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SOLUTIONS AND MITIGATION STRATEGIES AGAINST SOIL DEGRADATION

"Each one of us matters, has a role to play, and makes a difference. Each one of us must take responsibility for our own lives, and above all, show respect and love for living things around us, especially each other".

Jane Goodall.

Michaela Oriolo – FEEM

Francesca Morigi – FEEM

Summary

LIST OF FIGURES

LIST OF TABLES

1. SUSTAINABLE SOIL MANAGEMENT AND SOIL REMEDIATION

Land degradation is a global problem often caused by the combination of several factors such as poor land management, unsustainable agricultural practices, pollution and deforestation. Land degradation may exacerbate the impacts of natural disasters and contributes to social issues such as migration.
Land and soil are precious resources for life on our planet and they are estimated to run out over time. Therefore, it is necessary to act promptly to prevent their degradation and promote their use and management in a sustainable way [1].

Actions to address land degradation and desertification can offer co-benefits for other key environmental issues such as water stress and pollution, biodiversity loss, climate change and food insecurity. The development of techniques for the remediation and recycling of soils polluted or damaged by anthropic action is undeniable when serious environmental contamination has already occurred.

Unfortunately, the absence of a comprehensive and coherent policy framework aimed specifically at the protection of European land and soil resources still represents a key absence. This leads to a reduced effectiveness of the existing incentives and measures and to limits Europe's ability to achieve future objectives related to this topic [2]. Europe is not on track for achieving both the goal of the biodiversity loss prevention strategy and the strategic goal of "net land use equal to zero by 2050" [1]. Furthermore, among European countries, there is a strong heterogeneity of measures and policy actions aimed at limiting the degradative phenomena, accompanied by a lack of reliable, adequate and consistent monitoring systems [2].

Progress on sustainable development in Europe will be observable if and only if land and soil resources are properly addressed. All these factors together further contribute to the development of soil degradation across the European territory and the precariousness and inefficiency of existing policies [2].

Attention must now be paid to expanding, accelerating, rationalizing and implementing the many solutions and innovations, both technological and social, that already exist, while stimulating additional research and development, catalyzing behavioural changes and listening to and involving citizens [2].

This e-library aims to illustrate the concepts and principles of sustainable soil management and to briefly describe the main soil remediation technologies and initiatives against soil degradation. In addition, the European policy framework and the objectives set by the new political cycles will be illustrated, to understand the European efforts towards sustainable management of soil and land resources in the medium and long term.

1.1 Sustainable soil management

1.1.1 General aspects

There is a deep interdependence between soil quality and soil management practices.
First of all, soil quality means "*the ability to function within an ecosystem and with respect to the land use by maintaining bio-logical productivity, maintaining environmental quality and promoting plant and animal vitality*" [3].

Better and more efficient soil management systems entail both direct and indirect benefits in environmental, economic and food terms; in particular [4]:

- The improvement of the efficiency and effectiveness in the use of resources (e.g. nutrients and water) allows to reduce the input costs (e.g. fertilizers and pesticides) and the quantities of extra nutrients released by leaching into the surface and/or underground aquifers.
- The adequate management of soil biota allows to protect diversity, improving soil resilience and at the same time reducing the risk of pollution and degradation of ecosystems and natural resources.
- The adoption of more sustainable management and production practices entails the improvement of agricultural yields, the quality of food products and the vegetative growth of crops.

Furthermore, the concept of sustainable soil management plays an extremely important role for the United Nations Framework Convention on Climate Change (UNFCCC), the Convention to Combat Desertification (UNCCD) and the United Nations Convention on Biological Diversity (UNCBD) because it allows to address many of the existing global challenges and achieve the objectives and targets imposed by international policies and initiatives, such as [5]:

- The United Nations Sustainable Development Goals of the 2030 Agenda;
- The "Zero Hunger" Goal for the end of hunger and malnutrition in the world;
- Mitigation and adaptation to climate change concerning the 2015 Paris Agreement;
- The fight against desertification and drought, as well as the commitment to obtain a "neutralization of soil degradation worldwide (UNCCD COP12);

– Aichi's objectives[1] aimed at preserving biodiversity and the provision of ecosystem services essential to life.

How the soil is managed and used by humans has a profound effect on its quality and properties and consequently on the environmental and economic sustainability of the agricultural sector [1], [3], [6]. Remember that soils have different physical, biological and chemical properties that determine different responses to management practices, the ability to provide ecosystem services and the vulnerability to the processes and phenomena of degradation to which they are subject.

Furthermore, the future holds other challenges for land and soil resources, which are required to respond to the [7]:

– Increase in the world population;
– Increasingly worrying effects of climate change;
– Spread of the phenomenon of water stress;
– Requirement to reduce the strong dependence on fossil fuels;
– Need to meet the needs of future generations with increasingly scarce primary resources;
– Potential social unrest.

Therefore, new strategies have to be adopted to produce more with less, decreasing waste production, reducing land and soil losses and encouraging a more efficient use of these resources [8].

1.1.2 Sustainable soil measures-circular economy-bioeconomy nexus

Sustainable soil management is achieved by implementing measures and actions strongly linked to the basic principles of the circular economy.
Let's start with two definitions:

1. "*Soil management is sustainable if the support, procurement, regulation and culture services provided by the soil are maintained or improved without significantly compromising the soil functions that allow them*" [5];
2. "*A circular economy is an industrial system that is restorative or regenerative by intention and design*" [9], [10].

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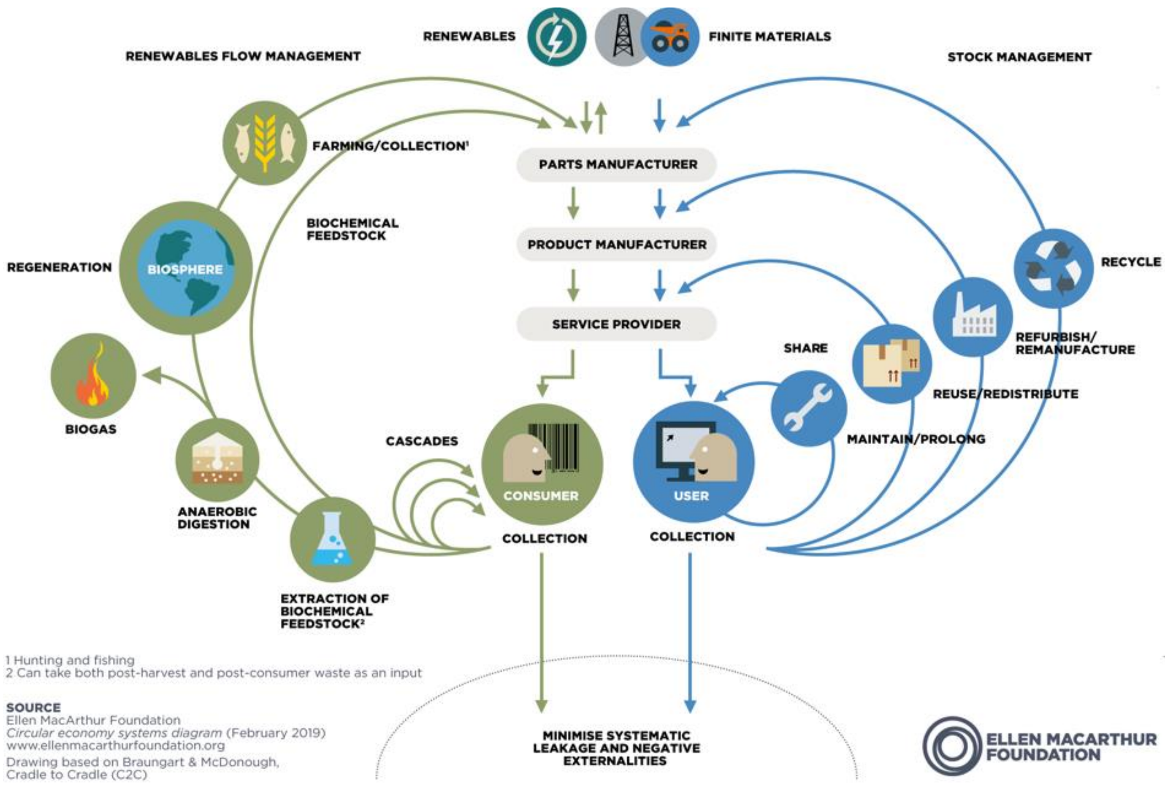
[1] 20 goals set by the Strategic Plan for Biodiversity 2011-2020, drawn up in Nagoya, Aichi prefecture, Japan, in 2010. The plan had identified 20 goals to be achieved by 2020 to fight biodiversity loss, reduce direct pressure on biodiversity, promote sustainable use, safeguard ecosystems and genetic diversity, enhance benefits from biodiversity and enhance implementation [77].

Figure 1. Circular economy key principles. Retrieved from [10], *Index 16.*

The circular economy has three basic principles (Figure 1): design out waste and pollution, keep products and materials in use and regenerate natural systems [10]. In other words, the circular economy aims at durability, reuse, regeneration and recycling of products in subsequent production cycles. In a circular economy, the flows of materials can be biological (capable of being reintegrated into the biosphere) and technical (destined to be revalued without entering the biosphere).

Therefore, it promotes the circularity of the production and consumption processes, in such a way as to consider waste as a new resource and reduce the wastes' production (see Figure 2).

Figure 2*. Circular economy system. Retrieved from* [9], *p.24.*

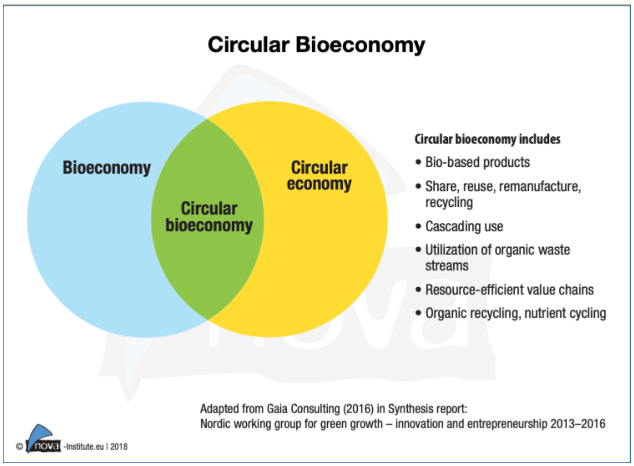


A circular economy provides and lays the foundations for promoting the adoption of sustainable management practices by ensuring more efficient use of land and soil resources. On the other hand, sustainable soil management and the initiatives derived from it represent a strictly necessary tool to demonstrate and illustrate the benefits resulting from the transition to a circular economy, not only for the economic and industrial system but also for society and the environment.

The initiatives proposed by sustainable soil management (use of organic waste, renewable, clean and green energy sources, production of bio-based and organic products, etc.) are also associated with the bioeconomy, namely the economic theory that "*encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, feed, bio-based products and bioenergy*" [11], [12].

In particular, the bioeconomy contributes to climate change mitigation by realizing products with low GHG emissions processes, providing renewable materials capable of breaking down the strong dependence on fossil fuels and creating new business opportunities, jobs and investments [13].

Figure 3*. The circular bioeconomy schematic representation. Retrieved from* [13]*, p.4.*



The bioeconomy, in turn, contributes and completes the circular economy in various ways. For this reason, some experts prefer to speak about "*circular bioeconomy*" to indicate the intersection between the circular economy and the bioeconomy, as they present different but complementary approaches [13] (see Figure 3). Points common to the two systems are a more efficient use of resources, reduction of the GHG footprint, lower demand and use of fossil fuels and waste enhancement [13].

1.1.3 Improvement techniques for sustainable land use and management

Sustainable soil management involves the adoption of practices, interventions and techniques, the main objective of which is to preserve the health and quality of the soil, improve the soil organic matter (SOM) content and minimize the occurrence of land degradation phenomena by [7], [8], [14]:

- Reducing natural resource losses;
- Compensating for disturbances caused by traditional cultivation and harvesting practices;
- Balancing nutrient cycles;
- Minimizing external artificial inputs;
- Strengthening recycling mechanisms.

This, in most cases, translates into the improvement of agronomic management practices and the agricultural system.

On the other hand, the adoption of these techniques and technologies is particularly complex, as the solutions are many and strongly site-specific and crop-specific [8], [15], [16]. Therefore, there is no "*silver bullet solution* [7]", but each strategy is unique and specific for each case. The overall effectiveness of sustainable management practices depends on [7], [15]:

- Type of soil;
- To what extent the nature, scope and severity of the degradation processes are addressed;
- The bio-physical, social, economic and political context;
- Climatic conditions, including the high uncertainty and variability created by climate change.

Thus, to develop effective strategies it is necessary to adopt integrated, coordinated and multisectoral approaches capable of considering different visions, contexts and conditions to adapt the interventions to the political, ecological, environmental and social framework of the area in which we act, considering its peculiarities, prerogatives and available resources [8], [15].

Some of the interventions aimed at the sustainable development of soil, agriculture and other natural resources will be briefly discussed below.

Conservation agriculture

Conservation agriculture (Figure 4) is an agricultural system aimed at ensuring soil protection and the enhancement of its conditions, reducing land degradation and promoting the efficient use of water and nutrients [17].

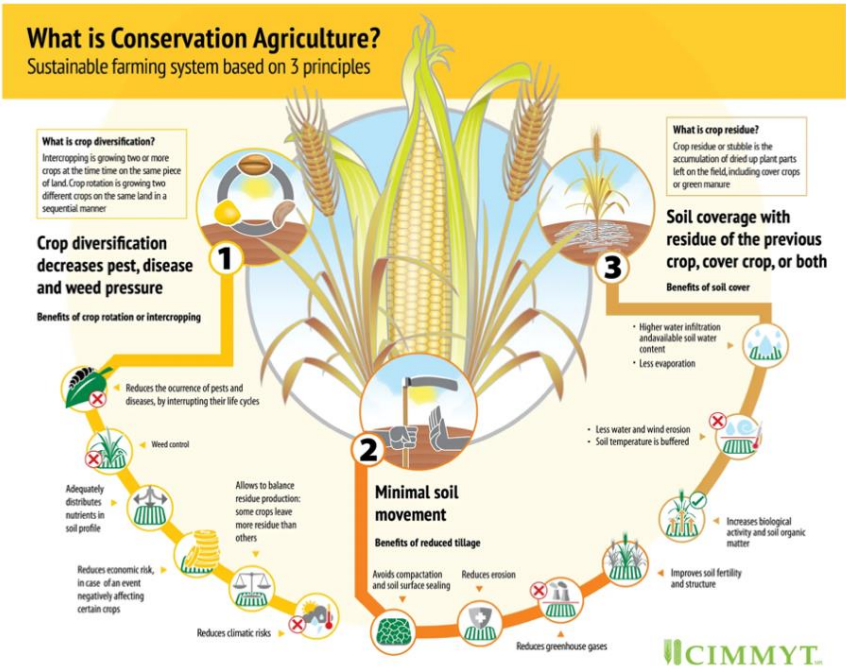
Conservation agriculture has three fundamental principles [8], [16]–[18]:

1. Minimum mechanical soil disturbance. Among the techniques promoted are no-tillage and conservation tillage. These practices slow down and/or reduce erosion phenomena, compaction and imperviousness, promote root growth and improve the soil organic carbon content (SOC) [15], [18];
2. Permanent soil coverage through conservation of crop residues and cover crops. The latter is defined as "*plant biomass grown to provide a protective cover to prevent soil erosion and to limit nutrient loss by leaching or in runoff*" [16]. Many plants can be employed as cover crops, among the most widely used are legumes (e.g. soybeans, peas, and beans) and grasses (including cereals), even if there is a growing interest in brassicas (turnips, mustard, and

forage radish) and buckwheat [20]. In addition to monoculture, combinations of cover crops are also preferred to maintain or increase the concentrations of carbon and nitrogen in the soil and provide additional crop residues [16].

3. Crop diversification by introducing varied crop sequences and associations with at least three different crops [15], [17]. This solution, universally applicable to all agricultural and rural contexts, involves the improvement of crop yields and guarantees food security [15].

Figure 4. *Conservation agriculture in a nutshell. Retrieved from* [19].



To avoid interfering in the biological processes that occur within the soil ecosystems the conservation agriculture proposes the integrated management of nutrients and the optimization of the application of phytosanitary products (e.g. pesticides) [8], [15]. In particular, it is recommend an adequate balance between chemical and biological fertilizers, the recycling of organic by-products and the application of organic amendments (e.g. biochar) and green fertilizers (e.g. algal-based biofertilizers) [7], [8].

In general, the conservation agriculture entails the following benefits [7], [8], [15]–[17], [21]:

– Minimization of erosion and soil compaction;
– Reduction of water pollution;
– Improvement of soil structure, fertility and physical properties (e.g. water infiltration);

- Improvement of biodiversity and biotic activity of the soil;
- Improvement of the of the soil
- Greater carbon sequestration and increased SOC content. Thus, the adoption of conservation cultivation practices contributes to the fight and mitigation of climate change by ensuring a reduction in CO_2 emissions [22];
- Reduction of energy consumption and in the use of fossil fuels;
- Increase in agricultural yields.

Among the limits that influence its adoption are the strong market pressures towards monoculture production, the climatic conditions, the availability and access to technologies and incentives and the lack of adequate training and information [15].

Agroecology

The current food system does not provide good nutrition and threatens food security, contributing to environmental degradation and biodiversity loss [23].
Agroecology is an ecological theory that, through the introduction of ecological concepts and agricultural practices, aims to create and optimize the biological interactions and synergies between the components of the agroecosystems (e.g. plants, animals, humans and the environment) [23], [24].

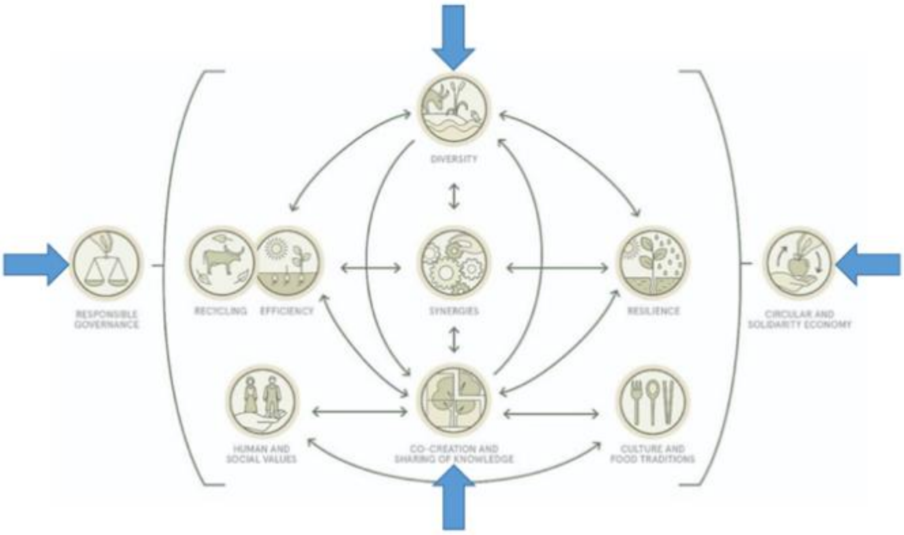
In particular, thanks to a careful analysis of the biological literature, thirteen principles, well aligned with the ten elements of agroecology defined by FAO, have been developed and consolidated (see Figure 5) [23]. These principles imply the adoption of diversified and adaptable practices to the specific local, social, environmental and political context, promoting knowledge and the exchange of information between the principal players in the sector [23].

The agroecology, therefore, supports the transition towards more sustainable and equitable agri-food systems through the implementation of approaches and paths easily adaptable to local economies and markets, such as to strengthen the economic viability of rural areas and ensure a better quality of life [23], [24], providing better means of subsistence and contributing to the mitigation of climate change.

***Figure 5**. (a) Agroecology consolidated principles. Adapted from* [23]*, p.9. (b) FAO agroecology elements. Retrieved from* [23]*, p.9.*

(a)

(b)



This ecological theory is a transdisciplinary, multisectoral and participatory approach and, thus, offers several sustainable benefits, including [15], [18], [23], [24]:

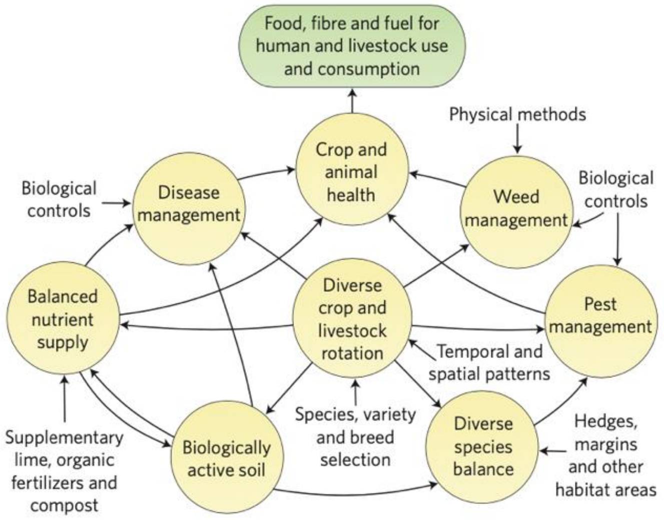
- Optimization of species diversity and genetic resources, preserving above and underground biodiversity;
- Improvement in the provision of ecosystem services;

- Reduction in the use of external resources;
- Minimization of waste production and pollution;
- Adaptation to climate change;
- Increase in productivity and reuse-use efficiency;
- Support for production and food safety;
- Empower people and communities to overcome poverty, hunger and malnutrition;
- Promotion of human rights and the elimination of gender inequality;
- Creation of new market opportunities.

Organic Farming

Organic agriculture, also known as biological or ecological agriculture, results from the union of traditional and modern farming methods [25].

***Figure 6**. Organic farming methods. Retrieved from* [25], *p.2.*



By adopting modern equipment, improved crop varieties and soil and water conservation practices [25], it emphasizes soil fertility, crop rotation, natural pest management, crop and animal diversification and the use of green compost and fertilizers [18], [25]. It also encourages integration and collaboration between multiple farms [25].

Organic agriculture aims to produce high-quality food in sufficient quantities, to interact with natural cycles and systems with constructive and life-enhancing approaches; to encourage and promote biological cycles within the agricultural sector, to maintain and protect soil fertility and biodiversity, to promote the adoption of renewable, organic, green and clean resources, to minimize any form of pollution, to ensure a better quality of life for all and to develop a socially and ecologically responsible production, distribution and consumption chain [26].

In recent decades, the organic farming sector has experienced a rapid development with high rates of implementation [15], [26] thanks to the growing awareness about the severely negative effects on food security and the environment caused by industrial agriculture (e.g. phytosanitary and agrochemical products, groundwater pollution and soil degradation) [26]. In particular, in Europe the total area cultivated in organic farming continues to increase and for the year 2019 it constituted 8.5% of the total agricultural land of the Union [27].

Organic farming generates numerous environmental and social advantages, which, however, are accompanied by disadvantages and obstacles that limit and hinder its adoption. Table 1 briefly summarizes these advantages and disadvantages.

Table 1*. Advantages and disadvantages of organic farming* [7], [25].

ADVANTAGES	DISADVANTAGES AND/OR BARRIERS
Production of food products with reduced, and in some cases zero, content of synthetic pesticide residues compared to those produced by conventional agricultural methods	Lower yields than traditional and conventional agriculture
Improvement of soil quality and water retention capacity	Political and economic constraints
Improvement of the activity and biological level of the soil and landscape	Lack and/or scarcity of information and knowledge
Improvement in SOC stock	Lack and inadequacy of infrastructures
More effective delivery of ecosystem services and social benefits	Cultural perceptions and prejudices
Minimization of erosion	Lack of public and private funding for research and development
Reduced or zero pollution from synthetic pesticides for groundwater and surface water	
Mitigation of climate change thanks to lower energy consumption (lower consumption of fossil fuels) and greater CO_2 sequestration	
More profitable, sustainable and environmentally friendly systems	
Improvement of food security	
Less variability and greater stability of the cultivation system	
Strengthening the economic development of the community, social interactions and cooperation between farmers and consumers and greater employment opportunities	

Agroforestry

Agroforestry is one of the few strategies for the sustainable intensification of agricultural practices which simultaneously contributes to food security and mitigation and adaptation to climate change by preserving and strengthening environmental resources [28].

FAO defines agroforestry as "*a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as crops and/or animals, in some form of spatial arrangement or temporal sequence*" [29].

Agroforestry, therefore, finds in the diversification of products and production systems a key element to promote complementary interactions between the various protagonists of agronomic systems [30] and to ensure sustainable forestry and agriculture [31].

As the environmental, climatic, economic and socio-cultural conditions vary, it is possible to distinguish a disparate series of agroforestry systems, which, therefore, are site-specific and cannot be adopted everywhere [28]. The best-known systems are showed in Table 2. Agroforestry provides environmental, economic and social benefits, including [15], [18], [28], [30], [31]:

– Soil fertility improvement;
– Provision of ecosystem services;
– Protection and conservation of biodiversity (e.g. local and indigenous crops and animal breeds);
– Improvement of the nutrient cycle, water retention capacity and buffering and filtering properties of the soil;
– Carbon storage and sequestration improvement;
– Slowing down and reversal of soil degradation processes, mainly erosion, and deforestation;
– Reduction of dependence on fossil fuels and GHG emissions;
– More productive, sustainable, resilient and profitable agricultural systems;
– Agricultural productivity improvement.

Unfortunately, the adoption of such systems and practices has political and economic limitations.

***Table 2**. Some agroforestry systems* [15], [30].

AGROFORESTRY SYSTEM	PRACTICES' DESCRIPTION
Agrosilviculture (also known as silvoarable)	• Alley cropping (Trees planted in rows and a companion crop between rows) • Intercropping of trees with annual or perennial crops to obtain fruit, fuel, wood, timber and other services
Silvopasture	• Intercropping of trees on pasture for the production of fruit, fuel, wood, timber, other services and forage • Combination of orchards grazed with pastures
Agrosilvipasture	Production of crops, animal/dairy and wood products within the same area
Forest farming and grazing	Use of forested areas respectively for the production of naturally standing species and forage
Homegardens	Combination of trees/shrubs with vegetables in urban and peri-urban areas

Other sustainable management practices

In addition to the already mentioned and in-depth practices and techniques, there are others, which for simplicity have been summarized in Table 3.

***Table 3**. Other soil sustainable management practices and techniques* [15], [32].

SOIL SUSTAINABLE MANAGEMENT TECHNIQUE	MAIN CHARACTERISTICS
Precision Farming	Adoption of information technologies to observe, measure and respond almost in real-time to the demands of crops, fields and animals
Enhanced plants genetics	Introduction of plant species with high adaptability to drought and climate change within the crop cycles
Urban planning, "grey" land recycling and "green" land recycling[2]	Realization of connections between urban areas, biodiversity and ecosystem services through the development and improvement of green infrastructures (e.g. green roofs, urban forestry, urban greening) and the reuse of waste material from building activities
Pasture management	Rotation of pastures, association of breeding with vegetable cultivation and ecological and sustainable management of weeds and parasites
Forest restoration	Reforestation techniques that provide for the planning and control management of fires, the monoculture of native species, protection from spontaneous and natural vegetative regrowth and enrichment with tree species of high commercial, social and economic value
Sustainable deforestation and the establishment of protected areas	Minimization of deforestation and biodiversity loss through landscape planning, maintenance of vegetative corridors, restoration of degraded forests and agroforestry
Management of invasive species	Eradication[3], control and replacement with native species
Wetlands restoration	Recovery of hydrological dynamics, revegetation and removal of invasive species

[2] "Grey" land recycling refers to the reuse of built areas; whereas 'green' land recycling refers to the creation of green or open urban areas [37].
[3] Systematic elimination of species in a specific area.

1.1.4 Promotion of sustainable soil management

To create a favourable environment leading to the adoption of sustainable soil management practices and initiatives, some actions need to be implemented. They are summarized in Table 4.

Table 4*. Action to implement for the adoption of sustainable soil management approaches* [5], [33].

PROMOTION ACTIONS	
• Strengthening the agri-food policies and relative integration with agricultural and environmental policies	• Greater availability of incentives and responsible investments
• Promotion and strengthening of research activities with a specific focus on soil resources	• Prevention and reduction of degradation phenomena affecting soil and land resources, adopting remediation, recovery and recycling approaches
• Promotion of effective educational programs to be also integrated into school programs and subsequently extended to the professional sphere	• Provision of suitable and sustainable technologies to guarantee higher production with lower quantities of raw materials
• Integration of interventions aimed at the protection and remediation of land in emerging markets	• Increasing the extension of land managed with sustainable practices
• Improving the remediation of degraded soils and promoting sustainable production processes through the use of biological resources, more efficient and rational use of water resources, sustainable use of technical means and equipment and recycling of agricultural by-products	• Strengthening of monitoring capabilities and knowledge relating to soil conditions and the evolution of its functions. This would, in turn, improve the orientation and ad hoc selection of remediation interventions
• Improvement of the exchange of knowledge, technologies and information on soil issues on an international scale	• Promotion of dissemination and communication activities on sustainable soil management practices

An important signal was launched with the approval of the Voluntary Guidelines for Sustainable Soil Management by the FAO Council in December 2016. They present easily accessible and understandable technical and political principles and recommendations to a wide range of stakeholders to promote sustainable soil management. Therefore, these are recommendations and technical references to be applied based on a specific context of intervention [5]. The Voluntary Guidelines essentially provide for [5]:

1. Minimization of soil erosion;
2. Optimization of the soil organic matter content;
3. Promotion of the soil nutrient balance and cycles;
4. Prevention, minimization and mitigation of soil salinization and alkalinization;
5. Prevention and minimization of soil contamination;
6. Prevention and minimization of soil acidification;
7. Protection and improvement of soil biodiversity;
8. Minimization of soil sealing;
9. Mitigation of soil compaction processes;
10. Improvement of soil water cycle.

1.2 Soil remediation

Soil pollution and contamination are concerning environmental problems as they are becoming increasingly serious every year, threatening human health and food safety, due to the presence of many contaminated sites and general potentially toxic concentration levels [34], [35].

Furthermore, the nature and extent of these problems are constantly evolving, creating new challenges and a need for constant research for new and appropriate technologies capable of overcoming the problem [34]. Therefore, it becomes imperative to adopt soil remediation approaches.

The remediation involves a series of processes aimed at the removal, control, containment or reduction of contaminants (e.g. hydrocarbons, heavy metals, pesticides and many others) from the soil so that the contaminated site no longer poses any significant risk to human health or the environment [36].
The remediation, therefore, has a dual benefit: reduction of the negative effects on the environment and humans and regeneration of the soil environmental functions [36]. In general, when it comes to soil remediation, a distinction must be made between soil restoration, recycling and rehabilitation, as reported in Figure 7.

***Figure 7**. Soil restoration, soil rehabilitation and land recycling* [15], [37].

Soil remediation processes are required to consider the soil as a complex system influenced by physical, chemical and biological factors and components [15]. Therefore, the effectiveness of these processes depends on [15], [36]:

- the nature of the landscape and type of soil to be recovered;
- methods of characterization (typology, extent and severity) of the degradation phenomena;

– type of pollutants to remove;
– biophysical characteristics of the intervention site;
– social, economic, cultural and technical factors;
– climatic conditions.

Soil remediation is considered a challenging task since it develops on different temporal, spatial, organizational and decisional scales and is context-specific and site-specific [15]. In Europe, as reported in the JRC Technical Report "*Status of local soil contamination in Europe. Revision of the indicator Progress in the management contaminated sites in Europe*", "*significant progress has been achieved on the identification of sites where polluting activities took/are taking place*" and "*around 19% of registered sites in Europe need, or might need, remediation or risk reduction measures, including natural attenuation*" [36]. The same report states that, based on the collected and received data, the most used remediation procedure in Europe appears to be the ex-situ '*dig-and-dump* ' technique, which involves the excavation and off-site disposal of contaminated soil [36].

1.2.1 Stages of the remediation process

The remediation process consists of several stages (Figure 8).

1. Characterization

   It is a site-specific analysis that consider the characteristics and the particular context of the area to remediate to identify the most suitable technological solution. It provides for the acquisition of sufficient information and data relating to the type of pollutant and the current state of contamination (distribution within the site of interest).

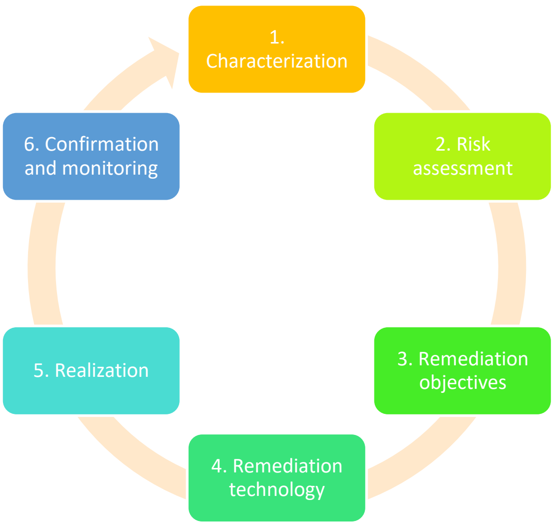
   The characterization of a site is often a long and very expensive process; therefore, it is recommend the implementation of an effective characterization strategy to optimize efficiency and costs [34].

2. Risk assessment

   The assessment aims at identifying the presence of unacceptable risks to human health and other receptors considered relevant within a particular site.

   The starting point for a risk assessment is the development of a Concept Model of the Site aimed at identifying three main elements: the source of contamination, the migration paths

Figure 8. *Remediation project life cycle.*



of pollutants through environmental matrices and the receptors of contamination within or around the contaminated site. The risk arises if and only if all three elements are present and connected [38].

3. Remediation objectives
   If unacceptable risks are identified, possible risk management options are evaluated and an appropriate risk management and/or remediation strategy is developed [38].
4. Remediation Technology
   At this point it is necessary to identify feasible remediation options and conduct a detailed assessment in order to identify the most appropriate one and produce a Remediation Strategy, namely "*a plan that involves one or more remediation options to reduce or control the risks from all the relevant pollutant linkages associated with the site*" [38].
5. Realization
   After identifying a suitable technique, a remediation plan is prepared and the design and implementation of remediation start [38].
6. Confirmation and monitoring
   All the remediation activities will be subjected to continuous planning and monitoring controls [38] to ensure the efficient achievement of the planned remediation objectives with appropriate quality assurance.

1.2.2 Remediation technologies for soils

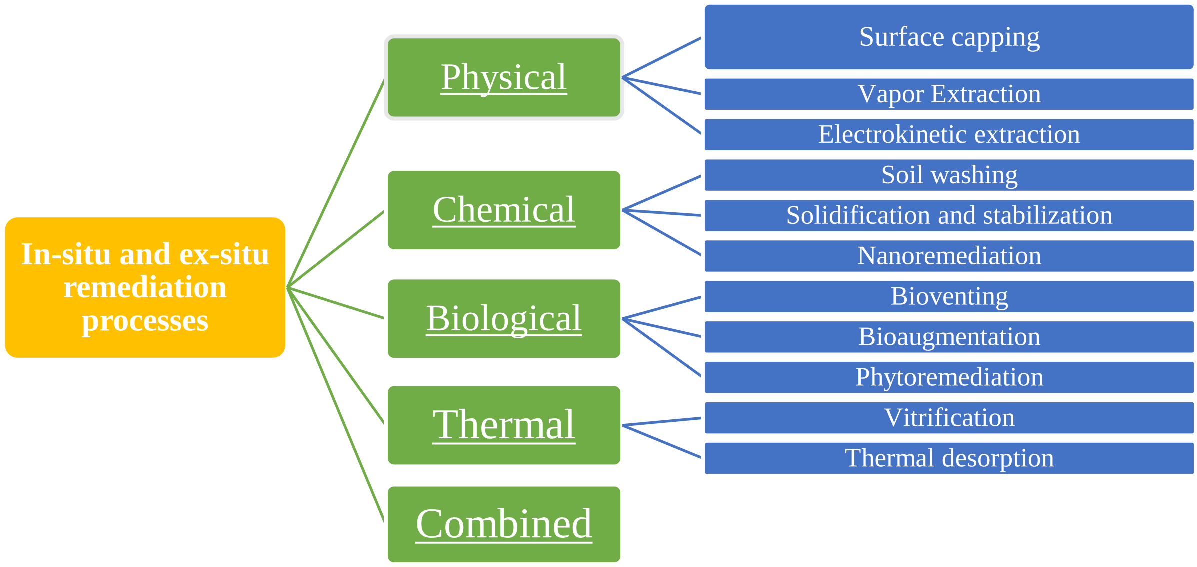
The remediation technologies of contaminated sites can be classified considering [35]:

1. Type of intervention (in-situ and ex-situ).
   In-situ remediation involves the treatment of pollutants in the place of origin without soil handling or removal; while ex-situ remediation concerns treatment outside the contaminated site through excavation or soil treatment.
   In general, in-situ remediation provides greater benefits than ex-situ remediation and reduces contacts between people and the contaminated medium. These technological solutions are particularly suitable for the treatment of contaminated areas of great extension, as they generate little interference in the site, they are simple and less expensive operations when compared with ex-situ processes. The latter is particularly suitable for the immobilization and containment of contaminants. They can be on-site or off-site depending on whether the soil movement or removal takes place, respectively, inside or outside the contaminated site.

2. <u>Nature of the processes.</u>
   They are divided into physical, chemical, biological, thermal and combined processes. Furthermore, they can also be classified considering the method of action against contaminants in containment, transport and transformation.

Figure 9 schematizes the remediation processes that will be discussed below.

***Figure 9**. Classification by nature of the remediation processes that will be briefly described in this e-library. Adapted from* [35].



Physical processes

The physical remediation processes aim at the immobilization or removal of contaminants from the soil through the adoption of physical means [35]. The principal technologies used are briefly illustrated in Table 5.

***Table 5**. Main physical remediation processes* [35], [39], [40].

	SURFACE CAPPING	VAPOR EXTRACTION	ELECTROKINETIC EXTRACTION
Process description	Considered by many experts as a process of containment of contaminants and not just as a technology, this solution involves the simple coverage of the site exposed to	In-situ technology aimed at removing volatile and semi-volatile organic contaminants by the generation of airflow inside the soil employing a vacuum system. The air, forced to circulate in the pores of the soil, is enriched with the contaminants present in it and	A low-density electric current is applied to the soil via electrodes accurately placed on the subsurface, such a way to create a migration of ions from the soil to the electrodes

	contamination using low permeability material	subsequently extracted from the unsaturated zone of the soil.	
Advantages	Limited passage of water, reduced movement of contaminants in the soil and human risk of exposure to contamination	Quick and efficient removal of pollutants, simple and low cost, easy for operation, flexible, small impacts on the surrounding unpolluted soil	Easy to operate, cost-effective, suitable both for in-situ and ex-situ remediation
Disadvantages	Loss of the environmental functions of the soil that can be reused only for civil purposes (e.g. parking lots)	Site-specific and pollutant-specific	Site-specific and soil-specific.

Chemical processes

Chemical processes are the most widely used in the field of remediation of contaminated sites. Also in this case, the main technologies of a chemical nature are presented in Table 6.

Table 6*. Main chemical remediation technologies* [35], [41]–[43].

	SOIL WASHING	**SOLIDIFICATION AND STABILIZATION**	**NANOREMEDIATION**[4]
Process description	Ex-situ and water-based process that aims to remove or transfer organic and inorganic contaminants from soil to a liquid stream employing chemical-physical extraction and separation processes [41]	It prevents the contaminants movement inside soil by capturing them (solidification) in solid form using cement, asphalt and other products or immobilizing them (stabilization) by adding chemical agents[5] (e.g. lime, apatite, calcium hydroxide, bauxite, etc.) to the soil	In-situ and ex-situ innovative technology aimed to stabilize and reduce the concentrations of organic and inorganic contaminants in the soil through the adoption of nanomaterials[6], such as Zero-Valent Nanometals (e.g. iron, nickel and palladium)

[4] The advantages and disadvantages are referred to Zero-Valent Iron Nanoparticles.
[5] They not represent a risk for workers and local communities because they are commonly employed in building activities [78].
[6] Nanomaterials are chemicals or materials composed of particles with dimensions between 1-100 nanometers. Many products of daily use containing nanomaterials are already present on the European market (e.g. batteries, coatings, antibacterial and cosmetic clothing) [79].

Advantages	Feasible for several organic contaminants, reduced soil volume to treat, cost-efficient, fast, able to treat and recover large volumes of contaminants, control of the ambient environmental conditions	Quick, low cost, versatile (both in-situ and ex-situ) and effective against a wide range of organic and inorganic contaminants	Great reactivity, highly efficient and versatile for several pollutants, solving heterogeneous contaminated site in the same intervention, low toxic material, preservation of soil characteristics, no soil excavation and no interferences to further remediation solutions
Disadvantages	Soil and site-specific, effects on natural ecosystem due to excavation, worker exposition to hazardous materials, high management cost of the washing solution	Minimization of soil ability to support plants and micro-organism	Nanoparticles aggregation, potential ecological and human risk, lack information concerning long-term and toxicity effects

Biological processes

The term bioremediation is used to indicate a set of biological processes that use living beings (e.g. plants, animals, micro-organisms, algae) to remediate, reduce or remove contaminants from the soil [35], [44]. Below, some of the best-known biological processes will be explored.

Bioventing

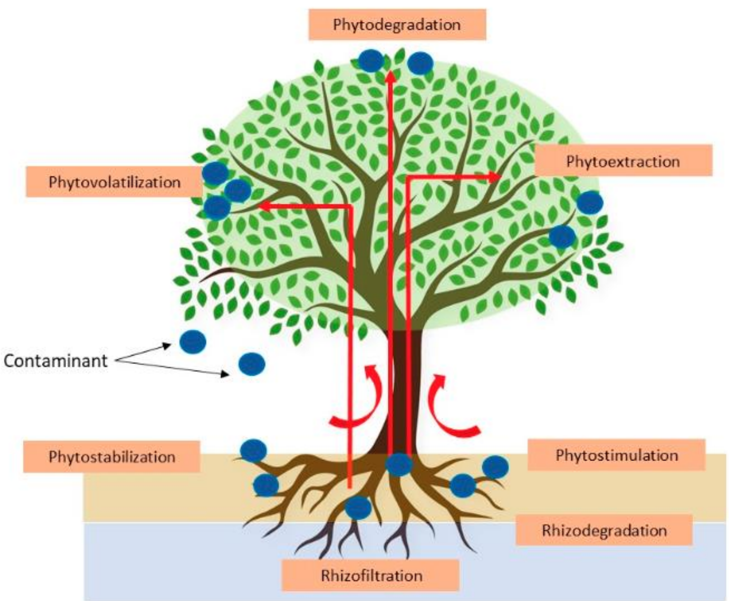
This in-situ technique involves adding an airflow into the soil voids to stimulate the growth of micro-organisms. The oxygen present in the air stimulates the microbial metabolism of the contaminants inside the soil, which, acting as a substrate, starts the biodegradation process [35], [44].

Bioaugmentation

This in-situ process involves the enrichment of the native microflora present on the contaminated site with non-present or genetically modified micro-organisms and/or microbes to accelerate the degradation of contaminants [44]. External micro-organisms are chosen by considering their physiology and metabolic capacity to degrade substances to be removed [35].

Phytoremediation

Figure 10. *Phytoremediation's mechanisms. Retrieved from* [44], *p.10.*



The phytoremediation is an in-situ technique, recognized as a green technology because it uses plants or other vegetative organisms to reduce the toxicity of contaminants (mainly heavy metals, radioactive elements and organic compounds) by promoting different biological, physical and chemical interactions [35], [44].
This technique includes a disparate series of different mechanisms, schematically shown in the Figure 10 and Table 7.

Table 7*. Brief description of some of the phytoremediation mechanisms* [35], [44].

	PHYTO EXTRACTION	PHYTO DEGRADATION	PHYTO VOLATILIZATION	PHYTO STABILIZATION	RHIZO DEGRADATION
Process description	Contaminant removal from the soil and their subsequent accumulation in some parts of the plant (e.g. roots, leaves)	Contaminant removal by plant parts and subsequent transformation into a less toxic form through the plant metabolism or the release of specific enzymes	Contaminant removal from the soil through absorption by plant roots and conversion into a volatile product, subsequently released into the atmosphere	Immobilization of pollutants in the soil leading to avoid soil erosion and creating an association with hummus	Plant-biodegradation during which roots release compounds that stimulate the degradation of contaminants

Thermal processes

The thermal processes allow the elimination of the contaminants in the soil by heating the subsoil. Among them:

– Vitrification [34], [35].
  It is a technique that can be used in-situ and ex-situ and allows to encapsulate contaminants in a chemically stable, leach-resistant, glass and crystalline material resulting from the warming and

the consecutive cooling of the soil by the application of an electric current. The high temperatures reached during the process facilitate the destruction and removal of organic substances. Vitrification can be used for toxic and radioactive contaminants and involves subsequent land reuse only for agricultural purposes.

- Thermal Desorption [35].
  The process can be applied in-situ and ex-situ and the removal of contaminants takes place following a temperature raise achieved or through the opening of wells in the soil (in-situ) or through the installation of a treatment unit on the site of the contaminated soil (ex-situ).

Combined processes [35]

The combined processes result from the combination of multiple processes of a different nature. Some authors believe that they represent the best possible option for remediation of contaminated sites by multiple organic and inorganic pollutants.
An example of a combined process is nano bioremediation, deriving from the union of physical-chemical processes with biological processes. In particular, nano bioremediation uses first nanoparticles to perform an initial treatment of contaminated soil and then micro-organisms to conduct the remaining part of the degradation process of pollutants.
The combined processes:

- Realize higher efficiencies of remediation;
- Solve problems encountered following the adoption of a single technology;
- Conduct more sustainable remediation treatments.

1.2.3 Sustainable remediation

The remediation interventions are not intrinsically and automatically sustainable, as every corrective action has consequences that embrace many contexts (e.g. environment, economy, society, politics, etc.) [35].
The association of remediation processes and sustainability principles took place for the first time with *green remediation*, which, however, by neglecting social and economic factors, cannot be considered as a complete approach [35]. Thus, the sustainable remediation term was introduced. It includes environmental, social and economic factors in soil risk assessment and risk-management decisions and applies the principles of sustainable development to remediation practices [38].

Although there are different definitions [35], sustainable remediation could be defined as "*the process of management and reclamation of a contaminated site, aimed at identifying the best solution, which maximizes the benefits of its execution from the environmental, economic and social point of view,* *through a shared decision-making process with stakeholders*[7]" [45]. Therefore, a sustainable reclamation path has the objective of [45]:

1. Identify environmental, social and economic benefits and impacts for each remediation option;
2. Adopt solutions that in the long term allow using more efficiently environmental, social and economic resources;
3. Pursue and promote sustainable development in full compliance with industry policies.

Fundamental for sustainable remediation is the involvement of stakeholders and the territory within the decision-making process through adequate, transparent and complete information and communication paths [45]. Although the Sustainable Remediation Forum (SuRF) was created[8], adoption on a global scale strained to take off due to [35]:

- Absence of a standardized and universal method for assessing the sustainability of remediation solutions;
- Cultural, social and economic obstacles;
- Absence of specific policies.

To summarize, the main minimization solutions for each process of soil degradation have been grouped in Table 8.

Table 8. *Main solutions for each type of degradation process* [7], [8], [15], [16], [18], [21], [22], [46].

	SOLUTIONS	
Erosion	• Restoration of marginal terrain; • Vegetative coverage improvement; • Conservation agriculture (no-tillage, cover crops); • Agroforestry;	• Application of green fertilizers; • Planning variations of soil use (e.g. deforestation, grazing conversion to cultivated land); • Reduction in the use of plant protection products; • Terraces (valid solution especially for steep soils).
Loss of organic matter	• Conservation agriculture (cover crops, integrated nutrient management, cultivated residual use, no-tillage);	• Agroecology; • Agroforestry; • Enhanced Plants Genetics; • Modification of diets.

[7] Definition developed at the beginning of 2013 in SuRF Italy scope [45].
[8] It led to the creation of a coalition dedicated to sustainable remediation and focused representatives of the government, industry, consultancy and academy. Currently, it offers an international forum with associated partner groups in different countries, including the United Kingdom, Brazil, Netherlands, New Zealand and Australia, Canada, Italy, China, Japan and Colombia [35].

	• Use of cultivated and organic residues as substitutes of synthetic fertilizers; • Permanent land coverage, even during the winter; • Introduction of cultural rotation and perennial crops;	
Loss of biodiversity	• Diversification of agricultural practices. Conservative agriculture and biological agriculture are recommended; • Extension of protected areas; • Slowdown in the conversion of natural land and deforestation practices; • Restoring degraded land; • Management of invasive species and protection of vegetable native species, animals and microbes;	• Intercropping with leguminous; • Green infrastructure; • Agroforestry; • Modification of diets; • Changes in production and consumption systems.
Contamination	• Integrated nutrient management; • Green infrastructure; • Characterization of irrigation water; • Minimization of waste production;	• Appropriate waste collection, management and disposal; • Soil remediation; • Avoid leaving waste.
Salinization	• Better quality irrigation water and irrigation with alternative water sources; • More effective and efficient drainage systems; • Reduction of groundwater withdrawal; • Introduction of best water-soil management practices (e.g. drip irrigation); • Cultivation of tolerant crops;	• Reduced use of heavy vehicles; • Green fertilizers; • Restoration of marginal soils; • Bioremediation, particularly phytoremediation with halophyte.
Soil sealing	• Green infrastructure and ecological corridors; • Reduction of buildings on agricultural and natural soils; • Urban and territorial regeneration of artificial areas disused, underutilized and/or degraded;	• Use of more sustainable materials; • Desealing.

2. SOIL EU POLICY

1.3 Soil and SDGs

In 2015, all the Member States of the United Nations (UN) adopted the Agenda 2030, which, with 17 Sustainable Development Goals (SDGs), provides a shared model to ensure peace and prosperity for people and for the entire planet. In particular, the UN SDGs recognize the importance of acting, through the establishment of a global partnership, to end poverty, improve health and education, fight climate change, reduce inequalities and stimulate economic growth while respecting the principles of sustainability [47].

The achievement of many of the Objectives and Targets proposed by the Agenda 2030 depends directly or indirectly on the provision of ecosystem services which, in turn, is closely related to the soil characteristics, properties and functions [48].

Figure 11 shows the soil-UN SDGs nexus. Particularly, the Target 15.3 of the UN SDGs is the most directly linked to the soil and concerns the *Land-Degradation-Neutrality*, namely "*a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems*" [49].

Thus, the phenomena of land degradation pose severe obstacles to the successful implementation and achievement of the UN SDGs, as it is essential to have healthy soils [49].

***Figure 11**. Soil and the UN SDGs. Retrieved from* [50].

1.4 Policy framework

The European political framework broadly considers thematic as prevention and restoration of land and soil degradation [2]. Indeed, there is still no specific framework aimed at regulating soil protection within the territory of the Union as there are no binding targets, incentives and measures addressed to soil and land. Furthermore, not all soil threats are adequately and equally considered by European policies [2]. For example, existing legislation does not address issues such as soil compaction, salinization and sealing.

In addition to the absence of an adequate and effective monitoring system, the policies and measures are extensively and considerably heterogeneous and variable across the EU countries [2]. All of these factors continue to exacerbate the processes of soil degradation in many countries of the Union [2]. Table 9 shows a summary of the EU Soil Policy. Furthermore, a series of activities with a focus on soil and land resources have been carried out both at the European and international level. These have been briefly summarized in the Table 10.

***Table 9**. EU soil policy in brief* [2], [51]–[59].

EU POLICY	DESCRIPTION	MAIN OBJECTIVES AND TARGETS CONCERNING SOIL
Tematic Strategy for Soil Protection	It proposes a framework directive that defines common principles for soil protection throughout the Union to promote a more rational and sustainable use	• Prevention of further soil degradation, preservation of its functions and restoration of degraded soil • Integration of the soil protection into relevant EU policies
Environmental Liability Directive (2004/35/CE)	It establishes a framework based on the "polluter-pays" principle to prevent and remedy environmental damage. It sets the most appropriate measures to remediate land damage	Prevention and remedying of environmental damage (including soil)
Industrial Emission Directive (IED, 2010/75/EU)	Main EU instrument regulating pollutant emissions from industrial installations. It provides an integrated approach to prevention and control the emissions into air, water and soil, ensuring that the operation of an installation does not lead to a deterioration of the quality of soil and groundwaters	Achieve a high level of protection of the human health and the environment by reducing harmful industrial emissions across the EU
Environmental Impact Assessment Directive (EIA, 85/337/EEC)	This Directive foresees the environmental impact assessment of public and private projects that could generate significant effects on the environment, including soil as an environmental matrix	Appropriate identification, description and evaluation of the direct and indirect effects of a project considering different factors (e.g. humans, fauna and flora, soil,

		water, air, climate and landscape, material assets, etc.)
Sewage Sludge Directive (86/278/EEC)	It encourages the use of sewage sludge in agriculture and regulates its use to prevent harmful effects on soil and other matrixes	
Regulation on fertilizers (EU 2019/1009)	It establish rules to make 'EU fertilising products' available on the market. It also defines thresholds for contaminants presence in fertilising products to minimize soil pollution	
Mercury regulation (EU 2017/852)	Regulation that "*establishes measures and conditions relating to the use, storage and trade of mercury, mercury compounds and mercury mixtures, and the manufacture, use and trade of mercury-added products as well as the management of mercury waste, to ensure a high level of protection of human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds*" [60]	Identify and assess sites contaminated by mercury and address risk (including soil contamination)
Regulation on land use, land use change and forestry (LULUCF 2018/841)	Regulation that sets a new EU governance process aimed to monitor how each Member State accounts emissions from land use through the adoption of more recent benchmarks for performance in order to enhance the accuracy of the assessments	Ensure that emissions do not exceed removals in the LULUCF sector (no-debit rule)
Common Agriculture Policy (CAP)	The common policy for all EU countries aims to support and safeguard the European farmers, contribute to tackling climate change and the sustainable use of natural resources, preserve rural areas within the territory of the Union and support the rural economy. Furthermore, it has the potential to advance soil protection in both agriculture and forestry	Ensure sustainable management of natural resources and climate action
7th EAP	The 7th EAP Programme is a common strategy that has guided the European environment policy action until 2020. It identifies three priority areas (protection of the European natural capital, resource-efficient and low carbon growth, reduction of threats caused by pollution, climate change and dangerous chemical) and sets a long-term direction by 2050	No net land take by 2050
Roadmap to a resource efficient Europe	It defines a vision towards structural and technological change whose milestones illustrate what will be needed for Europe to take a path towards resource-efficient and sustainable growth	Reduce soil erosion, increase the soil organic matter and promote remediation actions on contaminated sites

United Nation SDGs	The 2030 Agenda provides a shared model to ensure peace and prosperity for people and the entire planet	Target 2.4 (food security), 3.9 (soil pollution), 15.2 (sustainable agricultural and forest management) and 15.3 (land degradation neutrality)

Table 10. *European and international activities addressed to soil and land* [61]–[63].

	BRIEF DESCRIPTION
Guidelines on best practices to limit, mitigate or compensate soil sealing - 2012	It provides a collection of policies, funding schemes, local planning tools, information campaigns and other good practices and it is mainly addressed to the competent authorities of the Member States, professionals and all the interested parties
LIFE Programme	EU funding instrument addressed to the environment and climate that, through projects aimed at improving soil conditions in Europe, has allowed greater knowledge on the soil threats, providing adequate conservation and improvement solutions. The LIFE program (2014-2020) focused more attention on cost-efficiency and soil consumption and protection [64]
Horizon Europe	The framework program aims to provide, through research and innovation, solutions to some of the biggest challenges inherent to the soil quality and food system safety
International Year of Soil (IYS) - 2015	2015 was proclaimed as the "International Year of Soil" by the 68th General Assembly of the United Nations. It saw full collaboration between the European Commission, FAO and the Global Soil Partnership
FAO political, awareness and dissemination activities	FAO has developed a common vision and an integrated approach to promote sustainability in sectors such as agriculture, forestry and fisheries, including at the top of its work the need to protect the soil
Global Soil Partnership (GSP) - 2012	Voluntary partnership from FAO that mainly aims to promote sustainable soil management and improve soil governance, ensuring healthy and productive soils. Thanks to the GSP it was possible to generate awareness of the importance of soil for the achievement of the UN SDGs. *Main milestones*: the International Code of Conduct for the sustainable use and management of fertilizers (2019); the Global Soil Organic Carbon Map (2017); the Voluntary Guidelines on Sustainable Soil Management (2017); the Status of the World's Soil Resources report (2015) and the Revised World Soil Charter (2015)
United Nations Convention to Combat Desertification (UNCCD) - 1994	The most ratified environmental convention and the only legally binding international agreement that links the environment and development to sustainable land management. It aims to combat desertification and mitigate the effects of drought, especially in arid, semi-arid and arid sub-humid areas. In 2017, it adopted its 2018-2030 strategic framework, which focuses on achieving the Target 15.3 of the UN SDGs. *Main achievements*: World Atlas on Desertification (2018); Global Land Outlook (2017); The future we want (2012); UNCCD Knowledge Hub

Convention on Biological Diversity (Biodiversity Convention, CBD) - 1993	It is aimed at the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits deriving from the use of genetic resources. In 2002, it decided to "*establish an international initiative for the conservation and sustainable use of soil biodiversity as a cross-cutting initiative within the agricultural biodiversity work program*". During COP14, objectives were adopted to promote the conservation and sustainable use of soil biodiversity
The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) - 2012	Independent intergovernmental body aimed at strengthening the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development. *The most significant results*: The IPBES Global Assessment on Biodiversity and Ecosystem Services (2019) and The Assessment Report on Land Degradation and Restoration (2018)
United Nations Framework Convention on Climate Change (UNFCCC) - 1994	Strengthens the existing link between climate change and land degradation, highlighting how many activities aimed at combating degradation and desertification can at the same time contribute to the adaptation and mitigation of climate change by creating co-benefits for both topics
The Intergovernmental Panel on Climate Change (IPCC)	United Nations organization that provides governments with scientific information for use in developing climate policies. The special report Climate Change and Land (2019) also demonstrates how climate change and soil degradation are highly correlated with environmental issues
United Nations Environment Programme (UNEP)	Leading environmental authority in the United Nations system that aims to provide leadership and encourage collaboration in environmental care to meet the needs of future generations
The International Resource Panel (IRP) - 2007	Launched by UNEP following the Commission's "Thematic Strategy on the Sustainable Use of Natural Resources" (COM (2005) 670), it aims to promote the sharing of knowledge and information to improve the way how resources around the world are used. *Main milestones*: Resource Efficiency and Climate Change (2020); The Global Resources Outlook 2019: Natural Resources for the Future We Want (2019); Land Restoration for Achieving the Sustainable Development Goals (2019); Assessing Global Resource Use: A Systems Approach to Resource Efficiency and Pollution Reduction (2017); Food Systems and Natural Resources (2016); Assessing Global Land Use: Balancing Consumption with Sustainable Supply (2014).

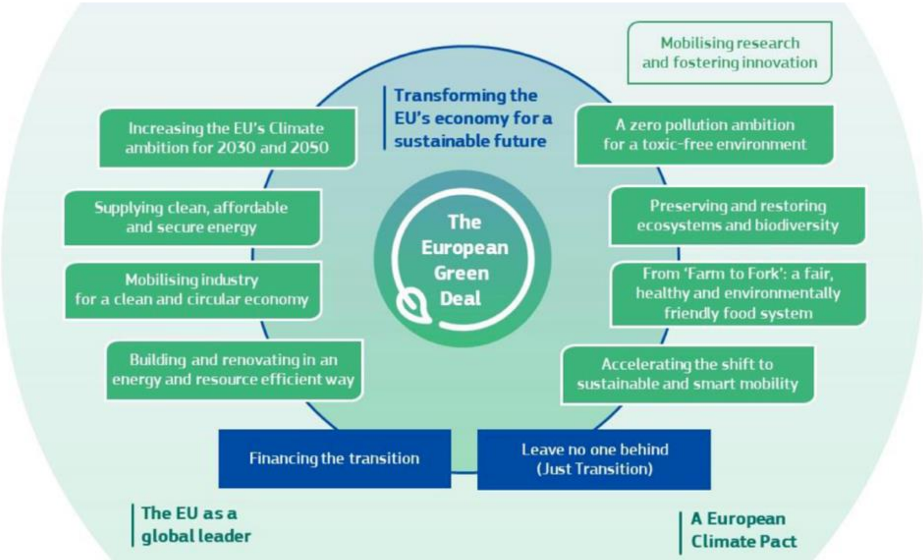
To overcome all the previously mentioned problems it will be necessary to establish coordination between the various policies of European countries, to review the current Thematic Strategy on Soil (EC, 2006) and to propose the adoption of a holistic and integrated approach on various areas for terrestrial systems. Furthermore, criteria, thresholds and incentives will have to be developed to promote more rational, efficient and sustainable use of soil and land [2] resources.

1.5 Soil and European Green Deal

In December 2019, the European Commission presented the European Green Deal, which is a plan to make the EU economy sustainable and to be able to address climate and environmental challenges by turning them into opportunities and making the transition just and inclusive for all [65].

The European Green Deal, compared to previous policies, is a long-term strategy with the widest visions and perspectives; in fact, it sets goals to be achieved by 2050 and it is mainly aimed at achieving climate neutrality [66].

Figure 12*. European Green Deal objectives. Retrieved from* [66], *p.3.*



The objectives of the European Green Deal (Figure 12) embrace various sectoral policies that are strongly interconnected and mutually reinforcing. Therefore, it is necessary to rethink the policies for the supply of clean energy taking into account all sectors of the economy from industry, transport, food, agriculture, construction, etc.

In particular, soils are explicitly mentioned both in the Farm to Fork Strategy and in the Zero Pollution Action Plan and are indirectly considered in the Climate Law, since land degradation neutrality by 2030 (SDG 15.3 target) is a precondition for the achievement of a neutral climate by 2050. Indeed, the adoption of sustainable soil management practices and the implementation of land remediation activities result in an improvement in the conservation of organic carbon reserves in agricultural soils [67] and in the consecutive reduction of CO_2 emissions. Furthermore, land degradation and remediation will also play an important role in the Biodiversity Strategy aimed at environmental protection.

Table 11 briefly show how the individual strategies of the European Green Deal address soil.

***Table 11**. European Green Deal and soil.*

	DESCRIPTION	MAIN SOIL-RELATED OBJECTIVES AND TARGETS
Farm to Fork Strategy [67]–[69]	This Strategy aims to make food systems fair, healthy and environmentally friendly. To achieve this goal, it becomes necessary to ensure healthy soil. Thus, the Strategy also focuses on the soil pollution theme.	• 50% reduction in the use of chemical pesticides; • 50% reduction of more hazardous pesticides by 2030; • 20% fertilizer reduction use; • At least 50% decrease of nutrient losses without deterioration of soil fertility.
EU Biodiversity Strategy for 2030 [67], [70], [71]	The comprehensive, ambitious and long-term Strategy will help Europe towards environmental remediation by 2030 and will create the conditions to ensure the well-being and economic prosperity of present and future generations in an intact and healthy environment	• At least 30% of the EU's land area legally protected; Reduced urban sprawl; • Reduced pesticides risk; • At least 10% of agricultural area under high-diversity landscape features brought back; • Put forward the 25% of the EU's agricultural land as organically farmed; • Progress on remediation processes for contaminated soils; • Reduced land degradation.
European Climate Law [67], [72], [73]	The climate action aims to protect people and the planet, well-being, prosperity, food systems, integrity of ecosystems and biodiversity against the threat of climate change in the context of the 2030 Agenda and in pursuit of the objectives of the Paris Agreement	Adoption of sustainable soil management and land remediation practices
Zero Pollution Action Plan [74]	Action Plan aiming to reduce pollution quickly and effectively and protect Europe's citizens and ecosystems	• Reduce pollution from large industrial installations; • Improve prevention of industrial accidents; • Protect citizens against dangerous chemicals with a new chemicals strategy for sustainability for a toxic-free environment.
A new Circular Economy Action Plan [75], [76]	It aims to provide a future-oriented agenda for achieving a cleaner and more competitive Europe in co-creation with economic actors, consumers, citizens and civil society organizations based on the circular economy actions implemented in 2015	• Reduce soil sealing; • Rehabilitation of abandoned or contaminated brownfields; • Sustainable and circular use of excavated soils

3. CONCLUSION

How land and its resources are used strongly influences the quality, characteristics and functions of soils as well as the environmental and economic sustainability of many sectors. We should also consider the pressures that presently weigh on soil and land resources and that will persist and change in the future (population increase, climate change, degradation and pollution). Therefore, urgent actions must be taken by promoting sustainable soil management models and through the adoption of soil remediation technologies.

Sustainable soil management, perfectly aligned with the principles of the circular economy and the bioeconomy, promotes multidisciplinary, integrated and inclusive management approaches and practices aimed, in most cases, at the improvement and efficiency of agricultural systems. In particular, it generates a disparate series of environmental, economic and food benefits, such as a more efficient and sustainable use of natural resources, the protection of biodiversity and natural landscapes, the minimization of land degradation phenomena and the improvement of agricultural yields. Another positive aspect of sustainable management is the possibility of contributing positively to other environmental problems, such as the mitigation and adaptation to climate change, hunger, desertification and many others.

Soil pollution is one of the most worrying environmental problems today, the minimization of which requires the implementation of soil remediation interventions. These, although generating considerable environmental benefits, present some implementation difficulties because they are highly site-specific, slow, not very sustainable and complex to execute. In Europe, slight improvements have been observed in the field of remediation. In recent years, the so-called sustainable soil remediation has been introduced to integrate sustainability principles into the remediation practices and decision-making methods connected to it.

Unfortunately, unlike air and water, there is a lack of a comprehensive and coherent policy framework for soil and land protection resources in Europe. Binding targets, incentives and measures are also absent in land and soil European policies. In addition, there is a strong heterogeneity and fragmentation of soil policies across the European countries and the absence of a centralized and homogeneous monitoring network. As a consequence, Europe is not on track in addressing environmental challenges in the short- and long-term. Fortunately, the European Green Deal pays more attention to the soil and land resources, as it arises from the awareness that it is necessary to have healthy soil to ensure a more sustainable and zero-emission Europe.

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