The mapping of Radon in Italy and in the Lazio region: from the Geogenic Radon Potential to Indoor Risk

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Introduction – The *EU Directive 2013/59*

- *Member States shall establish national reference level for indoor Rn in workplaces and private building not higher than 300 Bq/m^3 (Artt. 54 and 74);*
- *Under the national action plan (Art. 103), Member States shall promote action to identify dwellings, with radon concentrations exceeding the reference level and encourage, reducing measures (up to 100 Bq/m^3);*
- *Member States shall identify areas where the radon concentration (as an annual average) in a significant number of buildings is expected to exceed the relevant national reference level. (Art.103/3) (Radon Prone Areas, RPAs)*
- *Member States shall ensure that appropriate measures are in place to prevent radon ingress into new buildings.*
- *Strategy for conducting surveys of indoor radon concentrations or soil gas concentrations to estimate the distribution of indoor radon concentrations, and for the establishment of other relevant parameters (such as soil and rock types, permeability and radium-226 content of rock or soil).*

LIFE-RESPIRE main objectives

One of the main objective of the LIFE-RESPIRE project is to provide an integrated methodology of geological/geochemical monitoring of Rn for the assessment and the protection of human health from exposure to natural radioactivity.

The demonstration character of the project will include new techniques for identification and mapping of the GRP as well as of the RPAs, in selected municipalities where to applied a modified/innovative rapid remediation system for the monitoring of indoor radon.

LIFE-RESPIRE is aimed to fill the gap between research and policy to improve innovative solutions for land use planning and remediation.

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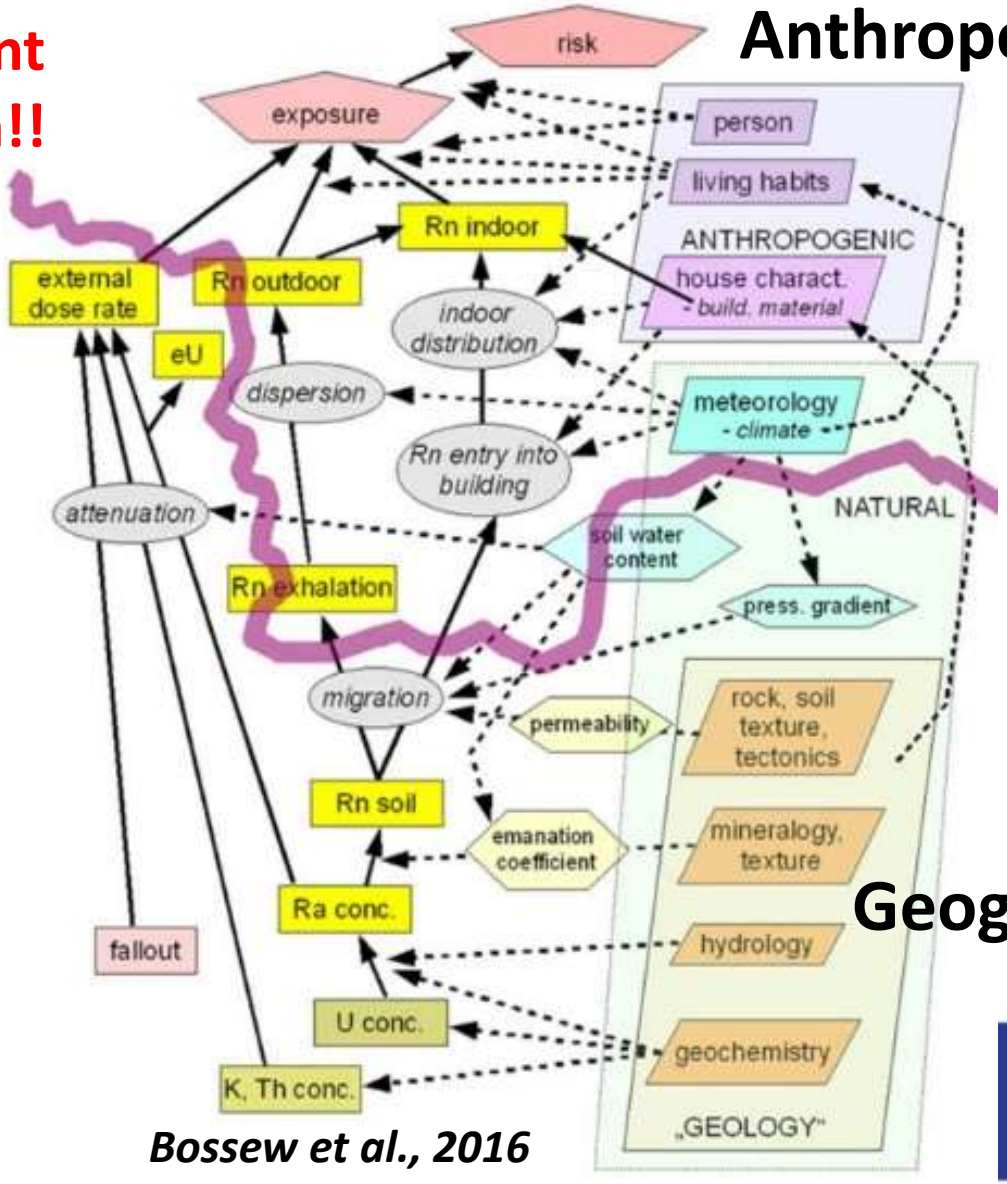
From the geological environment to Indoor Risk

Radon in the environment is a very complex system!!

It is defined by a series of heterogeneous proxy variables, sometime not well known and/or blurried, that can interact in complicated way

Results:

- **Difficult to define the dependence of Rn with the proxies;**
- **High variability (especially Rn indoor)**



Bossew et al., 2016

The Geogenic Radon Potential and the Radon Prone Areas

The Geogenic Radon Potential (GRP)

It measures "the radon delivered by the Earth", and measure the availability of Rn exhaled by the ground that can enter the building. It is actually defined by the: (Neznal, 2003) (**to be improved!!**)

$GRP=C_{Rn}(soil)/(-\log_{10}(k)-10)$

CRn (soil), radon concentration in soil/rock (kBq/m^3); k, gas permeability (m^2)

Radon Prone Area (RPA)

defines an area where the probability of high indoor Rn concentrations is increased by geological factors. However, in most cases the indoor Rn concentration is disconnected by the GRP, as in actual buildings it is mostly affected by anthropogenic factors, i.e., presence of basement, isolation, ventilation habits, elevation above ground floor, etc.

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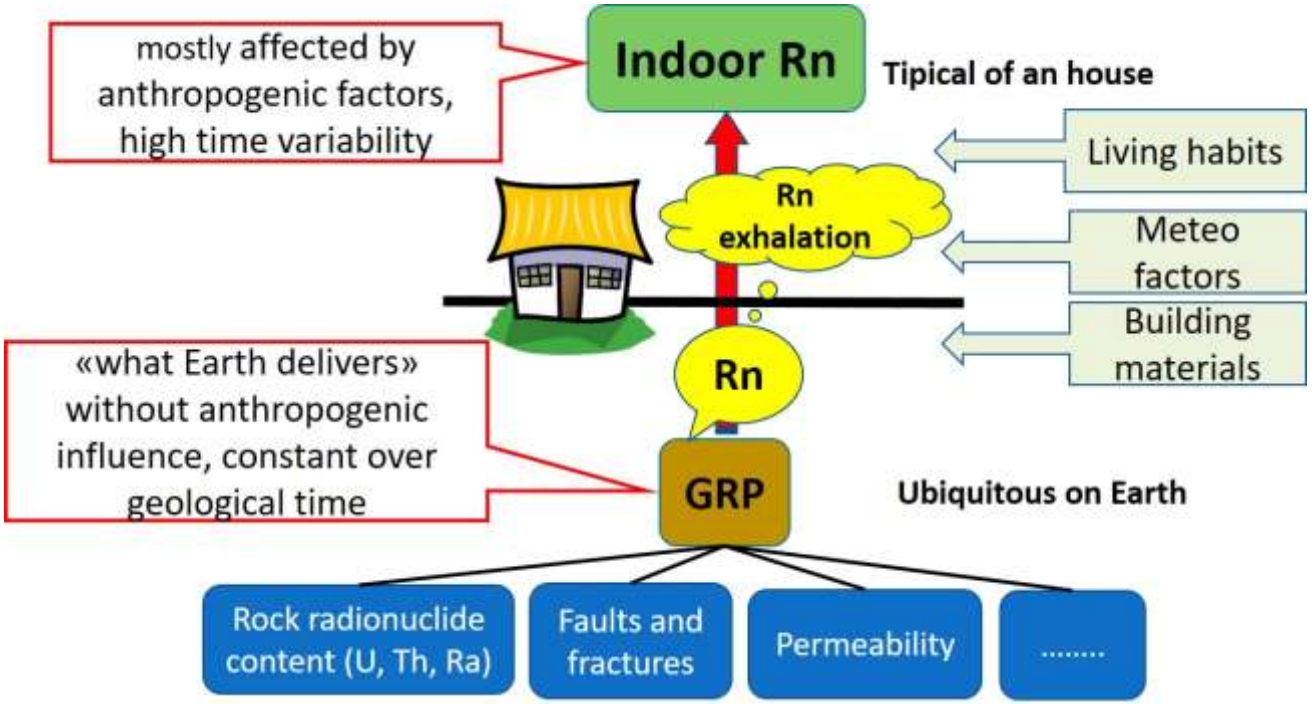
The estimation and mapping of the GRP

GRP of an area is directly measurable in the field by the Rn concentrations in the soil pores. Considerable work is being invested into developing methods to estimate GRP (from small to large scale) by using observed/easily available proxies (geological data and/or indoor Rn measurements) in the case of not available soil gas data.



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Input variables

GRP: the geogenic radon available to enter the buildings

Soil gas radon: Rn concentration in soil air

Rn exhalation: Rn movement from the surface

Radionuclide content: U, Ra content in the rock/soil

Soil permeability: affects the radon movement in the subsoil

Terrestrial gamma dose rate

Geological units

Additional Factors: presence of features affecting radon quantities and movement toward surface: faults, caves, mines, geothermal gradient, ...

Indoor Rn concentration: radon content in a building

Harmonization among these variables is needed:

different datasets and measurements techniques

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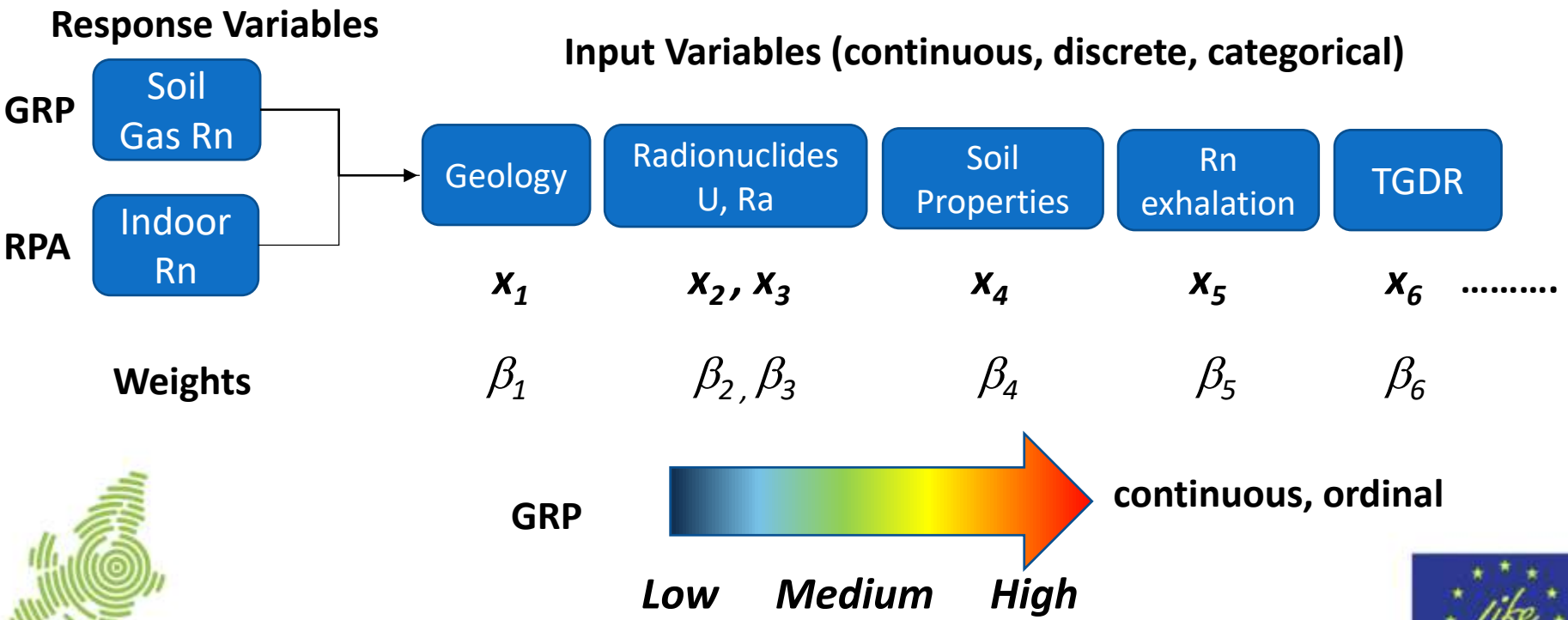
The multivariate approach

To date a multivariate classification approach following Ranked models, Global (OLS) or Local (GWR) regression models is under consideration for the calculation and mapping of the GRP.

$$Y_{(u,v)}=\beta_{0(u,v)} + \beta_{1\,(u,v)}x_{1i}+ \beta_{2(u,v)}x_{2i}+.....+ \beta_{n(u,v)}x_{ni}+\varepsilon_{(u,v)}$$



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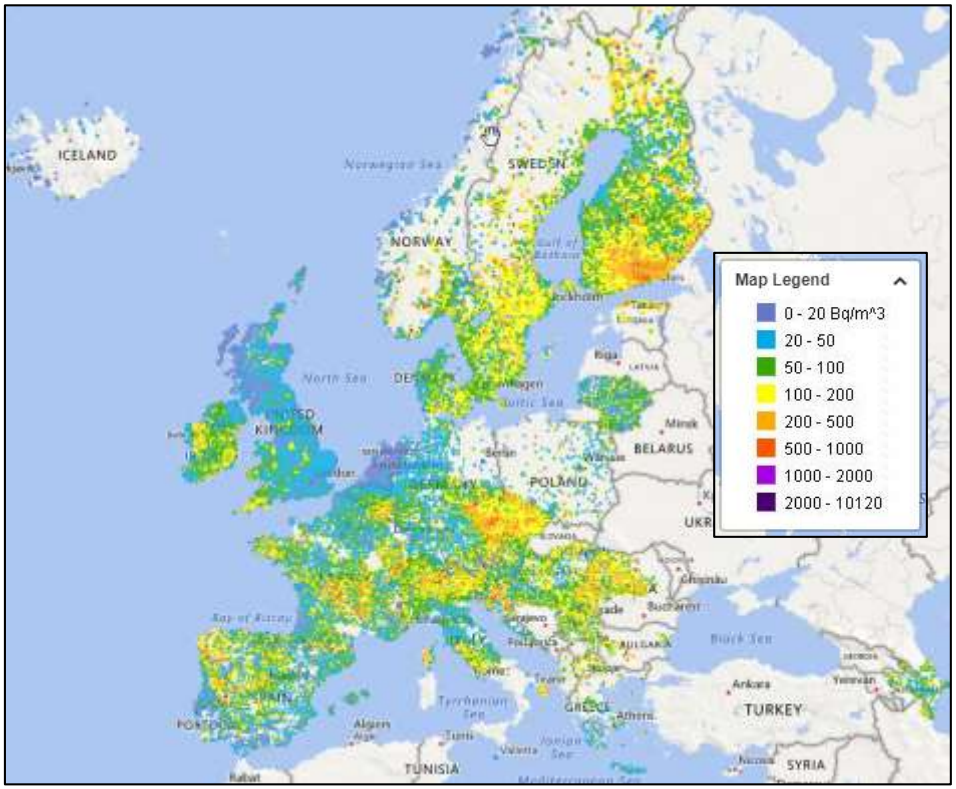
Existing data at European scale

Indoor radon concentration



Since 2010, the Radioactivity Environmental Monitoring (REM) group at the Joint Research Centre (JRC) of the European Commission is working on the development of the **European Atlas of Natural Radiation (EANR)**, a collection of maps displaying the levels of radioactivity caused by different natural sources in Europe.

https://remon.jrc.ec.europa.eu/About/Atlas-of-Natural-Radiation

Since 2013 the JRC has undertaken to map "what Earth delivers" in term of GRP. The map is in progress due to the heterogeneity of data sources and need to develop models fro estimating and harmonised quantity which is able to quantify the radon potential.

https://remon.jrc.ec.europa.eu/About/Atlas-of-Natural-Radiation/Geogenic-radon/Geogenic-radon

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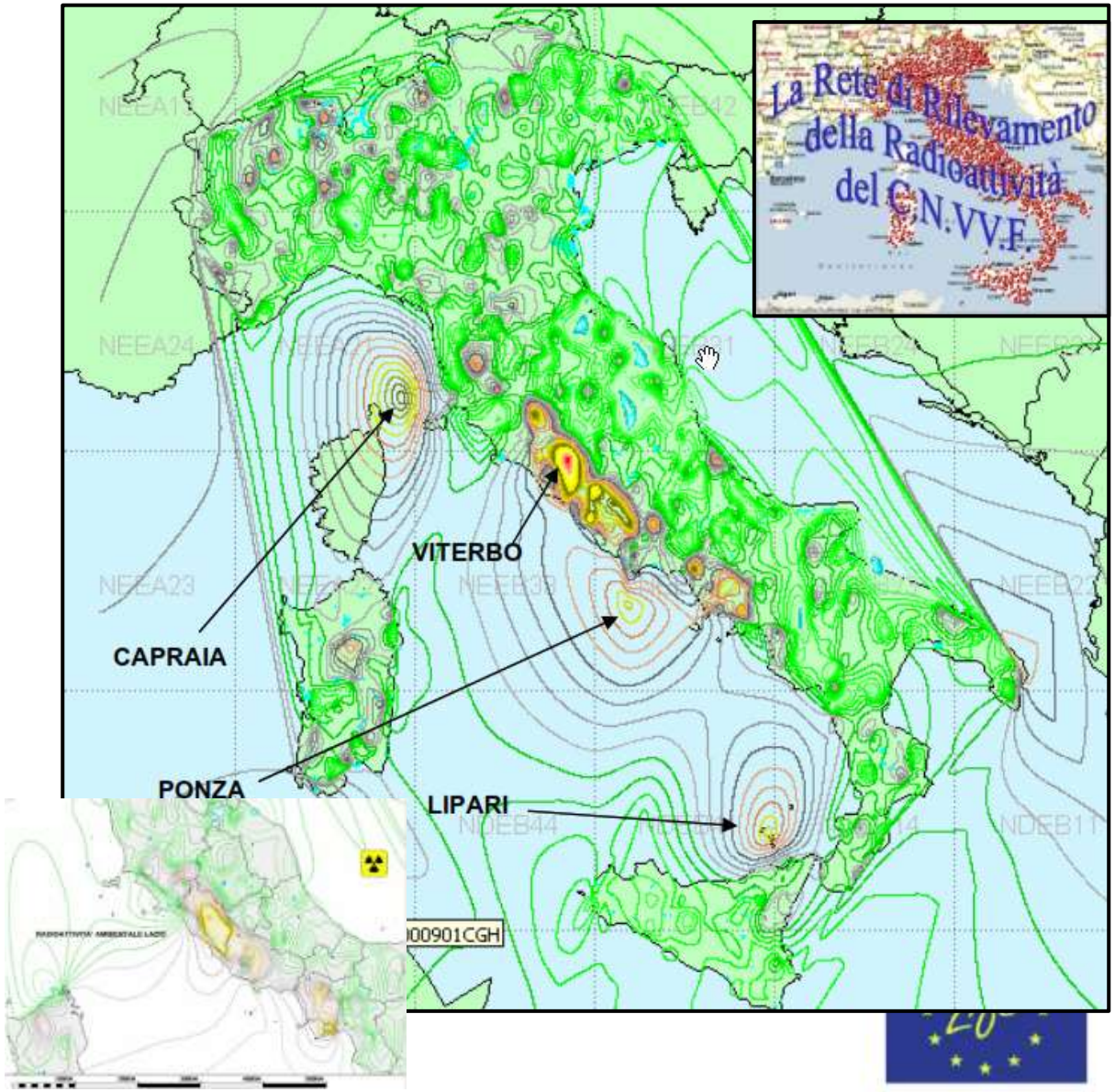
Existing data at national scale

At Italian national scale a GRP map does not exist. A picture of the Italian natural radioactivity can be obtained by the Monitoring Network of the C.N. VV.F. (National Corp of Firefighters) (Riggio and Giuliani, 2008) (Law 469/1961 - Art. 10 Law 421/1996).

The Network incudes 1237 real-time monitoring stations which measure the dose rate (cGy/h).



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The GRP of Italy: a preliminary exercise

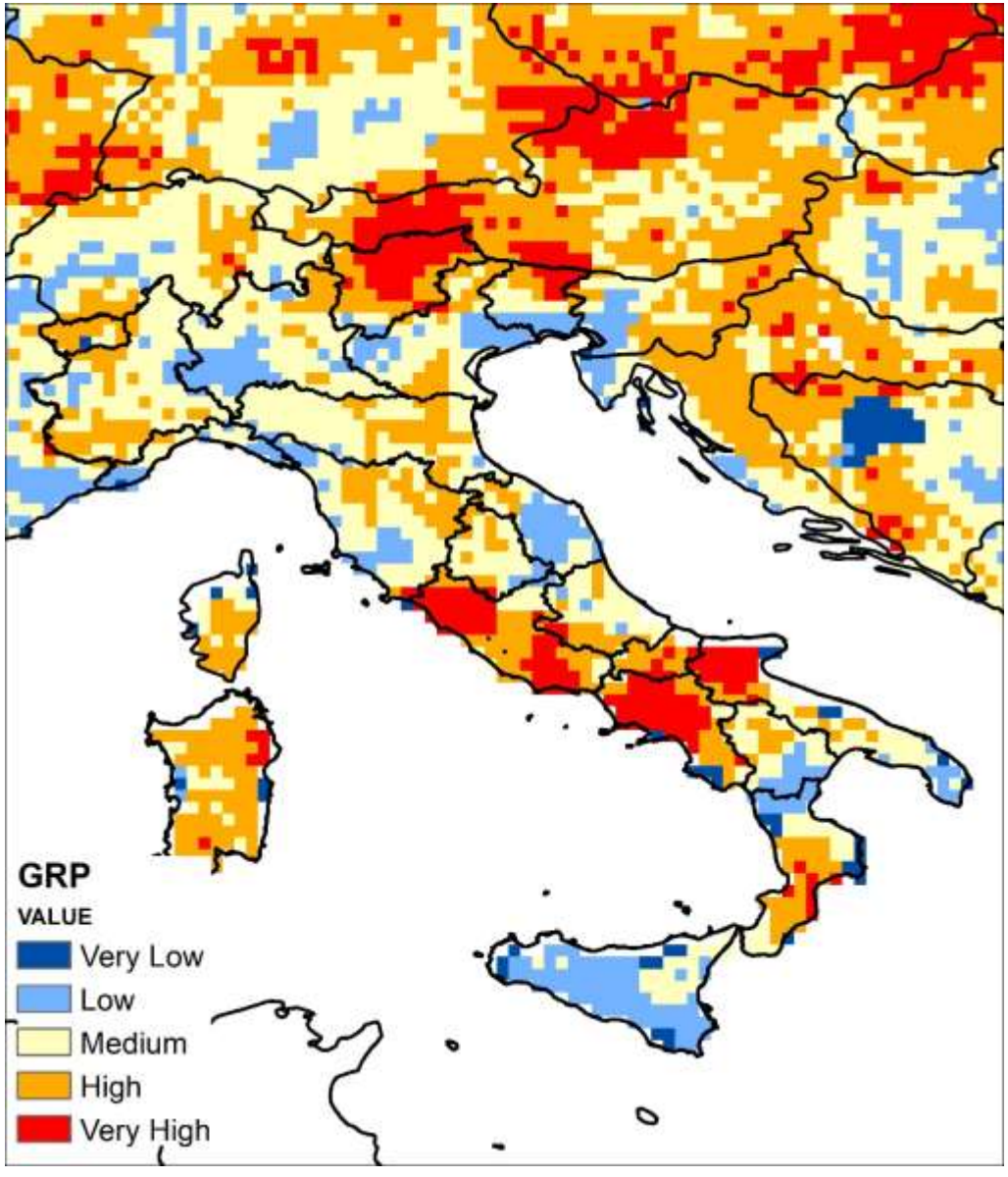
A preliminary attempt to construct a GRP map of Italy starting from proxy variables (available in the literature or on the web). This approach does not suggest that soil gas Rn and permeability measurements should be bypassed, but it can easily and quickly help establish a preliminary GRP estimate of an area.

Used proxy variables:

- U, Th, and K radionuclide content in soil (GEMAS (http://gemas.geolba.ac.at/) and FOREGS (http://weppi.gtk.fi/publ/foregsatlas/index.php, https://remon.jrc.ec.europa.eu/About/Atlas-of-Natural-Radiation)
- soil permeability in terms of topsoil fine fraction (LUCAS database, Ballabio et al., 2014)
- active faults (Global Faults layer from ArcAtlas, ESRI)
- location of earthquakes of local magnitude > 4 (INGV)
- Global Volcanism (Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution)
- Heat flow map of Europe (International Heat Flow Commission of the International Association of seismology and Physics of the Earth's Interior, IASPEI).

The Italian GRP: a preliminary exercise

The map has been constructed according to a grid of 10x10km, following the grid used for the maps of the European Radon Atlas (Ciotoli & Bossew, in preparation)



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The GRP of the Lazio region

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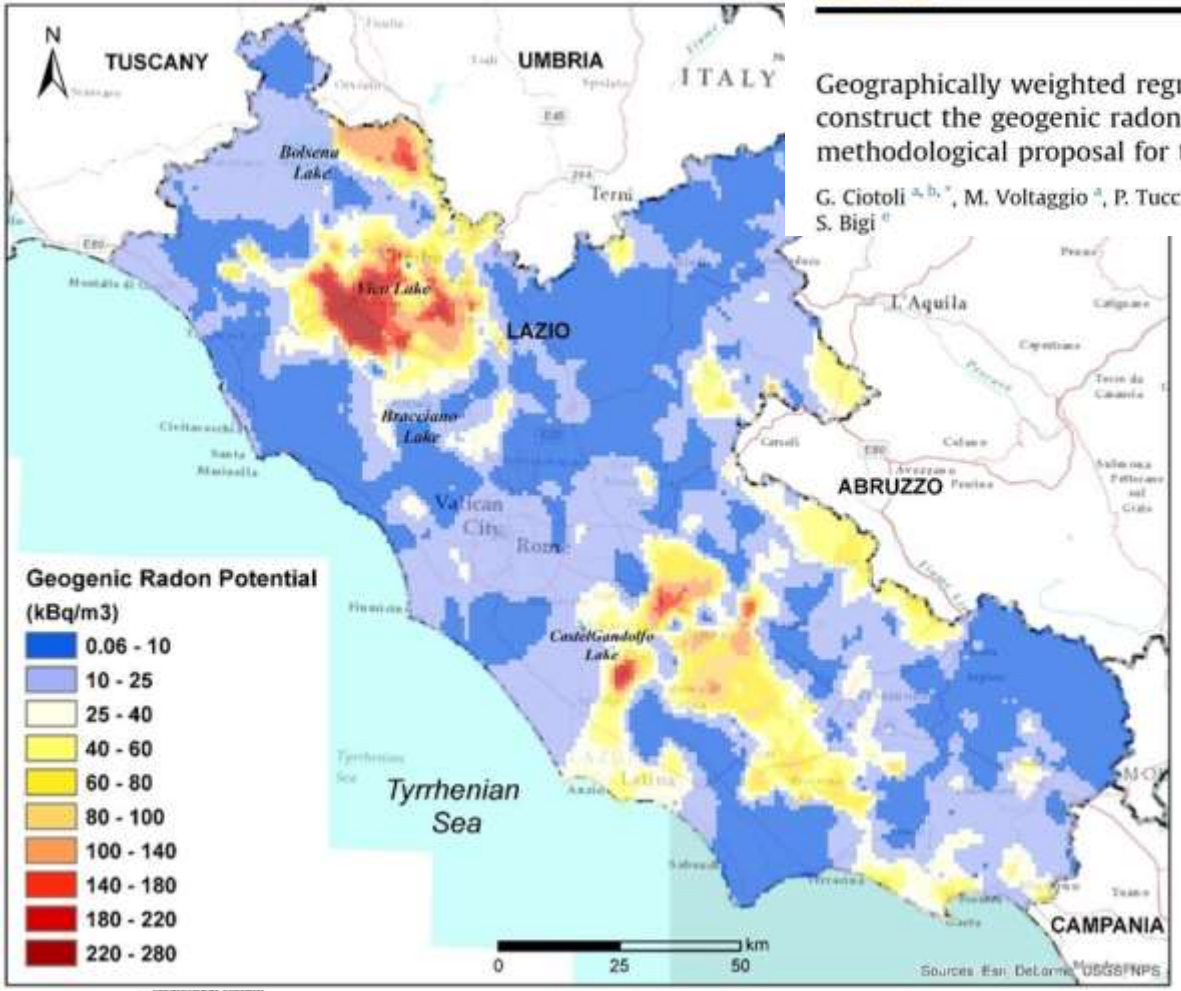
Geographically weighted regression and geostatistical techniques to construct the geogenic radon potential map of the Lazio region: A methodological proposal for the European Atlas of Natural Radiation

G. Ciotoli [a, b, *], M. Voltaggio [a], P. Tuccimei [c], M. Soligo [c], A. Pasculli [d], S.E. Beaubien [e], S. Bigi [e]



The Indoor Rn in Italy

Regulation:

1988 – IARC classified radon as a human carcinogen

1996 – EU Directive 96/29/EURATOM protection of workers from natural radiation (action levels: 400 Bq/m^3 for existing buildings, 200 Bq/m^3 for new buildings)

2000 – D.Lgs. 241/00, characterization of the Italian regional territories by the measurements of the annual average of radon in working places (action level: 500 Bq/m^3)

Difficulties for the application of this regulation:

- *Lack of technical protocols of monitoring and mapping of RPA*
- *The action level is valid for all working places, but the obligation to measure is for only the underground places - Lack of definition of underground place*
- *Lack of criteria for the definition of high probability of Rn indoor*

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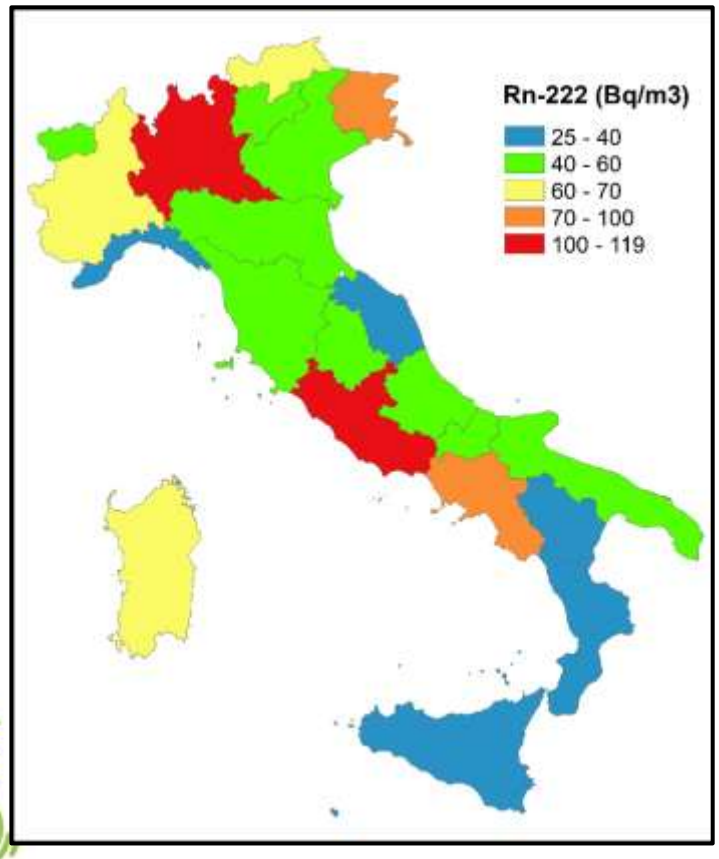
The estimation and mapping of RPAs

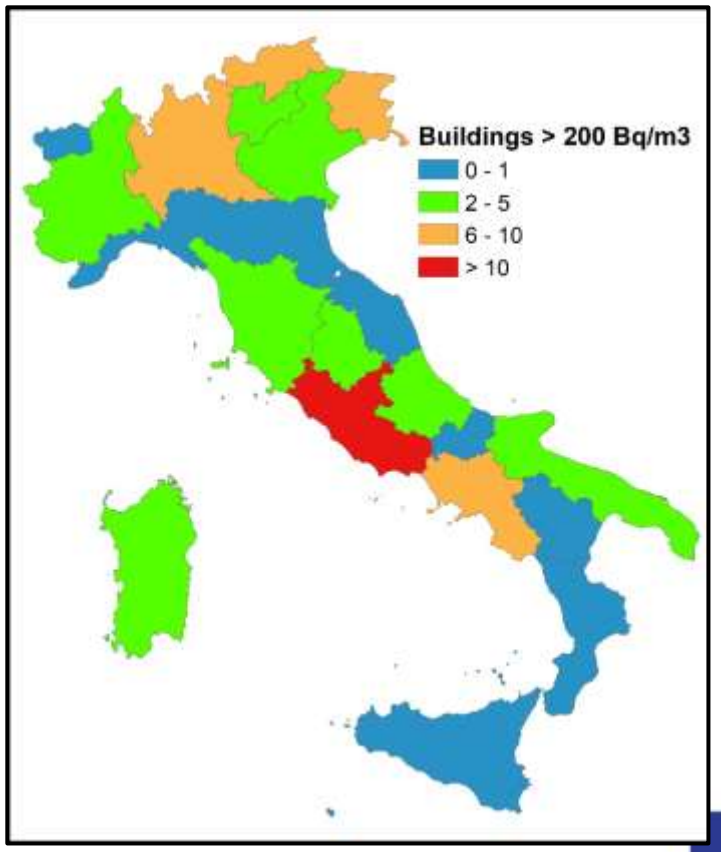
- ICRP suggests that radon prone areas might correspond to the areas where at least 1% of dwellings have radon levels more **than ten times** the national average.
- The geographical variation of indoor Rn and the selection of the action level will affect the definition of the RPAs, therefore, the definition of the RPAs result in a crucial topic for the monitoring of dwellings and definition of the risk areas.
- Statistical techniques applied to represent indoor Rn measurements can provide an estimation of the percentage of dwellings above an action level (raw and/or standardized data).
- Geostatistical techniques (i.e., probability kriging) can provide a map of the probability to exceed the action limit. However, caution needs in the application of kriging because of the clustering of indoor measurements.

The Italian Rn Indoor Map

Map of Rn indoor in Italy. Period 1989-1997 (Annuario APAT, 2005-2006). Average concentration



Map of % buildings > 200 Bq/m^3. Period 1989-1997 (Annuario APAT, 2005-2006).



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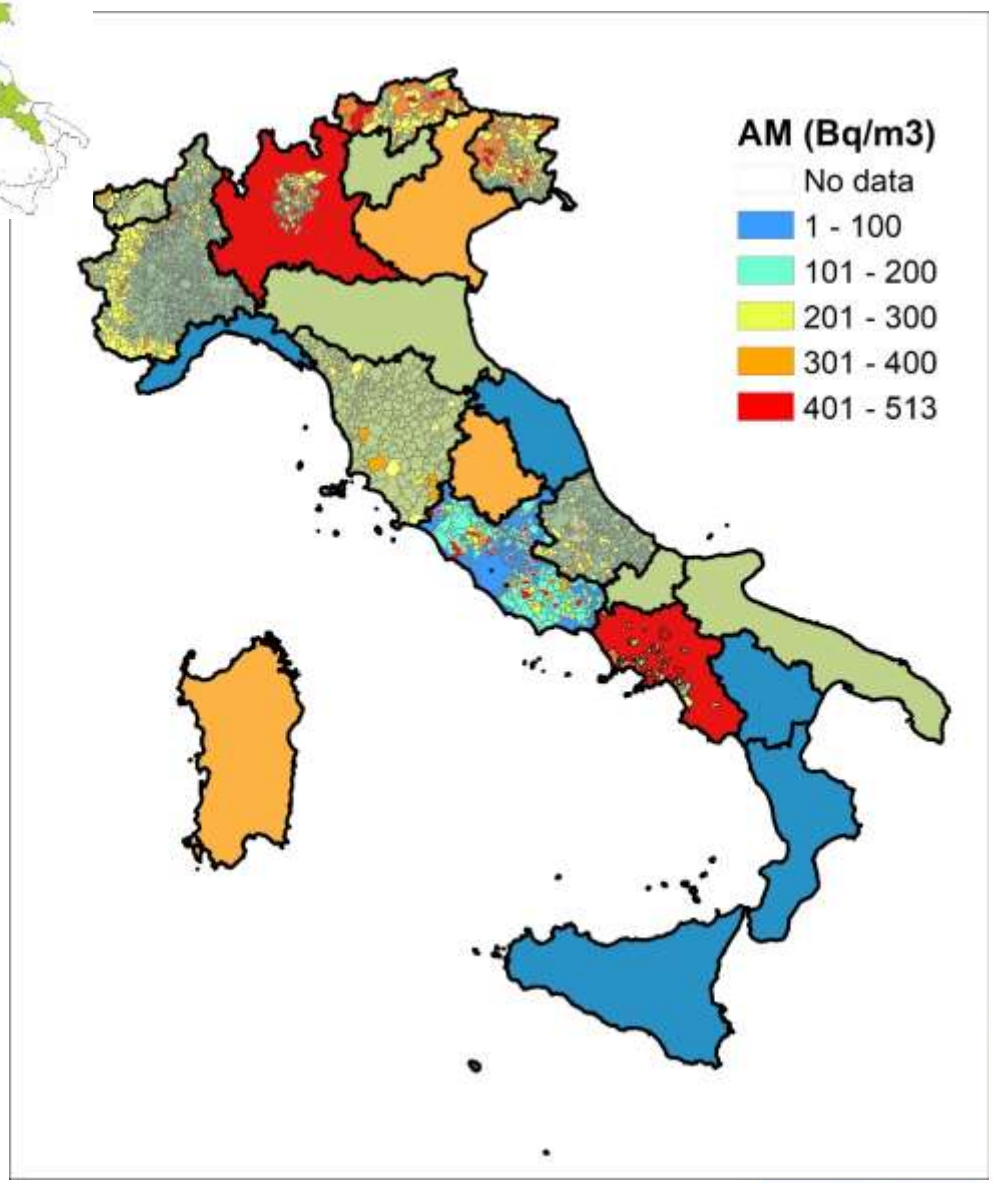
The Italian Rn Indoor Map - 2

Regions with actions aimed at the indentification of RPAs

Statistics recalculated by using data available from the different ARPA websites

Region	Mun	Meas	AM	GM	Min	Max	STD
VDA	38	609	83	75	22	221	45
PIE	1206		88	82	28	847	47
LIG							
LOM	172	834	219	124	8	6514	361
TRE							
BOL	116	3265	227	135		2362	
VEN							
FVG	679*	2462	161	122	18	1812	145
ERO							
TOS	287	1981	51	40	9	344	45
MAR							
UMB							
LAZ	378	5281	121	86	4	2154	135
ABR	283	2205	65	53	1	1181	
MOL							
CAM	382		309	126	8	7784	816
PUG							
BAS							
CAL							
SIC	411		80		11	1197	
SAR							



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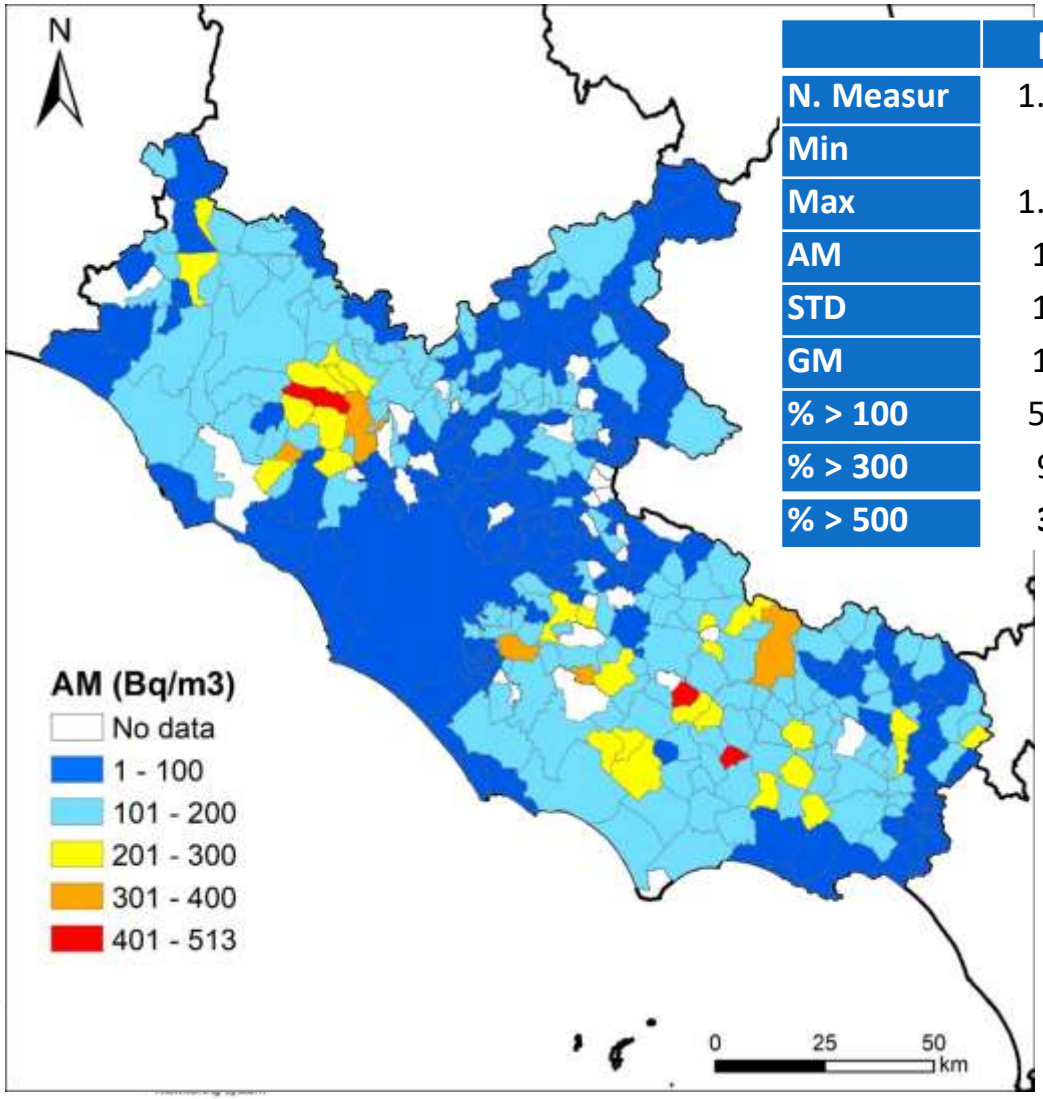
The Lazio Rn Indoor Map

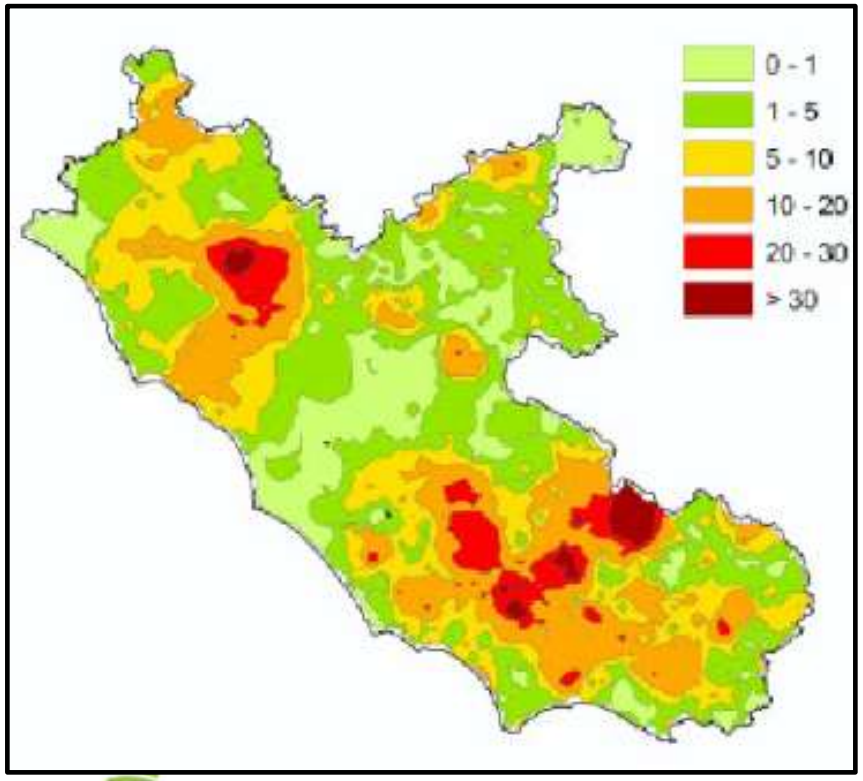
Indoor radon in the Lazio municipalities (ARPA Lazio, 2013)



	FR	LT	RI	RM	VT	TOT
N. Measur	1.288	675	1.036	1.418	864	5281
Min	4	5	6	5	6	4
Max	1.953	1.692	626	2.154	2.075	2154
AM	142	127	104	96	144	121
STD	148	142	78	122	170	135
GM	101	90	82	67	104	86
% > 100	51%	43%	38%	29%	51%	41%
% > 300	9%	7%	3%	4%	9%	6%
% > 500	**3%**	**2%**	**0%**	**1%**	**3%**	2%

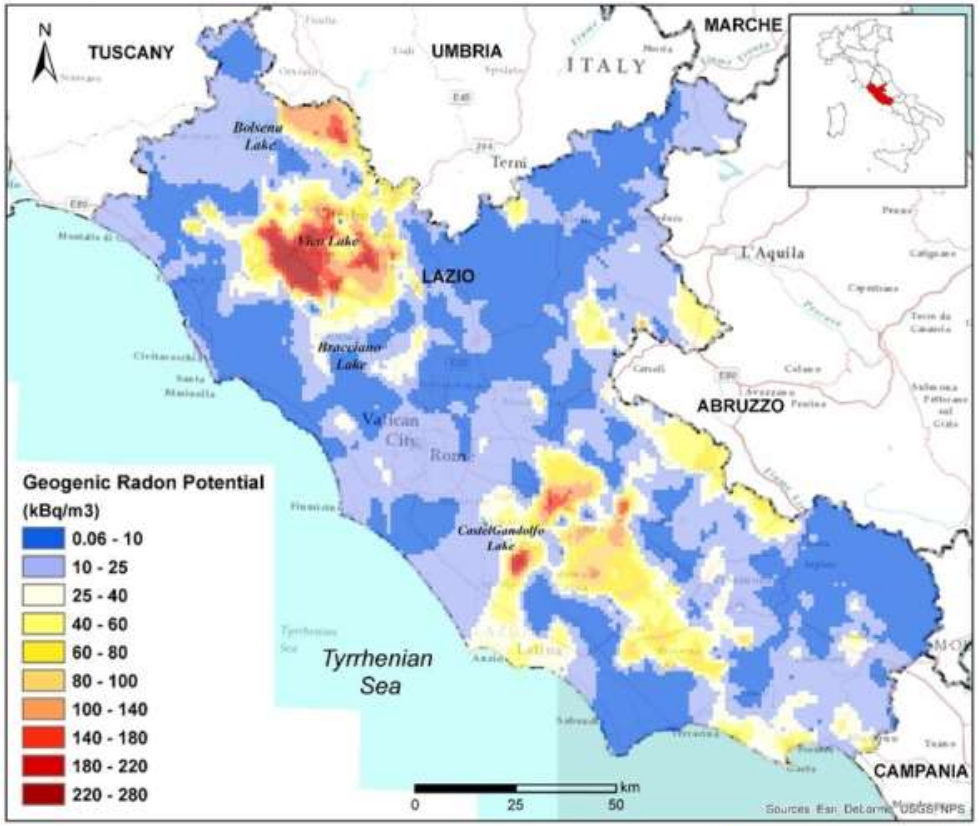
Comparison between GRP and RPA

Estimated probability to exceed the level of 300 Bq/m3 (ISPRA, 2013)



Maybe we are going in the right way??

GRP map of the Lazio region



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The estimation and mapping of the GRP and RPA

Work in progress!!

1. The direct interpolation of indoor radon values to identify RPAs

- **Less robust approach**
- **Strong variability (even at short scale)**
- **Meaning only within the inhabited areas**
- **Spatially clustered due to distribution of houses within the inhabited zones.**
- **Mostly useful for the individuation of the remediation sites**

2. The construction of multivariate models including geological data constrained by soil gas data (when available) for the estimation of GRP

- **More stable**
- **it is easier to find a correlation**
- **Spatially autocorrelated (the values depend on the values at neighboring sites)**

useful to:

- **to define priority areas for further study and land-use decisions**
- **to allocate resources to plan more detailed surveys**
- **to plan remediation and monitoring of houses in affected areas**
- **to focus radon policies and regulation in priority areas**

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Conclusion

- Radon in the environment is a very complex phenomenon constituted by a series of heterogeneous proxy variables, sometime not well known and/or blurried, that can interact in complicated way
- The mapping of the GRP and of the RPAs constitutes and important tool for the analysis of radon risk and the organization of action plans (as requested by the EU Directive 2013/59), i.e., detailed investigations, prevention, land use planning and remediation actions. **We would like to remind that the EU Directive must be transposed in the different EU countries starting from February 2018.**
- Some multivariate approach are proposed, but further development is necessary to define uncertainty of the different concurrent variables, as well as of the applied models.

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The position of LIFE-Respire project

LIFE-RESPIRE project:

- will implement an integrated methodology to improve the geological/geochemical database at the selected sites, as well as the collection and monitoring of the indoor Rn data including meteorological data and building characteristics
- all collected data will be stored in a geodatabase and will be available to stakeholders through a WebGIS and Web Mapping Applications for fast data handling (the database will also include the monitored data after the installation of the remediation system)
- the construction of this robust database will enable an accurate mapping and recognition of RPAs, as well as dissemination of the results, useful to national and local authorities for land-use decisions and regulations, as well as for the site remediation.

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Conclusion

The modelling of the radon potential map!!

Fruit Basket by Giuseppe Arcimboldo
(ca. 1527–1593)

THANK YOU FOR THE ATTENTION!!

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