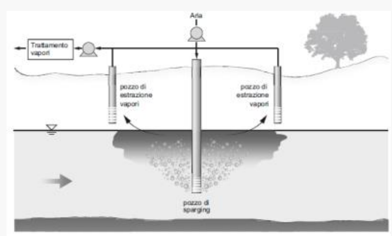
Remediation of contaminated soil and aquifer

- **Tank removal** is always performed when possible
- **Biopiles**: removal of soil around the tank, with aeration to promote aerobic degradation of fuel
- **Bioventing/Air sparging + Soil Vapour Extraction**: injecting air to promote aerobic degradation + recovery and treatment of vapors
- **Bioremediation**: Injection of Oxygen Release Compound (ORC), also with inoculi of bacteria
- **Pump and Treat**: water pumped and treated before reinjection. Not very effective with fuels, which have low water solubility
- **Monitored Natural Attenuation**: aerobic degradation of fuels occurs in the subsurface, yet monitoring should be performed to assess whether it is a degradation or just a dilution

Tank removal

Biopile (source: https://goo.gl/Rqzg2z)



Air sparging + SVE (Source: Di Molfetta and Sethi, 2012)

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Administrative procedure for remediation in Italy

- The owner/responsible of the UST must contact competent authorities
- Emergency measures: removal of tank and surrounding ground, if possible
- Soil sampling and analyses:
  - Different concentration limits of light (C<12) and heavy (C>12) hydrocarbons
  - If soil phase concentration limits are respected, the procedure is closed, otherwise…
- (Plan of) site characterization: site (hydro)geology and stratigraphy, spatial distribution of contamination
- Sanitary risk analysis on different contamination paths:
  - Soil:
    - Contaminant release to groundwater → risk on drinking groundwater abstracted from the site border
    - Vapor inhalation on site → risk analysis or soil gas sampling
  - Groundwater: water phase concentration limits should be respected on the site border, so that no groundwater use is limited or prevented to well owners around or downstream the site
- Depending on the outcome of the risk analysis, an active remediation could be requested or not by the public authorities
- In the case an active remediation is implemented, the environmental protection agency assists the public administrations to monitor its results and, finally, declare the site as remediated.

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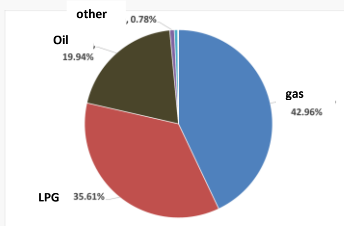
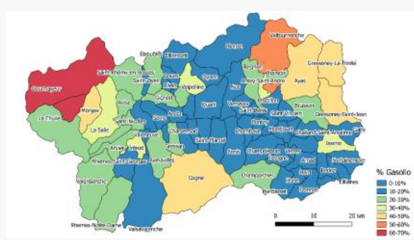
USTs in Valle d'Aosta (VdA)

- Known and monitored USTs are only a minor part of the total:
  - 102 gasoline stations
  - 50 deposits
- Heating oil USTs are not monitored
- Estimate of oil boilers:
  - 4930 based on the heating plant cadastre (~40% coverage)
  - Large diffusion of oil heating due to large areas not covered by methane grid. For the same reason, also LPG is very diffused



Heating plant cadaster of VdA as of 30/06/2018 (N=24723). Wood biomass systems are missing



Oil heating diffusion in the municipalities of VdA (based on the cadastre; wood heating systems are not counted)

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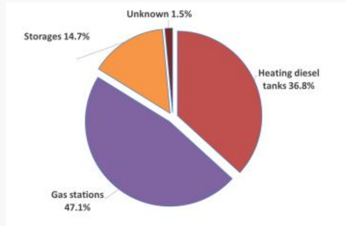
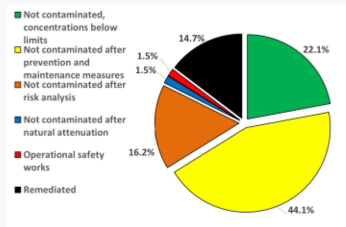
Remediation of leaking USTs in VdA: facts and figures

- Administrative procedures on leaking USTs in Valle d'Aosta (VdA) between 1999 and 2019 were studied by ARPA VdA and POLITO
- Figures:
  - 68 procedures completed
  - Highest occurrence in gasoline stations
  - Duration of the procedure from 1 to 201 months (median: 13 months)
  - 10 active remediation actions implemented, with costs from 50k€ to 200k€ per site



Contexts of administrative procedures on contaminated sites in VdA



Outcome of the the remediation procedures

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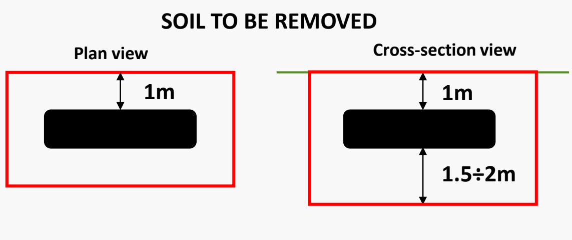
Removal and disposal of ground from USTs

- Leaking USTs were almost always removed from the ground and, in case, replaced
- No official figures are available on them
- Typical cost: 400 – 500 €/m^3
- A "buffer" of soil around the tank is generally removed as shown in figure



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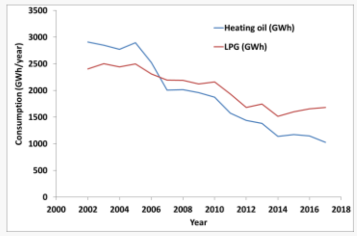
Technical alternatives for the phase-out of oil heating

+ The figures presented highlight the need to phase out oil heating to:
  + Remove a diffused environmental threat
  + Reduce greenhouse and air pollutant emissions
  + Reduce the costs for heating
+ The use of oil and LPG has declined due to:
  + Diffusion of gas grid in VdA
  + Diffusion of wood heating
+ Main technical alternatives:
  + LPG boiler
  + Wood and derivates
  + Heat pumps:
    + Air-source
    + Geothermal



From 2002 to 2017 the use of oil and LPG for heating in VdA has declined, respectively, of 65% and 30%

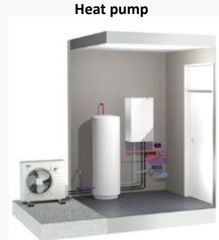
LPG

Wood logs

Wood chips

Wood pellet

Heat pump



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Analysis of pros and cons of heating technologies

Technology	Pros	Cons
LPG	- Low installation costs - A few modifications required	- Still UST needed (but no contamination) - Bounded to the LPG dealer
Wood logs	- Possibility of fuel self-production	- Large storage space required - Manual plant management
Wood chips	- Possibility of fuel self-production	- Huge storage space required
Wood pellet	- Relatively simple fuel storage	
Air-source heat pump	- Ease of installation	- Requires low-temperature terminals - Less efficient in cold climates
Geothermal closed-loop	- Efficient also in cold climate	- Requires low-temperature terminals - Requires space for BHEs
Geothermal open-loop	- Very efficient, also in cold climates - Possibility of free cooling	- Requires low-temperature terminals - Long authorisation procedure

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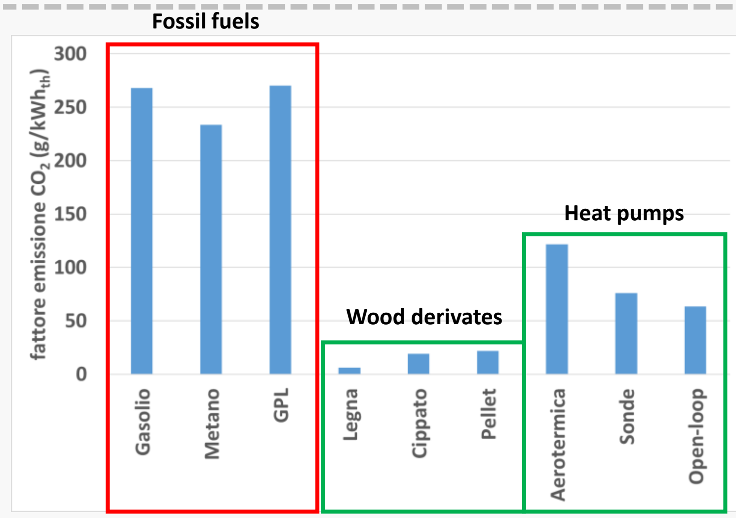
Environmental impact of heating boilers

- Space heating with boilers results in two main categories of emissions:
  - Greenhouse gases (GHG): CO_2, CH_4, N_2O
  - Pollutants: PM, NOx, NMVOC, SOx
- The environmental impacts is assess through emission factors, i.e. the quantity of GHG or pollutant emitted per unit energy produced (e.g. gCO_2/kWh)
- The mission factors of boilers depends on:
  - Fuel type (LPG, wood logs etc.)
  - Fuel quality (e.g. pellet is classified into different categories)
  - Boiler quality (combustion has improved with technological evolution, thus reducing the emission factors of pollutants)
- The emission factors of heat pumps depends on:
  - Energy mix adopted for the electricity production: national grid or self-produced (e.g., photovoltaic)?
  - COP of the heat pump: the emission factor of a heat pump is the ratio between the one of the electrical grid and the COP, hence, the higher the COP the lower the emission factor of the heat pump

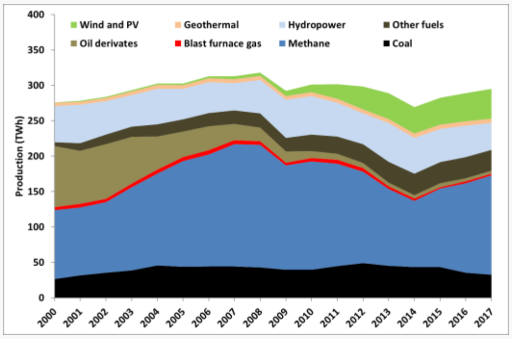
CO_2 emission factors for heating



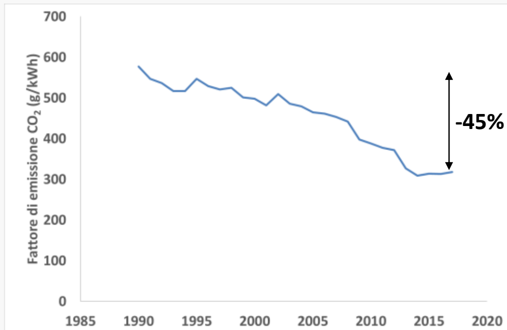
Wood derivates are still the least carbon-intensive heating technique but…

CO_2 emissions of the Italian electrical grid and its time evolution

… but 1) the Italian energy mix for electricity production is becoming greener and greener, and the CO2 emissions almost halved in last 30 years



Evolution of the energy mix for electricity production from 2000 to 2017 (source: TERNA)



Evolution of the CO_2 emission factor from 1990 to 2017 (source: TERNA)

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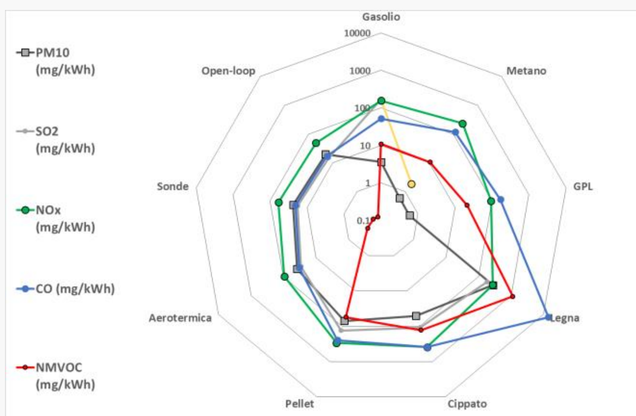
Analysis of pollutant emission factors

…and 2) wood burning is a strong air pollutant!

+ Which fuel pollutes:
  + Wood:
    + logs>chips>pellet
    + PM10 for wood and oil
    + SOx for oil
    + CO for wood logs
+ Effects:
  + Respiratory diseases (PM10, SOx)
  + Photocatalytic smog or tropospheric ozone (NOx, NMVOC)
  + Acute intoxications (CO)



Source: database GEMIS http://iinas.org/gemis.html

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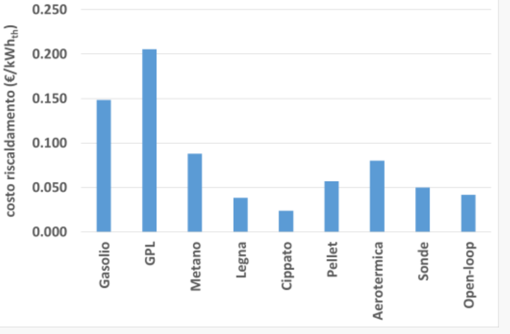
Unit costs for heating in Italy

- Unit prices
  - Oil: 1.28 €/l including the tax reduction (~0.12 €/l) for non-methanised areas
  - LPG: 1.35 €/l with tanks lent by the dealer
  - Wood logs: 115 €/ton
  - Wood chips: 67 €/ton
  - Wood pellet: 3.90 €/bag (15 kg)
  - Electricity: 0.20 €/kWh
- Replacing oil with LPG leads to a strong price increase
- Gas is much cheaper than oil, so we assume all oil boilers were replaced where gas is available
- Wood derivates are the cheapest fuels, but heat pumps are competitive



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Hypotheses of intervention (1/3)

- We assessed the techno-economic feasibility of phasing out oil heating in 2 benchmark buildings:
  - Detached house: 15 MWh/year heating, 4 MWh/year Domestic Hot Water (DHW), 30 kW peak power (instantaneous production of DHW)
  - Block of flats (50 apartments): 300 MWh/year heating + 50x2 MWh/year DHW produced independently by each flat

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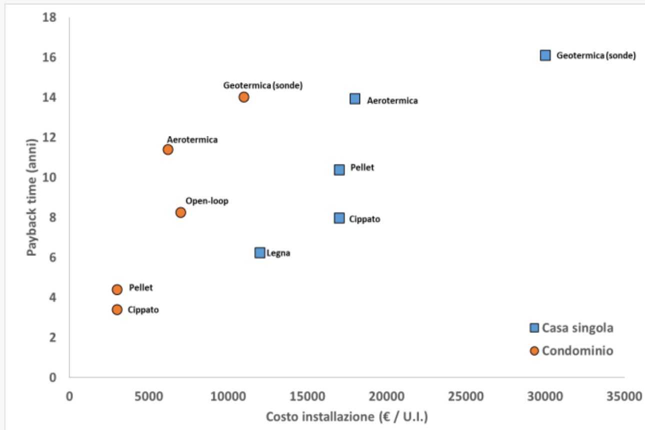
Hypotheses of intervention (2/3)

+ DHW production:
  + Replacing electric water heaters with dedicated / embedded heat pump
+ Heating system:
  + Wood or LPG boilers do not require to replace radiators
  + Heat pumps require the installation low-temperature radiators
+ Payback times:
  + Lower for the block of flats compared to the detached house (economies of scale)
  + Lower for wood derivates, but heat pumps are competitive
  + Incentives of 65% on capital expenditures strongly reduce these payback times



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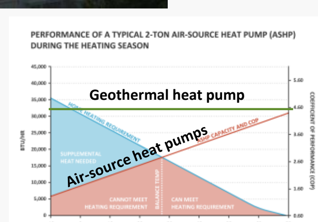
Hypotheses of intervention (3/3)

+ Other evaluations should be performed, not limited to economic convenience
+ Disadvantages of wood derivates
  + Air pollution
  + Large storage space required
+ Advantages of heat pumps:
  + Synergy with photovoltaic systems through the increase of self-consumption of the energy produced
  + Integration of heating and cooling systems
+ Specific advantages of geothermal heat pumps:
  + No freezing
  + The efficiency is insensitive to cold air temperatures
  + Possibility of implementing groundwater free cooling
  + Noise reduction thanks to the indoor installation

Air quality impact of biomass burning in Thessaloniki, Greece. Source: Saffari et al., 2013

Freezing issues of air-source heat pumps



Power and COP of air-source heat pumps: dependence on air temperature

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Conclusions

- Oil heating is expensive, air polluting, has high CO_2 emissions, but it is still very diffused in Valle d'Aosta outside of the gas grid
- Heating oil USTs are a diffused and scarcely controlled threat to groundwater. In the case of leakage, they could lead to long and expensive remediation activities
- Technical solutions for the phase-out of oil heating:
  - LPG boiler: low installation cost, minimal intervention on the building, yet higher heating costs
  - Wood and derivates: low heating costs, short payback times, strong reduction of GHG emission, but heavily pollutant
  - Heat pumps: low heating cost, strong reduction of GHG, no emissions on site
  - Geothermal heat pumps provide additional advantages (low noise etc.) but have higher installation costs and slightly longer payback times compared to air-source heat pumps

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  - Facebook: https://www.facebook.com/greta.alpinespace/
  - LinkedIn: https://www.linkedin.com/company/10922281/
- Contacts at POLITO
  - Website: http://www.polito.it/groundwater
  - PI at POLITO alessandro.casasso@polito.it

TUM: Kai Zosseder (project leader), Christine Haas (project manager), Fabian Boettcher; **POLITO:** Rajandrea Sethi, Alessandro Casasso, Simone Della Valentina, Arianna Bucci, Matteo Rivoire, Bruno Piga; **ARPA VdA:** Pietro Capodaglio, Alessandro Baietto, Marcela Olmedo, Ilaria Stringa, Marta Padoan; **EURAC:** Pietro Zambelli, Valentina D'Alonzo, Roberto Vaccaro, Simon Pezzutto, Andrea Vianello, Chiara Scaramuzzino; **Regione Lombardia:** Francesco Spinolo, Francesca Messina; **BRGM:** Charles Maragna, Fanny Branchu, Aline Humbertclaude; **GEOZS:** Joerg Prestor, Simona Pestotnik, Dušan Rajver; **GBA:** Magdalena Bottig, Stefan Hoyer, Gregor Goetzl; **Climate Alliance:** Andreas Kress, Janina Emge; **INDURA:** James Gilbert; **Triple-S:** Reiner Wittig; **Universitaet Basel:** Peter Huggenberger
…e altri ancora!

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