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IL RAPPORTO TRA CONSUMO DI SUOLO E DINAMICHE DEL CARBONIO

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THE RELATIONSHIP BETWEEN SOIL CONSUMPTION AND CARBON DYNAMICS

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Abstract

The aim of this thesis is to present the relationship between soil consumption and carbon dynamics. In fact, soil is consumed for various purposes in the modern world such as construction, farming, and other uses. Today, urbanization has become a problem and urgent actions are needed to handle the problem.

In this thesis, the way carbon is stored in order to handle climate change is discussed. Soil Organic Carbon (SOC) stores are quickly depleted by soil usage, which includes land deterioration, erosion, and extensive agricultural mining. Overuse of soils upsets the natural carbon balance. Degraded soils lose their carbon, releasing greenhouse gases into the upper atmosphere and accelerating climate change, whereas healthy soils serve as a worldwide carbon sink. Carbon and soil health have a delicate and cyclical interaction. It depends on a careful balancing act among carbon outputs and inputs. After absorbing CO_2 from the atmosphere, plants transform it into protein and exudates from the roots, which are then released into the soil.

Keywords: soil consumption, carbon, carbon dioxide, urbanization, soil degradation.

Astratto

L'obiettivo di questa tesi è presentare la relazione tra il consumo di suolo e le dinamiche del carbonio. Infatti, nel mondo moderno il suolo viene consumato per diversi scopi, come l'edilizia, l'agricoltura e altri usi. Oggi, l'urbanizzazione rappresenta un problema e sono necessarie azioni urgenti per affrontarlo.

In questa tesi, viene discusso il modo in cui il carbonio viene immagazzinato per contrastare i cambiamenti climatici. Le riserve di carbonio organico del suolo (SOC) si esauriscono rapidamente a causa dell'utilizzo del suolo, che include il degrado del terreno, l'erosione e l'intenso sfruttamento agricolo. L'eccessivo sfruttamento del suolo altera il naturale equilibrio del carbonio. I suoli degradati perdono il loro carbonio, rilasciando gas serra nell'atmosfera superiore e accelerando i cambiamenti climatici, mentre i suoli sani fungono da serbatoio di carbonio a livello globale. Il carbonio e la salute del suolo hanno un'interazione delicata e ciclica. Essa dipende da un attento equilibrio tra le emissioni e gli apporti di carbonio. Dopo aver assorbito CO_2 dall'atmosfera, le piante la trasformano in proteine ed essudati dalle radici, che vengono poi rilasciati nel terreno.

Parole chiave: consumo del suolo, carbonio, anidride carbonica, urbanizzazione, degrado del suolo.

Key Concepts

Soil: As a vital habitat, water filtering, and nutrient store that sustains 95% of the world's agricultural output, soil is the cornerstone of terrestrial ecosystems. It supplies the structural foundation for plant life and controls the climate by storing enormous amounts of carbon—more than that of the atmosphere and vegetation put together. The thin outer part of the land is made up of tin materials, living compound of materials, carbon-based material, gases, small animals, and living things called soil. It is necessary for life because it filters water, recycles nutrients, and promotes plant growth (Nortcliff, 2012, p. 400). The section of clay, sand, and silt in soil determines its texture. In general, 25% air, 20% water, 5% nutrient reservoir, and approximately 45% inorganic substances make up healthy soil.

Soil consumption: The long-term absence of natural or agricultural soil as a result of land sealing caused by human activity, such as urban growth, infrastructural development, and industrial-scale construction, is known as soil consumption (Fazia et al, 2024, p. 323). Ecosystem services including biodiversity, water filtering, and food production are lost as a result of the transformation of previous, living soil into impervious surfaces (Buol, 2003, p. 30). Although soil consumption refers to the actual covering of soil, it is a component of a larger, more serious trend of soil deterioration. Approximately one-third of all soils on Earth are currently moderately to severely deteriorated, which lowers fertility and increases erosion (Buol, 2003, p. 30).

Therefore, to lessen these consequences and maintain the long-term wellness of soil ecosystems, sustainable land management techniques including raising soil organic carbon and lowering compaction are essential.

Land taking: The government's authority and private sector to purchase private land for public uses like infrastructure or development whereas compensating the owner is known as "land taking" (Botticini et al, 2022, p. 20). Since the state owns all land in many jurisdictions, the president can purchase land for public purposes, frequently for investments, roads, or schools.

Soil erosion: The movement of the rich, organic topsoil layer due to human activity including deforestation or natural factors like water and wind is known as soil erosion. It significantly lowers agricultural production, deteriorates ecosystem services, and contaminates aquatic ecosystems by means of chemical discharge and silt. The environmental impact of soil erosion is shaped by its sources and consequences. When tree canopies are removed, the soil is directly impacted by strong winds as well as heavy rainfall. Overgrazing, planting too much, and leaving fields barren all weaken the soil's structure and increase its vulnerability to washing or blowing away. Wind and water erosion rates are accelerated worldwide by heavy rainfall events and protracted droughts (Firoozi, 2024, p. 5).

Constant community involvement greatly improves soil erosion management's sustainability. Communities have a stake in the effectiveness and durability of measures to prevent erosion provided that they actively participate in their implementation, monitoring, and improvement. Members of the community who watch and document the results of conservation tactics develop into strong advocates for ongoing action, assisting in the long-term maintenance of these practices. Soil conservation initiatives become more dynamic and sensitive to shifting ecological and community demands as a result of this continuous involvement, which helps to establish a loop of criticism and progress (Firoozi, 2024, p. 5).

In order to evaluate soil stability and comprehend the effects of various erosion processes, geotechnical engineering explores the mechanical and physical characteristics of soils. This field's emphasis on how soils respond to different stressors yields crucial information for evaluating and forecasting erosion trends and possible mitigation strategies. Promoting an indepth knowledge of soil erosion is a major focus. This entails incorporating many viewpoints from disciplines like geotechnical engineering. A more thorough investigation of how soil erosion connects with and affects various ecological systems and everyday life is made possible by an interdisciplinary approach. This thorough perspective is essential because it gives readers the information they need to understand soil erosion's richness transcending its physical effects (Firoozi, 2024, p. 6).

List of Figures and Tables

Chapter 1 – Introduction

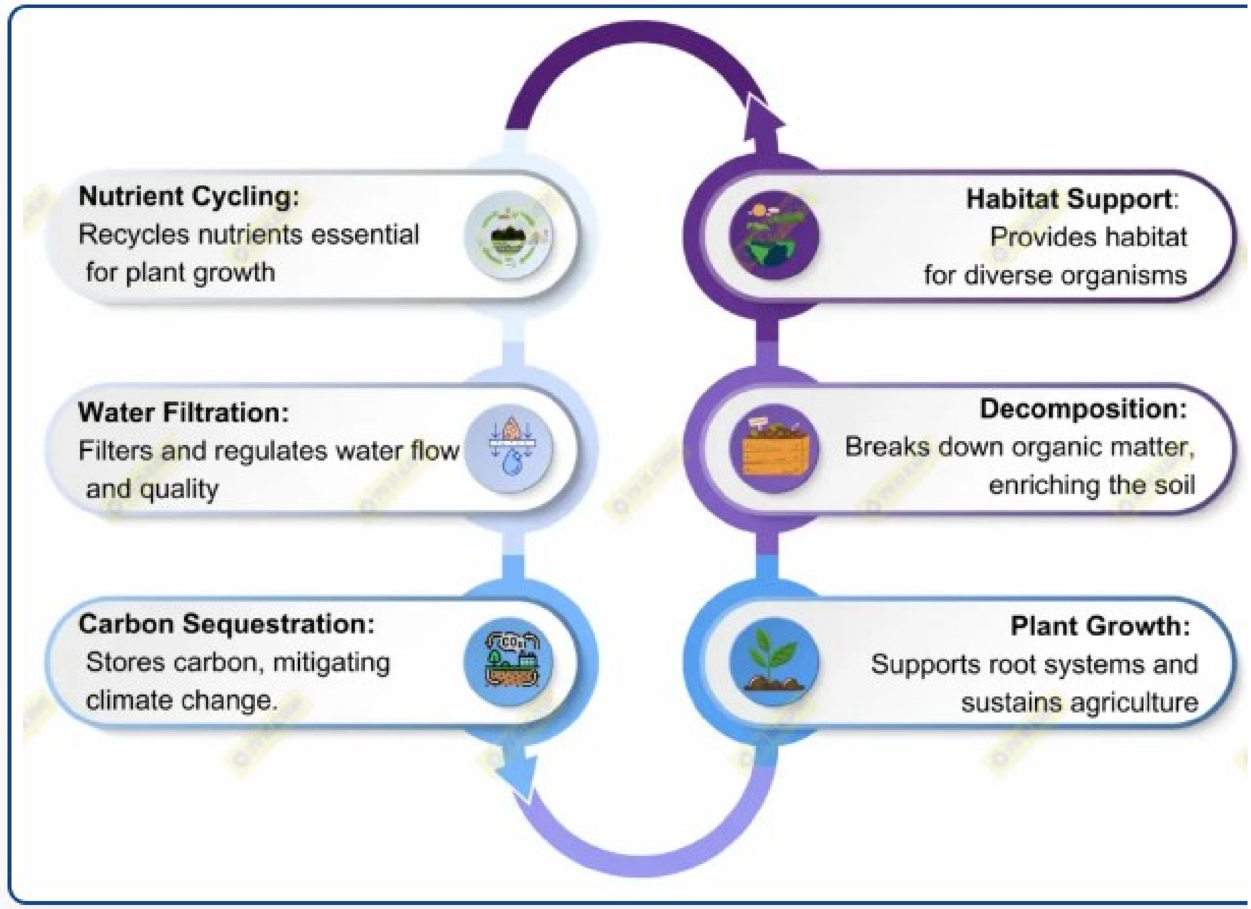
1.1 Background (soil importance, ecosystem role)

By serving as the main substrate for the growth of plants, recycling nutrients, controlling water, and storing carbon, soil is a fundamental, living ecosystem that sustains life on earth (Gama, 2023, p. 555). In addition to supporting biodiversity, it is home to twenty-five percent of all species on Earth. It also filters water and controls greenhouse gas emissions to maintain the ecological balance of the planet. Plants receive nutrients, water, and structural support from the soil (Gama, 2023, p. 555).

Organic matter is broken down by soil microorganisms into nutrients such as nitrogen and others that are vital for tree viability as well as agricultural production. Water is absorbed, stored, and filtered by soil, which has a major effect on water quality by removing contaminants before they reach groundwater (Pereira et al, 2018, p. 10). By holding more carbon than the surrounding environment and all living vegetation put together, soil serves as a vast carbon store that helps slow down global warming (Pereira et al, 2018, p. 10).

In addition to giving plants and animals a place to live, soil transforms minerals and organic substances into a complex, biological structure that forms the basis of ecosystems. Because agricultural demands and erosion can deteriorate these vital processes, sustainable management is necessary to preserve soil health. The dynamic, diverse population of organisms and their physical surroundings found in the soil are referred to as the soil ecosystem (Ponge, 2015, p. 647). It contains a wide range of living things that interact with non-living elements like minerals and air, from microorganisms including microorganisms and others up larger organisms such as plant roots and earthworms. This ecosystem is vital to the equilibrium of natural processes that are necessary for life on Earth, such as nutrient cycling and plant growth.

Figure 1: Soil importance in ecosystem



Source: SPMIAS ACADEMY, Q. 17 What do you mean by soil ecosystem? What are its components? Describe the functions of soil ecosystem, https://spmiasacademy.com/mains_exam/q-what-do-you-mean-by-soil-ecosystem-what-are-its-components-describe-the-functions-of-soil-ecosystem/

By sequestering organic carbon, soils serve as a substantial carbon store that helps slow down climate change. The foundation of all terrestrial ecosystems is soil. By giving vital nutrients, water, and a sturdy framework for roots to grow, it sustains plant life (Dias and Coates, 2014, p. 1). Plants would not flourish without proper soil, and the food chain that is dependent on them might break apart. In addition to plants, soil is home to a diverse range of species, including tiny bacteria to larger creatures such as earthworms and insects, which all support soil health and, as a result the ecosystem.

1.2 Why soil matters for carbon

As the second-biggest active carbon sink on Earth, soil stores more carbon over air and all plants put together, making it essential for managing carbon emissions (Yadav et al, 2025, p. 2). Stored carbon comes from roots, leaves and wood. It enhances agricultural output by promoting soil fertility, retention of water, and biodiversity while reducing global warming by keeping CO_2 around air.

By storing carbon in organic matter, clay keeps CO_2 from reaching the atmosphere. Carbon dioxide emissions can be substantially absorbed by soil (Trivedi and Singh, 2018, p. 3). Carbon dioxide emissions can be substantially absorbed by soil. Soil with high carbon content is more fertile, less prone to erosion, and better at holding onto water. Microbes residing in soil are vital to the remaking of nutrients and prevention of illness, mostly use carbon.

In addition to requiring fewer artificial inputs, healthy soil can provide farmers with additional sources of income through carbon credits. Through photosynthesis, plants absorb CO_2 from the atmosphere, which they then transport to the soil using their roots and breakdown (Westerband et al, 2022, p. 856). Heavy tillage, deforestation, and industrial farming all cause damage that exposes stored carbon to oxygen and turn it as greenhouse gases that exacerbate global warming. Numerous soils are now degraded and require restoration, but with techniques such as regenerative agriculture, they can be transformed from an emitter of emissions toward a carbon sink.

Table 1: Soil characteristics

Soil Type	Clay	Silt	Sand
Particle size	Small	Medium	Large
Pore size	Small	Medium	Large
Total porosity	Large	Medium	Small
Water Retention	High	Medium	Low
Mineral element retention	High	Medium	Low
Oxygen movement to roots	Poor	Medium	Good

Source: Daniel K. (2020). Soil Basics for Improved Plant Health, https://purduelandscapereport.org/article/soil-basics-for-improved-plant-health/

The most important factor for healthy soil is thought to be carbon. Because it holds aggregates of soil together, taking nutrients, holds onto water and provides home and clean power to underground microorganisms, it is the soil's glue and sponge. Carbon (C) is a necessary nutrient because crops absorb carbon from the soil. Nevertheless, it is crucial, because crops are susceptible to stressors and illnesses without carbon (Lal, 2013, p. 440). Among the most viable options for mitigating climate change is soil carbon sequestration. Over 10 percent of the world's anthropogenic greenhouse gas emissions can be stored in soils, according to FAO estimates.

Because it provides the medium and nutrients required to sustain our population, soil is the foundation of our society. In addition to helping to control the delivery of nutrients, microbial life, and moisture levels in the soil, carbon in organic form is known as a crucial indication of the quality of soil. The interplay of ecosystem processes like photosynthesis and decomposition determines the volume of carbon included in soil (Kutz, Stackhouse- Lawson and Thompson, 2021, p. 5). Plants utilize photosynthesis to remove carbon dioxide from the atmosphere. In fact, plants are able to develop new roots, leaves, and branches. Farmers and ranchers must enhance agricultural management techniques in order to raise soil carbon. One technique that may help preserve soil carbon stores in healthy rangelands and boost soil carbon content in damaged soils is the use of appropriate grazing management. A large amount of carbon is kept in soil over all of the plants and air put together, making it the second-most carbon storage sink on Earth. It is an essential component of environmental wellness and global warming management since it serves as both an absorbent and a carbon storing vault. Soil organic matter—the live, dead, and decomposing biological components of soil—is based on soil carbon. Microorganisms that provide nutrients to plants eat this debris. In order to prevent the earth's surface from being swept away by heavy rains or carried off by the wind, carbon helps tie soil fragments firmly into durable clumps. The basis of soil biological material is soil carbon. Microorganisms that provide nutrients to plants eat this debris. It is possible to counteract greenhouse gas emissions into the atmosphere by increasing the amount of carbon kept in soils used in agriculture. But those emissions will increase when soil carbon is lost. During plant breathing and the decomposition of dead plants, most of this carbon is emitted back towards the cloud as carbon dioxide. Some are excreted by grazing animals or enter the soil as decomposing plant materials. The atmosphere, plants, and soil all continuously exchange carbon. As they develop, plants utilize photosynthesis to absorb atmospheric carbon dioxide from the air.

1.3 Research purpose and questions

This thesis's purpose is to present:

Analyze how soil consumption (soil destruction / land use change) affects:

- Carbon sequestration capacity
- Carbon emissions
- Understand what happens when soil is used for: roads, buildings and urban expansion.

Research questions are:

1) How does soil consumption affect carbon sequestration?

2) What are environmental consequences of change in land use?
3) What differences exist between soil consumption and land taking?

Chapter 2 – Scientific Literature Review

2.1 Findings from nature/science articles

The naturally occurring carbon cycle is destroyed by soil consumption, which is sometimes referred to as "soil sealing" because of urbanization. When land is covered with pavement or asphalt, the soil's capacity to take in new organic matter is fully stopped; critical gas exchange is restricted, and its ability to operate as a carbon sink is permanently eliminated (Nath et al, 2023, p. 93). Key biological and climate studies have shown that the link between soil condition and carbon is an essential component of terrestrial ecosystems: Approximately 2,500 billion tons of carbon can be stored in soil, making it the greatest terrestrial carbon reservoir—more than atmospheric air and vegetation put together. During photosynthesis in plants and microbial decomposition of organic debris, it effectively stores carbon.

The carbon and mineral-related organic compounds are two of the main forms of carbon found in soil. These elements determine its stability: As microorganisms digest away plant material, they provide nutrients and, by means of respiration, release carbon dioxide. Carbon is safely stored in soil aggregates and mineral linkages in healthy soils, keeping it from readily fleeing towards the atmosphere (Stoeva & Tsvetkova, 2026, p. 821). The dynamics of the environment are upset when soil is consumed. The entry of fresh organic material is totally stopped by surface imperviousness. The microbial breakdown of previous organic matter frequently quickens as land has been cleared or surfaced, releasing stored carbon as atmospheric greenhouse gases towards the upper atmosphere. In essence, soil sealing increases surface runoff, raises the surrounding temperatures, and restricts water penetration.

It is necessary to measure the impacts of various uses of land types on the structure of soil organic carbon (SOC) and nitrogen in the upland environments, as well as surface soil properties (0–5 cm). Standardized methods of analysis and statistical evaluations were used to measure pH, total nitrogen (TN), and their corresponding stocks throughout forest and agricultural sites. With the exception of pH, all soil metrics were greatly impacted by land use. In comparison to grasslands, the bulk density and SOC stores of forest soil were lower (Stoeva & Tsvetkova, 2026, p. 821). The results show that reducing disturbance to the soil and preserving permanent green space can significantly increase the amount of organic material in the soil content in mountainous places, particularly when uncontrolled pastures are maintained. Unmown meadows showed the maximum SOC.

Vital resources of nature, soil helps plants grow for food and basic supplies, controls water by means of filtering and preservation, and are crucial to the cycles of carbon and nutrients. In addition, soil supports structures structurally, acts as a home for a variety of creatures, regulates the climate, and lessens the effects of natural disasters like flooding (Khan & Chiti, 2022, p. 6). For delicate ecosystems like those found in mountainous regions, the characteristics of soil and its capacity to offer a variety of ecosystem services are especially crucial. Because of their steep slopes, flat profiles, and extreme environmental conditions that hasten erosion, reduced nutrients, and structural degrading, highland soils are extremely vulnerable.

In general, the findings demonstrated that, with the exception of grassland, and conventional methods for managing soil can substantially ($p < 0.001$) affect the dynamics of carbon and stored carbon from the soil itself and vary across land use but do not change over time. However, from 2009 to 2015, carbon stored climbed by 8.33 percent for farmland, 16.56 percent for forest areas, and 29.79 percent for pastureland. As time passed, carbon storage grew considerably ($p < 0.001$) in pastureland rather than in farmland or forestry land and this also showed a growing pattern **(**Ontl**,** 2012**,** p**.** 35**)**. Findings further demonstrate that, for every type of land applications other than wooded areas, the carbon structure had a positive correlation with digital soil mapping indices and a negative correlation with temperatures.

Successfully forecasting future terrestrial-climatic carbon feedbacks depends on soil carbon stores and their release into the atmosphere. Data-driven estimations of these factors, however, show significant variation between studies. All freely obtainable worldwide maps of heterotrophic respiratory and soil carbon reserves produced from observational data were gathered, transforming into data form, and calibrated to a geographical precision of 0.5 °C. To create harmonizing maps worldwide of both variables that are standardized, the median, which is the highest, smallest and minimum numbers for every single grid cell are computed (Hashimoto, Ito & Nishina, 2025, p. 1). They also calculated predictions of carbon in the soil cycling duration and its thermal responsiveness using these standardized records. In Earth's ecosystem research, the generated items offer helpful guidelines for the creation, assessment, and limitation of continental cycle of carbon models.

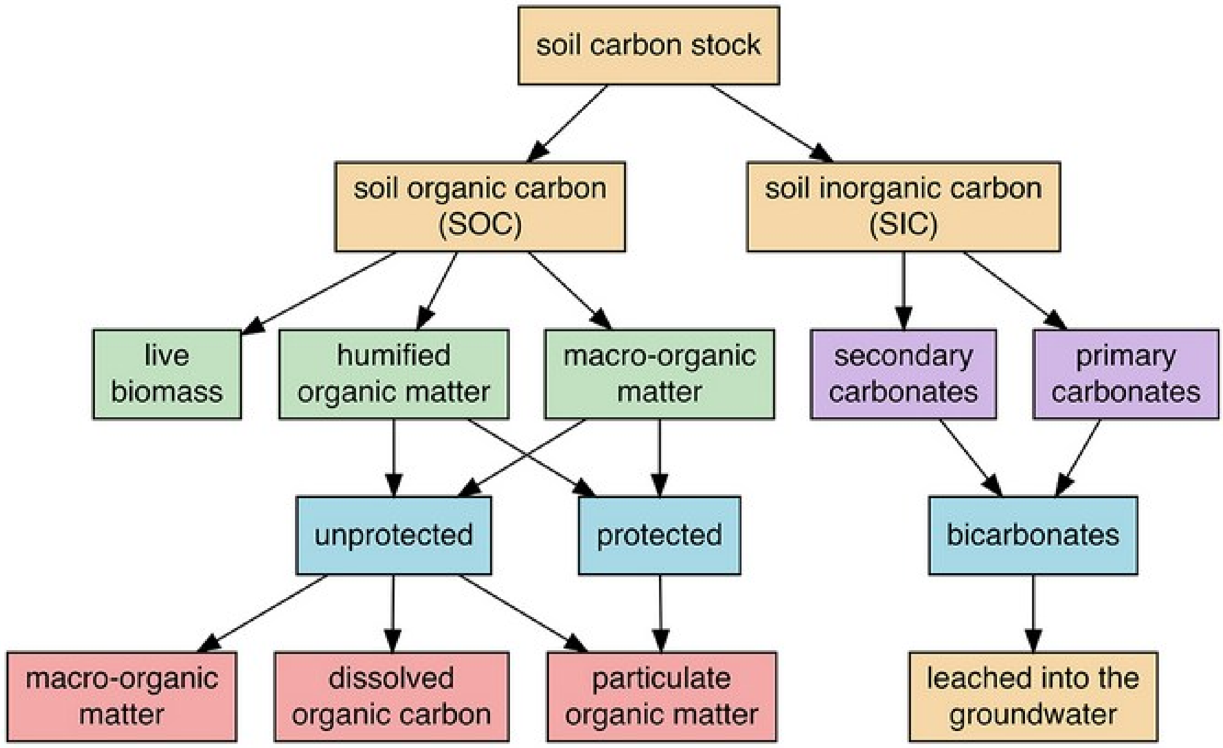
Studies on soil carbon sequestration has traditionally concentrated on the upper 0–30 cm of the underlying soil layer, omitting subsurface layers that may also react to management. Subsoil C could get far more important as a sink and source for atmospheric CO_2 over surface C since the majority of subsoil strata provide over fifty percent of the overall soil C reserves notwithstanding their small C concentration. Thus, the impact of land use modifications on C emissions is predicted using the understanding of SOC dispersion and regulations on C sequestration across standard profiles of soil (Garcia-Palacios & Chen, 2022, p. 1332). This section attempts to summarize the implications of land utilization on the dynamics of SOC across various managerial situations.

2.2 Soil biology and carbon processes

The agricultural carbon cycle is driven by soil biology, which stores atmospheric carbon dioxide and converts it to a solid soil organic matter (SOM). This system that changes depends on a number of vital chemical and biological procedures to balance intake (plant-based photosynthetic) with emissions (bacterial breathing). Carbon-based sugars, essential amino acids, and basic organic acids are actively released by living roots to nourish helpful microorganisms in the rhizosphere. Dead plant matter and exudates from roots are digested by germs (microbes, fungi), microorganisms, and microbial species (Almendros & Gonzalez-Perez, 2025, p. 6689). A part of the carbon is released and then returned to the environment as carbon dioxide when bacteria consume and decompose organic stuff. The structure blocks for sustainable stored soil carbon are the carcasses of dead microorganisms, which are extremely resistant.

The reduction and recovery of global soil organic carbon (SOC) is significant since it comprises significant amounts. According to current estimates, worldwide emissions of carbon from all sectors are caused by people's actions. Among the three metrics utilized by the Sustainable Development Goals (SDGs) and the Convention of the UN to Prevent Desertification in order to evaluate the degree of deteriorated surface area, quality of soil, and recovery efficacy is the level of and shift in SOC (Noordwijk et al, 2023, p. 1). Water management, cereal and grazing cultivation, drought and flood mitigation, risk reduction, nitrogen cycle regulation, biological diversity, ecosystems, and ecological services are all fundamentally related to SOC.

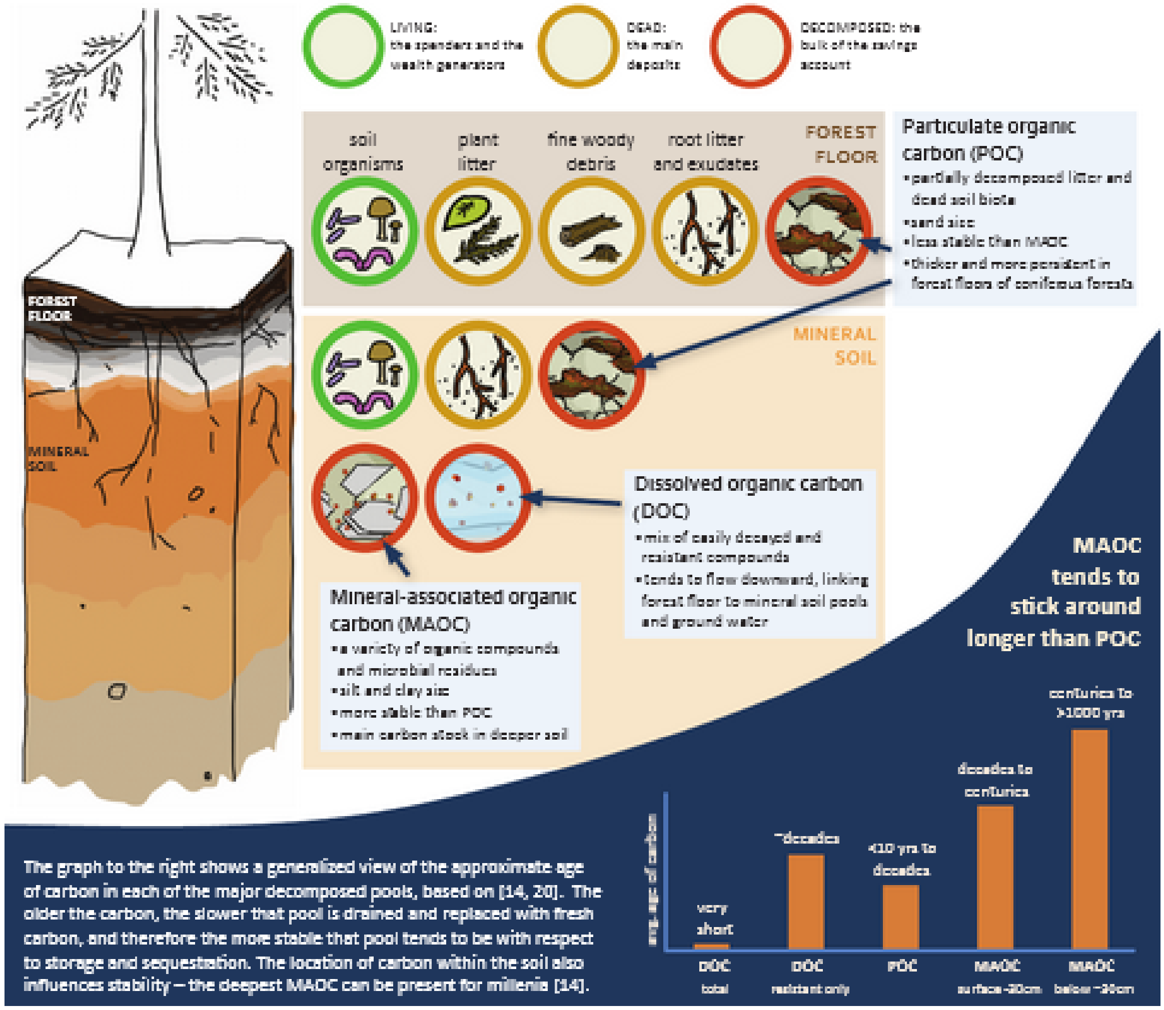
Figure 2: Elements of soil carbon stock



Source: Nepal J, Xin X. (2025). Understanding soil carbon: Key ingredient to build healthy soils, https://www.sciencesocieties.org/publications/csa-news/2025/june/understanding-soil-carbon-key-ingredient-to-build-healthy-soils?q=publications/csa-news/2025/june/understanding-soil-carbon-key-ingredient-to-build-healthy-soils/

Because it increases soil composition, stimulates microorganisms, promotes resistance in response to environmental shocks, and promotes fertility by supplying nutrients, carbon from soil is crucial to the fitness of soil. A variety of techniques, including incorporating livestock, growing cover crops, lowering tillage, introducing organic soil alterations, and changing cropping practices, are used to increase soil carbon. The formation of tiny aggregates that improve soil porosity and permit water and air to flow easily through the soil is mostly dependent on soil carbon (Maddison et al, 2021, p. 2). In organic farms, for example, well-aggregated soil typically has higher rates of water infiltration, which lowers runoff from the surface and erosion of soil. An ideal habitat for crops is created by strong soil conditions, which also facilitates penetration of roots.

Figure 3: Soil carbon in ecosystem

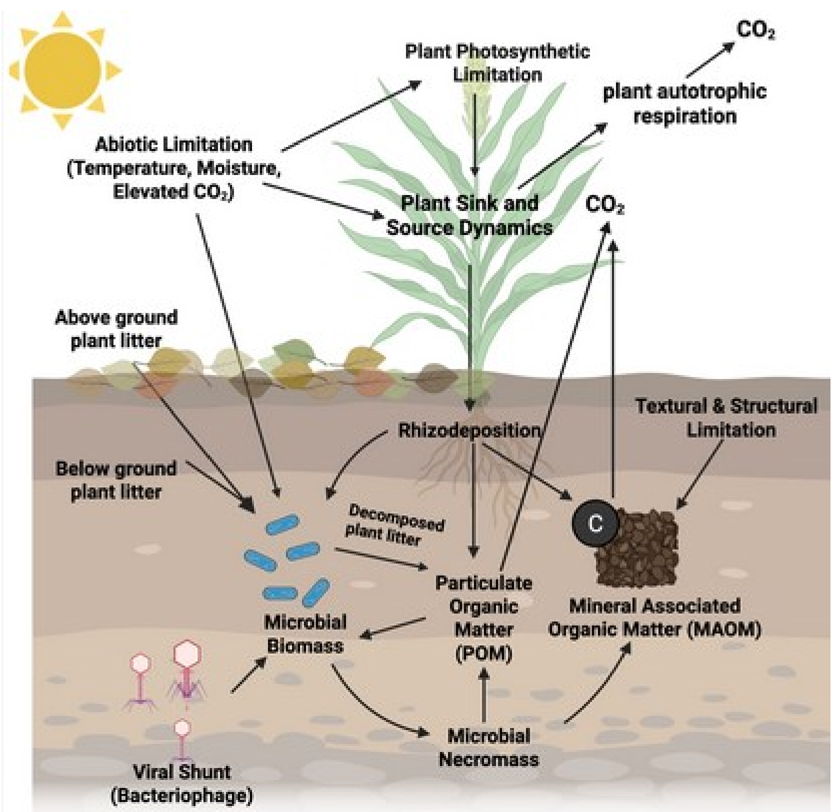


Source: Maddison J et al. (2021). Soil Carbon in Forest Ecosystems: Pools and Processes, Government of British Columbia, p. 2.

The action of soil microbes and fauna releases soil carbon, which acts as a massive reservoir of minerals. This mechanism is vital to the provision of vital elements to plants, such as sulfur (S) and nitrogen (N). Soil carbon increases the supply of nutrients to plants and lessens the need for artificial fertilizers by retaining them in the area of roots for extended periods of time. For instance, in organic matter-rich soils, microorganisms mineralize nitrogen, which eventually becomes accessible to plants, lowering the need for artificial fertilizers (Das et al, 2025, p. 6015). Additionally, soil organic matter enhances the capacity of soil to increase growth capacity, which promotes the continuation of strongly charged nutritional ions including Ca, K, Zn, and several micronutrients.

Excessive carbon soils are more resistant to ecological pressures such as excessive salinity, flooding, and nutrient scarcity. For example, organic carbon improves the capacity of soil to keep water, which eventually lessens the negative effects of drought on agricultural output. Soil carbon serves as a buffer in areas vulnerable to unpredictable weather conditions, promoting steady yields and for a long time production in agriculture. Additionally, beneficial microorganisms can improve plant health by outcompeting dangerous pathogens. Because little carbon from organic materials impacts the formation of soil, it is highly vulnerable to water and erosion from wind (Ingvarsson, 2025, p. 2). Excessive surface runoff after heavy rains is a result of poorly integrated soils' lack of cohesiveness. For instance, topsoil is simple to clean away in regions with heavy tillage and minimal organic material input, which lowers land productivity.

Figure 4: Soil carbon sequestration process



Source: Das S et al. (2025). Soil Carbon Sequestration: A Mechanistic Perspective on Limitations and Future Possibilities, Sustainability, 17(13)

Lack of carbon in the soil reduces the amount of food available to microorganisms, which lowers biodiversity and microbial activity. The soil's natural defenses are weakened by this loss, making it more susceptible to illnesses and pests. For instance, the lack of helpful microorganisms including mycorrhizal fungi might make plants more vulnerable to root infections in deteriorated soils with little organic intake. Inadequate fertility in the soil results from slowed nutrient cycling caused by insufficient soil carbon (Laban, Metternicht & Davies, 2018, p. 4). Lower yields and reduced growth are the results of crops' inability to obtain essential nutrients. For example, farmers may be forced to use a lot of chemical fertilizers because carbon-deprived soils may not have the amount of microbes required to transform organic nitrogen into forms that plants can use.

For the sake of performing a wide gap of strategies, procedures, as well as managerial techniques and achieve measurable results, augmenting SOC necessitates significant thought and strategic preparation. Management measures should maximize organic matter inputs while minimizing disruptions including eroding, solidification, and extensive exposure of soil in order to improve SOC. Individual techniques alone are often insufficient, but an integrated approach that incorporates several strategies allows for faster and more significant changes. The capacity of cover crops to raise SOC is one of their main advantages (Wang et al, 2025, p. 3375). Cover crops absorb airborne carbon dioxide from the environment through photosynthesis and transform it into biological material that is then deposited in the soil. This method enhances nutrient content, retained water, and general soil resilience in addition to reducing climate change through carbon sequestration.

Because they provide throughout the year soil covering, cover crops are strategically important for preserving soil that is healthy. Soil erosion is prevented, soil aggregation and structure are improved, and nutrient cycling is improved by this constant coating. Cover crops strengthen fitness of soil by supplying organic material for the soil, thus fosters growth of beneficial organisms residing in soil such as small living things and earthworms. To maximize the advantages of cover cropping, the type of cover crop chosen is essential. The special capacity to handle atmospheric nitrogen and make it accessible plants is possessed by legume-based cover crops like clover and vetch (Wang et al, 2025, p. 3375). Additional advantages like weed suppression, insect management, and soil aeration are provided by other kinds of cover species of crops like grasslands and brassicas, among others.

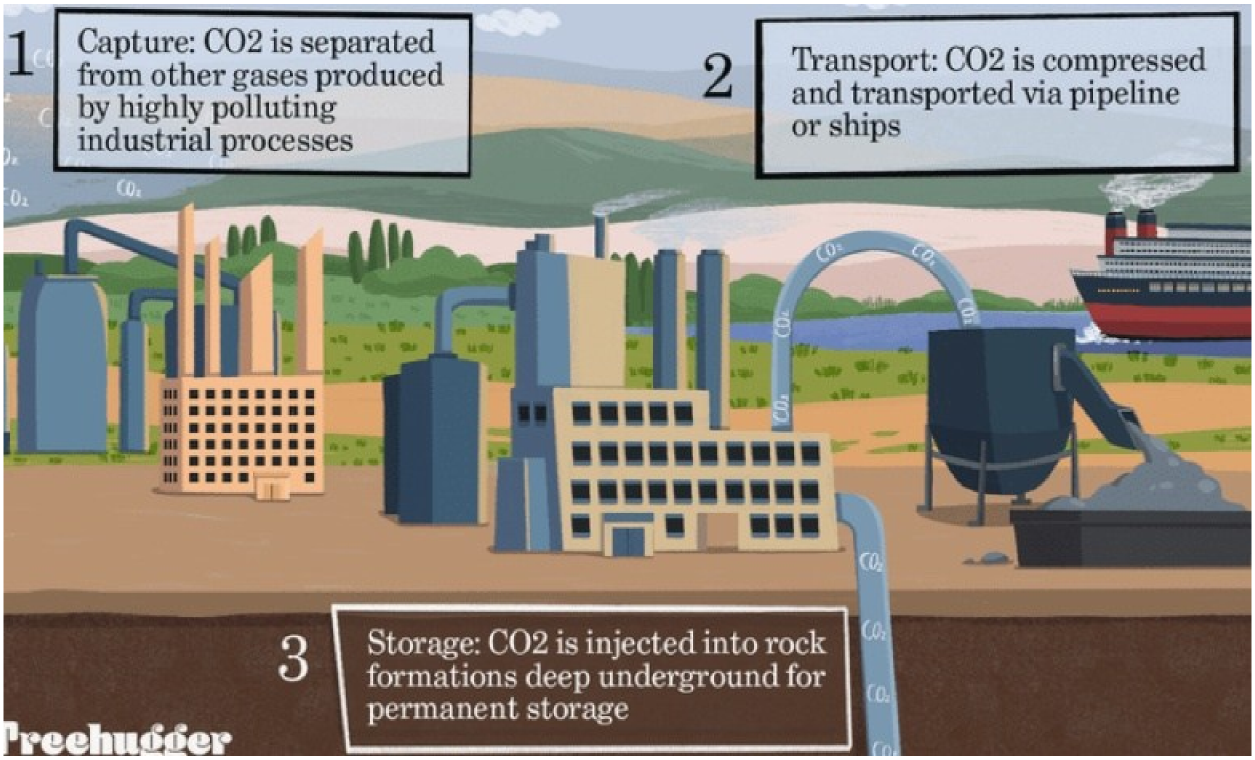
Chemical methods like pesticides or mechanical methods like rolling or mowing can be used to end cover crops. To maximize nutrient release, reduce weed pressure, and guarantee the effective creation of the future cash crop, terminated scheduling ought to be thoughtfully planned (Hu et al, 2025, p. 1). Although cover crops have many advantages, managing them can be difficult. For instance, improper management can turn some cover crops into weeds. For some farmers, the expense of covering plant seeds and the duration needed for installation and closure might also be obstacles. However, with thoughtful preparation, effective management, and the utilization of existing assets and assistance programs, these difficulties can be addressed.

2.3 Carbon as a carbon storage system

In the storage of carbon facilities, commercial carbon dioxide is either captured and stored permanently underground or absorbed by natural ecosystems. By eliminating extra greenhouse gases from the environment, the procedure helps to slow down global climate change. Carbon dioxide is captured at manufacturing processes and stored deep within the earth through a process known as geologic sequestration. Deep below, carbon dioxide is poured into formations of porous rocks after being compressed into a liquid-like supercritical condition (Moretta & Craig, 2022, p. 5). To completely eliminate it from a typical carbon chain, it is either dispersed in subterranean fluids or forcibly contained by impervious caprocks. This system, often referred to as biologic sequestration, draws and retains carbon through organic biological processes. During photosynthesis, vegetation and grasses absorb atmospheric CO_2 and transform carbon dioxide into soils and tissues that are living.

Carbon capture and storage (CCS), is regarded as the main way of reducing emitted CO_2 from large areas of industries, other approaches are being researched to try to lower global CO_2 emissions. CO_2 is taken from industrial areas, moved, and then kept in an appropriate location as part of CCS. The taking of CO_2 from the surrounding environment, is another definition of CCS (Kuti et al, 2025, p. 684). The process of removing CO_2 from emissions (generated by industrial operations) and then moving it (by pipeline or ship) for long-term storage is known as the capture and storage of carbon, or CCS. The goal of CCS is for capturing emissions at their source and prevent them from ever entering the atmosphere, rather than to lower or balance emissions.

Figure 5: The way Carbon capture and storage works



Source: Rhode E. (2022). What Is Carbon Capture and Storage (CCS)?, https://www.treehugger.com/carbon-capture-and-storage-5119849

A crucial element in the effort to lower emitted CO_2 and handle global warming is carbon capture technology. The first of the three phases of carbon capture and storage is called carbon capture. Large-scale industrial operations like power plants and the passage of ships as part of international shipping can produce CO_2. Preventing CO_2 created during industrial activities from reaching the atmospheric environment is the primary goal of carbon capture (Kuti et al, 2025, p. 684). The 2015 Paris Agreement established a challenging goal to keep future rises in temperatures to 1.5°C. To do this, all industries—including shipping—will need to work together globally. All industries place a high premium on the requirement for more ecologically friendly operations.

A mechanism whereby carbon dioxide (CO_2) is absorbed and retained in natural ecosystems, mainly through biological processes including photosynthesis in plants on earth, fungi, and microbiological processes in soils, is known as carbon storage. This process helps lower CO_2 in the atmosphere levels. A crucial method of mitigating climate change, carbon capture and storage (CCS) removes CO_2 wastes from manufacturing processes as well as saves them below the soil to limit them towards penetrating the atmosphere (Castilla, 2024, p. 9). Millions of tons of carbon dioxide are currently stored annually by carbon capture utilization storage (CCUS) projects worldwide. However, so as achieving the goals of the Paris Agreement, millions must become billions. Focusing on CCUS hubs, typically absorb carbon dioxide across various places, is one strategy to speed up CCUS implementation.

Chapter 3 – Soil Consumption Analysis

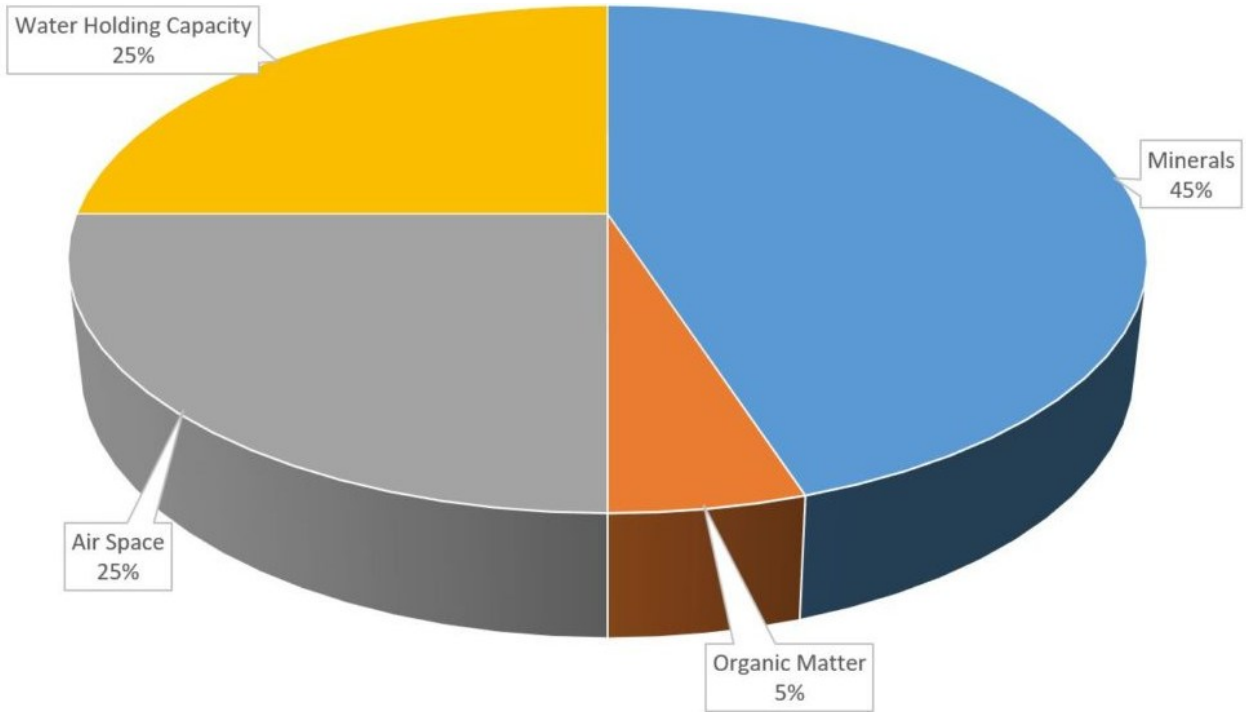
3.1 What happens when soil is destroyed

The capacity of soil to promote plant development and maintain life is lost when it is destroyed or seriously damaged. This sets off a series of catastrophic local and worldwide repercussions, such as decreased food production, an rise in landslides and floods, and hastened climate change. The following are the main effects of soil deterioration. Farmers are forced to extensively rely on costly synthetic fertilizers as a result of decreased crop yields caused by the loss of fertile topsoil. Deeper susceptibility to droughts and severe surface runoff results from compacted, degraded soils' inability to absorb or hold water. There is more to soil than just dirt. Food production, water purification, fossil storage, and biodiversity all depend on this live, breathing environment. When the biological and physical characteristics of the soil are compromised, it becomes less functional. This is known as soil degradation (Dai, Ma and Zhang, 2022, p. 16046).

The deterioration of soil quality through human and natural processes is referred to as soil degradation. It may be biological, chemical, or physical. Increased weather events, such as more frequent and powerful hurricanes, less snow and more rain, and excessive water can all contribute to soil erosion. Preventing soil erosion is another way to combat climate change. Nature is more densely packed than anywhere else in the world. There are more creatures in a spoonful of soil than there are individuals on the planet. Soil accumulates as a result of eroding rocks, decay, and the decomposition of dead organisms and animals (Bayata, 2024, p. 16-34).

The procedures that exist in soil and they deteriorate. These outputs lead to a decrease in the quality of soil, critical thinking, and productivity, which causes problems for huge socioeconomic balance at various stages and causes huge environmental problems such as land migration and floods. Important nutrients are lost and organic matter cannot be recycled or replenished as land in nature, such as a forest, is moved toward farmland. In fact, it lowers the ability of soil to keep carbon from 50% to 75%. This should be a huge way backward, since decreasing in temperature is among the most pressing problems related to environment in the modern day. When wet soil and a heavy weight—such as cumbersome farm equipment—combine, the result is soil compaction (Göncüoğlu, 2015, p. 48).

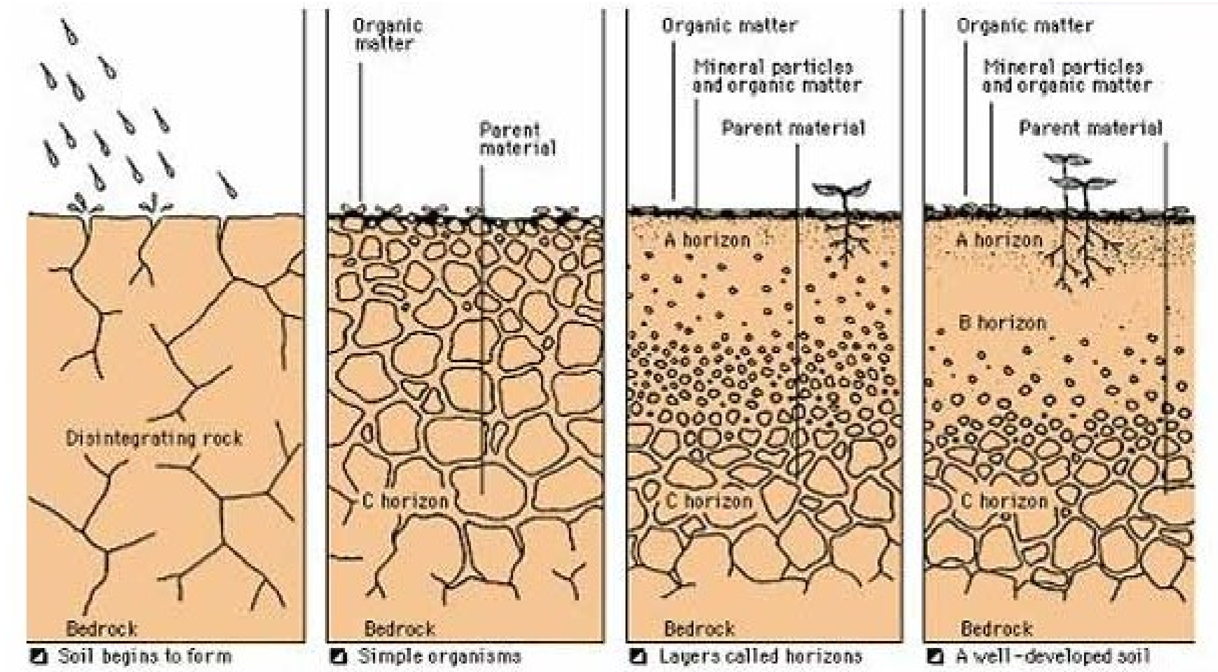
Figure 6: Soil components



Source: Daniel K. (2020). Soil Basics for Improved Plant Health, Purdue University

Farmers are forced to extensively rely on costly synthetic fertilizers when the nutrient-rich topsoil is removed. In the end, it results in desolate territory. Compacted and degraded soil no longer retains water like a sponge. This significantly raises the likelihood of both severe local droughts and flash floods. Sinkholes, storms of dust, and hazardous mudslides can result from soil that is readily washed away or blown away in the absence of deep root systems and matter that is organic keeping it together. Soil that is in good health is a huge carbon sink. Degradation of the soil accelerates climate change by releasing stored nitrogen as well as carbon into the atmosphere. Globally, people are pushed away from unusable land in looking for fertile ground elsewhere due to the demise of viable topsoil, which results in soil refugees (Göncüoğlu, 2015, p. 48).

Figure 7: Soil degradation



Source: Michaels J. (2026). What is Soil Degradation? , https://nativeseedgroup.com/resources/blog/what-is-soil-degradation

A living ecosystem is found in soil. Beneficial bacteria and fungi are eliminated by chemical abuse or physical destruction, which prevents the land from organically breaking down organic matter or cycling nutrients. Deep plowing and extensive tillage are examples of wrong ways of farming, which enhance soil erosion and change sphere of the ground. By establishing ways to keep nutrients balancing, environmental pollution, and land acidification, poor usage of fertilizer may destroy profitable organisms and deteriorate the health of the soil. As increasing grazing lowers plant-covered area and raises groundwater, it causes an effect to soil. Toxic contaminants as well as chemicals released by industrial spills, insufficient disposal of waste, or agricultural runoff can contaminate soil, endangering both human health and the ecosystem (Bayata, 2024, p. 17).

Table 2: Types of soil erosion

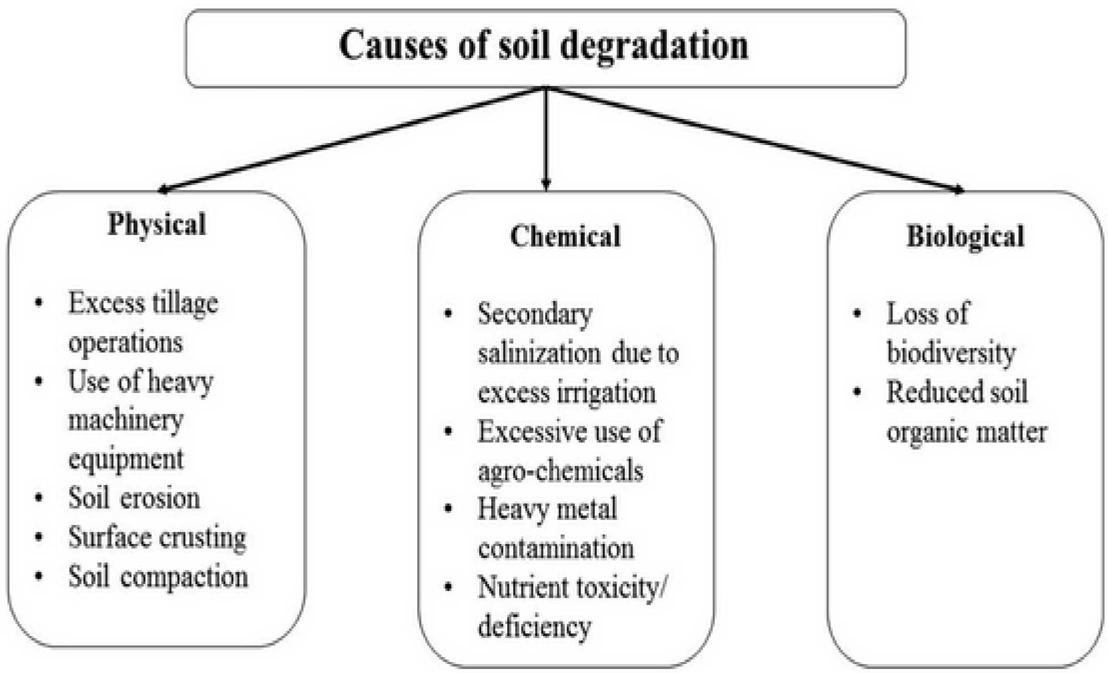
Types of erosion	Mechanisms	Key characteristics	Typical impact areas
Water-induced	Detachment by raindrop impact, runoff	Causes gullying, sheet, and rill erosion	Agricultural lands, riverbanks
Wind	Particle detachment and transport by wind	Most effective in dry, loose soils	Arid regions, exposed farmlands
Chemical	Soil structure breakdown by chemical change	Salinization, acidification	Irrigated agricultural lands
Thermal	Cracking due to temperature changes	This leads to increased vulnerability to other erosion types	Areas with extreme temperature variations
Biological	Soil disturbance by organisms	May increase porosity and susceptibility to erosion	Forest floors, agricultural fields

Source: Firoozi A, Firoozi A. (2024). Introduction to Soil Erosion: Scope, Significance, and Framework, IntechOpen Limited.

Around the world, soil degradation can have catastrophic consequences like floods and landslides, increased pollution, desertification, and a drop in food production. Land deterioration and the resulting decline in soil production pose one of the greatest risks to our prospects for food security. Among the regions most likely to be impacted are poor countries that often provide services and products to high-income countries. The majority of people from less developed countries seemed to move from their houses seeking productive land and security that may result in the reduction in cultural heritage along with potential political and economic upheaval elsewhere (Michaels, 2026).

Crop rotation enables a variety of plants to flourish in a given area of soil annually. It allows the upper soil to replace nutrients that have been depleted following the yield of certain kind of trees. Compost, fertilizer, and crop leftovers are examples of material in organic form that can be included in enhancing the soil, water retention and cycling of nutrients. But different types of organic nitrogen behave differently in soil. In order to get rid of naturally occurring nitrogen, traditional additions primarily depend on microbial breakdown, which may result in competition between soil bacteria and crops. Farmers can create resilient soils that directly feed crops and promote long-term soil health through the integration of microbial-based biological material with non-microbial nitrogen that is organic (Bayata, 2024).

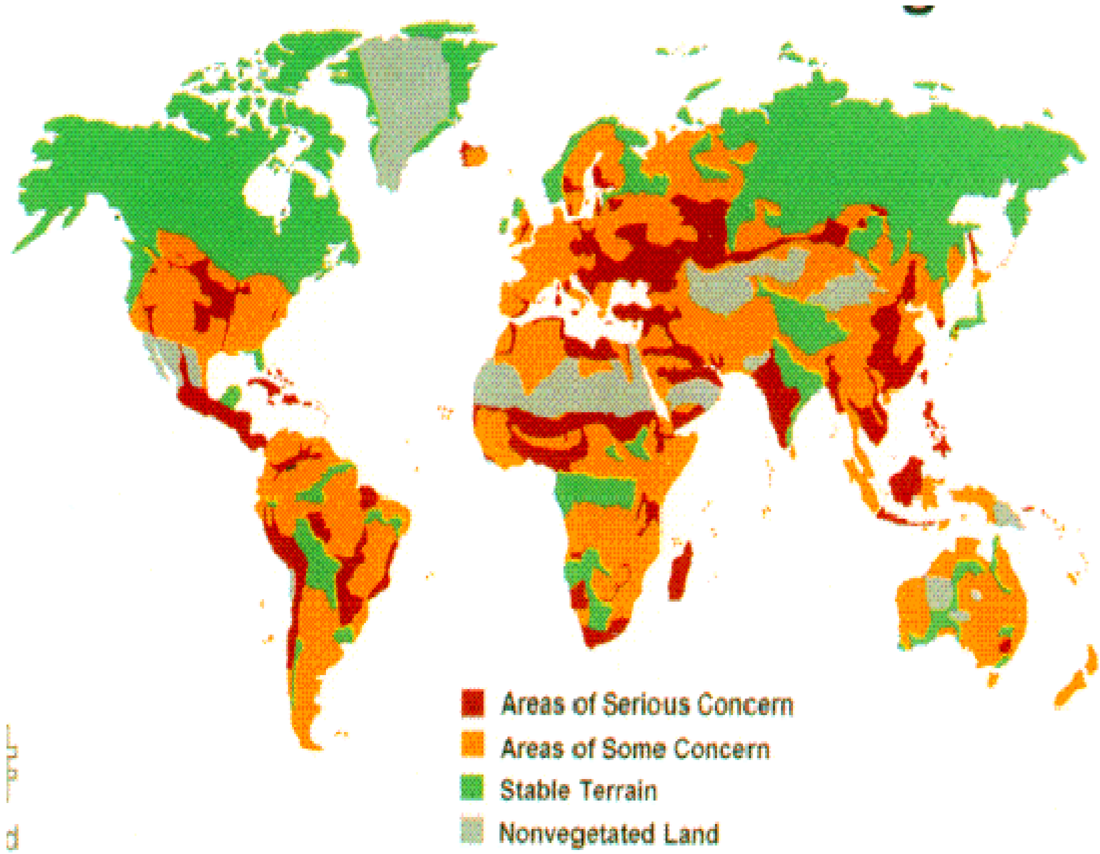
Figure 8: Causes of soil degradation



Source: Kumar R et al. (2021). Soil Degradation Challenges for Sustainable Agriculture in Tropical India, Current Science, 120(3):492

All living creatures are impacted by the serious environmental problem of soil deterioration. There would be no arable ground for farming and crop growth without fertile soil. There may be fewer food supplies available, and numerous species or organisms may start to suffer extinction or endangerment. Increasing vegetation, improving agricultural techniques, and implementing erosion control measures are some of the ways that humans must keep working to preserve soil and stop deterioration. The world's food supply is at risk due to the alarming rate at which soil degradation develops, affecting land fertility and productivity. Degraded soil, particularly is caused by environmental and human issues, poses a threat to long-term sustainability, ecological wellness, and food security globally (Bayata, 2024, p. 18).

Figure 9: Areas with serious soil degradation



Source: Folnovic T. (2026). Soil Degradation, https://www.agrivi.com/blog/soil-degradation/

Grains of worn rock and the body parts of dead, decomposing plants make up the majority of soil. However, it is by no means a lifeless, inactive material. Microbes, fungi, insects, worms, and other invertebrates abound in soil, which is a living system. All of these are crucial for material breakdown, plant nutrient delivery, and soil fertility maintenance. They have discovered a variety of microorganisms that can improve the natural rhizosphere, which is made up of colonies of bacteria in the soil surrounding plant roots that consume plant secretions and provide nutrients to the plants in exchange. Most plants cannot thrive without this invisible ecosystem, which is a frequently disregarded feature of plant growth (Pierzynski, Caon and Vargas, 2017).

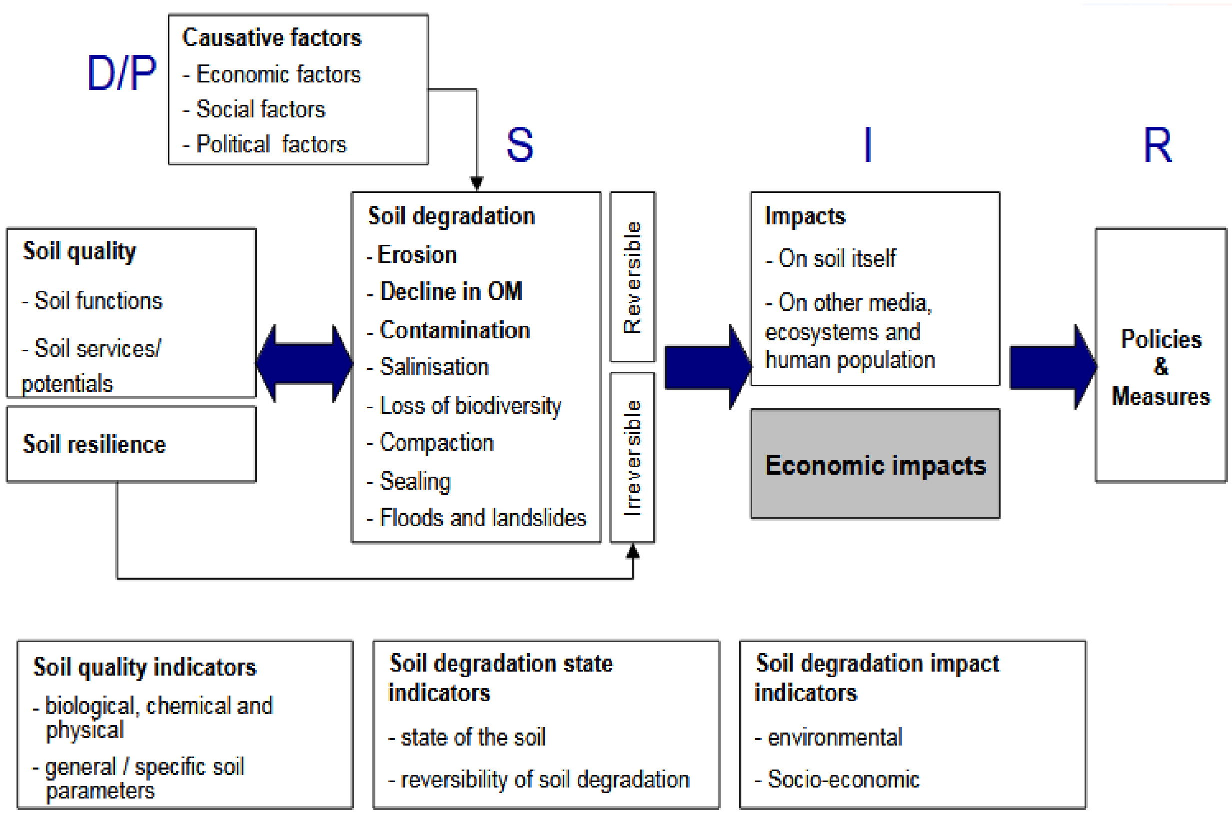
Table 3: Soil degradation causes

Causative factor	Definition	Soil degradation type
Agricultural causes	Improper management of cultivated arable land: intensive agriculture (incl. greater specialisation and monocultures; insufficient or excessive use of fertilisers and plant protection agents; shortening of the fallow period in shifting cultivation; poor water and irrigation management; absence or bad management of erosion control measures; improper use of heavy machinery; etc.	Erosion (water or wind), compaction, salinisation, contamination (by pesticides or fertilisers), organic matter decline, biodiversity decline
Overgrazing	Actual overgrazing of vegetation by livestock and trampling, a phenomenon of excessive numbers of livestock.	Soil compaction and decrease of plant cover, both of give rise to water or wind erosion, organic matter decline and biodiversity loss
Over-exploitation of vegetation for domestic use	A degeneration of the remaining vegetation, e.g. excessive gathering of fuel wood, fodder, (local) timber, etc.	Erosion
Deforestation or removal of natural vegetation	(Near) complete removal of natural vegetation (usually primary or secondary forest) from large areas, e.g. by converting forest into agricultural land, large scale commercial forestry, road construction, urban development, etc.	Erosion, organic matter decline, biodiversity decline, floods, landslides
Industrial activities	All human activities of a bio-industrial nature: industries, power generation, mining, waste disposal, infrastructure and construction, etc.	Soil contamination of different kinds (either point source or diffuse), salinisation, soil sealing
Urbanisation and transport	Increasing surface area consumption for residential uses or tourism as well as associated transport infrastructure	Soil sealing, soil contamination through storm water runoff, floods, landslides, habitat fragmentation

Source: Görlach B et al. (2004). Assessing the Economic Impacts of Soil Degradation Final Report, European Commission

Converting woods and grasslands into agricultural areas and grazing is supported by increasing requirement for farming products. The majority of given crops such as rice, maize, and others, may worsen soil health over what the land can sustain on its own. The shift from natural vegetation to agriculture frequently fails to retain the quality of the soil. Dating back 150 years, the distinction of topsoil occurred. Other elements of agriculture have an impact on the effectiveness of soil without the occurrence of erosion. Given effects contain soil salinity, decreasing of nitrogen, compaction, as well as a decrease in soil form. These are real, sometimes serious problems (Dragovic and Vulevic, 2020, p. 1).

Figure 10: Impacts of soil degradation



Source: Görlach B et al. (2004). Assessing the Economic Impacts of Soil Degradation Final Report, European Commission

The declining of fertile land is just not the only effect of degraded soil. Streams are now clogged and other species are declining as a result of higher levels of contamination and sedimentation. In fact, eroded areas have a poor ability to retain water, which exacerbates flooding. By avoiding soil erosion and degradation as well as the declining of precious areas till desertification, environmentally friendly usage of land may reduce the impacts of agriculture. Producers, as well as others around the globe, whose lives depend on properly run agriculture that starts with the underground soil, are primarily concerned about the health of the soil. Maintaining healthy soil presents numerous problems, but there are creative ways to preserve the delicate ecosystem that supports biodiversity (Steiner, 1996, p. 5).

Degradation of fertile soil reduces agricultural productivity, contaminates waterways, forms emerging deserts, and may transform the manner in which water flows around the environment, possibly raising the time of flooding. The droughts and dry conditions the landscape experiences as an outcome caused by human degradation of fragile natural environments are what define desertification. The degradation of land, eroded soil and dead zones, and a reduction of species are among the effects, which have significant financial consequences for countries where deserts are expanding. Any terrain that is suitable for growing crops is considered arable land. Many of the methods used to cultivate those crops result in the deterioration of soil qualities that enable agriculture and the disappearance of topsoil (Kopittke et al, 2025, p. 746).

Fungicides and other chemicals used on areas, and soil erosion around land, flow towards rivers and other water areas. Aquatic and maritime areas, and local populations that rely on them, may be harmed by this pollution and sedimentation. A woodland or related ecological terrain, like swamps and flood zones, is frequently converted into an agricultural field or pasture. Flooding is more frequent because the changed soil is unable to absorb water. In addition to restoring and maintaining aquatic ecosystems, there exist ways to increase the capacity of soil for keeping water (Görlach et al, 2004, p. 22).

Figure 11: Desertification

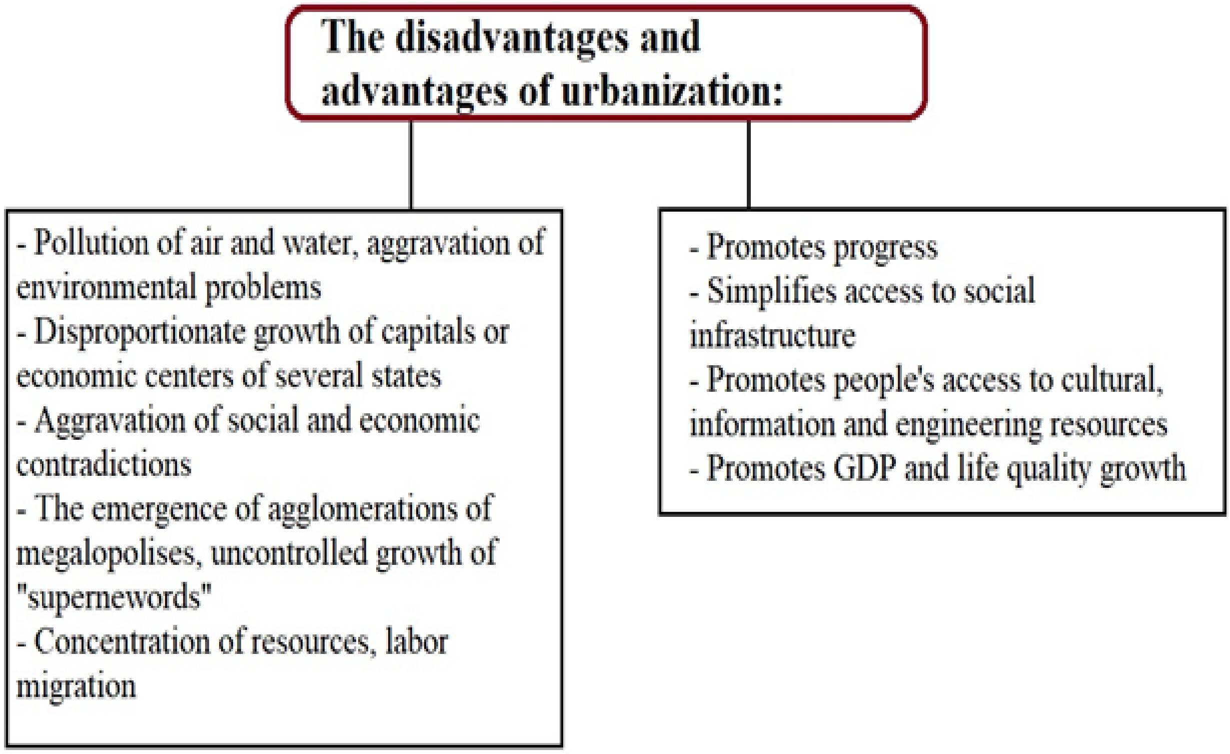
Source: Pattikonda, desertification, https://internationaljournalofresearch.com/2020/07/29/desertification/

It is believed that 33 percent of all land is either severely or moderately deteriorated due to damage from erosion, acidic conditions, or other reasons, notwithstanding the difficulty of quantifying the level of soil degradation worldwide. In fact, agriculture makes till 29 percent of deteriorated parts, although making up just 13 percent of the world's covered area. This deterioration occurs more frequently in farming soils. By 2050, land degradation is predicted to affect the economy by around $23.2 trillion USD. The soil degraded affect crops for people as it exploits soil wealth. In fact, soils vanish by degrading at rates ranging from 10–100 times quicker than natural decay of 0.025–0.125 mm annually due to climate (Kopittke et al, 2025, p. 750).

3.2 Effects of urbanization and infrastructure (roads, buildings)

Although infrastructure expansion and urbanization promote economic growth and enhance service accessibility, they frequently lead to serious environmental and social problems. Planned growth raises living standards and productivity, but unchecked, rapid growth puts a pressure on resources, exacerbates the effects of climate change, and widens socioeconomic gaps. Cities create agglomeration economies that lead to more innovation, better access to healthcare and education, and higher incomes. Inadequate housing, the growth of unofficial communities (slums), and rising urban poverty are often the results of moving from villages to towns in the absence of strategic planning. The danger of disease transmission is increased in areas with low and middle incomes by crowded living situations and overburdened sanitation systems. Urban growth causes deforestation, declines in biodiversity, and the urban areas impact by transforming ecosystems into built-up areas (Sharma, 2025).

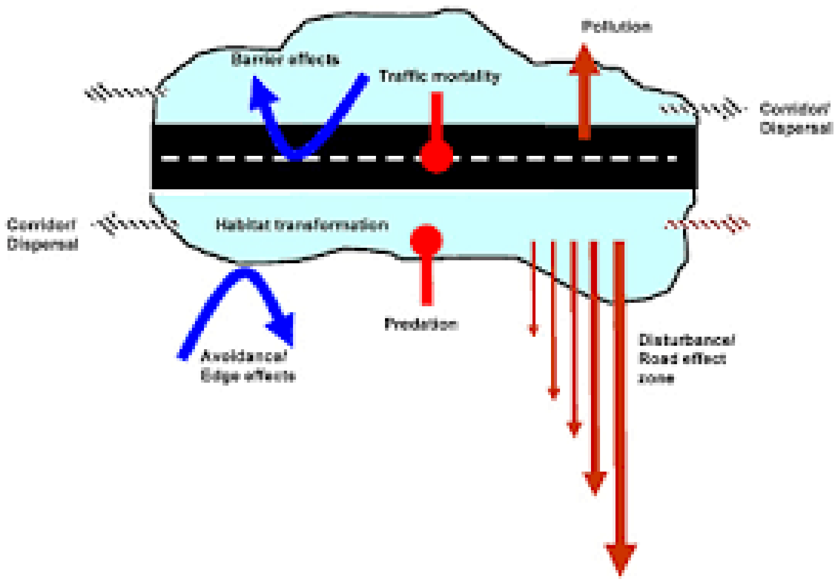
Figure 12: Advantages and disadvantages of urbanization



Source: Shevshenko et al. (2018). Urban agglomerations: positive and negative features of the urbanization of modern society, Economic development research journal, 330(3): 316

As one among permanent effects of activity related to people on the ecosystem is the conversion of surface of the planet to urban uses. Highly productive agriculture is lost more quickly, energy demand is impacted, the climate is changed, hydrological and biological processes are altered, habitats are fragmented, and biodiversity is decreased. These consequences are evident on several levels (James, 2023, p. 57).

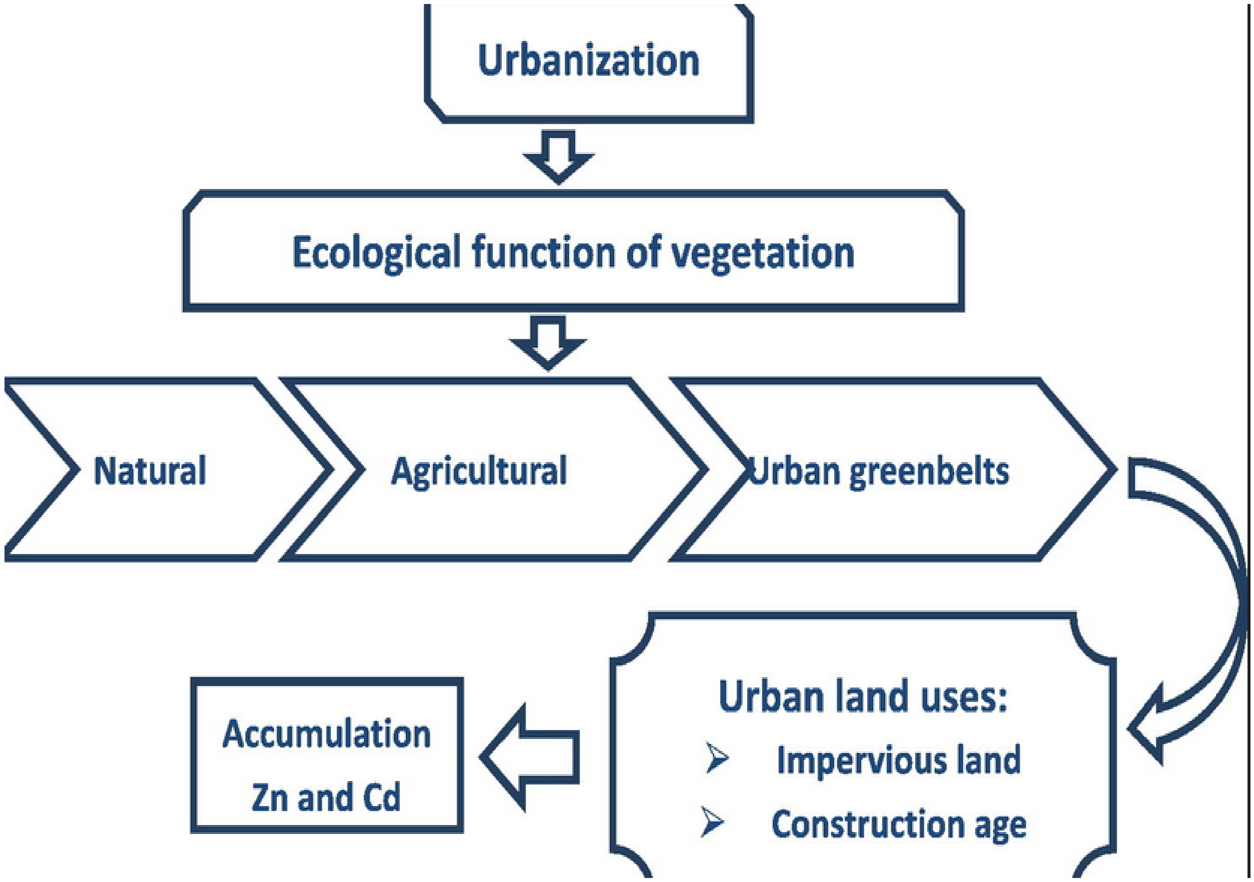
Figure 13: Effects of roads to species



Source: National Academies Press. (2005). Effects of Roads on Ecological Conditions, https://www.nationalacademies.org/read/11535/chapter/5

For instance, extremely valuable environments will be directly threatened by projected growth in cities: areas of high biodiversity that were mostly unaffected by development of cities in 2000 would probably see the greatest amount of land transformation over the coming decades. The type of urban growth within cities also has a significant role in determining how susceptible urban residents are to stress related to the environment (James, 2023, p. 57).

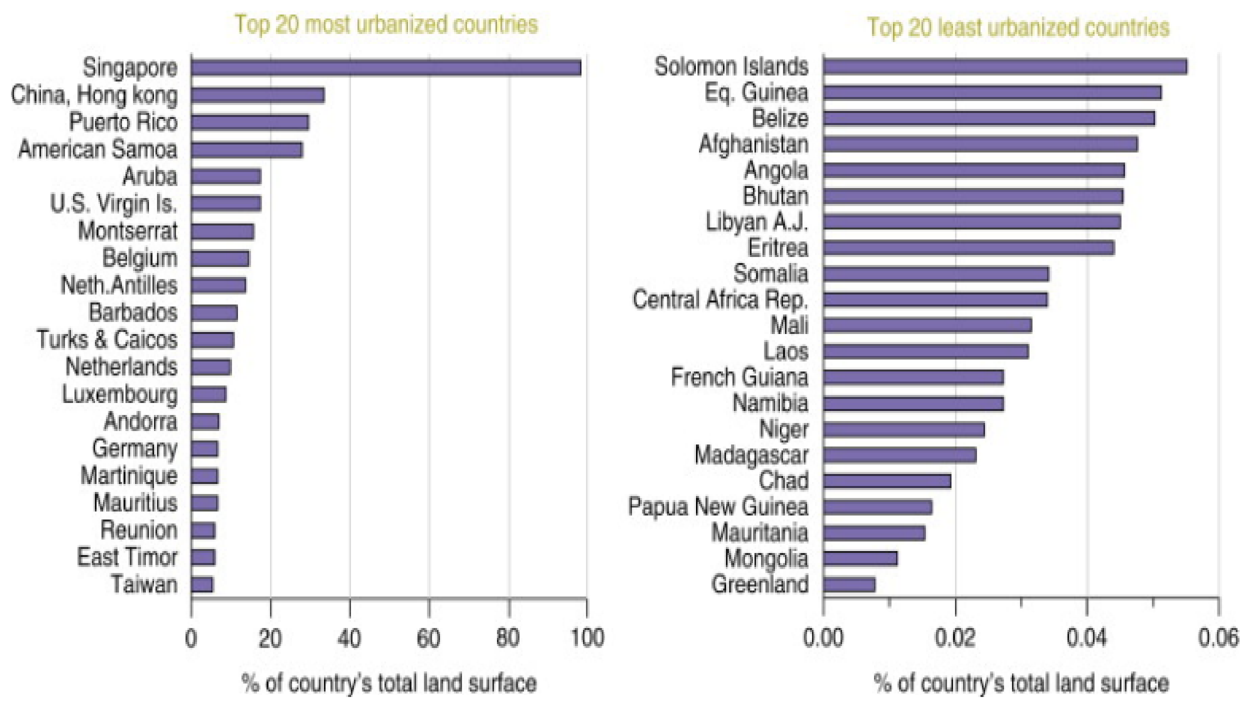
Figure 14: Effects of urbanization



Source: Wang M, Liu R, Chen W, Peng C, Markert B. (2018). Effects of urbanization on heavy metal accumulation in surface soils, Beijing, Journal of Environmental Sciences, Vol. 10.

Pollution of the atmosphere and emissions of greenhouse gases (GHG) worldwide are disproportionately caused by cities. Because paved, impermeable surfaces don't absorb water, they interfere with the water that is natural cycle and make flash floods more common. Severe traffic congestion, decreased productivity, and a rise in traffic deaths are caused by poorly planned road systems and funded public transportation systems. Sinkholes and persistent floods are frequently caused by outdated drainage and utility infrastructure that are unable to keep up with population development (Strulak-Wojcikiewicz and Deja, 2022, p. 4260).

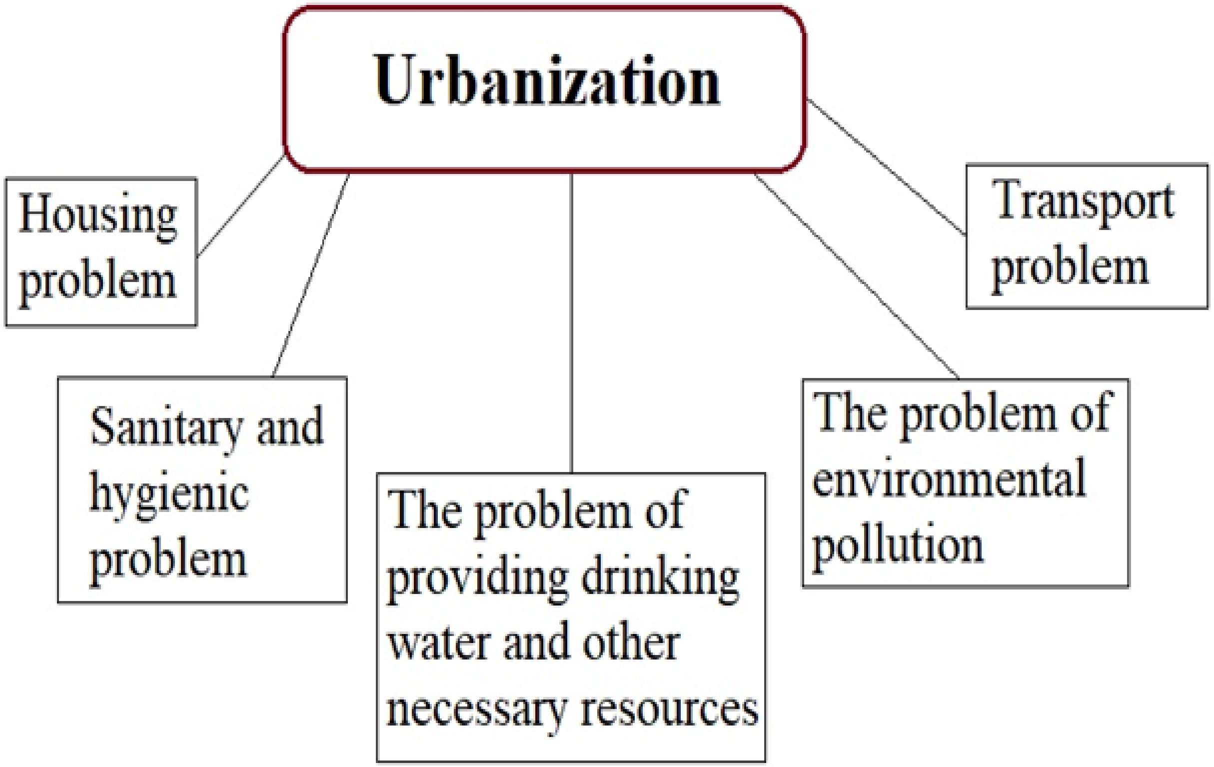
Figure 15: Top and least urbanized countries



Source: Levin S. (2013). Encyclopedia of Biodiversity, Elsevier Inc

My opinion is that infrastructure development and urbanization promote economic growth and enhance service accessibility, but they frequently put a strain on resources when demand exceeds supply. Unplanned growth can lead to serious socioeconomic inequality, inadequate housing, transportation congestion, and environmental deterioration. Cities are hubs of innovation and employment, attracting skilled workers and generating a wide range of professional options. Well-developed metropolitan neighborhoods are typically closer to essential amenities like public transportation, healthcare, and education. Delivering public services and utilities at a lower cost is made possible by high population density. Slums and a shortage of affordable housing are often the result of infrastructure development lagging behind population expansion. Inadequate public transportation systems and poorly designed road networks cause heavy traffic, lengthy commutes, and reduced output.

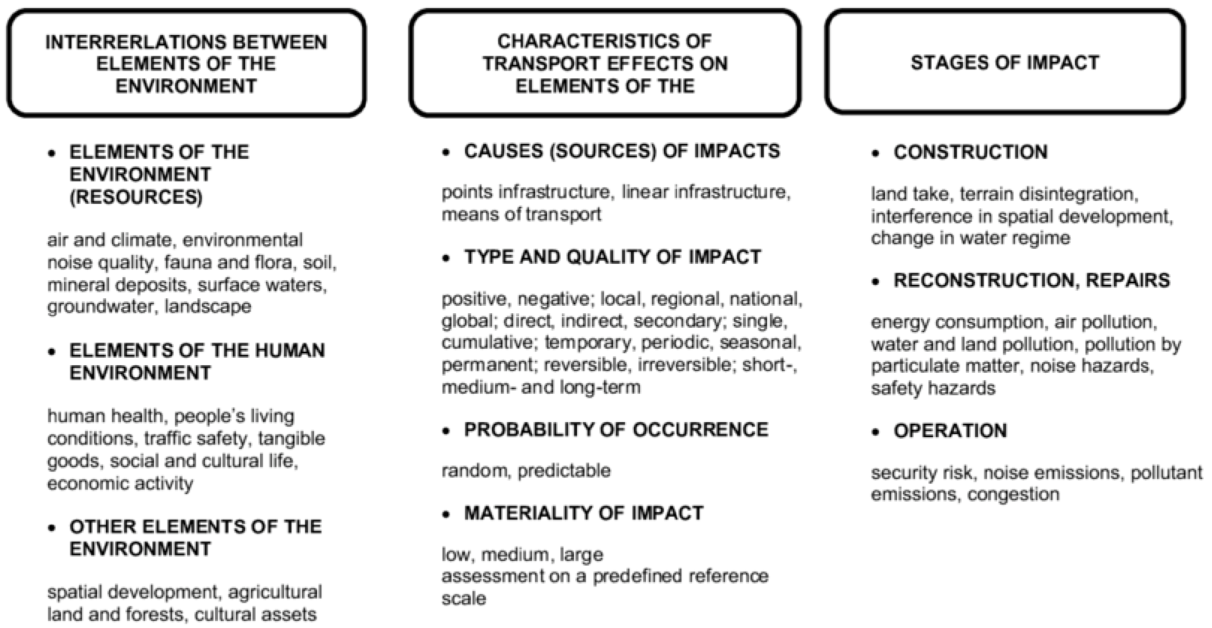
Figure 16: Problems of urbanization



Source: Shevshenko et al. (2018). Urban agglomerations: positive and negative features of the urbanization of modern society, Economic development research journal, 330(3): 316

Urbanization is one of the many amazing transformations that the world is experiencing in the twenty-first century, and it involves key effects on global warming and environmental dynamics. According to estimates, 56% of people on earth were living in cities by 2024, and by 2050, that number is expected to rise to 70%. According to these predictions, urbanization may hasten economic expansion, but it may also make climate-related problems worse. Rising greenhouse gas (GHG) emissions are the main way that urbanization affects climate change. Approximately 70–80% of the CO_2 pollution originated from towns, mostly from human activities, energy demand, as well as vast shipping networks (Strulak- Wojcikiewicz and Deja, 2022, p. 4262).

Figure 17: Impacts of construction to the environment

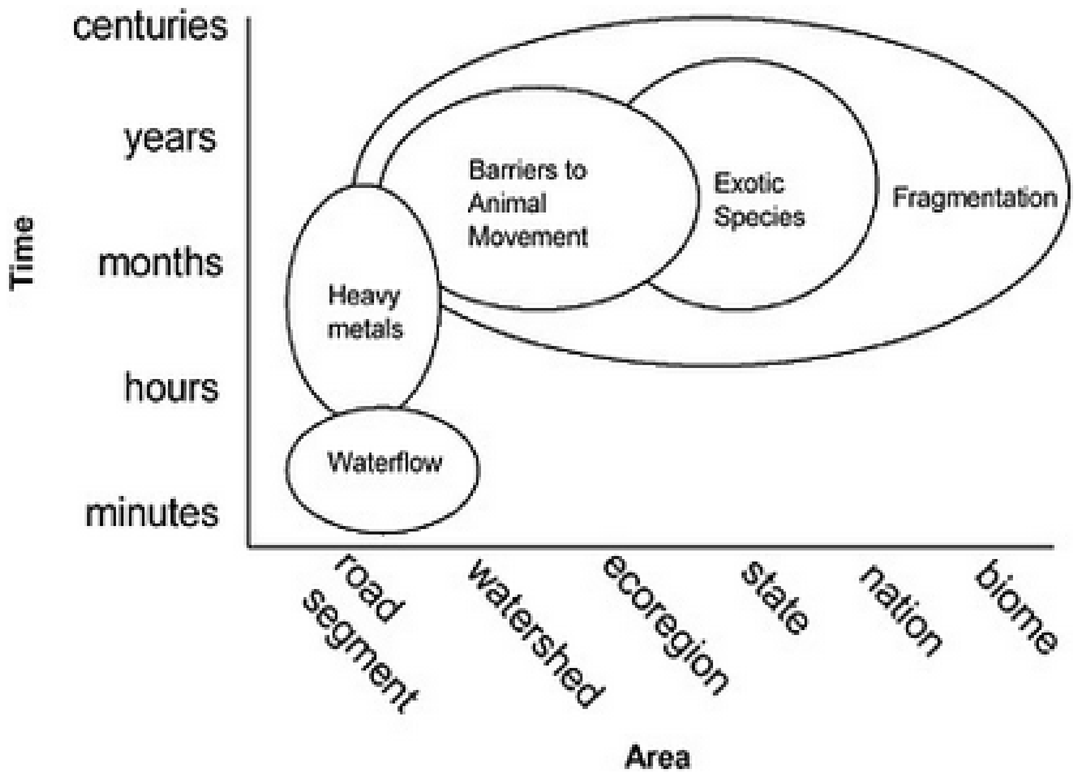


Source: Strulak-Wojcikiewicz R, Deja A. (2022). A concept for an IT platform to assess the impact of transport infrastructure investments on ecological safety and security, Procedia Computer Science, Vol. 207, No. 1, pp. 4258-4267

The most residents on the planet live in cities. Till 2050, more than 2.5 billion additional humans will stay in towns worldwide, mainly in Asia as well as Africa, due to expanding urbanization and population growth. Towns over the globe increase, yet numerous towns and cities are dealing with issues including unemployment, homelessness, growing squatter settlements, poor infrastructure and services, insufficient health and schooling, and excessive pollution levels (El-Bouayady, Radoine, El-Faouzi, Tayi and Ozkan, 2024).

Cities become warmer than the surrounding rural areas due to the displacement of green spaces by extensive concrete and pavement. Transportation networks and industrial operations generate pollutants that affect human health and concentrate greenhouse gas emissions. Roads and buildings are examples of impermeable surfaces that hinder water absorption, raising the possibility of rapid rainfall and runoff-related water pollution. Schools and universities in cities are typically superior to those in rural locations. This is another significant element that contributes to urbanization, particularly among middle-class people. Although it may come as a surprise, most people believe that cities are safer than rural places because they have greater access to trauma care, fewer auto accidents, and less gun injuries. Once more, this is a crucial consideration for families looking to relocate from rural areas (El-Bouayady, Radoine, El-Faouzi, Tayi and Ozkan, 2024).

Figure 18: Temporary and spatial dimensions of ecological effects brought by roads



Source: National Academies Press. (2005). Effects of Roads on Ecological Conditions, https://www.nationalacademies.org/read/11535/chapter/5

Transportation networks and other infrastructure-related land use changes seriously deteriorate the environment. Greater surface discharge from impermeable surfaces, habitat fragmentation, extensive deforestation, and increasing temperatures in cities are some of the main consequences that call for coordinated and environmentally friendly treatment. Building highways and electricity lines disrupts continuous ecosystems, limits mobility, and jeopardizes the survival of species. These are only a few of the crucial ways that infrastructure-driven land use affects the world. The land's inherent ability to absorb water is diminished when permeable soils are turned into concrete and asphalt. Stormwater runoff is greatly increased as a result, increasing the risk of extreme rainfall and water contamination. Local microclimates are created when natural vegetation is replaced by structures and dark pavement, which raises ambient temperatures and increases energy need for cooling (El-Bouayady, Radoine, El-Faouzi, Tayi and Ozkan, 2024).

Table 4: Comparison of sustainable and traditional construction

Aspect	Traditional Construction (Past)	Sustainable Construction (Present & Future)
Material Sourcing	Focus on low cost, availability, virgin materials (e.g., high-carbon concrete, new timber).	Prioritize recycled, renewable, local, and low-embodied carbon materials (e.g., fly ash concrete, bamboo, mycelium).
Energy Use (Construction)	High reliance on fossil fuels for machinery and material production; less focus on efficiency.	Increased use of electric equipment, renewable energy on-site, optimized logistics, less energy-intensive material production.
Energy Use (Operation)	Poor insulation, inefficient HVAC, high reliance on grid power.	Energy-efficient designs, smart systems, on-site renewables (solar), passive heating/cooling. Aim for Net-Zero.
Waste Management	Significant waste generation, primarily destined for landfills.	Waste reduction strategies (prefabrication, precise ordering), extensive recycling, material reuse, design for disassembly.
Water Management	Runoff contamination, inefficient water usage on-site and in buildings.	Rainwater harvesting, greywater recycling, erosion control, water-efficient fixtures, permeable surfaces.
Design Philosophy	Focus on function, aesthetics, cost, and speed; limited environmental consideration.	Integrate environmental impact from conception; focus on life-cycle assessment, health, and resilience.
Technological Integration	Limited digital tools; manual processes, basic machinery.	BIM, IoT, AI, drones, 3D printing, advanced robotics for efficiency and sustainability.

Source: Archdesk. (2024). How does Construction affect the environment?, https://archdesk.com/blog/how-does-construction-affect-the-environment

One of the key causes of emitted greenhouse gas on the globe is the clearing of vast areas of land for construction and urban expansion. It reduces natural carbon sequestration by depriving the planet of naturally occurring carbon sinks including forests. Localized climate conditions are altered by large-scale changes in land cover, which can occasionally reduce rainfall and interfere with agricultural output (El-Bouayady, Radoine, El-Faouzi, Tayi and Ozkan, 2024).

The impacts of the building industry are extensive, affecting everything from the water we drink to the air we breathe. It's a complicated system of resource mining, energy use, and garbage production; it's not simply about the large cranes and loud demolition. Dust is a common problem on construction sites, and that's only the beginning. Air pollution is caused by emissions from vehicles, chemical odors, and diesel-powered machinery exhaust. A large amount of air pollution worldwide is caused by construction. Imagine all those trucks and excavators working nonstop while simultaneously producing a cloud of toxic gasses and particles. Workers' and the surrounding communities' air quality is impacted, which has an effect on public health (Mustakim et al, 2025, p. 880).

In the past, the construction sector has harmed the environment. The industry has struggled to advance more sustainable project delivery methods due to antiquated methods and technology. However, a reputation for having a detrimental effect on the environment carries a great deal of responsibility for successful reform. Reducing injury has been a major focus of efforts to promote sustainability in building. It makes logical to lessen the bad consequences of construction first, even though it is crucial to aim for beneficial outcomes as well. Lowering shipping costs and utilizing vendors may save emitted gases by utilizing less volume of fuel (Sandanayake, 2022, p. 140).

Businesses often have a positive impact on the environment as they give support to the given communities. In fact, building firms may preserve, promote, and improve biodiversity if they incorporate green areas for the health and well-being of the local population. In a similar vein, incorporating more transport alternatives into the design of new roadways may offer a variety of advantages. Travelled bike lanes as well as walking ways enhance living and offer a new option for driving that reduces carbon. Consequently, it is easier to integrate these walkways into the natural landscape, allowing the habitat to be integrated into the design. Reducing injury has been a major focus of efforts to promote sustainability in building (Sandanayake, 2022, p. 141).

Figure 19: Air pollution due to construction

Source: Archdesk. (2024). How does Construction affect the environment?, https://archdesk.com/blog/how-does-construction-affect-the-environment

In my opinion the construction of new public infrastructure and transportation corridors frequently results in a sharp rise in nearby land prices, which may cause gentrification and increasing numbers of low- and middle-class residents in metropolitan areas. Global food security is under increasing pressure as arable land is progressively consumed by the unrelenting spread of urban area surroundings into nearby areas. Global authorities are giving coordinated planning for land use and green construction solutions top priority in order to counteract these detrimental effects.

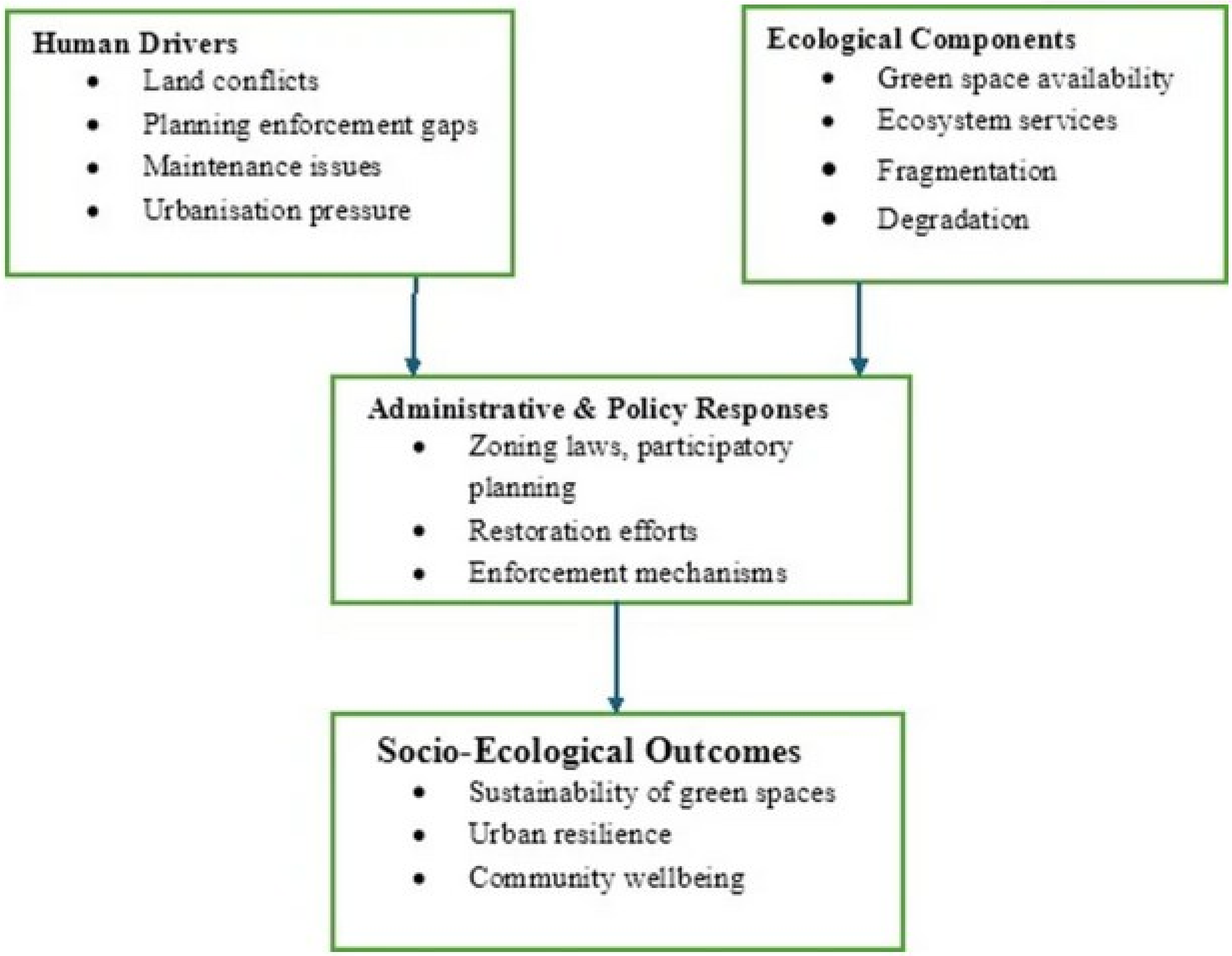
In this context, transportation, services and internet connections are all integrated into adaptive spatial networks through urban infrastructure development. By protecting public space before fast population development overtakes city operations, proactive enough, strategic planning for the future reduces growth in cities and lowers expenses for upkeep. Congestion and emissions are reduced when road networks are integrated with mass transit. For both health promotion and competitiveness in the economy, robust wastewater treatment and dependable water distribution systems are essential.

Smart grid installations and fiber-optic networks are the foundation of contemporary, effective urban ecosystems combines investment from the business sector with government oversight to speed up project completion. Mapping infrastructure and land use together guarantees that transportation lines and utilities grow in proportion to the expanding population. Basic services are guaranteed to be accessible to poor and unofficial urban areas through local, tiny businesses community buildings investments.

The idea of "green infrastructure" appears as a crucial factor influencing how cities will develop in the constantly changing fabric of urban environments. The need for resilient and sustainable urban settings grows as our globe gets more urbanized. In conversations about mitigating and adapting to climate change, a delicate equilibrium among urbanization and safeguarding the environment is at the forefront. Increased temperatures and the loss of natural resources provide problems for urban areas, which are frequently described as concrete jungles. The incorporation of green areas into cities has changed from being a luxury to a must in reply to these difficulties. Programs that acknowledge the transformative potential of sustainable infrastructure in promoting urban ecological resilience, serve as prime examples of this conceptual shift.

For professionals in the construction industry, we have all experienced the excitement of witnessing a plan come to life and turning an idea into a physical structure. To be honest, though, the process of turning a vacant site into a completed structure hasn't always been good for the environment. Construction was a major contributor to environmental damage for many years, producing a garbage and contamination trail and using resources at a worrying rate.

Figure 20: Relationship among people and natural environment in socioeconomic aspects



Source: Mensah H et al. (2025). Urbanisation and green space management in peri-urban Ghana: mapping patterns and stakeholder perspectives, Discover Sustainability, 6(1433): 4

It is encouraging to note that things are starting to change. In order to create smarter and greener buildings, the industry is changing by embracing new technology and more effective construction techniques. Reducing injury has been a major focus of efforts to promote sustainability in building. However, it is crucial to aim for constructive effects on the environment.

Table 5: Road induced effects penetrate habitat

Road Effect	Distance	Reference
Heavy metals		
In soils and plants near roads	50-100 m	Ministry of Transport, Netherlands 1994
Chemical pollution		
Oxides of nitrogen changing plant communities	200 m	Angold 1997
Animal distribution		
Pink-footed geese (*Anser brachyrhunchus*) and graylag geese (*A. anser*)	100 m	Keller 1991
	150 m	Ortega and Capen 1999
Territory size of ovenbirds (*Seiurus aurocapillus*)		
Traffic noise	200-1,200 m	Van der Zande et al. 1980
Breeding bird density	40-1,500 m	Reijnen et al. 1996
Road lights		
Breeding bird density	200-250 m	De Molenaar et al. 2000
Avoidance zone		
Caribou (*Rangifer tarandus*)	5,000 m	Nellemann and Cameron 1998
	200 m	Rost and Bailey 1979
Deer (*Odocoileus hemionus*) and elk (Cervus *elaphus*)	1,000 m	
Grizzly bears (*Ursus arctos*) and black bears (*U. americanus*)		Kasworm and Manley 1990
Increase in edge species		
Component of bird community	100 m	Ferris 1979
Road density		
Wetlands species richness	2,000 m	Findlay and Houlahan
Moor frog (*Rana arvalis*) presence	750 m	1997
Leopard frog (*R. pipiens*) distribution	1,500 m	Vos and Chardon 1998, Carr and Fahrig 2001
Early melting of permafrost	100 m	Walker et al. 1987

Source: National Academies Press. (2005). Effects of Roads on Ecological Conditions, https://www.nationalacademies.org/read/11535/chapter/5

From my point of view, serious water contamination might result from construction activity. Soil, chemical-based paints, lubricants, and additional hazardous substances are frequently carried into sanitary sewers, streams, and possibly places that supply water for consumption by rainfall that flows from sites. Not only is this unsightly, but it also damages aquatic life and may render water unfit for human consumption. It affects ecosystems much beyond the construction borders, like a muddy, oily river that flows from the site.

It is important to note that from the production of building materials to the operation of structures, the whole building lifecycle is energy-intensive. Fossil fuels are frequently the source of this energy, which significantly contributes to the release of greenhouse gases and global warming. It contributes significantly to the world's usage of energy and is the main cause of atmospheric carbon dioxide.

Chapter 4 – Economic Perspective

4.1 Land use economics

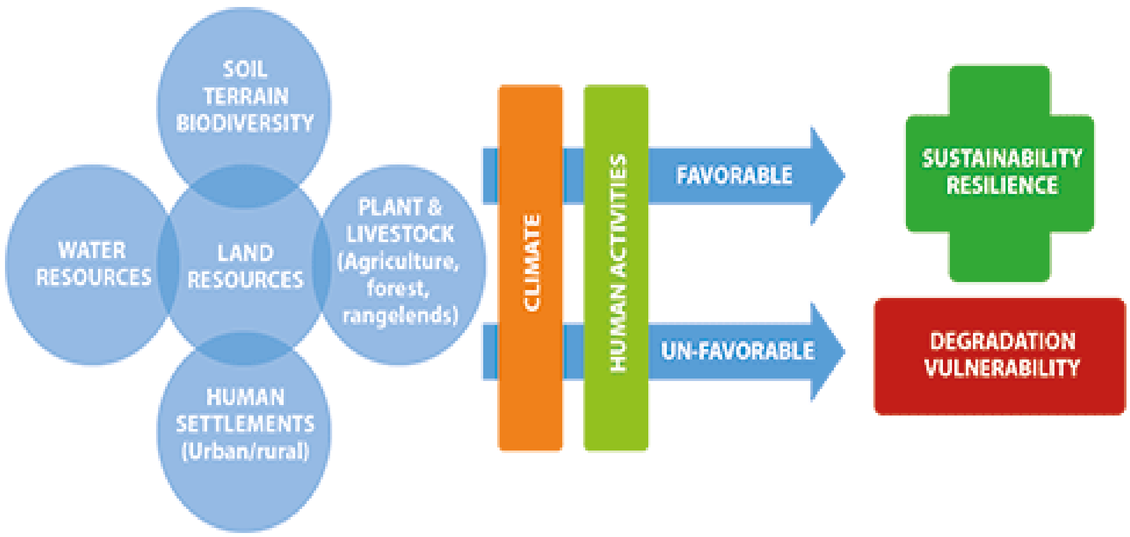
Land use economics studies how property rights and market pressures determine how land is distributed among industries, housing, and agriculture. It investigates how rules and scarcity affect land value and direct sustainable development. One of the four fundamental economic resources is land. As one gets farther away from the Central Business District (CBD), both land value and population density decline (Hubacek and Vazguez, 2002, p. 2).

It is my view that depending on which activity may make the most money at a particular place, prospective consumers bid for land. By lowering the possibility of asset expropriation, secure land rights offer monetary rewards for investments that are long-term like home constructions. Land management and zoning regulations strike a balance between public health, environmental sustainability, and economic growth. Restrictive laws, however, have the potential to raise housing costs and reduce affordability.

This policy brief emphasizes how crucial it is to take labor market and land dynamics into account when creating urban planning plans. It also lists the main issues that legislators must deal with: a) how to distinguish between public and private areas; b) how to use public space, especially when it comes to the provision of public goods; and c) what rules to enact on private areas, particularly responsibilities and rights (Wu, 2008, p. 7).

In my view, in an agricultural or urban setting, profit-maximizing behavior dictates the rents that are offered for a plot of land, and competition among possible users dictates the final use of that land. It has been demonstrated that methods newly established in urban land utilization theory are also applicable to land used for farming use, and they can be especially helpful when examining changes in land use along the urban periphery.

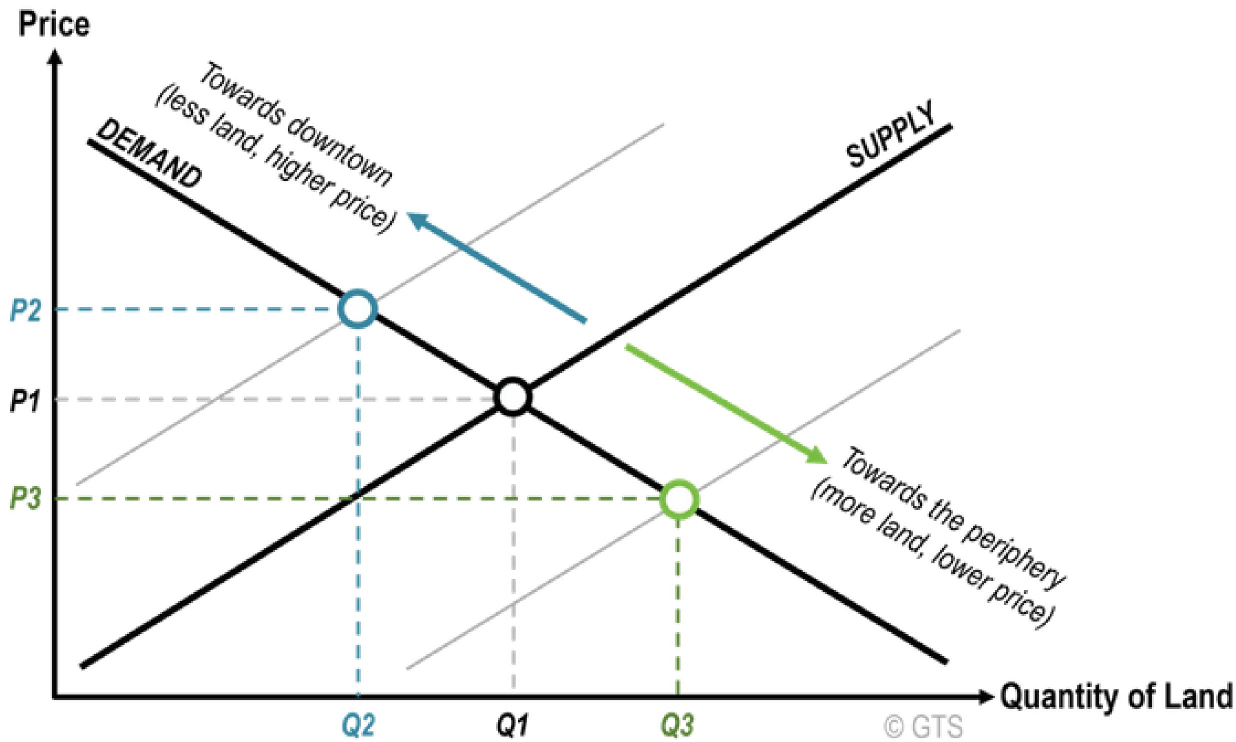
Figure 21: Sustainable land use and management practices



Source: FAO. (2026). Sustainable Land Management, https://www.fao.org/land-water/land/sustainable-land-management/en/

The planned distribution and control of land and other resources to strike a balance between human demands and environmental sustainability is known as land-use management. In order to provide basic services like food and public safety while safeguarding resources from nature for future generations, this multidisciplinary profession connects open spaces processes with the built environment. It entails working with a variety of stakeholders to create thorough land-use plans that support sustainable development and lessen environmental effects. There are still issues, especially in less developed areas where assets for environmentally friendly practices might be scarce, despite technological developments and increased awareness. The constant balancing act between short-term financial gain and long-term environmental well-being highlights how complicated land-use management is. In the end, it has a significant impact on how communities interact with their natural environments (Hu et al, 2024, p. 5039).

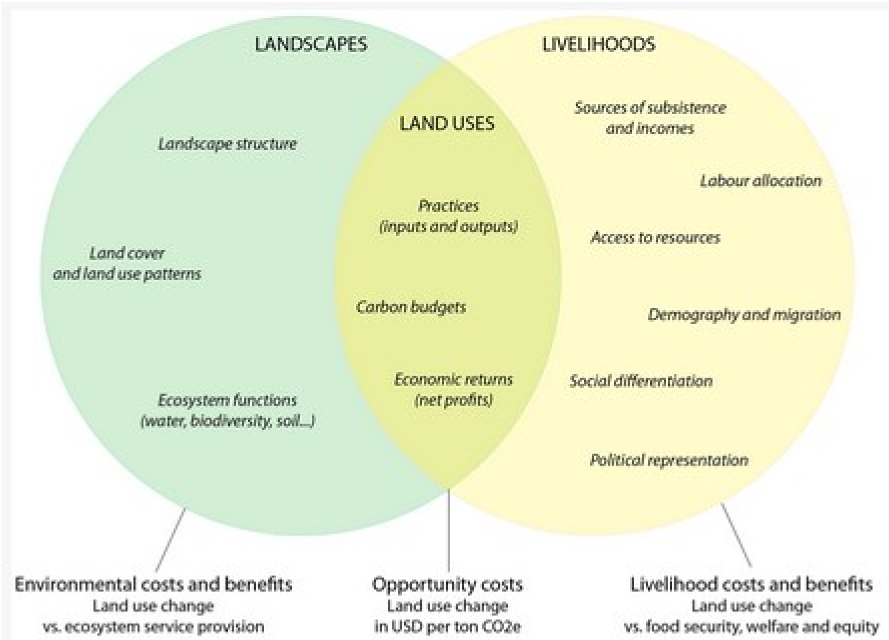
Figure 22: Land use economics



Source: Rodrigue J, Basic Land Economics, https://transportgeography.org/contents/chapter8/urban-land-use-transportation/land-economics/

The majority of urban land may prove freely bought or sold in a market economy. Therefore, how the expense of land in cities is determined and the way this value affects the kind, distribution, standard, and structure of land uses is the focus of land economics. The aforementioned image, which is based on the assumption that there exists a land-free market (the majority of the land is accessible for a transaction), shows some fundamental correlations between the amount and price of land. An amount of land is deemed accessible for a price in the city land market structure, which adheres to the usual connection among demand and supply, whereby an optimal price is attained. But what makes cities unique is that there is a fixed supply involving land at every location (Carol, 2022, p. 3).

Figure 23: Opportunity cost of land use

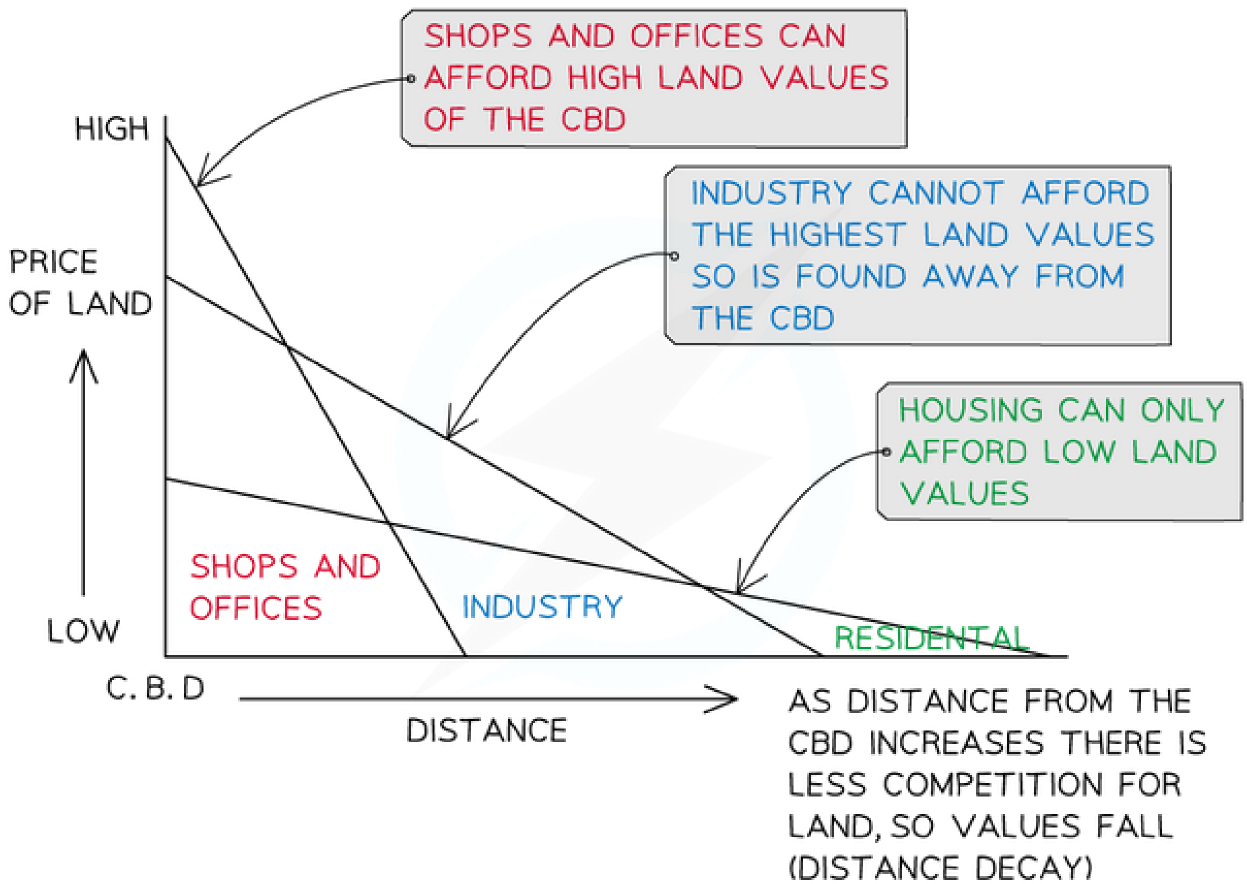


Source: Lestrelin G et al. (2019). A Nested Land Uses–Landscapes–Livelihoods Approach to Assess the Real Costs of Land-Use Transitions: Insights from Southeast Asia, Land, 8(1)

All resources that naturally occur are utilized to generate products and services are referred to as land in economics. Along with labor (work), finance (equipment), and entrepreneurial activity, it is one of the four fundamental elements of manufacturing—the inputs needed to generate anything in an economy (Metzemakers and Louw, 2005, p. 2).

From my perspective, land consists of raw materials, sunlight, oceans, agricultural soil, and geographic area. In general, the availability of land is limited and fixed by nature. Rent is the money landowners receive for letting their property be used for production.

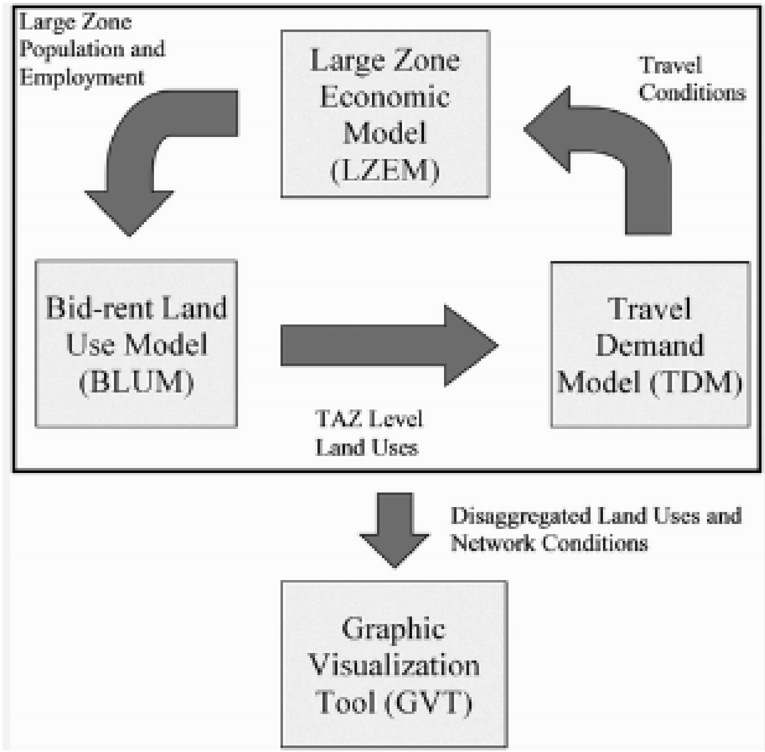
Figure 24: Bid-rent theory explanation



Source: Barrett B, Pattern of Urban Economic Activities (DP IB Geography: HL): Revision Note, https://www.savemyexams.com/dp/geography/ib/17/hl/revision-notes/urban-environments/the-variety-of-urban-environments/pattern-of-urban-economic-activities/.

Bid-rent theory: According to the bid-rent hypothesis, this is a geographical economic theory, real estate prices and demand decrease with getting farther from a central business district (CBD). Retailers, businesses, and homeowners are among the several land users who fight for the most approachable land and are prepared to pay different sums depending on their profitability. The structure of urban centers is determined by the theory and its fundamental principles. The most convenient location with the greatest concentration of resources and clients is the city core (CBD) (Narvaez et al, 2013, p. 6).

Figure 25: Bid-rent land applications

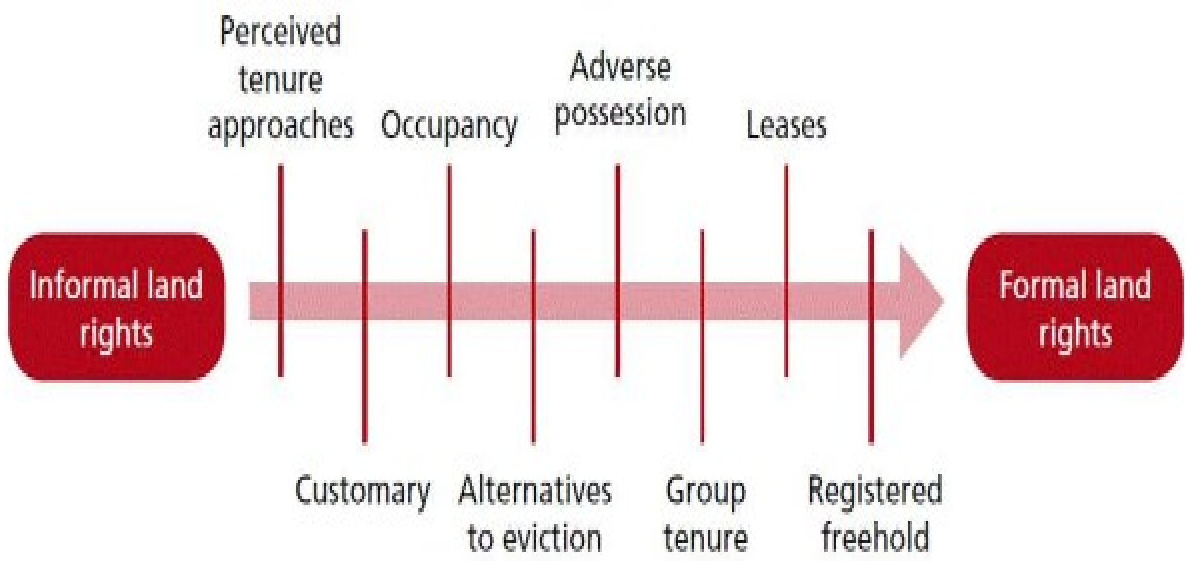


Source: Clay M, Valdez A. (2017). The Bid-rent Land Use Model of the simple, efficient, elegant, and effective model of land use and transportation, transportation planning and technology, 40(4): 449-464.

In my opinion, as the distance from the center increases, different sectors' willingness to pay for the high price of land is decreasing. The advantages to become in a highly approachable central location are traded off by land users for higher rent expenses.

Property rights and tenure: tenure and property rights specify who is able to utilize, manage, and transfer tangible assets (such as buildings or land) and for what duration. Property rights dictate what is possible to lawfully do with land, whereas tenure status indicates way it is maintained the particular rights associated with the item, like the ability to transfer ownership, use, access, and exclude others. In many parts of the world, land use restrictions and regulations are referred to as "planning" in the UK and "zoning" in the US. These regulations' justifiable goal is to forbid land uses that are harmful to the public at large and/or the property itself, as well as to stop the consequences of such improper land utilization (Feeny and Feder, 1991, p. 135).

Figure 26: Land rights types

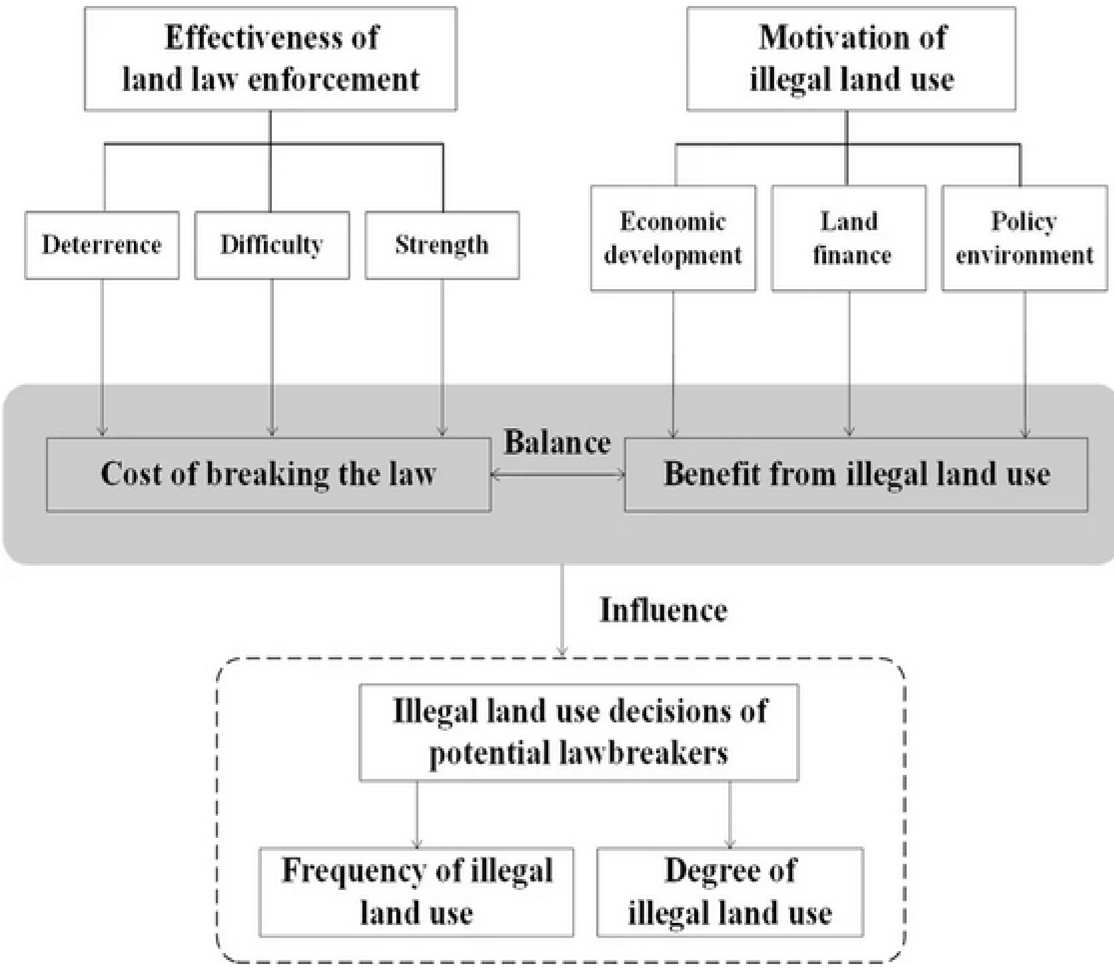


Source: Plessis J. (2014). The Continuum of Land Rights Approach, Global Land Tool Network

The study of how society distributes limited, immovable land resources among conflicting uses, including residential, farming, manufacturing, and conservation, is known as land use economics in today's world. In the current environment, it strikes a compromise between the need to maximize economic value and the rising urbanization, geographic pricing standards, and sustainability of the environment. The center of contemporary land use economics is cities. Because land has a permanent location, accessibility and spatial closeness play a major role in determining its value. Strict residential-only zoning is becoming less common in modern planning. Cities improve economic density, shorten commutes, and boost property values by combining business and residential areas. Due to logistical bottlenecks and environmental damage brought on by cities' outer expansion, several contemporary towns have adopted containment measures including urban growth borders (King and Benton, 2021, p. 8).

Food insecurity and biodiversity loss pose a "triple threat" to agricultural land use as the world's population grows. Economics encourages intensification—using technology and precision agriculture to create larger yields per acre—instead of destroying additional forests (large margins). The economic return of crops in relation to their expenses for transportation to market determines how agricultural land is used. The pressure to turn delicate ecosystems in the environment into farmland is lessened by modern globalization, which enables nations with limited farmland to depend on imports of food. Land now offers essential ecological-economic services and is no longer only seen as a platform for growth. Wetlands and forests are now valued monetarily by economists. This enables decision-makers to balance the conserved worth of nature against a chance cost of modernization (King and Benton, 2021, p. 9).

Figure 27: Effectiveness of land law



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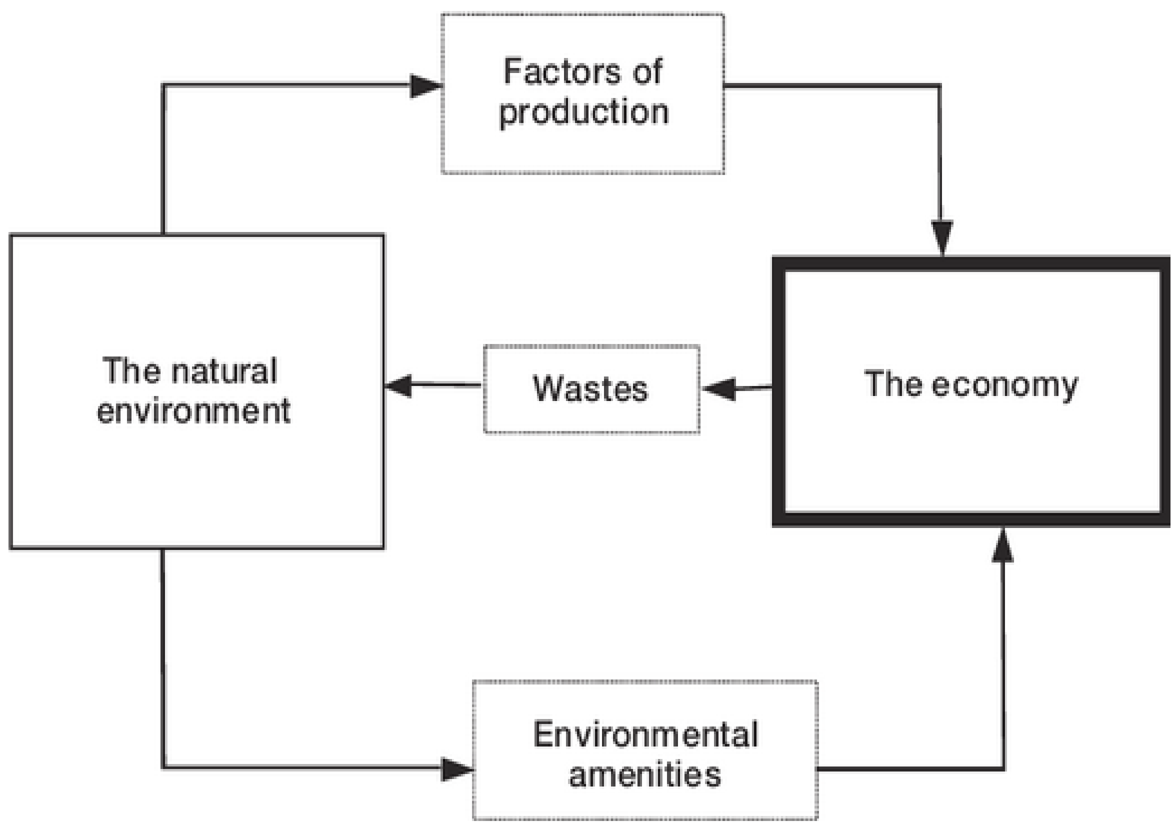
Source: Chen S et al`. (2021). Can improving law enforcement effectively curb illegal land use in China?, Plos One, 16(2).

Land use pressures are becoming one of the most important environmental issues. Over the next few decades, struggle for healthy and economically valued land, as well as for the services and assets it offers, is expected to get more intense due to the increasing need for land for agricultural production, mitigating climate change, and other vital uses. In the end, drastic adjustments to land usage and governance are necessary to create a land-rich planet. This entails lessening the amount of land that humans occupy, managing the world's land resources in a systematic and cooperative manner, and altering the way that land is highly regarded and funded for stewardship. Most importantly, governments need to prioritize land acquisition and implement institutional reforms that place land crisis planning at the core of financial, foreign, and national policies (Lambin and Meyfroidt, 2011, p. 3467).

4.2 Environmental economic perspective

The allocation of limited land resources by human activity is assessed by the environmental economic viewpoint of land utilization in modern times. It draws attention to the conflict between short-term financial gain and long-term deterioration of essential services and natural ecosystems (Zhu et al, 2023, p. 1).

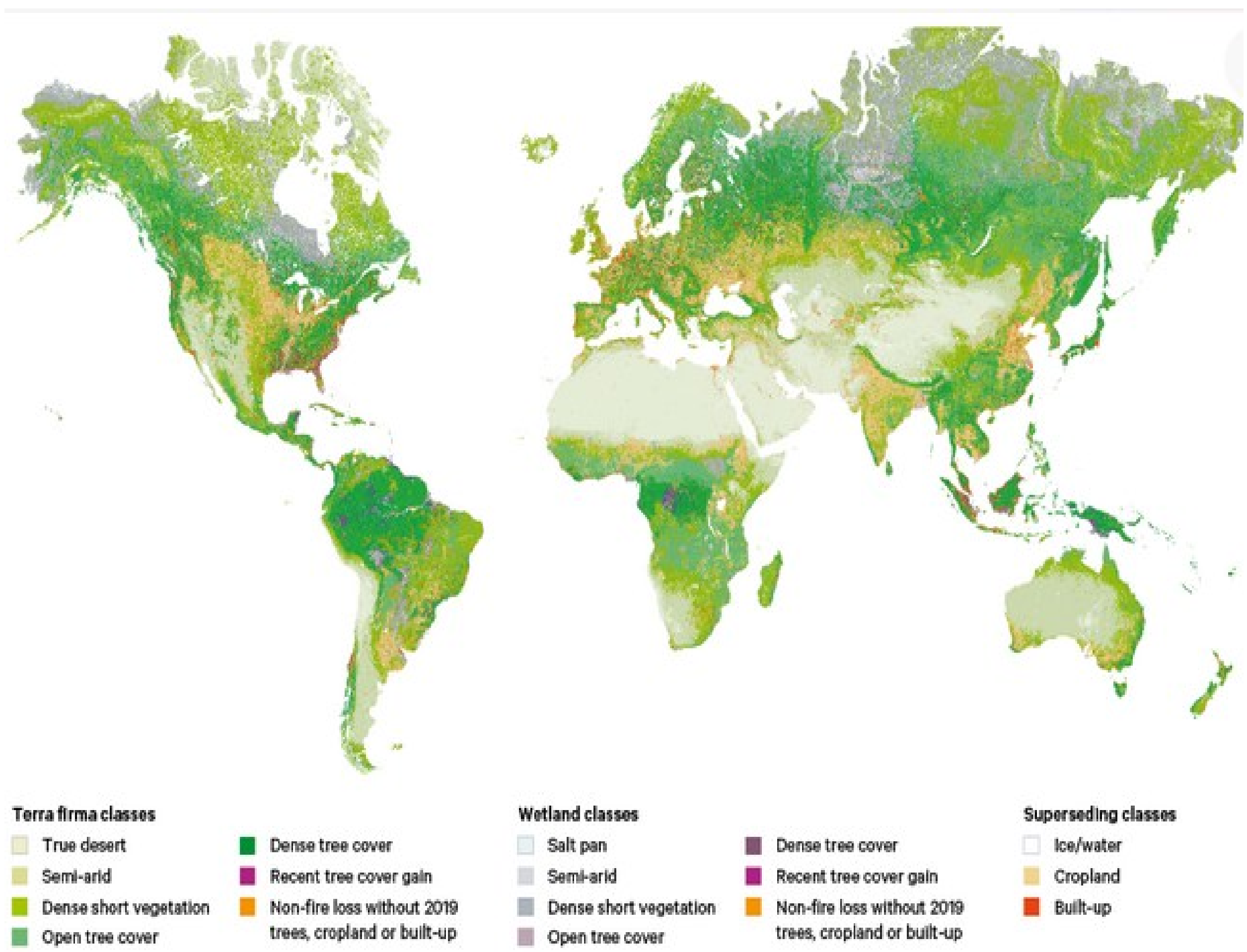
Figure 28: Principles of environmental economies



Source: Hussen A. (2004). Principles of Environmental Economics, Semantic Scholar

In my opinion not often do private businesses and property developers cover all of the environmental or social costs of their operations. These unaccounted-for expenses lead to inefficient land allocation and market failures. Researchers in environmental economics try to put an economic value on the advantages that natural environments offer, like biodiversity, water filtering, and carbon sequestration. This makes it possible to compare financial rewards from growth with environmental preservation.

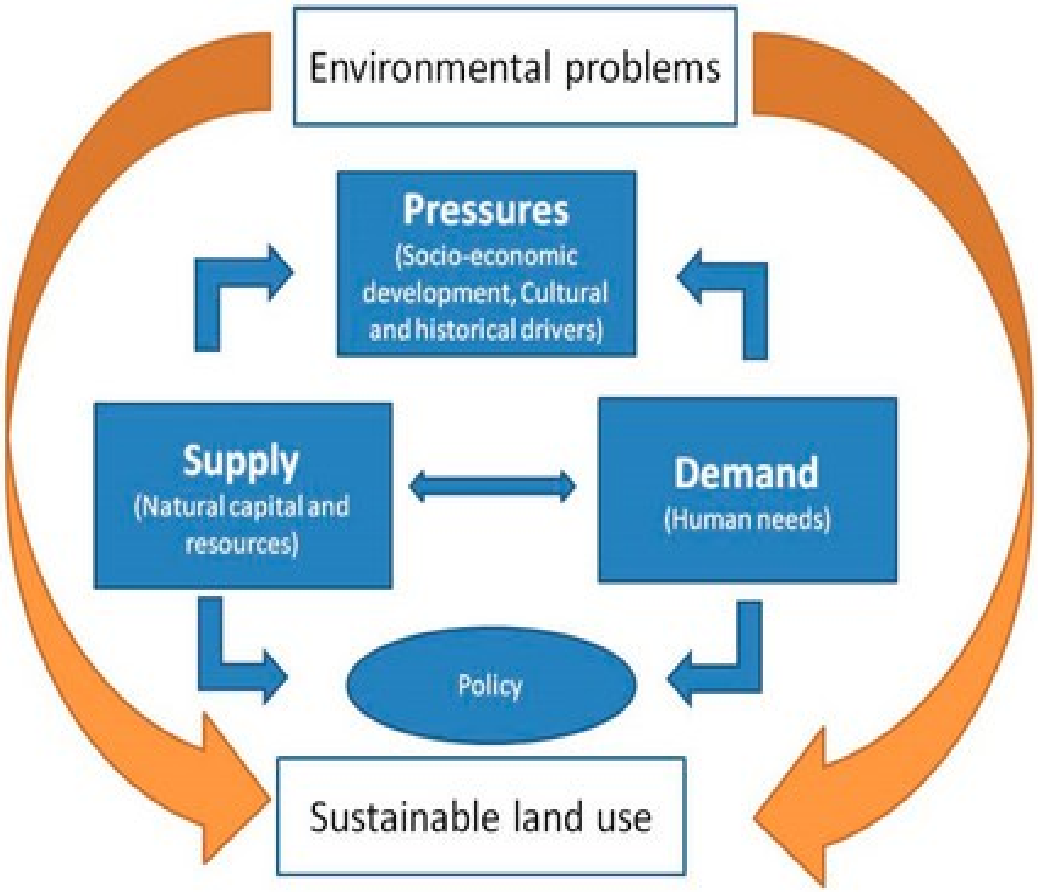
Figure 29: Land use activity and land cover in the world



Source: King R, Benton T. (2019). The emerging global crisis of land use, Chatham House.

The cost of opportunity of missing native ecosystems is represented by each acre that is used for agriculture or industry. Prioritizing short-term economic growth frequently irreversibly jeopardizes for a long time ecological health and the resilience of local communities since land is a tightly limited resource. The loss of arable land, increased transportation emissions, and habitat degradation are all consequences of rapid, expanding urbanization (Zhu et al, 2023, p. 2).

Figure 30: Environment problems policy



Source: Izakovicova Z et al. (2018). Integrated Approach to Sustainable Land Use Management, Environment, 5(3): 37

In my view to lessen their impact on the environment and increase economic efficiency, economists support urban development. Intensive farming, which often results in degradation of soil, contaminated water, and ecological damage, is driven by the need to feed the world's expanding population. Emissions of greenhouse gases are mostly caused by irresponsible land use modifications, including extensive deforestation. These modifications reduce the productivity of land, which worsens shortages of food and harms agribusiness.

Methods that preserve agricultural output and ecological health by preventing land degradation and repairing damaged soils. Financial systems that compensate private landowners for the ecological advantages they give, like protecting a forest or a watershed, in order to encourage them to conserve their property. Directing resources into safeguarding the environment, sustainable farming, and renewable energy in order to align the recovery of the global economy to copy up with the increasing temperature and changing ecological patterns is the target of most countries (Handavu et al, 2025, p. 5).

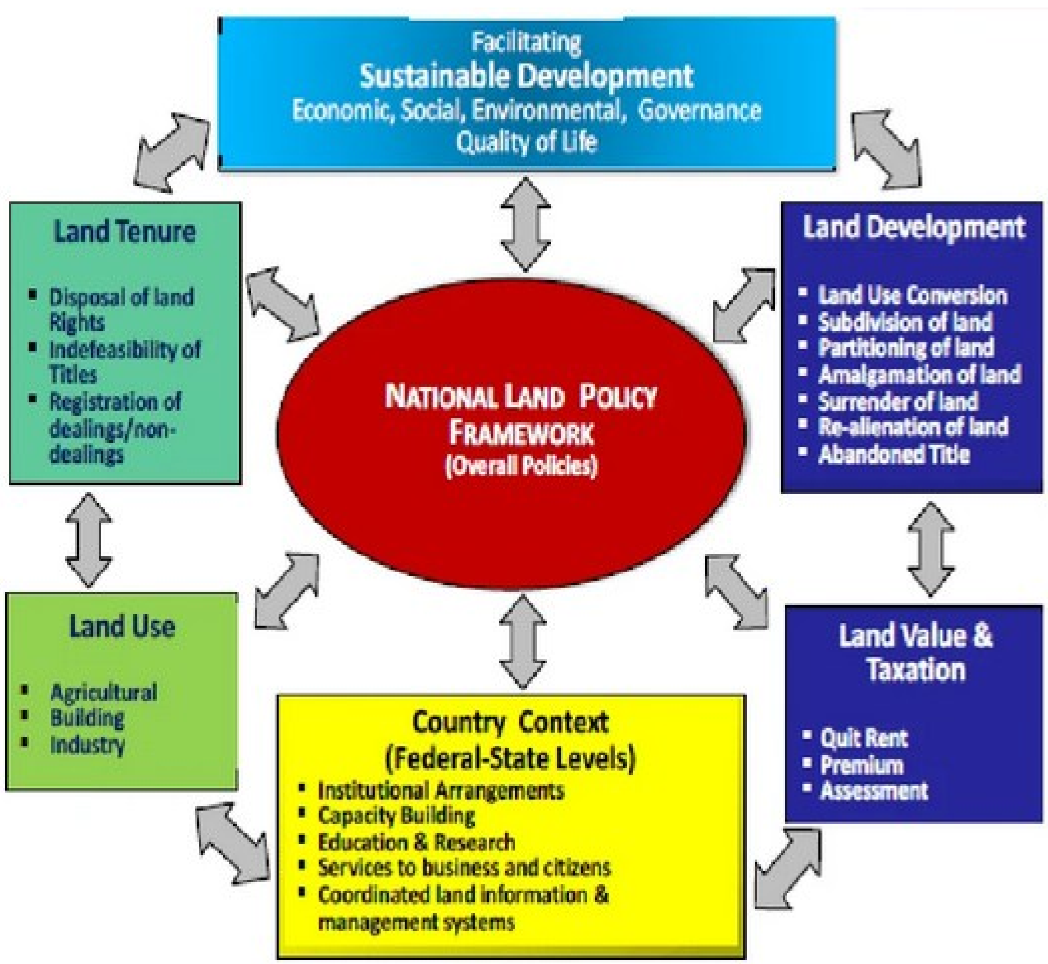
Figure 31: Land management

Source: INTOSAI, Land use and Land management practices in Environmental perspective, https://www.environmental-auditing.org/media/1219/land-use-research-project_draft.pdf, p. 8

The capacity of terrestrial materials to maintain providing ecosystem services is being threatened by unsustainable practices of food supply, freshwater usage, human settlement, and infrastructural development, in addition to climate change. Finding more unappropriated land through traditional frontier expansion—historically demonstrated by migration of people into forest or sparsely populated areas—is becoming less and less feasible. There aren't many true frontiers left, and when they are, the natural and ecological consequences of increasing humankind's impact on them are typically too high to justify. Although regions of clearly "spare" land are becoming more and more uncommon, some barren areas might be capable to supply more resources capacity for specific applications. All things considered, there is still a basic conflict between declining terrestrial resource availability, growing unsustainable demand, and rising environmental concerns (Ampofo, 2020, p. 2).

The UN has highlighted three issues that could have a significant impact on our well-being: land degradation, the loss of species of animals and plants, and climate change. Artificial surfaces that cover the ground are detrimental to biodiversity. Since our soil contains more carbon compared to the air as well as all organisms put together, it is also crucial. Driven by financial rewards, it can also absorb up to twenty-five percent of its weight in water, preventing disasters and acting as a long-term flood-prone area (Ampofo, 2020, p. 3).

Figure 32: National land policy framework



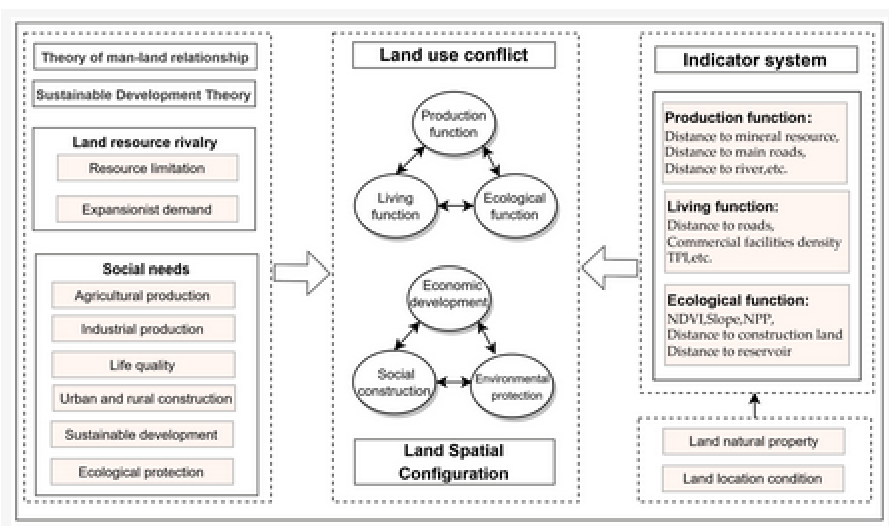
Source: Marzukhi M et al. (2018). Re-appraising Regulatory Framework of Planning and Land Law System towards Sustainable Development in Malaysia, Asian Journal of Behavioural Studies, 3(9).

From my perspective, while the population is frequently declining elsewhere, it is increasing in big cities. This trend is fueled by a large proportion of old individuals, low reproduction rates, and young people relocating from rural to urban areas in search of opportunities to improve their lives.

4.3 Policy implications

Globally, land use regulations determine how societies arrange and administer physical places. Important policy ramifications influence economic growth, biodiversity preservation, and food security. These frameworks strike a balance between conflicting interests, such as the preservation of land for farming and preserving wilderness against the expansion of urban development (Carrilho et al, 2024, p. 107046).

Figure 33: Land conflict



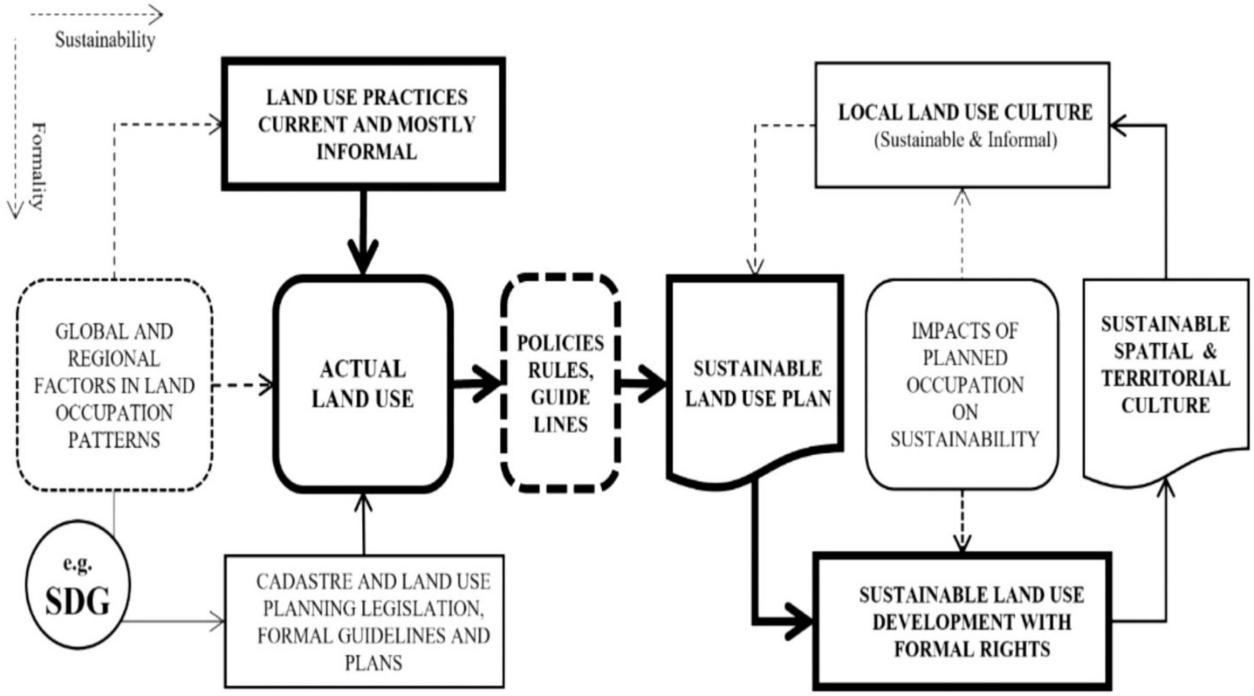
Source: Xiao J et al. (2024). The Identification of Land Use Conflicts and Policy Implications for Donghai County Based on the "Production–Living–Ecological" Functions, Land, 13(12).

It is widely recognized that a key component of nature-based climate solutions is land use. For the purpose of sequestering carbon, policies support the preservation of forests and peatlands. Preventing deforestation and striking a balance between land used for food production and environmental capabilities are the main priorities. Policies that provide fundamental socioeconomic needs without degrading the environment are necessary due to rapid urbanization. Green energy utilization, eco-friendly public transit, and multi-use developments zoning are key components of smart growth plans. This sector's policies control the allocation and intensification of land usage.

Human well-being is directly impacted by global land use policy, which determines public health, affordability of homes, adequate nutrition, and wealth fairness. The socioeconomic needs of expanding people must be balanced with environmental preservation for programs to be effective. Housing expenses may increase as a result of restrictive urban building and construction regulations. This drastically restricts the availability of jobs and high-quality healthcare by pushing lower-income residents to the periphery when combined with insufficient public transportation systems (Carrilho et al, 2024, p. 107046).

Local food security is directly impacted when industrial-sized agriculture, monetary crops, or manufacturing biofuel are prioritized over smallholder farming. This change frequently results in rural inhabitants being uprooted, which exacerbates income disparities. Collaborative land use management, in which community members actively participate in planning, safeguarding the environment, and construction decisions, is necessary to achieve a fair balance.

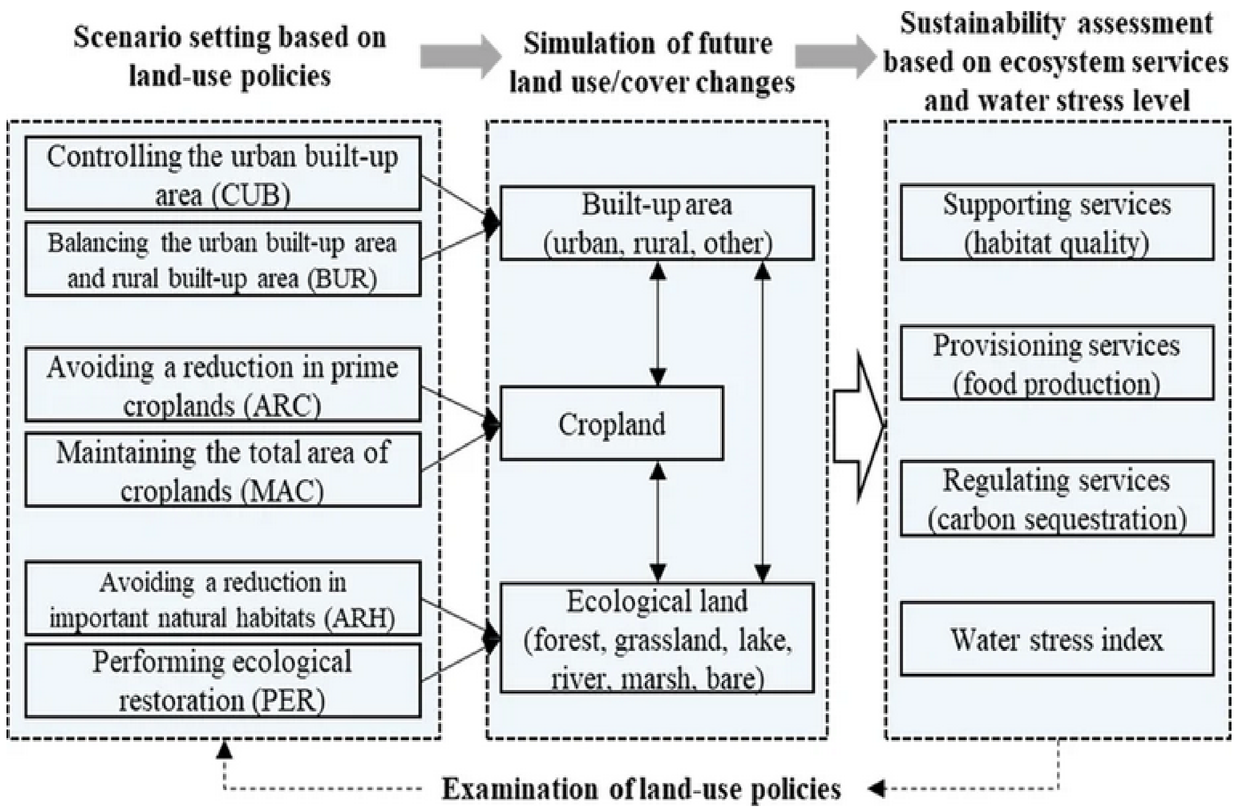
Figure 34: Policy implications of land use to attain sustainability



Source: Carrilho J, Dgedge G, Santos P, Trindade J. (2024). Sustainable land use: Policy implications of systematic land regularization in Mozambique, Land Use Policy, 138: 107046-107051.

This sector's policies control the allocation and intensification of land usage. They are intended to limit the quantity of land used for agriculture while satisfying the caloric requirements of an expanding world population. A major policy priority, particularly in developing economies, is to guarantee stable land ownership and rights. These regulations determine who has availability of resources from nature and have a direct impact on socioeconomic fairness, development in rural areas, and the generation of local wealth. An integrated planning strategy is essential for localized context, particularly in areas that rely on natural resources. In order to balance local demands with national aims, this integrates conservation, municipal, and farming initiatives (Bonin et al, 2012, p. 250).

Figure 35: Examination of land policies

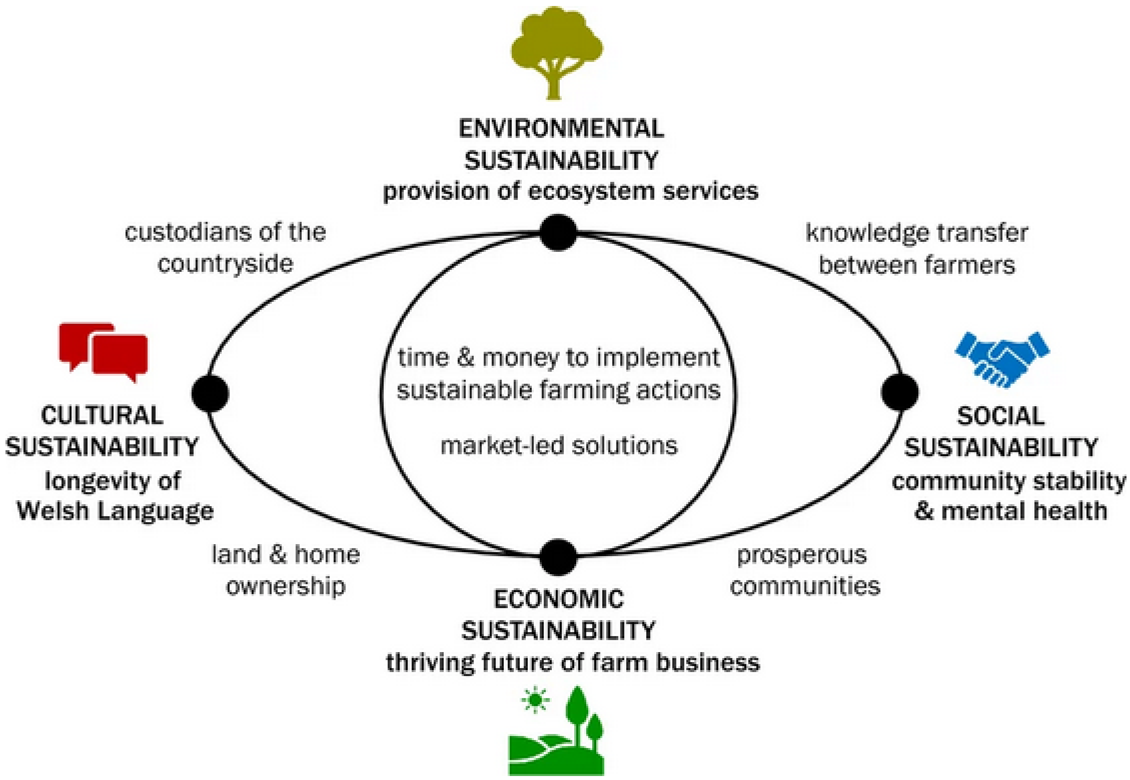


Source: Gong B, Liu Z. (2021). Assessing impacts of land use policies on environmental sustainability of oasis landscapes with scenario analysis: the case of northern China, Landscape Ecology, 36(1)

The frameworks and rules that societies employ to plan and oversee social and physical activity on land are referred to as land-use policies. Effective land-use policies are becoming more crucial for handling resources and ecological sustainability as population growth and concerns regarding the environment increase. In the past, religious and cultural considerations frequently influenced land-use decisions. However, as time went on, these regulations changed to suit more general social concerns, such as public health, planning for cities, and environmental preservation (Stanford and Stroud, 2024, p. 30).

As I see, land-use policy in modern times must strike a balance between conflicting goals, like ecological protection and economic growth. There are several methods, such as ecological planning, which takes long-term environmental effects into account, and conventional planning, which stresses zoning and development regulation. Both prescribed and results-based land-use policy implementation can result in creative solutions including preservation agreements.

Figure 36: Spatial relationship between social, economic and cultural aspects

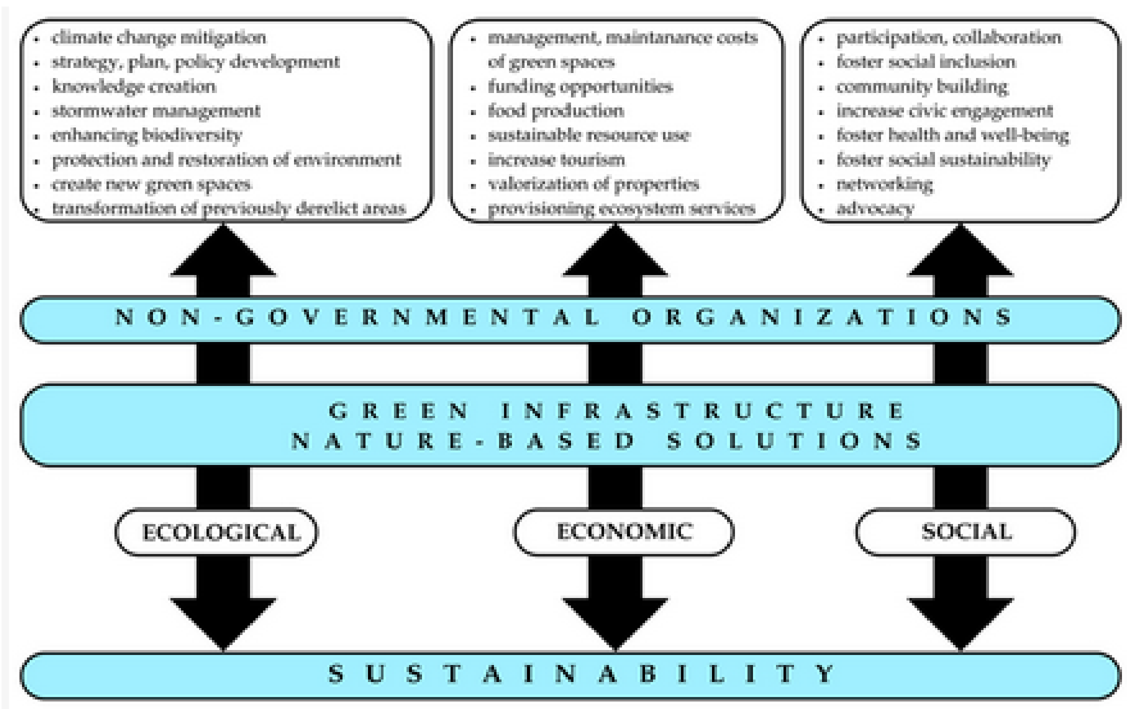


Source: Follett E et al. (2024). Working for the environment: farmer attitudes towards sustainable farming actions in rural Wales, UK, Environment Development and Sustainability, 27(6): 13545-13564.

Community consensus is essential because obstacles can occur, like unfair zoning practices and disputes over land rights. Furthermore, cultural and political settings have an impact on land management, as seen by the different land-use techniques observed in different regions from the thorough rules in Northern Europe to the more adaptable regulations in North America. In general, land-use policy affects not just local populations but also larger ecological and financial structures, making it an essential component of governance (Stanford and Stroud, 2024, p. 30).

The OECD provides systematic research and policy suggestions, recognizing the substantial monetary and sentimental importance of land and highlighting the necessity of integrated approaches across governmental policies impacting land utilization outside conventional zoning systems. In order to address global concerns, land-use policies—which are mostly overseen by regional and local authorities instead of national ones are essential. Strategic choices made today can have a big impact on solutions since there are few opportunities to alter land use. When tackling these issues, regional viewpoints are crucial. The cost of maintaining facilities and services in these contracting communities is increased by inefficient land use. The cost of services and infrastructure per person rises when people decline and become more dispersed over vast tracts of territory (Ahrend et al, 2024, p. 4).

Figure 37: Sustainability to handle ecological, economic and social aspects



Source: Slobodnikova K, Toth A. (2025). Planning for People with People: Green Infrastructure and Nature-Based Solutions in Participatory Land-Use Planning, Co-Design, and Co-Governance of Green and Open Spaces, Land, 14(9)

Locations vary in their capacity to offer vital ecosystem services as well as in the motivation to preserve or improve them. Communities can be encouraged to do so by financial incentives, which also give them extra money. Reducing artificial land cover is only one goal of smart spatial planning. Additionally, it encourages settlements that are sufficiently inhabited and have good public transportation connections. By doing this, it provides the advantages of both infrastructure cost reductions and safeguarding the environment. Cities that are sufficiently dense utilize land more effectively, but if there is a shortage of buildable land, housing costs can rise and significantly impact the budgets of lower-class people (Ahrend et al, 2024, p. 5).

Table 6: Land use policies - explanation

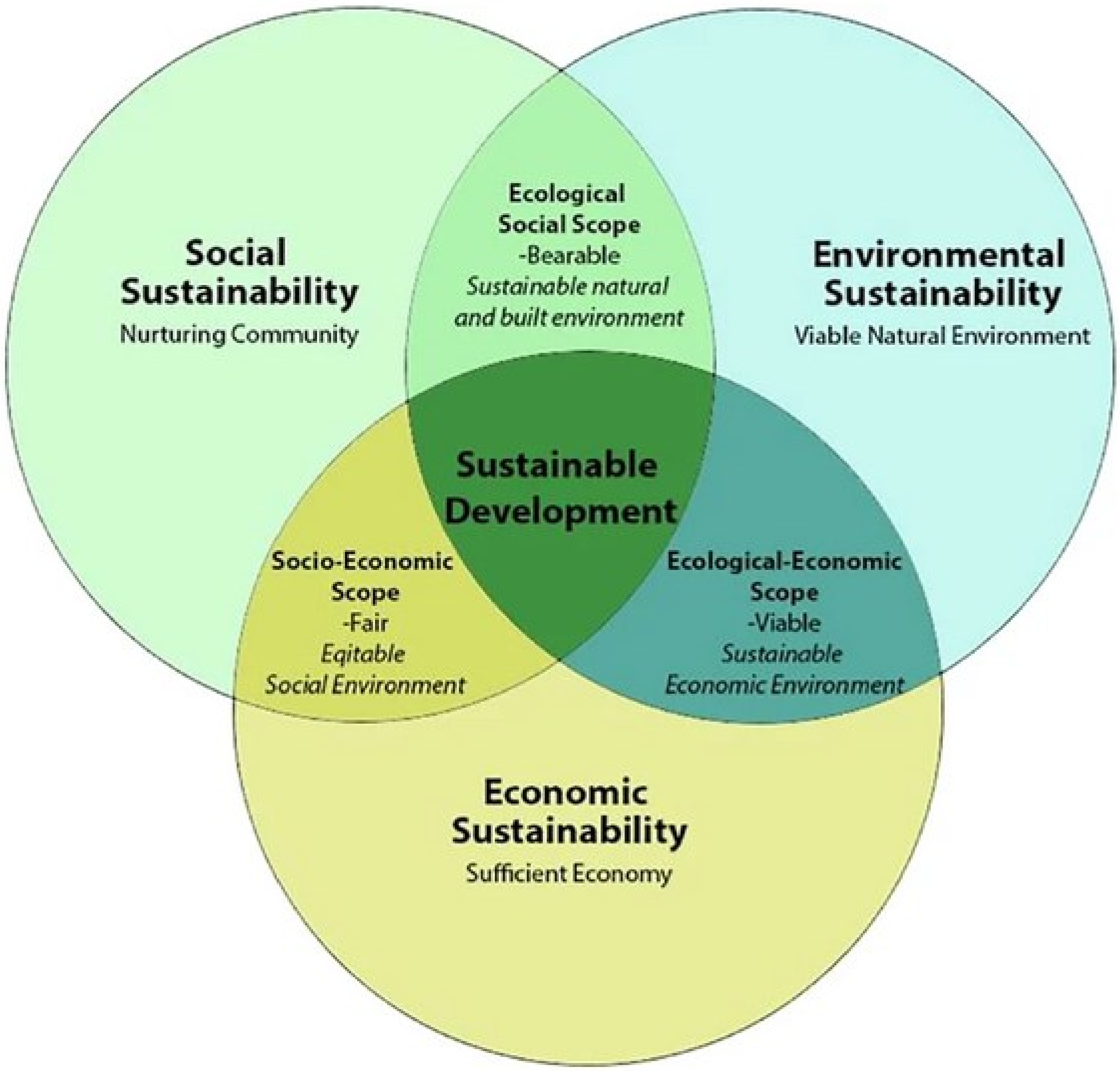
Land-use policy[a]	Explanation[b]
Controlling the urban built-up area (CUB)	Determines the urban built-up area based on a compact urban population density of 100 square meters per capita
Balancing the urban built-up area and rural built-up area (BUR)	The sum of the urban built-up area and the rural built-up area remains unchanged
Avoiding a reduction in prime croplands (ARC)	New built-up areas and ecological land do not occupy prime croplands
Maintaining the total area of croplands (MAC)	The sum of the cropland area remains unchanged
Avoiding a reduction in important natural habitats (ARH)	New built-up areas and cropland do not occupy important natural habitats
Performing ecological restoration (PER)	Increases high-quality ecological land (e.g., forest, grassland, lakes, rivers, marsh)

Source: Gong B, Liu Z. (2021). Assessing impacts of land use policies on environmental sustainability of oasis landscapes with scenario analysis: the case of northern China, Landscape Ecology, 36(1)`

This chapter has discussed about land use from an economic perspective. This includes the way price of land changes as location is far from busy and populated city center districts. As people move far away from CBD prices of land is decreasing. Also, it emphasizes the way land policy is used to manage the allocation of resources in a proper manner.

It is implied that when land policy is not well applied, then utilization of land becomes poor as no proper use of resources. People may build houses in unplanned areas, as seen in some places in Asia and Africa. Therefore, governments should increase seriousness to improve their land policies so that all stakeholders including investors respect them to attain environmental sustainability.

Figure 38: Sustainable development due to land policy



Source`Ergoz-Karahan E et al. (2023). Measuring "sustainable development" in vernacular settlements: a case study Behramkale, Türkiye, Journal of Cultural Heritage Management and Sustainable Development, 15(2)

It is good to use land for economic benefits, but also it is necessary to protect our environment for future generations. Therefore, seriousness is necessary to meet sustainable development goals set by the UN regarding environmental protection regardless of the level of development governments want to achieve in the long-term.

Table 7: Importance of land policy

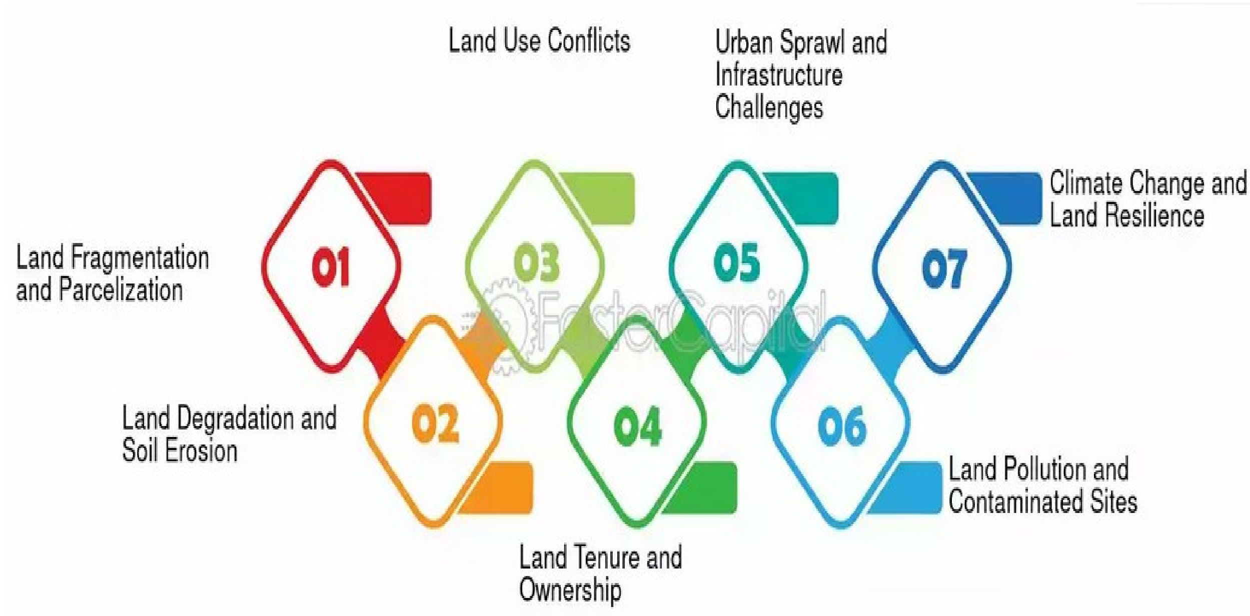
- Enhances tenure security and determines mechanism for distribution of land rights
- Promotes social stability (clarifies government goals/objectives)
- Basis for economic development (expectations and predictability)
- Sustainable land use and sound land management
- Development of legislation, regulations, and institutions (guidance, implementation, monitoring)

Source: Shahab S et al. (2022). Revisiting the Purpose of Land Policy: Efficiency and Equity, Journal of Planning Literature, 37(4): 575-588

It appears to me that when land policies are not respected, then the globe can face disaster in environment as land is finite and cannot be expanded; therefore effective utilization is only necessary. We should use land for profit but considering consequences for short and long time as well. In this way, the globe will be a safe and sustainable place.

The basic legal and socioeconomic framework that defines how land is held and managed is provided by land policy. It is crucial for local communities to provide tenure stability, avoid land disputes, and safeguard customary rights. Additionally, it encourages sustainable environmental management and gives underrepresented communities more influence. By prohibiting unlawful land grabs and arbitrary evictions, it safeguards the standard rights of indigenous people, smallholders, and pastoralists. It creates frameworks that are transparent, unambiguous, and legally binding to settle disagreements over usage rights and boundaries. It allows local families and landowners to use titles of land as security for loans and investments since it acknowledges the economic worth of land. It guarantees equal accessibility to land assets, thereby safeguarding the rights of marginalized groups such as low-income people, women, and exiled individuals.

Figure 39: Land use policy challenges



Source: Faster Capital. (2026). Land challenge: How to Overcome Land Challenges and Solve Them, fastercapital.com/content/Land-challenge--How-to-Overcome-Land-Challenges-and-Solve-Them.html

Land has been necessary since the old days, that's why our ancestors used it properly, although they had some challenges. In this way, we still have inherited land which is healthy and suitable for various purposes.

The evidence suggest that builders can also minimize damage and potentially improve the environment by disposing of garbage properly. First, reusing materials increases a product's lifetime value. Another excellent strategy to reduce landfill trash is to use biodegradable products. Responsible waste management can reduce the detrimental effects on the environment when recycling or reuse are not a possibility. Every company that generates garbage has a waste duty of care, which includes looking for recycling facilities to guarantee that waste is disposed of appropriately.

Figure 40: Applying sustainable land practices

Source: Faster Capital. (2026). Land challenge: How to Overcome Land Challenges and Solve Them, fastercapital.com/content/Land-challenge--How-to-Overcome-Land-Challenges-and-Solve-Them.html

In my opinion, sustainable growth requires efficient land zoning and planning. We can maximize land utilization by allocating particular regions for industrial, residential use, agriculture, and conservation. Planting trees and creating self-sustaining ecosystems (permaculture) in conjunction with agriculture can increase land production while protecting biodiversity. The availability of food and ecological wellness are under risk due to soil degradation. Soil loss can be reduced by using contour farming, terracing, and erosion control techniques.

Current literature highlights that reforestation, afforestation, and wetland restoration are methods for rehabilitating degraded land. These initiatives protect animals, stop desertification, and sequester carbon. Property rights are essential to the development and usage of land. Different types of ownership, including fee simple, leasehold, and communal ownership, are recognized by different legal systems. Effective land governance requires an understanding of these rights.

Typically, land is divided into various use categories by zoning restrictions. Efficient zoning strikes a balance between social justice, environmental preservation, and economic growth. Land boundary, ownership, and use disputes are frequent.

The conflict resolution is aided by legal systems including tribunals, courts, and centered around communities mediation. Due to traditional customs and practices, indigenous tribes frequently have distinctive interactions with the land. It is essential to acknowledge and defend these rights.

It is important to note that systems for transparent land administration lower the likelihood of corruption. Accountability is improved via digital land record platforms. National land policies are influenced by international accords such as the Convention on Biological Diversity and the Paris Agreement.

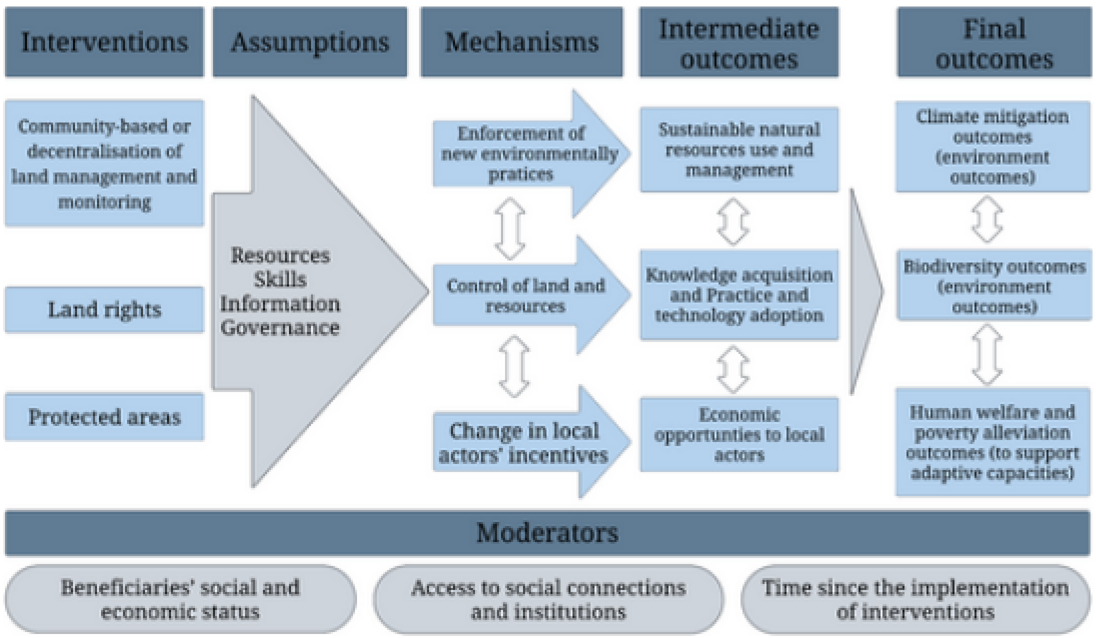
Figure 41: Regulatory and legal issues in the community to achieve sustainability

Source: Faster Capital. (2026). Land challenge: How to Overcome Land Challenges and Solve Them, fastercapital.com/content/Land-challenge--How-to-Overcome-Land-Challenges-and-Solve-Them.html

In my opinion, it is crucial to align local legislation with international obligations. A comprehensive strategy that balances conflicting interests, promotes transparency, and takes into account a variety of viewpoints is needed to handle legal and regulatory issues.

It can be argued that working together with stakeholders is essential to solving land-related issues and coming up with long-term solutions. To guarantee its appropriate use, land needs to be managed carefully and cooperatively by many stakeholders. We explore the complex process of working with stakeholders to address land-related concerns in this section. In land management, government agencies are crucial. They assign resources, make rules, and enforce them. Working together with agencies guarantees adherence to legal frameworks and more general objectives.

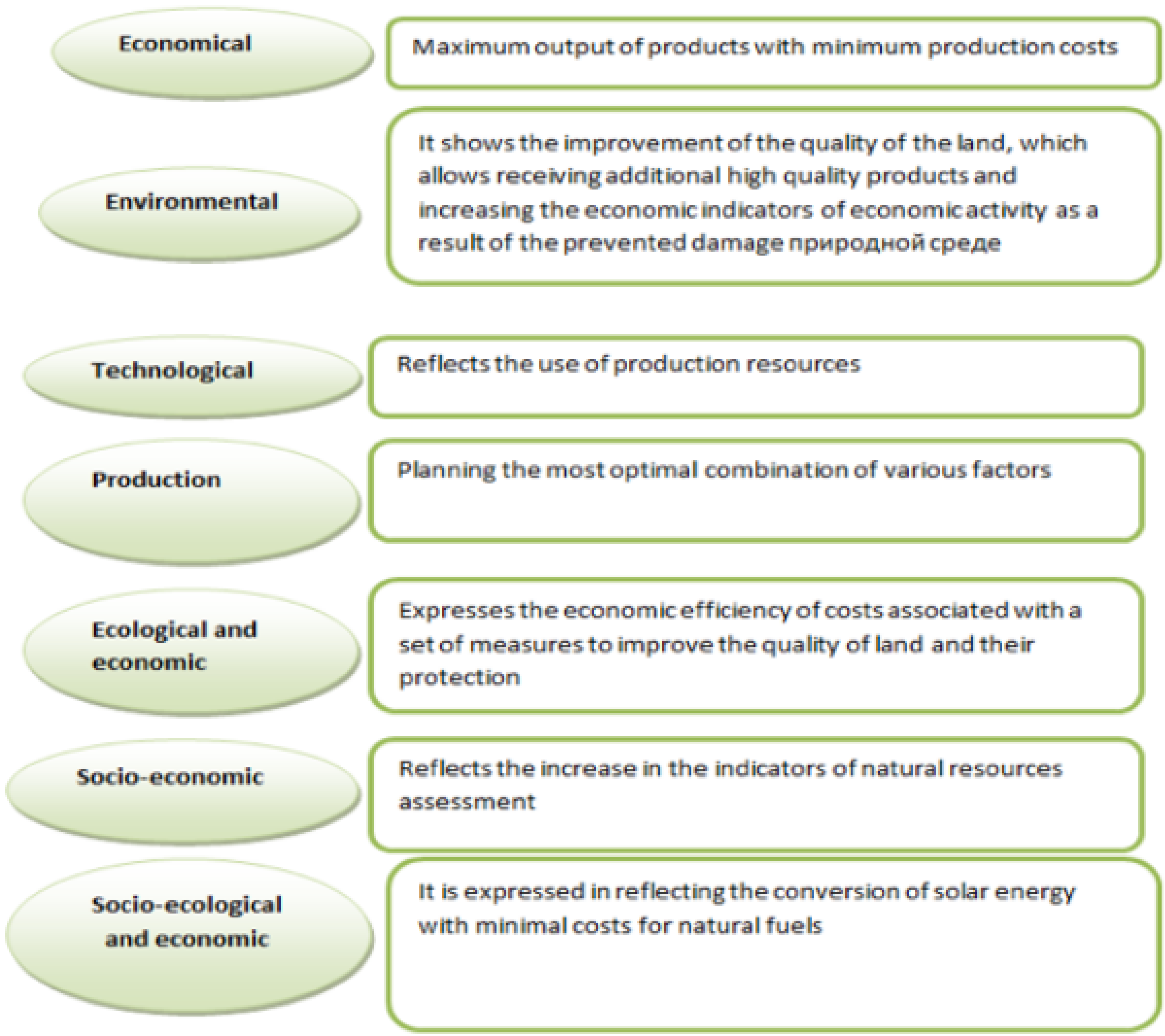
Figure 42: Land management intervention



Source: Marion P et al. (2025). PROTOCOL: The Effects of Land Management Policies on the Environment and People in Low- and Middle-Income Countries: A Systematic Review, Camp`bell Systematic Reviews, 21(4): 3

From my point of view, communities that live on or close to particular land parcels have important information. Their livelihoods and traditional knowledge are entwined with the land. Involving them promotes inclusivity and gives decision-makers more authority. Land is frequently sought after by companies, developers, and investors for a variety of uses. It takes communication and compromise to strike a balance between economic interests and issues related to society and the environment.

Figure 43: Efficiency of agricultural land use

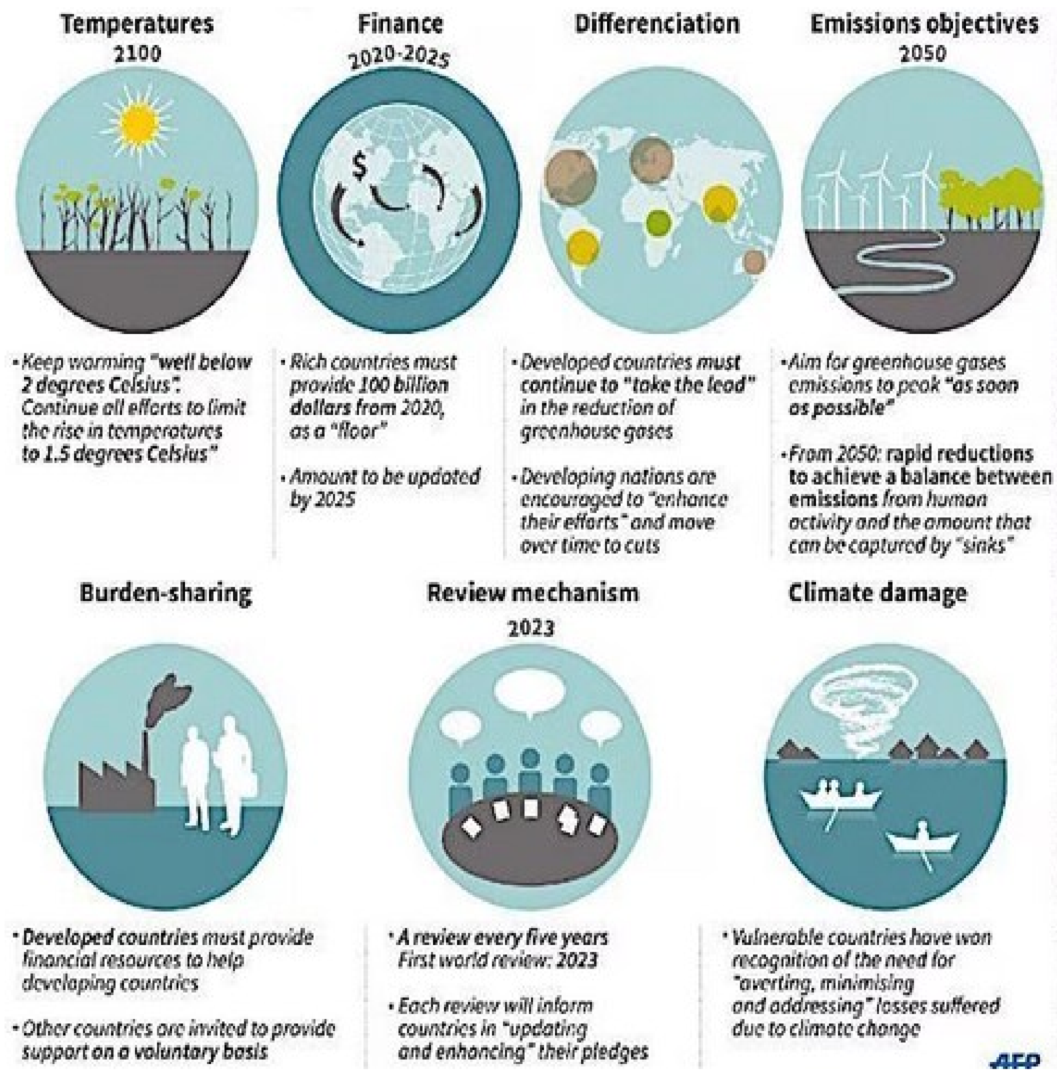


Source: Nikolaevna I et al. (2018). Efficiency of land use for agriculture, Revista Espacios, 39(26): 20

In this study, I argue that construction companies can minimize damage and possibly improve the environment by disposing of garbage properly. First, reusing materials increases a product's value over time. Another excellent strategy to reduce landfill trash is to use biodegradable products. Responsible disposal of waste can reduce the detrimental effects on the environment when recycling or reuse is not a possibility.

Every company that generates garbage has a waste duty of care, which includes looking for recycling facilities to guarantee that waste is disposed of appropriately. Reducing injury has been a major focus of efforts to promote sustainability in building.

Figure 44: Paris agreement objectives

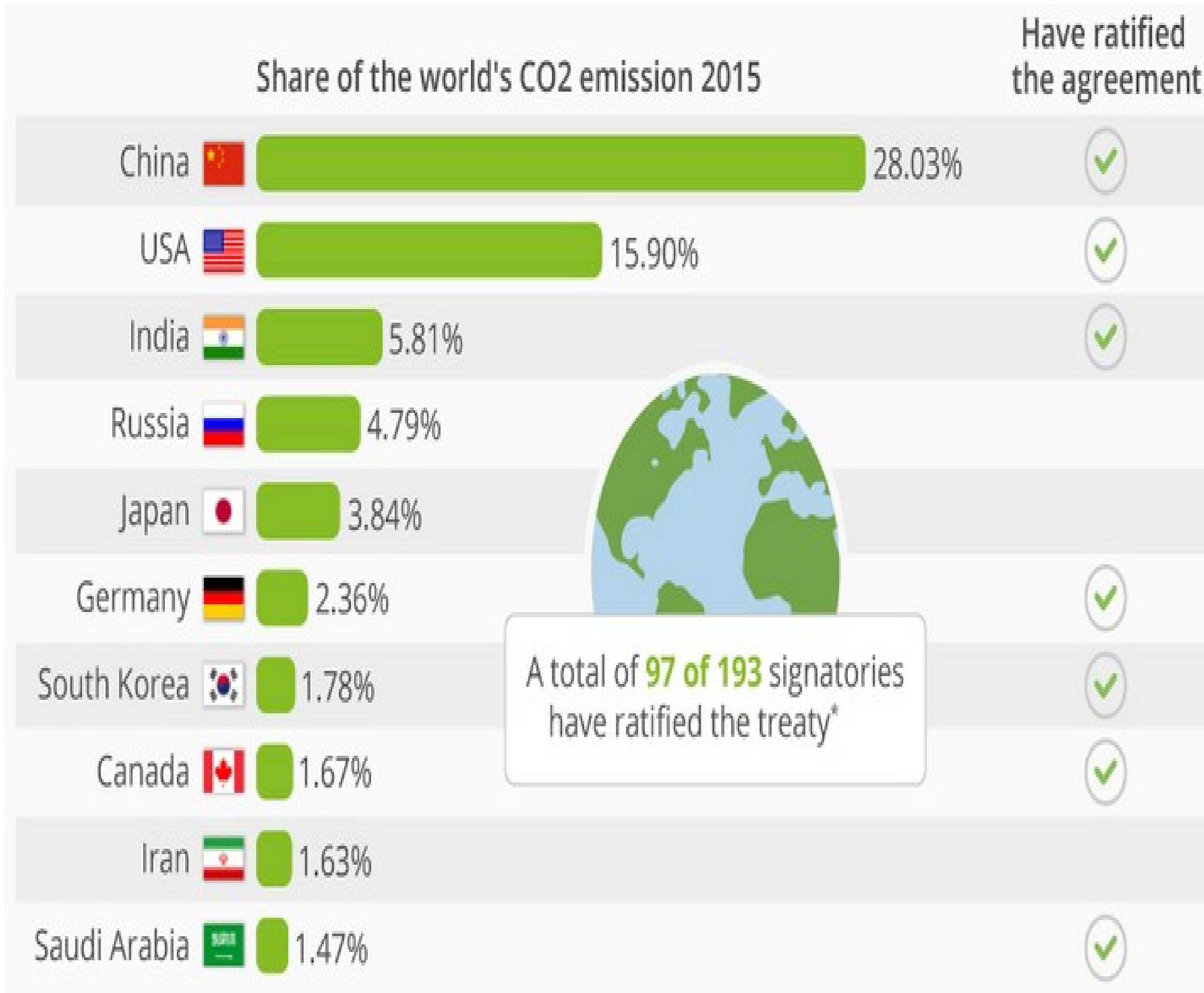


Source: Gray A. (2016). 5 charts that explain the Paris climate agreement, World Economic Forum

It is important to note that it is crucial to align local legislation with international obligations. A comprehensive strategy that balances conflicting interests, promotes transparency, and takes into account a variety of viewpoints is needed to handle legal and regulatory issues.

One of the most significant issues the world is currently experiencing is global warming. In December 2015, 195 nations ratified the Paris Climate Agreement, which aims to keep global warming far below 2 °C and, if feasible, below 1.5 °C (Gray, 2016, p. 1).

Figure 45: Countries producing highest carbon emissions in the world

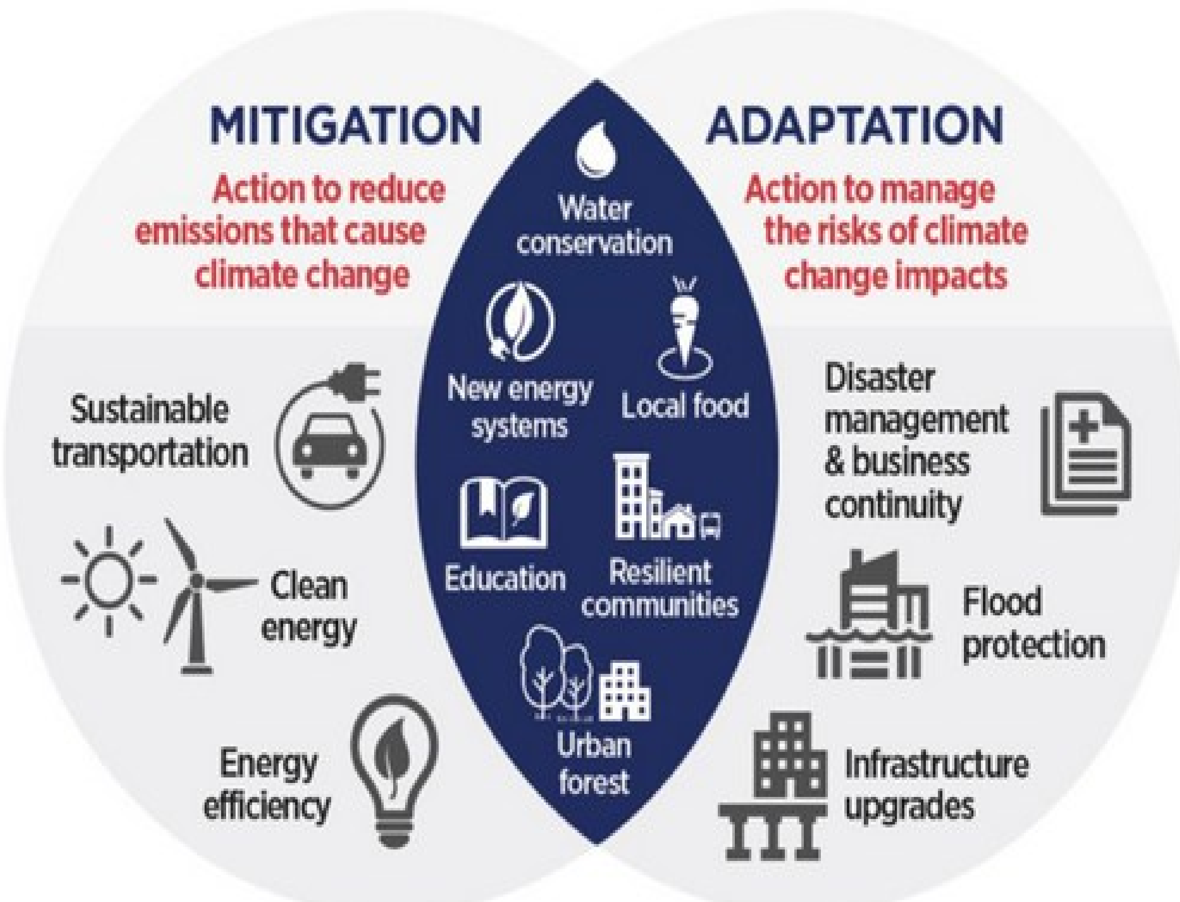


Source: Loesche D. (2016). Paris Climate Agreement Comes Into Effect, https://www.statista.com/chart/6572/paris-climate-agreement-comes-into-effect/?srsltid=AfmBOopuEiXdpgVX2787WMKTENTq7jaRzWUGnEWC0J3H2hBtHEKOl_pc

The convention's participants have said that they will use a variety of actions to accomplish their objective. Five times a decade, the agreement is scheduled to be evaluated. Rich and underdeveloped nations are held to different standards. The pact states unequivocally that industrialized nations have to guide the way in reducing greenhouse gas emissions (Gray, 2016, p. 1).

Traditionally, land-use planning has concentrated on physical measures, design, and specific environmental effects. However, planners' choices also affect the efficiency of commercial users of space, like supermarkets, and the availability and cost of homes and workplaces, for example. Concerns about the ecological viability of every action taken by humans on the planet have been raised by global manufacturing processes as a result of the progressively predictable but serious financial, ecological, and social issues facing humanity today.

Figure 46: Mitigation and adaptation of climate change



Source: New Water Ways, Climate Change Adaptation and Resilience, https://www.newwaterways.org.au/focus-areas/climate-change-adaptation-and-resilience/

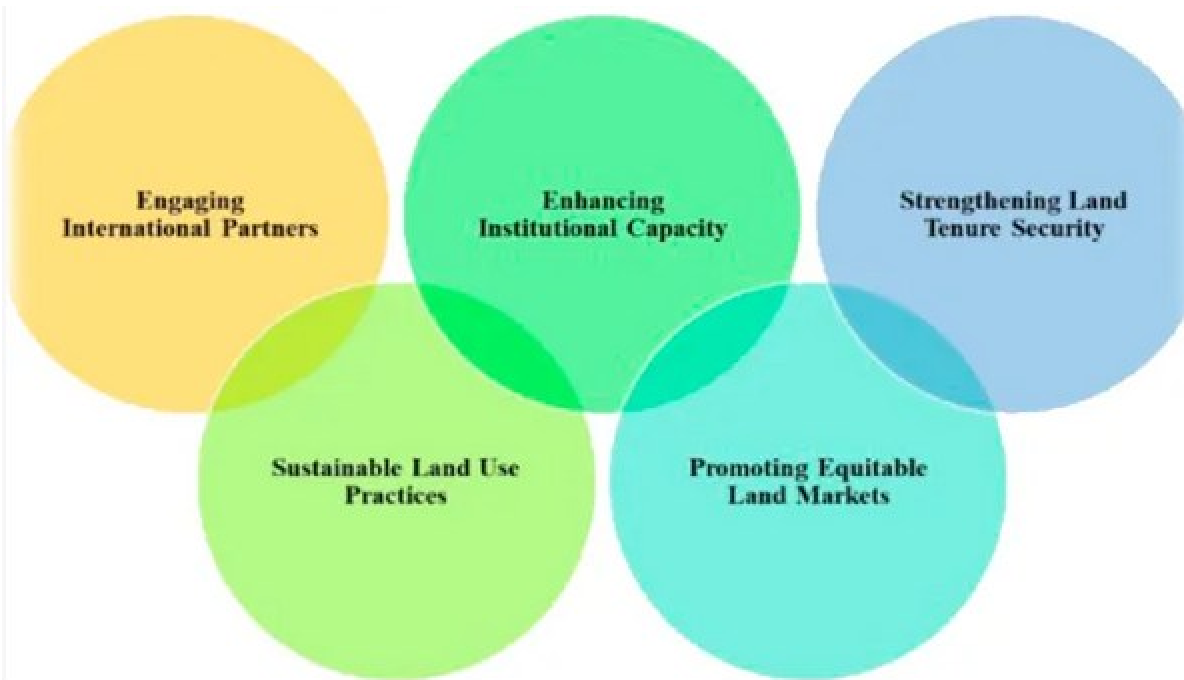
In addition to being seen as a crucial and necessary component of manufacturing, land and farm-based assets are vital to human existence and well-being since they serve as the foundation for all activities necessary for human survival, whether they be financial, social, or ecological.

Figure 47: UN environment programmes

Source: Greenfield E. (2O23). UNEP's Solution: All You Need To Know, https://sigmaearth.com/uneps-solution/

Yet in recent times, excessive land utilization and extraction of resources brought about by these activities of humans have led to unchecked damage to the environment, which has resulted in a decline of ecological ecosystems, climate change, deterioration of the worldwide aquatic system, modification of the planet's atmospheric chemical composition, and other problems plaguing civilization. A number of these, especially the decline of life forms, are occurring on a global level and are therefore serious issues for everyone.

Figure 48: Steps for applying policy recommendations



Source: Nguyen N et al.(2025). Market-oriented land transfers in rural Vietnam: navigating challenges for sustainable and equitable development, Frontiers, 13

As in figure 48 above, policy recommendations may strengthened through sustainable land use practices, promoting equitable land markets, strengthening land tenure security, enchancing institutional capacity, engaging international partners.

Chapter 5 – Conclusion

5.1 Summary of findings

The relationships of soil C and C sequestration as well as soil physical characteristics under different land management approaches were assessed in this study. Different management strategies responded differently to the individual factors used to determine soil quality. Overall, quantifiable changes in soil attributes were linked to variations in management techniques, which had a direct impact on soil functionality.

Long-term soil deterioration and decreased productivity are caused by intensive land use, which also contributes to soil particle disintegration, decreased soil organic material content, and disturbed nutrient cycle mechanisms.

In addition to upsetting aggregates of soil, soil intake—the loss of soil quality, nutrient content, and quantity due to intensive modifications to land use, development of cities, and topsoil erosion—exposes sequestered carbon to quick bacterial breakdown, and emits significant volumes of CO_2 and CH_4. Approximately 1,500 to 2,500 Pg (billion tonnes) of carbon are stored in the top meter of soils worldwide. This amount of carbon exceeds both the surrounding environment and all vegetation on earth put together.

Global greenhouse gas emissions are further accelerated by soil consumption, which releases this stored carbon by means of deforestation, urban development, and traditional agriculture.

Agricultural practices have reduced soil carbon reserves worldwide by an estimated 116 Pg since the beginning of human cultivation, turning sinks from nature towards total carbon providers.

The importance of green infrastructure is growing as cities struggle with the effects of fast urbanization and climate change. The general capacity for resilience of metropolitan areas is increased by the thoughtful development and maintenance of green spaces, which act as a safeguard against problems with the environment.

A change in perspective that recognizes the interconnectedness of life in cities and the natural environment is reflected in this intentional incorporation that nature provides through city planning techniques. Through the incorporation of green spaces, urban landscapes—often associated with concrete expanses—are undergoing a dramatic change toward a more robust and balanced future. These green spaces inside urban structures are more than just decorative; they are essential organs that greatly improve the health of the surroundings and its people.

One of the most important steps in lessening the environmental effects of urban living is to promote sustainable modes of transportation. For shorter distances, people can choose to use bicycles, carpool, or take public transportation. This encourages more active and healthy lives in addition to lowering carbon emissions. One practical method to support the growing of food locally and improve biodiversity is to take part in or support community gardening programs. In addition to producing fresh vegetables, converting abandoned urban areas into community gardens promotes a feeling of belonging and a connection to the natural world. Sustainable urban living requires careful water use. Installing rainwater harvesting systems lessens dependency on centralized water supply, prevents urban flooding, and conserves water resources. Urban water sustainability may be significantly impacted by this activity.

5.2 Final evaluation

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For the security of food, soil, water, and energy, soil carbon is an essential part of healthy ecosystems. Soils will be greatly impacted by changes in land use and climate. A dynamic reaction among soil and the surroundings will result from these factors' influence. Evaluating soil reactions to global ecological shifts at broad scales that take place across inherent gradients of the environment during decadal timeframes is crucial. The world's previous expenditures on soil analysis networks will be uniquely utilized by this endeavor, which offers a suite of fresh data on worldwide soil transformation.

Although integrated ecosystem strategies for handling ecological and economic assets have seen highly promising technical advancements, many developing nations still face significant obstacles to their implementation. The substantial initial costs associated with many of the more recent methods are among the most notable of these limitations. There is still little knowledge of these methods and their advantages in a lot of developing countries where they might have some of the greatest significant advantages. Although individuals are conscious of them, their ability to be implemented is restricted in some situations.

Furthermore, the structure of food consumption is changing fundamentally due to rising earnings and the growing percentage of people around the globe living in urban regions. Urban populations with higher incomes have more varied diets that include a range of significant amounts of food items, such as cattle, which require more resources to grow and process. This makes it more difficult to maintain and preserve the resilience of agricultural and natural ecosystems.

Based on these advancements, estimates suggest that by 2050, the world's food output will have to rise by 70%. Food production needs to rise by over 100 percent, or practically double, in several African nations where the problem is most severe.

Agriculture, the area of the world economy most susceptible to the consequences of climate change, including increasingly erratic rainfall and more catastrophic weather-driven events, bears the burden of this dilemma. At the same time, one-third of the world's greenhouse gas emissions come from agriculture and related land-use changes, making it one of the main causes of climate change.

Requirements for food and biomass are expected to double by 2050, which will have a significant impact on the strain that agriculture places on tropical forests along with additional natural ecosystems. These ecosystems are essential for both generating a home for biological diversity and sequestering carbon through their composition.

Soil is essential to farming and forest land usage since it is the fundamental resource. Soil quality and soil carbon are directly correlated. It plays a significant role in determining the soil's capacity to retain and distribute water and additional resources that are necessary for the growth of living things and their underlying structures.

Additionally, soil carbon is crucial for preserving the biotic ecosystems that provide land management systems with their resilience, sustainability, and resistance to deterioration. Reversing soil fertility loss, limiting outside GHG emissions, and lessening the effects of global warming on farming systems are all possible by means of carbon sequestration, the mechanism whereby ambient carbon dioxide is absorbed by vegetation by means of photosynthesis and kept as carbon in plant matter and standard soils.

By controlling trade-offs across sectors and space, soil carbon sequestration may prove optimized. In addition to tackling nutrition and rural income challenges, acting at the scale of the landscape can help mitigate the effects of climate change.

Numerous institutional and economic obstacles may prevent the widespread use of environmentally conscious land management techniques. These include the requirement for poorer farmers to make large upfront investments, the unavailability of certain inputs in market conditions, a lack of knowledge on the promise of upgraded techniques, and frequently insufficient ability to carry out the techniques. Traditional methods may not be consistent with some sustainable land management strategies.

There are three key ways that sustainable land management reduces carbon emissions. The initial issue is carbon preservation, because it keeps the vast amounts of carbon trapped in wetlands, grasslands, and natural forests as carbon stocks. In terms of mitigating and adapting to climate change, preserving this land-based carbon is a "cheapest alternative" that is crucial to boosting the resilience of farming ecosystems. The second advantage is carbon sequestration, whereby the expansion of natural and agriculturally produced biomass actively absorbs carbon from the surrounding environment and saves it in biomass and soil. Reducing carbon dioxide emissions from agricultural activity—including emissions from alterations to land use, where carbon reserves turn into resources of carbon when production from agriculture spreads into natural ecosystems—is the third advantage.

Profits as well as losses are dynamically balanced in the soil organic carbon pool. The amount varies as time passes based on the speed of decomposition and the quantity of photosynthetic C supplied. Carbon inputs from fallen litter and biomass from roots undergo cycling by means of degradation, organic material breakdown, and dumping under unaltered natural circumstances. Pedological variables, which determine the chemical and physical upper bound on carbon retention in the soil, are the main determinants of possible carbon sequestration. These variables include the amount of coarse pieces, dimension, density of mass, moisture content, and texture of the soil and clay composition.

5.3 Environmental implications

The physical coverage of land by infrastructure and urban growth, or "soil consumption," has detrimental effects on the ecosystem. Healthy farming land is destroyed, water supply cycles are disturbed, essential biodiversity is diminished, and climate change is accelerated by the release of stored carbon. Water is naturally filtered by soil, which also stores carbon and promotes plant growth. By eliminating these services, paving it over increases the likelihood of local flooding and the impacts of urban heat islands.

Large volumes of carbon from the soil are oxidized and emitted into the environment as greenhouse gases when topsoil is excavated, compacted, or coated with concrete. Soil is an intricate, living environment. The habitats of microbes, insects, and fungi that are essential for soil restoration and the cycling of nutrients are destroyed by urban growth.

Rainfall is absorbed by natural soil, which replenishes groundwater aquifers. Rapid surface runoff from paving it over results in soil erosion and groundwater depletion. Agriculture is forced into marginal or wooded areas as cities eat up productive soils. This exacerbates environmental damage by increasing the usage of synthetic fertilizers and driving deforestation. The basis of life on Earth is soil.

It performs vital tasks like promoting the development of plants, keeping and purifying water, circulating essential nutrients, helping to buffer breaking down pollutants, taking part in the Earth's carbon cycle, offering a home for a wide variety of living things, providing natural resources, and acting as a base for conventional buildings. However, despite its significance, soil is frequently overlooked and is becoming more and more vulnerable to pollution, urbanization, irresponsible land utilization, and climate change.

A limited natural resource is soil. The use of soil is under unprecedented pressure due to the rapid rise of the human population. About one-third of all soils are slightly to severely degraded, which leads to decreased water retention, higher levels of erosion, and decreased fertility. In addition to endangering human lives and food security, the deterioration of soil health damages ecosystems and speeds up climate change.

There is much more to soil than just the ground under our feet. Many facets of our environment, economics, and well-being are supported by this life-supporting system. Its influence extends well beyond agriculture; it is vital to biodiversity, raw material supply, food safety, management of water, regulating climate change, and cultural legacy.

The production of food and fiber is inextricably tied to soil. For the majority of the food we eat and the wood we use, soils supply vital nutrients, water, and structural support. In order to ensure food security for a growing world population, viable crops and effective food systems depend on healthy soils. Because it controls water penetration, sewage flow, and preservation, soil is essential to the water cycle.

The way water passes through and is held in the soil is determined by its physical characteristics, including its structure, organic matter concentration and particle size distribution. Proper water entry, retention, and circulation are made possible by soil that is healthy that have adequate organic content and structure. They guarantee that water is accessible for the growth of plants and aquifer recharging while lowering erosion and disasters.

Because of variations in primary material, weather conditions, species, topographic features, and the age of the landscape as it changes over the lengthy duration of soil formation, soils differ from one location to another. These elements affect the color, particle-size distribution, density, structure, restricted layers, and chemical content of the soil.

Because of the high rainfall and solid terrain, numerous tropical soils are usually deep, very worn, and nutrient-poor. Desert soils often have high salt concentrations and little organic content. Temperate soils often have more genuine fertility, greater organic content, and are less dense and less worn compared to tropical soils. Mountain soils are typically rocky and thin.

Soils store two times the amount of carbon as all live plants and three times the amount as the air, making them one of the planet's biggest carbon reservoirs. Carbon taken up by plants as CO_2 is transmitted to the soil through roots and plant wastes during the procedure of soil carbon sequestration.

By lowering atmospheric CO_2, raising soil carbon levels aids in the mitigation of climate change. Still, the sequestration process can be reversed by land management techniques like draining peatlands or traditional tillage operations, discharging carbon returned to the air as CO_2 and accelerating climate change. Clay, sandy soil, and mineral substances are among the raw elements found in soils that are employed in industry, construction, and gardening. Peat is used as a fuel and as a soil supplement in horticulture.

The term "land use" refers to how humans have altered the natural environment, mostly through manufacturing, settlement, and farming. These modifications have significant effects on the environment; they are a major contributor to resource depletion and climate change, and they drastically alter regional water cycles and local ecosystems. Examining land use's effects across a number of related domains is necessary to comprehend its environmental repercussions.

Worldwide emissions of greenhouse gases are attributed to alterations to land use, forest management, and farming. Huge quantities of carbon that is stored are released and returned to our atmosphere as a result of forest clearing. Monocropping, excessive grazing, and the use of bulky equipment are examples of intensive farming practices that decrease nutrients from the soil and increase the vulnerability of land to erosion from water and wind.

Frequent conversation fosters trust. Information worries and goals should be freely shared by stakeholders. Discussions are facilitated by town hall meetings, workshops, and internet forums. Land disputes are frequent. Mechanisms for negotiation, mediation, and dispute resolution are crucial. For example, a community may be against a mining proposal because of the risks to the environment. Finding common ground requires involving all sides.

Clear responsibilities, data sharing, and transparent procedures all improve teamwork. Transparent impact evaluations assist stakeholders in understanding potential repercussions when an innovator offers a housing project.

Stakeholders need to match their aspirations with those of sustainable development. Long-term advantages are ensured by striking a balance between social justice, economic prosperity, and environmental preservation. In order to mitigate and adapt to climate change, land is essential. Risks are reduced by working together on resilient land-use techniques (such as green buildings and water control).

Land problems are complex and call for creative solutions. Technology is essential to solving land-related problems in a world growing more interconnected by the day. Utilizing technology can result in more effective land management and improved community outcomes, from growing cities to sustainable farming. Important information on land usage, vegetation cover, and resources from nature is provided by geographic data. We can monitor changes, plan actions, and comprehend land dynamics by studying satellite photos and remote sensing data.

Blockchain technology provides immutability, security, and transparency. It can improve confidence, reduce fraud, and expedite real estate transactions when used to land registries. GPS as well as information analytics are combined in precision farming to maximize crop yield. Farmers can make better decisions by keeping an eye on the health of the soil.

Global environmental deterioration is being fueled by both climate change and increasing human land use. Natural or quasi-natural habitats are being diminished and fragmented by agricultural growth, deforestation, urbanization, and desertification, all of which are endangering biodiversity.

Land use pressures are becoming one of the most significant environmental issues of the modern era. Over the next few decades, competition for environmentally valued and productive land, as well as for the assets and amenities it offers, is expected to increase due to the developing "land crunch" caused by the need for land for cultivation, global warming mitigation, and other vital uses.

Managing land and global warming will worsen together in the absence of effective intervention. These shifts may pose a major risk to people's well-being and means of subsistence. By better protecting, conserving, and restoring water, soil, and biodiversity habitats, smarter land utilization can bring down the destructive cycle of diminishing land assets and climate change. In turn, these initiatives can improve wellness by helping to mitigate and adapt to global warming.

Businesses frequently have a good effect on the environment because they give local communities priority. For instance, building firms may preserve, promote, and improve biodiversity if they incorporate green areas for the health of the local population. In a similar vein, incorporating more transport alternatives into the design of new roadways may offer a variety of benefits. Accessible bike lanes and walking routes encourage active living and lower carbon emissions.

Improving the agricultural regions requires increasing the effectiveness of farmland usage. This effectiveness can be ascertained through a comparative assessment, which is required to comprehend the kinds of natural environments in which these or those activities, like crop and livestock production, are most productive. The efficiency of the utilization of land in farming can be evaluated both at the scale of a single sector and in the context of the nation's overall financial situation. In order to maximize the impact of land use efficiency, it is imperative to include all economic sectors and allocate land assets among them.

This measure entails giving provincial and/or local stakeholders control over natural resource administration and choice-making. Involvement from the community can take the form of monitoring on the utilization of natural resources, supervision of third-party executive power, or completely or partially decentralized land management. This kind of intervention seeks to protect and use natural resources in a sustainable manner by utilizing local knowledge and presence. Crowd-driven tracking and reporting systems, representation of the community in standardized forestry bodies, and community-driven forest administration are a few examples.

There has never been a greater pressing need to fight climate change. Earth's temperature is rising more quickly than previously believed. Now, nations must fulfill their commitments. National and international organisations are also incentivised to support these land management interventions as they are linked to the Sustainable Development Goals (SDGs), especially SDGs

13 and 15. SDG 15 is to preserve, rebuild, and encourage environmentally friendly utilization of natural environments, handle forests ecologically, fight desertification, mitigate and prevent damage to the environment, and stop biodiversity loss. SDG 13 is to take immediate measures to fight global warming and its effects (Marion et, 2025, p. 2).

The success of land utilization economics assesses the extent to which zoning, geographic, and regulatory strategies strike a balance between social well-being, preservation of the environment, and the greatest monetary output. It calculates the proportion of financial output to resource consumption. Compared to expansive suburban growth, cities that promote dense, multi-use zoning frequently exhibit greater fiscal effectiveness and smaller impacts on the environment. By means of taxes, value of property taxes, or planning standards, effective regulations enable towns to recover the expenses of public infrastructure caused by private development. Ecosystem services are incorporated into economic models through sustainable land use. It acknowledges that protecting agricultural land and green areas creates for years financial protection against problems including flooding and extreme temperatures. A choice between rental rates and an equitable society can result from excessively limiting zoning, which can raise the cost of housing and lower home accessibility.

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