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Society's willingness to pay its way to soil security

Cristiano Franceschinis [a], Alex McBratney [b], Luisa Eusse-Villa [a,*], Damien Field [b], Mara Thiene [a], Jürgen Meyerhoff [c]

[a] Department of Land, Environment, Agriculture and Forestry (TESAF), University of Padova, Padova 35122, Italy
[b] School of Life and Environmental Science & Sydney Institute of Agriculture, The University of Sydney, NSW 2006, Australia
[c] Department of Business and Economics, Hochschule für Wirtschaft und Recht (HWR), Berlin 10825, Germany

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ABSTRACT

Soils are a crucial part of terrestrial ecosystems, holding most of the soil carbon, one-quarter of the biodiversity, and are essential for food production. Human forcings, including climate change and land use pressures, threaten the security of the soil for the provision of a whole range of soil functions. Soil capability to carry out important functions has seldom been evaluated in economic terms. Importantly, the existing economic studies have not been embedded in the soil security framework. Therefore, we have limited knowledge of how the general population values these soil functions and whether they wish to see their maintenance and improvement as part of public policy. Consequently, in this study, we aim to contribute to filling this gap by providing an estimation of the value, expressed in monetary terms, that individuals place on several soil functions and compare such values across large regions of two G20 countries. We present here an estimate of willingness to pay for two publicly-funded soil management strategies: the creation of biodiversity credits based on soil microbial diversity and soil carbon insetting for achieving net-zero agriculture. We show via a discrete choice experiment addressing 3,000 citizens that societies in the distant and contrasting regions of Veneto in Italy and New South Wales in Australia are willing to pay for soil security and financially support soil management practices that improve soil functions in their regions. Further analysis shows that the stated willingness to pay corresponds to socio-demographics and attitudes toward soil protection and general environmental concerns. The aggregated monetary value of the selected soil functions for the entire population is $244 M for Veneto and twice as much for New South Wales. Our research findings give decision-makers and resource managers insights into societies' willingness to make trade-offs in favour of increased soil security. In contrast to climate change and loss of biodiversity, soil degradation and loss of soil functions have received much less attention. In this empirical research, we provide evidence of the importance of accounting for soil functions in resource management, as societies benefit from them and are willing to pay for their conservation.

1. Introduction

For the world's growing population to develop sustainably, we must address six existential environmental challenges—food, water and energy security, climate change abatement, biodiversity protection, and human health. Soil plays a pivotal and integrative role in each of these (McBratney et al., 2014). Indeed, it has been argued that soil and its security should be recognised as a seventh existential environmental challenge as the world's soil resources are under threat (Montanarella et al., 2015). Securing soils and their life-supporting functions has never been more critical, with the need to double agricultural production by 2050 while simultaneously maintaining functioning ecosystems.

Soil functions embody the inherent capacities of the soil, including (i) nutrient cycling (Cycling), (ii) water filtration and transformation (Water), (iii) source of raw materials (Materials), (iv) biomass and food production (Biomass), (v) carbon sequestration (Carbon), (vi) maintaining soil biodiversity (Biodiversity), and (vii) landscape and heritage (Cultural). Even though some authors have recently shed light on how the general population values these soil functions and whether they wish to see their maintenance and improvement as part of public policy (Bartkowski et al., 2022; Dominati et al., 2014; Eusse-Villa et al., 2021, 2022), there is still a lack of proper recognition of the value of soil functions (Bartkowski et al., 2020). Having more and detailed information about the economic value of soils might contribute to changing

* Corresponding author.
E-mail address: luisafernanda.eussevilla@phd.unipd.it (L. Eusse-Villa).

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their current use, which in the developed world, while improved, is far from sustainable. Widespread soil acidification and the decline of carbon in cropping lands, soil erosion, and nutrient imbalances continue largely unchecked and unabated. There is an urgent need to understand how soil responds to changes in climate and land use and to identify areas under threat of degradation before we can work towards halting this degradation and establishing regeneration pathways. This is evident in the commentary in the UN FAO Intergovernmental Technical Panel on Soils Report, which identified the paucity of current data and modelling, rendering key uncertainty in the assessments of threats to global soil functioning (Montanarella et al., 2015).

All over the world, soils are insecure due to degradation processes, such as soil erosion, acidification, loss of carbon, biodiversity and soil structure, and salinization, which in turn reduce their ability to function to provide a range of services for humanity and the planet. As a result, soil condition or health is impaired. The concept of soil security recognises that soil is multi-functional and that any unit of soil can be valued for any combination of the seven soil functions abovementioned (Bouma and McBratney, 2013). Soil functions will collectively affect the 6 global existential challenges differently (McBratney et al., 2014). For example, soil functioning as a habitat for biodiversity will also depend on the cycling of water and providing nutrients (Fig. 1). So, while it is assumed that most soils can provide each of the seven soil functions, the aggregation of soil functions required by the soil to sustain each of the global challenges will vary. It is also recognised that affecting soil functions to improve soil's ability to support a selected global challenge may positively or negatively affect the ability of the soil to support each of the other global challenges (McBratney et al., 2014).

One logical way to consider soil contribution to the UN Sustainable Development Goals (SDGs), particularly the seven identified in Fig. 1, is through one or more of the soil functions (Keesstra et al., 2016). The realization of these SDGs will depend on monitoring and evaluating a combination of the biophysical system, identified as the dimensions of capability and condition in soil security, and the socio-economic dimensions that value the soil, capital, and connectivity, or protect the soil using the soil security dimension of codification (Bouma, 2020; Field, 2017; Keesstra et al., 2016). The overall characteristics of these five dimensions are summarized in Table 1 (Field, 2020). The ability of soils to support a function is determined by their capability, which depends on soil capacity as affected by current conditions (McBratney et al., 2019).

Table 1
Characteristic of the five dimensions of soil security (Field, 2020).

Dimension	Description
Capability	Determines the reference state and is a measure of the biophysical ability of soil to carry out a function. This dimension reflects change over geological timescales and can be thought of as analogous to 'genosoils' (capacity) as affected by environmental management conditions. Capability = capacity + condition
Condition	Measures the ability of soil to carry out functions, reflects the soil's response to management, and is analogous to 'phenosoils.' Collectively, with soil's capacity, characterises the soil's capability.
Capital	Affords the production and human-demanded function and attendant ecosystem services. The larger the value is, the greater the attention for those functions and the role and importance of soil in social policy and the economy.
Connectivity	Between the soil and those who want to use its products and services. The greater the formal recognition of soil by society, the higher protection should be afforded to continue its functions.
Codification	The governance of the soil through public regulation of its use activities or private regulation awarding environmental sustainability accreditation and certification schemes.

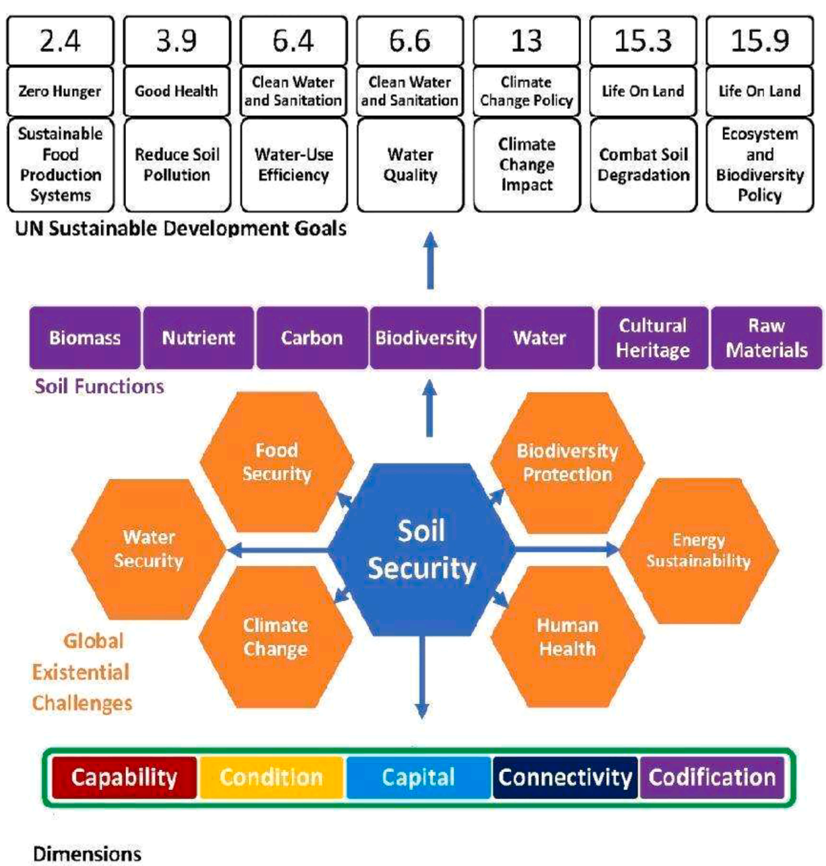

Fig. 1. A schematic describing the interconnection of Soil Security with the 6 global existential challenges, each regulated by an aggregation of the seven soil functions. Modified from McBratney et al. (2014).

The value that individuals place on the goods and services provided by soil will strongly influence decisions on its use over a given area for any period. Capital in the soil security concept is a mnemonic – it refers to the economic aspects of soil security, more particularly but not exclusively, the economic valuation of soil functions. There is a relationship between this concept and the concepts of natural capital (stocks) and ecosystem services (flows) (Bateman and Mace, 2020). Still, the relationship between the concepts has not been thoroughly evaluated thus far. Effective policy-making is needed to ensure that soil is appropriately regulated. There are examples at regional and national levels, but at the international level, codification is weaker (Bouma, 2020; Koch et al., 2012).

An approach provided by economists is to apply valuation methods capable of also capturing the public good part of soil functions. These methods rely on observed behaviour to reveal peoples' preferences (revealed preferences) or ask them directly about their preferences (stated preferences). Both methods, clearly not without shortcomings, have been applied manifold in environmental and ecological economics to inform decision-makers about the value (typically expressed in monetary terms, as the willingness to pay, (WTP)) the provision of certain goods would provide to societies. Such methods, however, have seldom been employed to value soil functions, and thus, substantial knowledge gaps exist concerning soil's economic value (McBratney et al., 2014). Importantly, the existing economic studies have not been embedded so far in the soil security framework (Uz et al., 2022).

In this study, we aim to contribute to filling the aforementioned gap by employing a discrete choice experiment survey (Mariel et al., 2021) in two distant and contrasting study areas: the Veneto region of Italy and the state of New South Wales (NSW) in Australia. The dataset used in this study was also exploited by Eusse-Villa et al. (2021, 2022) and Franceschinis et al. (2022). This study adds to our previous work by estimating the WTP values of citizens from both samples (Italy and Australia), comparing them, and identifying drivers for differences in values across the two countries using socio-economic data and environmental attitudes. Moreover, we provide a comprehensive picture of the value arising from reducing threats to soil security by aggregating the value estimates to Veneto and New South Wales populations. Finally, we have developed two programs focusing on specific soil problems that contribute to a comprehensive understanding of the soil security framework and how individuals place value on a range of soil attributes and functions.

The willingness-to-pay concept may give a fit-cut estimate of the economic value of various soil functions. It provides decision-makers and resource managers with information about societies' willingness to make trade-offs in favour of increased soil security. In addition, we investigated the drivers of the differences in willingness to pay values across the two countries by analysing the effect on WTP values of socio-economic characteristics, attitudes towards soil protection, and citizens' general environmental concerns. In this empirical research, we provide evidence of the importance of accounting for soil functions in resource management, as societies benefit from them and are willing to pay for their conservation. We anticipate our surveys to be a starting point for global mapping of soil function values to inform soil management and policy since the value individuals place on the services provided by soil should strongly influence decisions on its use over a given area for any period.

The structure of the paper is as follows. Section 2 discusses the study areas and explains the survey design and modelling framework. Sections 3 and 4 present and discuss the empirical results obtained together with the econometric estimates. The last section concludes the paper by raising policy implications associated with the results and suggesting future research directions.

2. Methods

2.1. Study areas

Societies from two distant and contrasting regions were chosen to understand how the general population values soil functions and whether they wish to see their maintenance and improvement as part of public policy. The Veneto region in Italy and New South Wales in Australia were selected as the focus of the study (Fig. 2). In Italy, the Veneto region has the characteristics that the majority of soils of the low Venetian plain are Calcisols and Cambisols (WRB IUSS Working Group, 2014), characterised by low natural fertility due to low organic matter and carbon contents and low cation exchange capacity, while they contain excessive amounts of calcium carbonates ($CaCO_3$) (Regione Veneto, 2005). They are often characterised by shallow groundwater levels (< 2 m).

Meanwhile, the state of New South Wales (NSW), situated on the eastern side of the Australian continent with an area of 801,137 km^2, has a high diversity of environmental and soil conditions. The soils in NSW include 12 of the 14 soil orders of the Australian Soil Classification system (Isbell, 2016), of which Vertosols occupy the greatest area, followed by Calcarosols, Chromosols, Kurosols, and Kandosols. NSW has considerable areas of historic soil erosion, soil carbon loss, structural decline, loss of soil biodiversity, acidification and salinisation.

To illustrate the insecurity of the soils of the chosen study sites, we use a set of suggested indicators describing the threats to soil functions in both regions (Table 2). The intensity of the threat is from expert opinion. Additionally, a range of threats across four of the functions that are important and capable of ameliorating are highlighted. Attending to these provides a useful initial strategy for sustainable soil management.

2.2. Survey design and implementation

Data collection was based on a discrete choice experiment, a stated preference approach based on the assumption that each good can be decomposed into a bundle of main characteristics or attributes, each of which can be valued (as welfare measures) and expressed into a monetary metric (willingness to pay values at the margin, marginal WTPs). This approach allows investigation of the underlying structure of preferences of the population. From an operational viewpoint, respondents are presented with a set of alternatives: each alternative is characterised by attributes of the good under investigation (soil functions here), which vary for a different mix of the levels/values of the attribute. The dataset used in this study was also exploited in Eusse-Villa et al. (2021, 2022) and Franceschinis et al. (2022), where more details on the experimental design, attributes, levels, and choice tasks examples are provided.

The identification of the attributes and related levels was achieved after an in-depth discussion with Australian and Italian soil scientists, as the aim was to define a set of realistic but meaningful soil functions underpinning ecosystem services. Being aware that most people are probably not familiar with the concept of ecosystem services generated by soil, in addition to a careful literature review, we dedicated much effort to overcoming this issue. Specifically, an extended and detailed description of each attribute, along with examples of environmental service/soil function improvement as a consequence of specific practices, was provided to respondents prior to the sequence of choice tasks. Table 3 reports the attributes and related levels list for Australia and Italy. The attributes are the same in both countries, except for one, due to the land's differing structural and morphological soil characteristics. Thus, salinity in groundwater was used in the Australian survey, and nitrogen in groundwater was used in the Italian survey, while soil carbon sequestration, earthworm density, rainfall water infiltration, and a household tax were used in both countries.

Attributes and related levels are as follows. Soil carbon sequestration is the soil capability to capture and store atmospheric CO_2, one of the main greenhouse gases. Increasing soil carbon sequestration has two

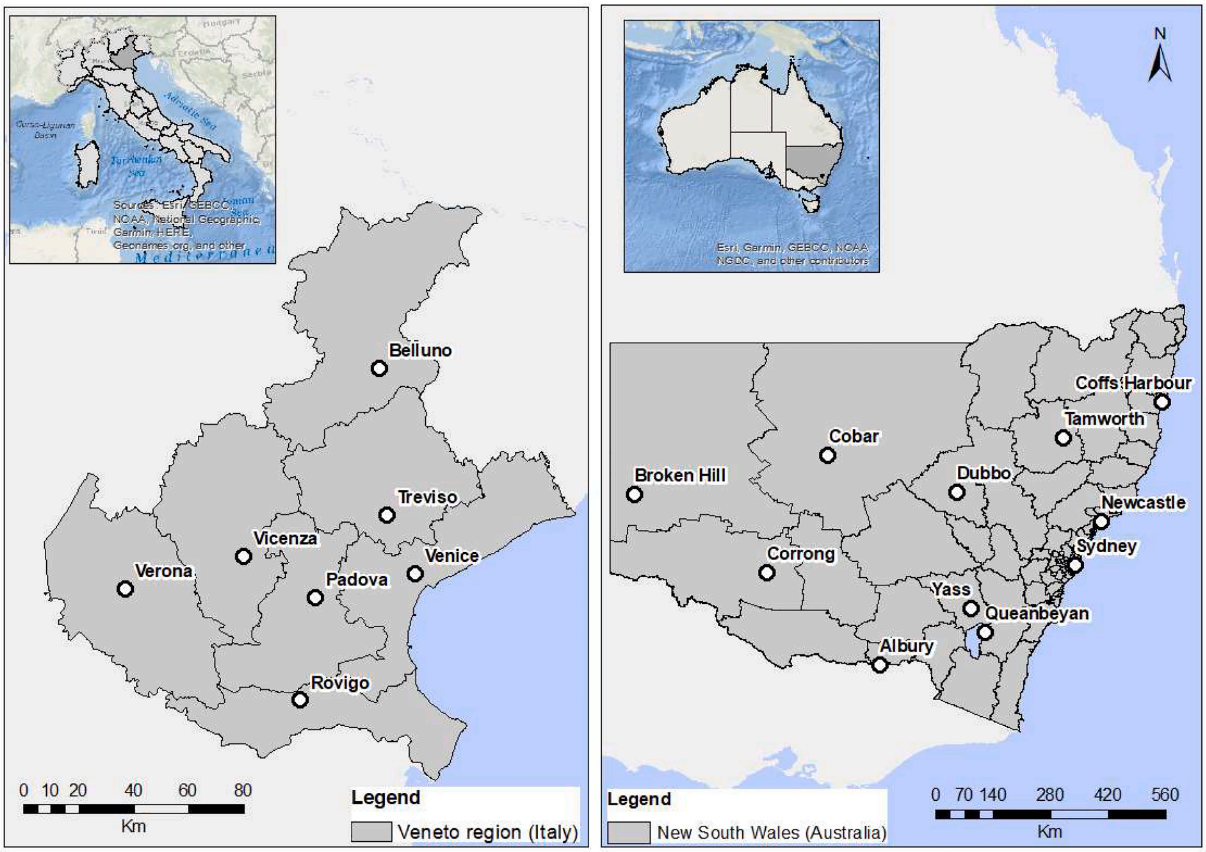

Fig. 2. Study area.

major benefits: (i) it helps to mitigate climate change, and (ii) it improves soil condition, health and fertility. Soil capability to sequester carbon can be increased by specific agricultural practices, such as conservation agriculture and cover crops. To ease comprehension, we provided respondents with specific figures related to the total amount of carbon sequestered by the associated hectares of agricultural land, compared to the total CO_2 emissions in the two countries. For example, Australian respondents knew that currently, agricultural land sequesters 0.1 % of the total carbon emitted, but such value could be increased up to 0.9 % by adopting the described practices. We acknowledge the challenge of providing an exact percentage for the increase in carbon sequestration through the adoption of sustainable practices in Australian agriculture. To align with the hypothesized scenarios presented in our study, we have based our scenario on the 4 per mille initiative (Minasny et al., 2017). This initiative, with its global significance in aiming to increase soil carbon content by 0.4 % per year, served as a reference in the creation of the attribute level. Understanding the concern one of our referees raised about the feasibility of uniformly applying this percentage across all regions, we emphasize that the last level of 0.9 % may not universally represent a reasonable approximation. Thus, we encourage readers to interpret these figures in the context of the inherent variability amongst regions.

Earthworm density refers to the number of earthworms living in the soil. Earthworms influence soil ecosystems by modifying soil's physical, chemical, and biological properties. Increasing earthworm density offers many benefits, such as increasing available nutrients, which can, in turn, improve farm productivity and sustain ecosystems. This process can be achieved through certain agricultural practices, such as the ones pertaining to the bundle of organic farming (e.g., cover crops, crop rotations, zero or minimum tillage, rotational grazing, etc.).

Rainfall water infiltration is the soil capability to absorb water at the land surface and either replenish the soil water store or the watertable depending on the soil texture. When rainfall hits the ground, a part infiltrates the soil, whereas the remaining part runs off the surface. Such runoff can initiate erosion, with losses of nutrients and agrochemicals. Rainfall water infiltration also increases the amount of water purified by the roots of crops, thereby contributing to the quality of water bodies and underground water. As such, preserving soil capability to infiltrate water is crucial to prevent erosion. Rainfall water infiltration can be increased by specific agricultural practices, such as the ones pertaining to the bundle of organic farming (e.g., cover crops, crop rotations, zero or minimum tillage, rotational grazing, etc.).

Nitrogen in groundwater is a major issue in the Veneto region (Italy), whereas in Australia it is not. Nitrogen pollution in water bodies and groundwater can cause environmental and health problems. An environmental issue is the flowering of algae in the Venice lagoon, which negatively affects fishing, aquaculture, and recreational activities. Nitrogen can also cause serious health issues for the population and, above certain concentrations level, can be fatal to newborn babies. Said issue has been handled in most developed countries through water purification systems, which generates costs to society. Soil can mitigate such problems by holding nitrates and preventing them from reaching groundwater and water bodies. The concentration of nitrates in groundwater can be reduced by using specific agronomics practices, such as conservation agriculture.

Salinity in groundwater is a major issue in New South Wales but not in the Veneto Region. Salinity is the quantity of salt dissolved in groundwater. An excessive level of salts in groundwater can cause several issues, such as (i) affecting crops and pasture production by interfering with nitrogen uptake; (ii) affecting the taste of drinking water (e.g., chloride). Sodium and magnesium sulphate levels in drinking water may also affect human health and reduce the suitability of a water supply for grazing animals; (iii) causing a lack of surface cover, which increases the vulnerability of soils to erosion. Overall, this

Table 2

Threats to soil functions, including suggested indicators for monitoring and amelioration strategies, ranked for their importance in each study region. Source: Adapted from Evangelista et al. (2023)..

Soil function	Threat	Indicator	Threat by region	
			Veneto	NSW
1. Biomass Production	(Accelerated) erosion	Aggregate stability; soil surface shear strength	*	***
	Decarbonisation	Genosoil's carbon content	**	**
	Acidification	pH buffering capacity	*	**
	Salinisation	Genosoil EC and ESP; deep drainage	*	***
	Contamination	Genosoil's biodiversity and CEC	**	*
	Soil sealing	Shrink-swell capacity	*	**
2. Carbon Storage	Decarbonisation	Current carbon content	*	***
3. Support biodiversity	Habitat loss/ degradation	Soil species richness	***	***
	Soil sealing	Land use intensity	**	**
4. Nutrient storage and regulation	(Accelerated) erosion	Aggregate stability; soil surface shear strength	***	***
5. Water storage, purification and regulation	Soil structural decline	Vulnerability to compaction	**	**
6. Contaminants filtering and remediation	Contamination	Genosoil's biodiversity and CEC	***	*
7. Source of raw materials	Soil sealing	Land use intensity	**	**
8. Cultural Heritage	(Accelerated) erosion	Aggregate stability; soil surface shear strength	**	**
	Acidification	pH buffering capacity	*	**
	Soil Sealing	Linear shrinkage	*	**

Note: the asterisks indicate the estimated significance of the threat in each region increasing from * to ***. Abbreviations. CEC: Cation Exchange Capacity; EC: Exchangeable Cations; ESP: Exchangeable Sodium Percentage.

issue can be partly solved with certain agricultural practices, such as the application of straw mulch and subsurface drainage.

The payment vehicle is a household tax, which describes how much it would cost the household to implement policies to increase ecosystem services. The costs consist of an annual state tax to be paid for the next 5 years. The tax would be used to financially support the implementation of land management plans and practices to increase ecosystem services at the state level.

The survey was carried out online in Italy (the Veneto region) and Australia (New South Wales) in 2019. It yielded 1548 complete interviews for the former and 1581 for the latter. The survey included a choice experiment and a bundle of items that collected the attitudes and preferences of the respondents towards environmental concerns based on the New Ecological Paradigm scale (NEP, Dunlap et al., 2000). The NEP scale is a set of fifteen validated statements aimed at measuring environmental concern. An example of a choice card presented to respondents in both countries is shown in Tables 4 and Table 5.

2.3. Econometric model

To analyse the choice data, we employed a Mixed Logit Model (MXL) specified in WTP space as described by Mariel et al. (2021) and Train and Weeks (2005). In this specification, the coefficients estimated for each of the x attributes serve as a direct measure of WTP values.

Table 3

Attributes and attribute levels for Italy (Veneto region) and New South Wales (Australia).

Attributes	Levels Veneto Region	Levels New South Wales
Soil Carbon Sequestration	0.20 t/ha/year (0.1 % of total CO2) 0.60 t/ha/year (0.3 % of total CO2) 1.20 t/ha/year (0.6 % of total CO2) 1.85 % t/ha/year (0.9 % of total CO2)	0.20 t/ha/year (0.4 % of total CO2) 0.80 t/ha/year (1.6 % of total CO2) 1.40 t/ha/year (2.7 % of total CO2) 2.0 % t/ha/year (3.9 % of total CO2)
Earthworm density	25 individuals/m2 (no increase) 50 individuals/m2 (200 % increase) 75 individuals/m2 (300 % increase) 100 individuals/m2 (400 % increase)	15 individuals/m2 (no increase) 25 individuals/m2 (167 % increase) 40 individuals/m2 (267 % increase) 60 individuals/m2 (400 % increase)
Rainfall Water Infiltration	23 % of rainfall (no increase) 28 % of rainfall (+5 %) 34 % of rainfall (+11 %) 40 % of rainfall (+17 %)	23 % of rainfall (no increase) 28 % of rainfall (+5 %) 34 % of rainfall (+11 %) 40 % of rainfall (+17 %)
Salinity in Groundwater		2000 μS/cm (no reduction) 1400 μS/cm (30 % reduction) 800 μS/cm (60 % reduction) 500 μS/cm (75 % reduction)
Nitrogen in Groundwater	11.9 mg/l (no reduction) 8.3 mg/l (30 % reduction) 4.8 mg/l (60 % reduction) 1.8 mg/l (75 % reduction)	
Household tax (A$)	5 € 10 € 25 € 50 € 100 € 180 €	10 A$ 20 A$ 50 A$ 100 A$ 210 A$ 375 A$

Table 4

Example of a choice card for the Australian survey.

Attribute	Alternative 1	Alternative 2	Status quo
Carbon sequestration (t/ ha/year)	0.2 (0.1 % of total CO2)	1.2 (0.6 % of total CO2)	None
Earthworms density (individuals/m2)	25 (no increase)	50 (200 % increase)	
Rainfall water infiltration (%)	40 (+17 %)	23 (no increase)	
Salinity in groundwater (mg/l)	800 (60 % reduction)	2000 (no reduction)	
Household tax (A$)	10	20	
I choose	○	○	○

Table 5

Example of a choice card for the Italian survey.

Attribute	Alternative 1	Alternative 2	Status quo
Carbon sequestration (t/ ha/year)	0.2 (0.4 % of total CO2)	1.4 (2.7 % of total CO2)	None
Earthworms density (individuals/m2)	15 (no increase)	25 (167 % increase)	
Rainfall water infiltration (%)	40 (+17 %)	23 (no increase)	
Nitrogen in groundwater (mg/l)	4.8 (60 % reduction)	11.9 (no increase)	
Household tax (€)	5	10	
I choose	○	○	○

Specifically, they quantify the mean marginal WTP for a one-unit change in the associated attribute. Our model selection facilitates a detailed understanding of individual preferences, enabling the direct quantification of the economic value associated with changes in the attributes under consideration.

The utility of alternative *I* for respondent n in choice occasion t is expressed as:

$$U_{nit} = \lambda_n^* \left(\omega_n^{'} X_{it} - p_{it} \right) + \varepsilon_{nit}$$

Where *X* is a vector of non-monetary attributes (in our case, the soil functions), *p* is the cost attribute and $\omega_n^{'}$ is a vector of marginal WTP values for each non-monetary attribute. λ_n^* is defined as $\lambda_n \delta_n$, where λ_n is the scale of the i.i.d Gumbel error ε_{nit} and δ_n is the coefficient of the cost attribute for respondent *n.*

The model was estimated by simulated maximum likelihood with the R package Apollo (Hess and Palma, 2019). Choice probabilities were simulated in the sample log-likelihood with 1000 Sobol draws. All the coefficients for the non-monetary attributes were assumed to follow a normal distribution, whereas a log-normal one was assumed for the cost coefficient. The dataset and code used during the current study are available from the corresponding author upon reasonable request.

2.4. Regression estimates

The model employed in this paper allows us to calculate estimates of individual-specific preferences. This is achieved by deriving the conditional distribution based on their known sequence of choices within the sample (Train, 2009). The derivation of individual-specific parameters is obtained using Bayes' theorem, where the conditional density for the random parameters is expressed through the following equation. These estimates are not standalone values for each individual but rather offer a mean and standard deviation estimate for the subpopulation that makes similar choices (Train, 2009).

$$p(\beta_n | Y_n, X_n, \theta) = \frac{L(Y_n | \beta_n, X_n, \theta) f(\beta_n, \theta)}{\int_{\beta_n} L(Y_n | \beta_n, X_n, \theta) f(\beta_n, \theta) d\beta_n}$$

Here,

Y_n denotes the respondents' chosen alternatives in their sequence of choices over the choice occasions, X_n includes all elements of X_{ntj} for all *t* and *j*, and θ represents the underlying parameters of the distribution of β_n.

To investigate the drivers of differences in willingness to pay values across the two countries, we analysed the effect on individual WTP values of socio-economic characteristics, attitudes towards soil protection, and general environmental concern. The derived marginal willingness-to-pay values (mWTP) at the individual level for each attribute served as the dependent variable in a regression analysis. This regression aimed to assess whether differences in these attitudinal and socio-economic variables could contribute to explaining the observed variations in WTP scores between the two countries. Table 6 describes the explanatory variables used in the regression.

3. Results

3.1. Sample characteristics

Table 7 presents the descriptive statistics of the sample. Starting from age, the distributions within the two samples are quite similar. For Italy, the mean is 46.10 years, and for Australia, it is 45.41 years. In both cases, the age segment 40–59 years old is the most represented (44.0 % for Italy and 39.61 % for Australia), and well represented are also the segments including older individuals (22.19 % for Italy and 22.96 % for Australia) and younger ones (around 35 % in both countries). Gender is evenly balanced in both datasets. Moving to education, most of the Italian sample is characterised by a secondary school level (65.10 %), while most of the Australian respondents are graduates (56.05 %). These data are well aligned with the different levels of education of the two countries: according to OECD data, 45.7 % of Australian citizens aged between 25 and 64 years have a tertiary education level, while the value is 19.3 % for Italy.

Table 6
Description of independent variables in regression analysis.

Variable	Description
Government should spend more on environmental protection	Respondent's perception of the need for increased government spending on environmental protection.
Citizens are the main responsible for environmental protection	Belief regarding the primary responsibility for environmental protection (citizens or others).
Importance of soil degradation	Perception of the significance of soil degradation as an environmental concern.
Importance of soil consumption	Perception of the significance of soil consumption as an environmental concern.
Average score NEP Scale	Average score on the New Environmental Paradigm (NEP) Scale, measuring environmental attitudes.
Age	Respondent's age in years.
Degree	Educational attainment level.
Income	Annual income level of the respondent.
Male	Binary variable indicating gender (1 for male, 0 for female).
Working in the agricultural field	Binary variable indicating whether the respondent works in the agricultural field (1 for yes, 0 for no).
Belonging to an environmental association	Binary variable indicating membership in an environmental association (1 for yes, 0 for no).
Australian	Binary variable indicating nationality (1 for Australian, 0 for Italian).

Table 7
Descriptive statistics for the two samples.

	Veneto Region		New South Wales	
	n	%	n	%
Age				
20 or less	69	4.57	66	4.34
21 - 39	431	28.54	503	33.09
40 - 59	675	44.70	602	39.61
60 or more	335	22.19	349	22.96
Mean	46.10		45.41	
Gender				
Man	761	50.40	757	49.80
Woman	749	49.60	763	50.20
Education				
None	3	0.20	6	0.39
Primary school	10	0.66	12	0.79
Secondary school	983	65.10	528	34.74
Degree	448	29.67	852	56.05
Postgraduate qualification	66	4.37	122	8.03

3.2. Willingness to pay for reducing threats to soil functions

Our analysis of the stated choices reveals that Australian citizens are willing to pay, on average, $14.6 for an additional ton of carbon sequestered per year per hectare (Fig. 3). In Italy, the value is substantially higher and amounts to $28.5. Moving to earthworm density, in Australia, the average willingness to pay equals $11.6 for ten additional individuals per square metre, while in Italy, the value is higher ($16.8). Rainfall infiltration shows a similar willingness to pay values across the two countries, with $4.7 for Australia and $5.1 in Italy (for a 10 % increase). On average, Australian citizens are willing to pay $8.0 for a decrease of 100 μS/cm of salinity in groundwater, and Italian ones $12.0 for a decrease of 10 mg/l nitrates. The values are expressed in Australian dollars (we converted the original values in euros from the Italian sample using OECD exchange rates adjusted for purchase power and

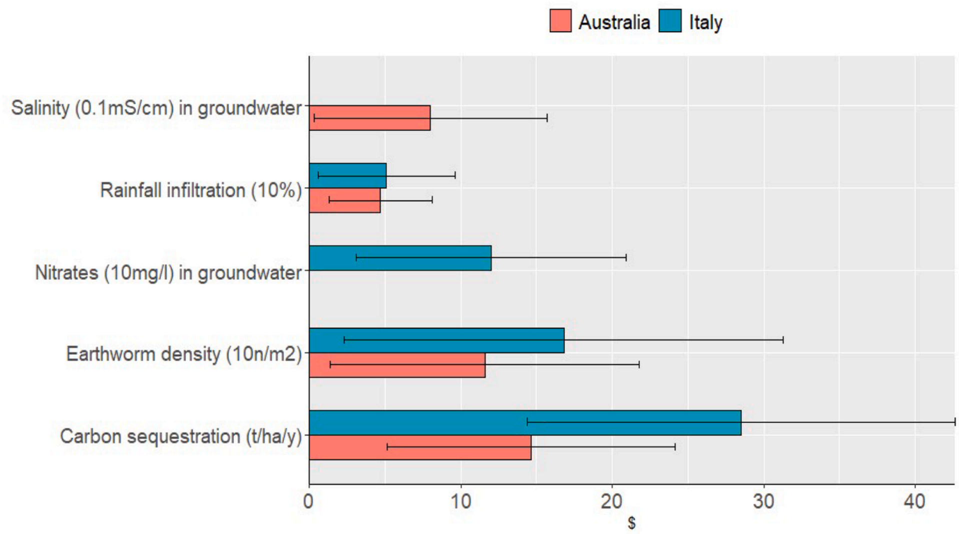

Fig. 3. Marginal willingness to pay in $ for soil attributes as an annual tax for the next 5 years. The values are expressed in Australian dollars, and for Italy, the original values in euros were converted using OECD exchange rates adjusted for purchase power and average salary. The error bars indicate standard deviations.

average salary).

Results from the regression analysis, where we regressed our individual WTP estimates on attitudinal and socio-economic variables, are presented in Table 8. Our findings highlight the role of attitudes towards environmental protection since a higher percentage of Italian citizens think the government should spend more on environmental protection and that citizens are mainly responsible for environmental protection. Italian citizens also score higher on average on the New Ecological Paradigm scale and seem to attach more importance to environmental issues.

Distinct differences between Italy and Australia emerge in socio-economic dimensions, revealing a higher percentage of Italians employed in the agricultural sector, while Australians boast higher average incomes and education levels. Delving into the impact of attitudinal traits on WTP values for carbon sequestration, our analysis reveals that individuals favoring increased government spending (8.980, $t = 15.93$) and considering citizens responsible for environmental protection (6.201, $t = 2.22$), along with those prioritizing soil degradation (1.834, $t = 3.05$) and holding elevated environmental concerns (3.123, $t = 2.56$), exhibit a higher willingness to pay. This profile is more prevalent in Italy, aligning with our hypothesis that attitudinal nuances contribute, at least partially, to disparities in WTP values between the two countries. Moreover, our results indicate that older (0.108, $t = 7.65$), affluent (0.147, $t = 1.91$), and less educated (−0.595, $t = 12.28$) males demonstrate a greater willingness to pay for carbon sequestration. The positive impact of working in the agricultural field (4.836, $t = 5.35$), notably more common in Italy, suggests a potential correlation with a deeper understanding of soil-related issues. Similar patterns emerge for earthworm density, where WTP values are notably higher in Italy, reinforcing the influence of both attitudinal and socio-economic factors on individual preferences for soil functions.

To provide a comprehensive picture of the value arising from reducing threats to soil security, we present the capital value of soil management programs that would result in sustainable soil capability in both regions, defined here as an improvement from baseline to third level of each attribute (Table 3). Aggregated value estimates show that the WTP value estimated for the entire population lies in the order of $244 M for Veneto and twice as much for New South Wales. Furthermore, we conducted estimations to quantify the economic benefits of maintaining or enhancing two specific programs: soil carbon insetting for achieving net-zero agriculture and creating biodiversity credits based on soil microbial diversity. The findings from these estimations are presented in Table 9. For the soil carbon insetting program, we obtained WTP estimates by keeping all other functions constant and considering the improvement from the baseline to the third level of carbon sequestration. The results indicate positive WTP values for both

Table 8
WTP regressions.

	Carbon sequestration		Earthworm density		Rainfall infiltration		Decreasing salinity		Decreasing nitrates	
Variable	Estimate	|t|	Estimate	|t|	Estimate	|t|	Estimate	|t|	Estimate	|t|
Intercept	−27.098	40.26	4.553	38.17	1.117	7.22	−0.813	8.12	−7.569	49.23
Government should spend more on environmental protection	8.980	15.93	1.162	20.29	0.071	7.71	0.011	0.76	0.265	2.76
Citizens are the main responsible for environmental. protection	6.201	11.07	0.224	3.36	0.010	0.97	0.011	0.64	0.021	0.29
Importance of soil degradation	1.834	3.05	−0.091	1.51	0.013	2.92	0.034	1.94	0.031	0.47
Importance of soil consumption	0.782	1.40	0.012	7.86	0.001	1.03	0.001	2.37	0.003	2.52
Average score NEP Scale	3.123	2.56	0.231	3.23	−0.109	0.98	0.025	3.21	0.009	3.21
Age	0.108	7.65	0.757	14.92	0.229	0.45	−0.003	0.20	0.057	0.95
Degree	−5.595	12.28	−0.012	1.54	−0.044	5.75	0.004	2.44	0.010	1.31
Income	0.147	1.91	0.720	11.45	0.004	0.28	0.004	0.19	0.065	1.13
Male	0.947	2.22	0.430	4.46	0.052	5.60	−0.007	0.30	−0.008	0.06
Working in the agricultural field	4.836	5.35	0.126	2.69	0.030	2.00	0.025	1.96	0.079	2.40
Belonging to an environmental association	−0.439	0.63	0.259	2.62	0.006	0.75	0.055	2.03	0.078	0.66
Australian	−3.709	2.30	−0.132	2.02	0.012	0.77	–	–	–	–
	R-squared: 0.61		R-squared: 0.64		R-squared: 0.41		R-squared: 0.51		R-squared: 0.39	
	F-statistic: 84.57		F-statistic: 18.81		F-statistic: 98.13		F-statistic: 2.232		F-statistic: 2.209	

Table 9
WTP for policy programs as an annual tax for the next 5 years.

Policy program		Veneto Region	New South Wales
Improvement of **all** soil functions from baseline to the maximum level	Average individual WTP ($)	49.80	69.47
	Total WTP ($)	**244,318,800**	**567,292,020**
Improvement of **carbon sequestration** function from baseline to the third level	Average individual WTP ($)	47.05	26.35
	Total WTP ($)	**230,827,300**	**215,174,100**
Improvement of **earthworm density** function from baseline to the third level	Average individual WTP ($)	24.68	18.18
	Total WTP ($)	**121.080.080**	**48.457.880**
	Total population	4906,000	8166,000

regions under study. Similarly, by considering the improvement from the baseline to the third level of earthworm density while keeping other functions constant, we derived WTP values for the creation of biodiversity credits based on soil microbial diversity policy program. Notably, the WTP values for the soil carbon insetting program were found to be higher than those for the biodiversity credits based on soil microbial diversity. However, it is noteworthy that residents from both countries showed interest in supporting both programs, indicating a willingness to contribute to these initiatives.

4. Discussion

Our study aimed to contribute to the literature on how the general population values soil functions and whether they wish to see their maintenance and improvement as part of public policy. We show via a discrete choice experiment of overall 3000 citizens interviewed on two continents that societies in distant and contrasting regions of Veneto in Italy and New South Wales in Australia are willing to pay for soil security and financially support soil management practices that improve soil functions in their regions. We are amongst the first studies to present an estimate of willingness to pay for publicly-funded soil management strategies.

The results presented here show positive WTP values for improvements in the provisioning of soil functions in both study areas. This indicates the importance of accounting for soil functions in resource management, as societies benefit from them and are willing to pay for their conservation. When comparing the estimates in monetary terms across the two countries, we investigated the drivers of the differences between them and found that socio-economic characteristics, attitudes towards soil protection, and citizens' general environmental concern influence the WTP values. Specifically, we found differences in the respondent's attitudes toward environmental protection. For instance, according to the NEP statements, Italian citizens seem to attach more importance to environmental issues. Such results are consistent with previous global surveys, which found that Italian citizens are more sensitive to environmental issues, such as climate change (YouGov, 2019). Similarly, characteristics at the macro-level partially explain differences in WTP values across the two countries, such as working in the agricultural field. This result is in agreement with Bartkowski et al. (2020), who stated that individuals from the same population might weigh soil ecosystem services diversely and, therefore, attach different values to a certain soil management program.

In our empirical study, a broad spectrum of soil-based ecosystem services was included employing a preference-based methodology, which so far has been scarce in the soil valuation literature (Bartkowski et al., 2020). We provided a more comprehensive picture of the value derived from addressing threats to soil security, revealing that the capital value of soil management programs is approximately $244 million for the population in the Veneto region and nearly double that amount for New South Wales, reaching $567 million. To contextualize these values for our readers, we compared them to Australia's current budget for environmental and agricultural programs, which stands at $148 million annually (Parliament of Australia, 2023). Notably, even in the absence of a specific allocation for soil health programs, the capital value of soil management programs for New South Wales alone far exceeds this budgetary figure. Similarly, in the Veneto region, where the budget allocation for environmental issues is €$8 million over 2023–2025 (Regione Veneto, 2023), our aggregated estimated value far surpasses this budget allocation. This comparison serves to underscore the substantial economic implications and the potential significance of prioritizing soil management programs. Furthermore, our results align with previous studies that have demonstrated a substantial willingness to pay for soil improvement as a public good (Bartkowski et al., 2022).

Our research findings give decision-makers and resource managers insights into societies' willingness to make trade-offs in favour of increased soil security. In contrast to climate change and loss of biodiversity, soil degradation and loss of soil functions have received much less attention. In our study, we used indicators related to the economic value of soil as a proxy to assess the capital dimension of the soil security framework in the two regions under investigation. For most of the soil functions recently listed and described by Evangelista et al. (2023), the economic valuation of soil-based ecosystem services plays a key role in the capital dimension. We have explored the link between the concept of soil security and economic valuation by investigating willingness to pay as an indicator to assess soil security quantitatively, in one of its dimensions, for a range of soil functions. It should be noted that soil functions related to the most significant potential threats to soil have been investigated in this choice experiment; however, many others should be investigated.

Within the soil security framework, economic valuation offers significant opportunities for policy development. One such area is the creation of biodiversity credits based on soil microbial diversity. Our choice experiment included an attribute related to earthworm density, allowing us to estimate the economic benefits of maintaining or enhancing soil microbial diversity. While we recognize that the chosen attribute directly measures biological activity rather than microbial diversity, it serves as a viable proxy for evaluating the impact of the microbial diversity program on the soil ecosystem based on its practicality and relative ease of measurement. Our findings showed positive estimates for the support of the program, which can guide policy-makers in designing financial incentives to encourage farmers to adopt land management practices that promote soil microbial diversity and, consequently, qualify for biodiversity credits. Notably, while biodiversity credits are currently being created in Australia for farmers, they do not yet encompass soil biodiversity; however, future inclusions are anticipated (Department of Climate Change, Energy, 2022).

Another area for policy development is in the context of achieving net-zero agriculture through soil carbon insetting. We have estimated the economic gains associated with soil carbon insetting through the adoption of agricultural practices that increase the retention of organic matter in the soil. These findings provide valuable information for policy-makers and agricultural stakeholders and highlight the value individuals place on soil attributes and functions, emphasizing the need for effective policies and incentives to promote soil conservation. It's crucial to highlight that the policy programs introduced in our study, despite not currently existing in any of the countries under consideration, serve as a demonstration of respondents' willingness to pay for soil conservation. This reflects the perceived relevance of these programs, thereby illustrating their potential applicability and importance across diverse geographical contexts.

Further research is needed across the world to recognise global norms, find hot spots and cold spots for willingness to pay, and relate these to the severity of soil insecurity. Full-scale soil amelioration plans could be budgeted according to the willingness to pay values for a wider range of soil functions than those investigated here to tailor funds devoted to soil protection to socially optimal levels of investment. Further work is needed to: (a) conduct similar studies worldwide to detect spatial patterns, (b) survey a wider range of potential threats to soil and management options, and (c) investigate mechanisms for translation into public policy.

5. Conclusions

In this study, we provided an estimation of the value, expressed in monetary terms, that individuals from two distant and contrasting regions place on several soil functions. Our analysis, with a focus on the Veneto region in Italy and New South Wales in Australia, constitutes a step forward in the global mapping of the soil insecurity problems of today. Furthermore, it evidences peoples' preferences to improve soil condition and, in the longer term, to achieve soil security. The next steps to expedite the global mapping would involve several similar studies, which may be achieved through the collaboration of international agencies such as the CGIAR institutions and the UN FAO Global Soil Partnership. Mapping global preferences for soil condition amelioration would offer the opportunity to apply benefit transfer techniques for assessing more expeditiously whether benefits justify management actions. Other steps that are required to achieve soil security include improved soil connectivity, which requires education and training of landholders and increased public and policy-maker awareness of soil-related issues and their resolution. There are regional differences, the causes of which remain to be ascertained. In this empirical research, we provide evidence of the importance of accounting for soil functions in resource management, as societies benefit from them and are willing to pay for their conservation. We anticipate our surveys to be a starting point for the global mapping of soil function values to inform soil management and policy since the value individuals place on the services provided by soil should strongly influence decisions on its use over a given area for any period (Table A1).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A

Table A1
Results of the mixed logit model.

	Veneto region		New South Wales	
	Coefficient	|t|	Coefficient	|t|
Mean Values				
Carbon sequestration (t/ha/y)	28.52	7.04	14.64	5.58
Earthworm density (n/m^2)	1.68	13.60	1.16	11.64
Rainfall infiltration (%)	0.51	11.42	0.47	10.26
Salinity (μS/cm) in groundwater	–	–	0.08	11.31
Nitrates (mg/l) in groundwater	1.20	14.95	–	–
Status quo	−60.78	7.41	−31.01	15.43
Standard deviations				
Carbon sequestration	14.12	10.58	9.51	5.60
Earthworm density	1.45	2.10	1.02	5.88
Rainfall infiltration	0.45	5.22	0.34	4.98
Salinity in groundwater	–	–	0.12	9.50
Nitrates (mg/l) in groundwater	1.58	16.99		
Status quo	25.29	20.40	14.32	17.58
Price/scale coefficient				
Mean	1.05	22.44	1.08	23.08
Standard deviation	1.06	21.51	1.13	27.87
Number of observations	18,084		18,240	
Log-likelihood	−13,986.55		−14,738.38	

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