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Connections between Renewable Resources, Epigenetic Mechanisms, and Human Development

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Abstract: The interconnections between renewable resources, epigenetic mechanisms, and human development reveal a complex interplay between environmental sustainability and biological adaptation. Renewable resources, when managed responsibly, provide the ecological stability necessary for healthy living conditions. These conditions can influence epigenetic processes, modulating gene expression in ways that impact physical, cognitive, and social development. Such biological responses may, in turn, affect community resilience and long-term human potential. Recognizing these links is essential for designing policies that integrate environmental management with health and developmental outcomes. This manuscript aims to examine the interconnections between renewable resources, epigenetic mechanisms, and human development, with a focus on understanding their mutual influences and potential implications for sustainable growth. This study is an integrative literature review; A structured synthesis process aimed at expanding both theoretical and empirical understanding of the topic to achieve the research objectives. Inclusion criteria included full-text national and international publications in Portuguese, English, or Spanish. Duplicate studies and those not aligned with the research objectives were excluded. The review followed the stages as shown in the figure below. This approach integrates diverse types of evidence, supporting conceptual, theoretical, and methodological analyses. The literature search was conducted using virtual libraries selected for their comprehensive coverage of health sciences and inclusion of studies from diverse cultural and methodological contexts.

Keywords: Environmental, Gene, Public Health, Socioeconomic, Sustainability.

Research Paper

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1.0 INTRODUCTION

Human development, in one of its primary interpretations, refers to the provision of resources that meet essential material needs and to the establishment of conditions in which individuals can fully realize their abilities and aspirations. A higher degree of human development is commonly associated with an improved quality of life. Advancing human development requires broadening people's choices and possibilities, fostering progress, and improving overall well-being. Measurement of this progress is often carried out through the United Nations Development Programme. This considers indicators such as life expectancy, years of schooling, and GDP per capita (Editorial team of Conceito.de, 2020; UNDP, 2023; UNDP, 2024a; UNDP, 2024b; United Nations Development Programme, 2025).

Recent evaluations Human Development report highlight growing inequality and the need to enhance people's sense of political empowerment and agency in a polarized world. Furthermore, media studies reveal that media outlets often equate HDI with "quality of life" and "well-being", especially when reporting on countries high in rankings (Morse, 2023).

Epigenesis proposes that the traits of living organisms are not fixed in the fertilized egg but emerge gradually throughout development. Within this framework, epigenetics focuses on how environmental influences, rather than heredity alone, interact with genes to regulate their activity. These processes can modify the functional expression of DNA without altering its sequence, through mechanisms involving chemical tags and structural changes. Epigenetic regulation plays a critical role in early human embryo development, in metabolic diseases, and in the interplay between aging, DNA methylation, and gene expression (Wu *et al.*, 2023; Chakrabarti, 2024; Xu *et al.*, 2025).

Although these markers are not genes, they shape genetic expression significantly outcomes: Section of the Human Genome Project in 2003 confirmed that genetic information alone does not determine biological outcomes; instead, a range of environmental and physiological factors influences cell function, development, disease susceptibility, and aging. Epigenetics seeks to understand and map these intricate relationships (Figure 1) (United Nations Development Programme, 2025).

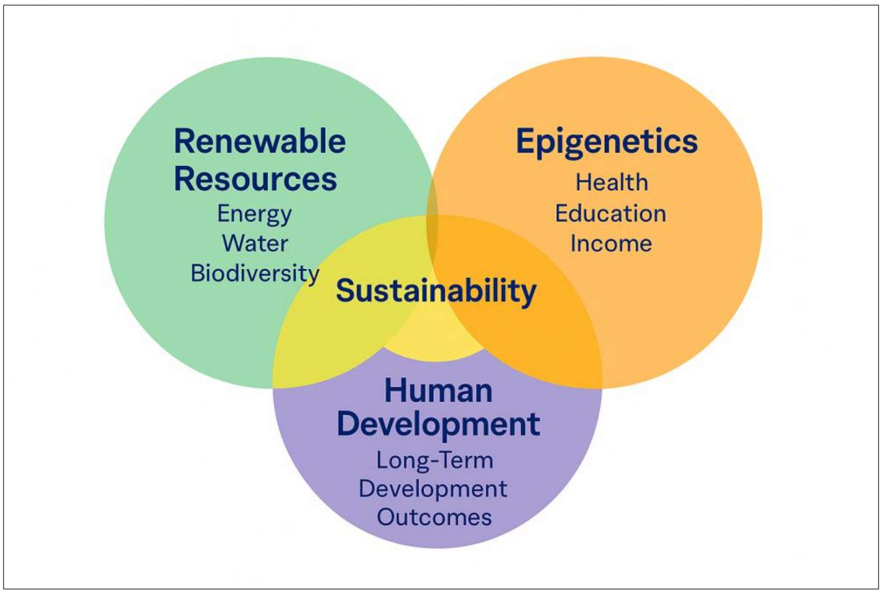

Figure 1: Interconnection between Renewable Resources, Epigenetics, and Human Development. Together, these dimensions highlight how environmental sustainability, biological mechanisms, and social equity reinforce one another in shaping a just and prosperous future

Source: Marco Santana, Institute

Renewable resources are fundamental for constructing a sustainable future. They include natural assets that can replenish themselves within human timeframes, either naturally or through responsible management. While "renewable energy" often brings to mind solar and wind, its scope extends to broader sustainability concepts supported by innovation, policies, and technology. Empirical studies, such as the impact in G-20 countries, underscore that innovation significantly increases renewable energy adoption, helping reduce CO_2 emissions. In Saudi Arabia, hydropower and wind energy have proven particularly effective in enhancing sustainable development across economic, environmental, and social dimensions (123 Ecos Editorial, 2025; Benhacene and Hussien, 2025; Han *et al.*, 2025; SAIS, 2025).

1.1. OBJECTIVE

This manuscript aims to examine the interconnections between renewable resources, epigenetic mechanisms, and human development.

2.0. METHODS

This study is an integrative literature review; A structured synthesis process aimed at expanding both theoretical and empirical understanding of the topic to achieve the research objectives. Inclusion criteria included full-text national and international publications in Portuguese, English, or Spanish. Duplicate studies and those not aligned with the research objectives were excluded. The review followed the stages as shown in the figure below. This approach integrates diverse types of evidence, supporting conceptual, theoretical, and methodological analyses. The literature search was conducted using virtual libraries selected for their comprehensive coverage of health sciences and inclusion of studies from diverse cultural and methodological contexts. This ensured a multidimensional and methodologically rigorous synthesis of the relevant literature.

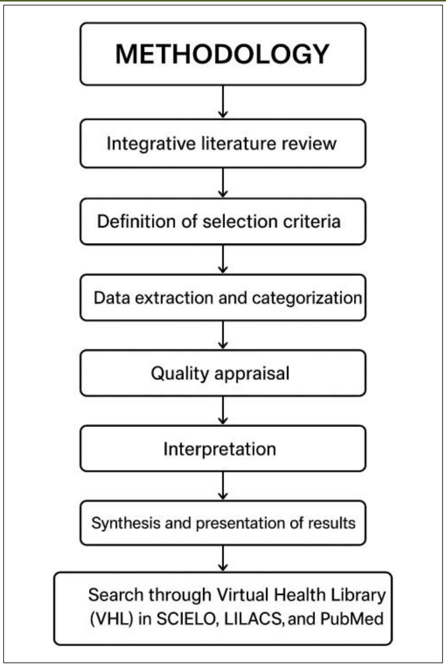

Figure 2: Workflow of the integrative literature review methodology
Source: Marco Santana Institute

3.0. STUDY SELECTION

3.1. Human Development: Concepts, Measurement, and Emerging Trends

Human development is a multidimensional process through which societies expand individuals' capabilities, enabling them to lead long, healthy, and creative lives, acquire knowledge, and access the resources necessary for a decent standard of living. This paradigm positions human well-being as the ultimate goal of development, treating economic growth as a means rather than an end. It emerged prominently through the intellectual contributions whose capability approach emphasized enhancing real freedoms and opportunities rather than increasing income levels (United Nations Development Programme, 1990; Sen, 1999).

3.1.1. Human Development Rests on Three Fundamental Pillars

1. **Health:** Represented by life expectancy at birth. The longer the expected lifespan, the higher the population's health index.
2. **Education:** Measured by the average years of schooling and access to both basic and higher education.
3. **Income:** Assessed through Gross Domestic Product (GDP) per capita, which reflects an individual's capacity to acquire goods and services (Lucidarium, 2025).

While these quantitative indicators are essential, human development also encompasses qualitative aspects such as safety, social participation, and freedom of choice. When a society prioritizes human development, it reaps multiple benefits. These include reducing social inequalities, improving quality of life and overall well-being, expanding access to education and health care, which in turn strengthens the workforce, enhancing social inclusion and civic engagement, and promoting sustainability alongside balanced long-term growth. Such benefits contribute to greater social stability, reduced violence, and increased foreign investment, creating a virtuous cycle of sustainable progress (Lucidarium, 2025).

3.1.2. To Enhance Human Development, Practical Measures Can be Implemented by Governments, Businesses, And Individuals. These Include:

1. Investing in quality education is accessible to all.
2. Expanding access to healthcare and ensuring efficient medical assistance systems.
3. Implementing social inclusion policies and poverty reduction strategies.
4. Promoting civic participation and freedom of expression.
5. Encouraging sustainability initiatives and corporate social responsibility (Lucidarium, 2025).

In addition, community-based projects and financial literacy programs play a crucial role in fostering a more cohesive society, better equipped to pursue sustainable development (Lucidarium, 2025).

To operationalize this conceptual framework, the United Nations Development Programme (UNDP) introduced the Human Development Index (HDI) in 1990. The HDI synthesizes three dimensions: Health, measured by life expectancy at birth; education, assessed through mean and expected years of schooling; and income, represented by Gross National Income per capita, into a composite measure that provides a broader assessment of progress beyond Gross Domestic Product (GDP). This innovation enabled comparisons of development performance across countries and over time (UNDP, 1990; UNDP, 1997; 2019).

Amartya Sen's capability approach, as elaborated in Development as Freedom, articulates five instrumental freedoms: political freedoms, economic facilities, social opportunities, transparency guarantees, and protective security. These freedoms expand people's capabilities to choose the kind of life they value, reinforcing the principle that development is about enlarging substantive human choices rather than merely accumulating wealth (Figure 3) (Sen, 1999).

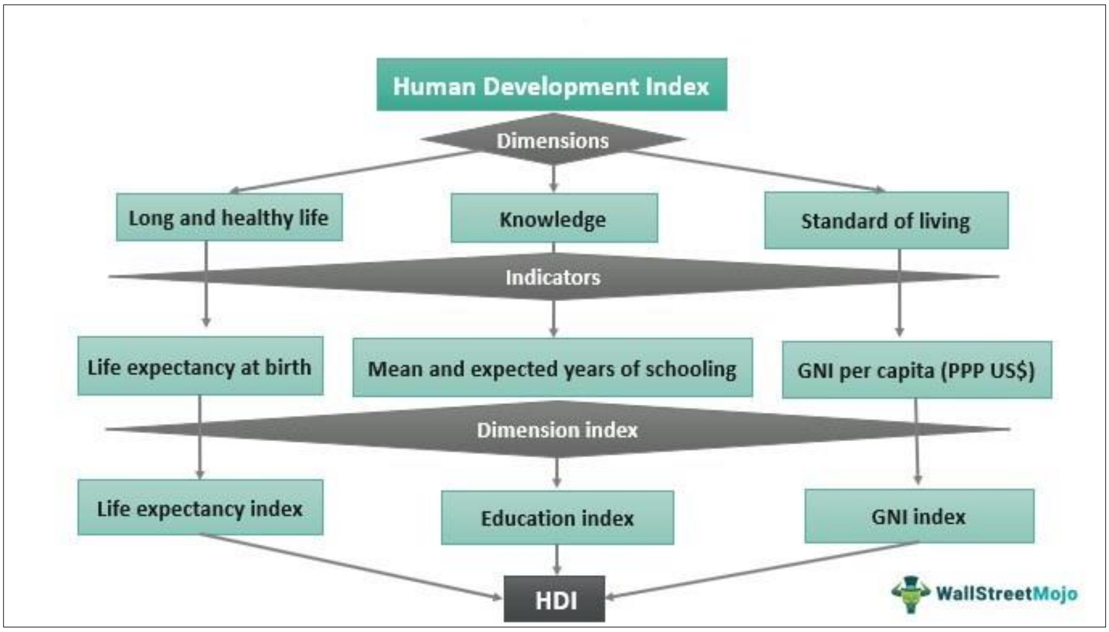

Figure 3: The Human Development Index (HDI) is a composite statistical measure designed to evaluate a country's overall level of human development. It considers three fundamental dimensions: longevity and health, access to quality education, and an adequate standard of living. By integrating social and economic indicators, the HDI provides a comprehensive perspective on national progress beyond mere economic growth
Sources: WallStreetMojo and https://www.wallstreetmojo.com/human-development-index/

Recognizing the HDI's limitations in measuring inequality and multidimensional deprivation, UNDP introduced additional tools such as the Inequality-adjusted IHDI and the Gender Inequality Index (GII). Additionally, in partnership with the Oxford Poverty & Human Development Initiative, the Multidimensional Poverty Index (MPI) was created in 2010. The MPI evaluates ten indicators across health, education, and living standards, helping policymakers identify not only who is poor but also how severe their poverty is (Alkire and Santos, 2010; UNDP, 2023; UNDP, 2024a).

Global MPI report demonstrated that poverty remains significantly deeper and more persistent in conflict-affected regions, where instability, economic disruption, and weakened social services hinder progress. This highlights the necessity of targeted, context-specific policy interventions to ensure that human development gains are equitable and sustainable. United Nations Member States adopted the Sustainable Development Goals (SDGs), a universal framework of 17 integrated objectives aimed at eradicating poverty, protecting the planet, and fostering peace and prosperity by 2030 (Investopedia, 2013; United Nations, 2015).

The SDGs complement the human development approach by embedding environmental sustainability, social inclusion, and economic growth into a unified agenda. Despite its broad utility, the HDI has faced criticism for oversimplifying complex realities. Limiting the measure to three dimensions excludes aspects such as environmental sustainability, political freedoms, cultural diversity, and intra-national inequalities. Moreover, reliance on national averages may obscure substantial regional disparities, limiting the effectiveness of policy responses (United Nations Development Programme, 2019; Plutus Education, 2024).

To address these limitations, indices such as the Subnational Human Development Index (SHDI) and the Planetary Pressures-adjusted HDI (PHDI) have been developed. The SHDI disaggregates data to subnational levels, revealing internal disparities, while the PHDI integrates ecological sustainability by adjusting scores for environmental pressures. The academic debate has been enriched by contributions from Martha Nussbaum, who expanded the capability approach by defining a list of central human capabilities. These include bodily health, bodily integrity, emotions, practical reason, affiliation, and political control over one's environment, thereby linking human development to justice, dignity, and the conditions necessary for human flourishing (Nussbaum, 2011; Stanford Encyclopedia of Philosophy, 2011; UNDP, 2024a; UNDP, 2024b).

3.1.3. New Developments in 2025

The 2025 Human Development Report (HDR), titled "A Matter of Choice: People and Possibilities in the Age of AI", highlights a significant slowdown in global human development progress, the slowest in 35 years. The report identifies widening inequalities between countries with high and low HDI, as well as persistent disparities within nations. It underscores that the future of human development in the era of Artificial Intelligence (AI) will depend not only on the technology's capabilities but also on the choices societies make to align AI deployment with human agency and inclusivity (United Nations Development Programme, 2025).

AI is identified as both a challenge and an opportunity. Survey data show that 70% of respondents in low- and middle-HDI countries believe AI could increase productivity, with two-thirds expecting to use AI tools within the next year in education, health, and work. The report calls for building economies where humans and AI collaborate, embedding human agency throughout AI's lifecycle, and modernizing education and healthcare to meet 21st-century demands (Table 1) (SweDev, 2025; United Nations Development Programme, 2025).

Table 1: Renewable resources, including solar, wind, hydro, and biomass energy, play a central role in reducing carbon emissions and promoting sustainability

Theme	2025 Highlights
HDR 2025 Publication Date	Launched on 6 May 2025, focusing on AI and human agency.
HDI Progress	Slowest growth rate since 1990.
AI Potential	70% in low/middle HDI countries see AI as a productivity booster
Strategic Recommendations	Human–AI collaboration; human agency in AI lifecycle; modernized education/health.
Inequality Trends	Widening gap between high and low HDI countries.
Country Case Study	India rose three ranks to 130th in HDI, emerging as an AI skills hub.

3.1.4. Human Development and Human Rights Human Development and Human Rights are Closely Interconnected Concepts That Reinforce One another:

1. **Human development:** It is centered on expanding people's freedoms, opportunities, and capabilities so they can live healthy, educated, and fulfilling lives. It is measured not only by economic growth but also by improvements in health, education, and overall quality of life (UNDP, 2024a).
2. **Human rights:** Are the fundamental freedoms and entitlements inherent to all human beings, regardless of race, gender, or background. They provide the legal and moral framework that ensures dignity, equality, and justice for every person (UNDP, 1948).

The two are complementary: without the protection of human rights, human development cannot be inclusive or sustainable, and without progress in human development, many rights remain inaccessible in practice. For example, the right to education and healthcare directly supports human development, while policies that improve well-being strengthen the realization of rights. Together, they provide a holistic vision for building fairer, freer, and more equitable societies (UNDP, 2024a; UNDP, 2024b).

3.2. Epigenetics: Foundations, Molecular Mechanisms, Clinical Applications, and 2025 Innovations

Epigenetics refers to heritable changes in gene expression that occur without modifying the underlying DNA sequence, mediated by mechanisms such as DNA methylation, histone modifications, chromatin remodeling, and non-coding RNA regulation. These processes enable living organisms to dynamically regulate gene activity in response to developmental cues and environmental stimuli. Through techniques like CRISPR-based epigenome editing, CRISPRoff, and FIRE-Cas9, researchers can reversibly modulate epigenetic marks with high precision, opening the door to functional genomic studies and potential therapeutic interventions without altering DNA sequences (Egger *et al.*, 2004; Feinberg and Tycko, 2004; Feil and Fraga, 2012; Tiffon, 2018; Epigenome editing, 2025; Nature Subjects, 2025; Tahir *et al.*, 2025).

In cancer epigenetics, recent reviews emphasize how aberrant DNA methylation and histone modification patterns critically influence tumor initiation, progression, metabolism, and the tumor microenvironment—highlighting epigenetic regulation as a key therapeutic target. In a Landmark 2025 study, scientists revealed complementarity between DNA and RNA epigenetics: DNA epigenetic alterations organize gene availability, while RNA-level modifications dynamically adjust gene usage, suggesting a tightly integrated regulatory system (Figure 4) (Bekdash, 2023; Fuks *et al.,* 2025; Marei, 2025).

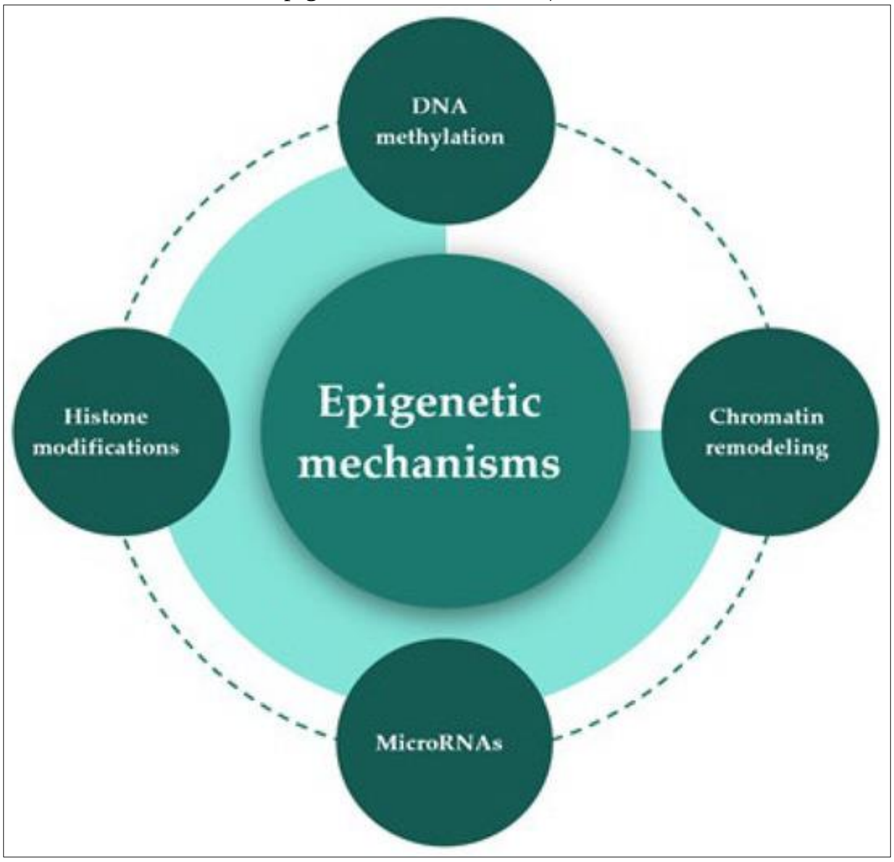

Figure 4: Epigenetic mechanisms. This is a schematic view of the epigenetic mechanisms that regulate gene expression. They are interrelated and include DNA methylation, histone modifications, chromatin remodeling, and the role of microRNAs

Source: Doi: doi.org/10.3390/ijms24032346

AI and deep learning approaches are now extensively applied to interpret complex epigenomic data. These computational models support the prediction of disease markers, chromatin state classification, enhancer–promoter interactions, and more, bridging biology and machine learning for enhanced understanding (Tahir *et al.,* 2025). Technological Innovations Include TET-assisted Pyridine Borane Sequencing (TAPS), a bisulfite-free enzymatic method enabling high-sensitivity, base-resolution detection of DNA methylation, including 5mC/5hmC with reduced DNA damage, now enhanced in 2025 with new TAPSβ adaptations (TAPS, 2025).

Multi-scale computational modeling is enhancing our understanding of chromatin epigenetic regulation. Techniques now connect molecular modifications, methylation to 3D genome folding, and cellular outcomes across timescales from milliseconds to multi-year periods. Emerging clinical diagnostics are utilizing cfDNA methylation signatures. A machine learning classifier trained on various epigenomic platforms distinguishes tissue and disease origin from minimally invasive samples with high precision, paving the way for scalable liquid biopsy diagnostics. A breakthrough AI-based classifier published in Nature Cancer accurately identifies over 170 tumor types using epigenetic data, reaching 99.1% accuracy, marking a significant milestone in non-invasive cancer diagnostics (Figure 5) (Moore *et al.,* 2013; Lee *et al.,* 2025; Mahajan *et al.,* 2025; Nature Cancer, 2025; Quarto *et al.,* 2025).

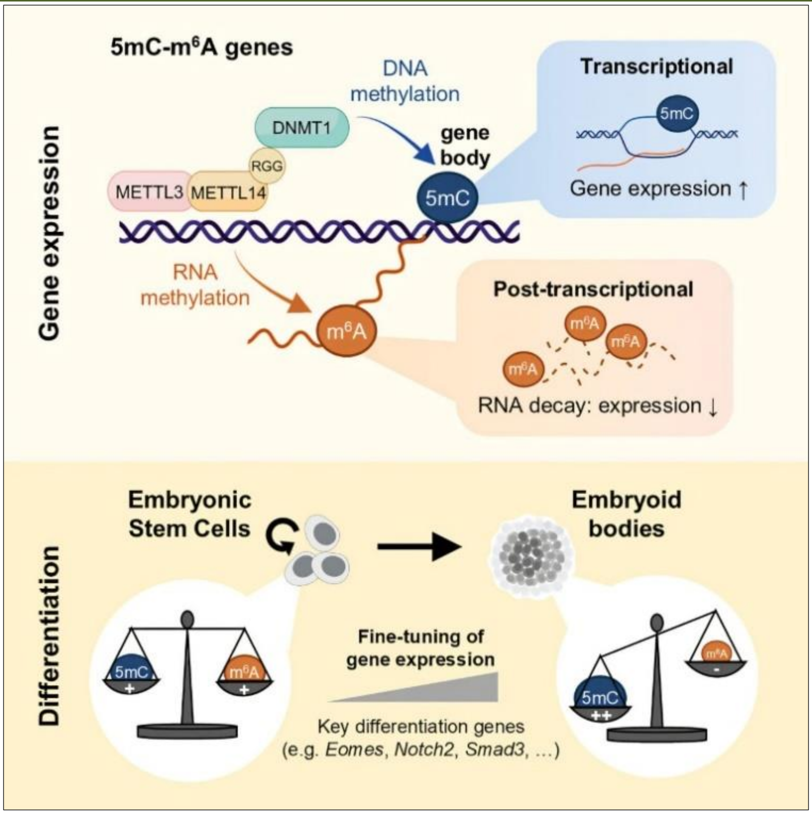

Figure 5: Gene expression is shaped not only by the genetic code but also by regulatory mechanisms that control its use. Epigenetic changes to DNA and RNA act as signals that influence gene activity without altering their sequences. Once thought to function separately, DNA and RNA epigenetics are now understood to interact as part of an integrated regulatory system

Source: Doi: 10.1016/j.cell.2024.12.009

The epigenetics market is rapidly expanding, driven by personalized medicine, AI integration, and multi-omics platforms. Forecasts show significant growth in epigenetics applications in healthcare, aging, and biotechnological sectors. Environmental epigenetics continues to evolve as a discipline. The 2025 special issue emphasizes how environmental exposures and the exposome, integrating genetic, epigenetic, and environmental data, inform precision environmental health strategies. A fresh theoretical perspective likens DNA structure to human language, demonstrating that DNA segments encode information redundantly, and linear epigenetic memory can exist independently of chromatin structure, opening new frameworks in computational epigenetics (Table 2) (Holliday, 1987; Extrapolate, 2025; Men *et al.*, 2025).

Table 2: Epigenetics mediates the interaction between environmental exposures and gene expression without altering DNA sequence. Lists major epigenetic mechanisms, methylation, histone modification, and non-coding RNAs, together with drivers such as pollutants, diet, and stress

Theme	2025 Highlights
Epigenome editing	CRISPR-based tools (CRISPRoff, FIRE-Cas9) enable reversible epigenetic modulation
Molecular cancer regulation	Detailed epigenetic drivers in tumor behavior and metabolism.
DNA–RNA epigenetic integration	Complementary DNA/RNA epigenetic systems.
AI in epigenomics	Deep learning models for chromatin, markers, and enhancer–promoter dynamics.
TAPS technology	Sensitive, enzymatic methylation sequencing.
Multiscale chromatin modeling	Computational models connecting molecular marks to structure and phenotype.
cfDNA diagnostics	ML classifiers predict tissue/disease origin from cfDNA methylation.
Tumor typing via epigenetics	AI model distinguishes 170+ tumor types with 99.1% accuracy.
Market trends	The growing epigenetics market, driven by personalization and biotechnology.
Environmental exposome	Exposome-integrated precision environmental health approaches.
Epigenetic memory, linguistic	DNA segments encode redundancy; epigenetic marks as linear memory.

Epigenetics represents a transformative field in understanding how environmental, lifestyle, and physiological factors influence gene activity without altering the underlying DNA sequence. By revealing the dynamic interplay between genetic potential and external influences, epigenetic research challenges the notion of genetic determinism and highlights the adaptability of biological systems. These insights not only deepen our comprehension of development, disease mechanisms, and aging but also open new avenues for preventive strategies, personalized medicine, and therapeutic interventions. Ultimately, the study of epigenetics underscores that our health and development are shaped by an ongoing dialogue between our genes and the environment, offering a powerful perspective for advancing human well-being (Moore *et al.*, 2013; Lee *et al.*, 2025; Mahajan *et al.*, 2025; Nature Cancer, 2025; Quarto *et al.*, 2025).

3.3. Renewable Resources

Renewable resources are natural resources that replenish within a human timescale, including solar, wind, hydro, biomass, and geothermal energy. Their sustainable use is fundamental for reducing environmental degradation, ensuring long-term energy security, and promoting economic resilience. Renewable resources form the foundation for building a more sustainable future. They include any natural resource that can be naturally replenished within human timescales or through proper management Meadows *et al.*, 1972; Panwar *et al.*, 2011; IEA, 2023).

While the term is often associated primarily with renewable energy, such as solar and wind power, renewable resources are far broader, encompassing a diverse range of elements essential to sustaining life on Earth. These resources can be naturally restored over time, provided they are managed sustainably. They differ from non-renewable resources, such as oil and coal, which exist in finite quantities and may take millions of years to regenerate if they regenerate at all. Renewable resources are found across multiple sectors, from energy generation to food production and biodiversity conservation. In essence, they are vital for ensuring economic development while preserving (Bach, 2020; Jaiswal *et al.*, 2022; Tze-Zhang *et al.*, 2022; Osman *et al.*, 2023; IRENA, 2025; Kafumu and Ojija, 2025).

3.3.1 Types of Renewable Resources

The Main Types of Renewable Resources Influence Various Aspects of Society and the Economy:

1. **Solar energy:** It is one of the most widely recognized forms of renewable resources, harnessing sunlight to generate electricity or heat. It is virtually inexhaustible, and the use of photovoltaic solar panels has expanded significantly due to declining costs and the global demand for cleaner energy sources. Installed solar capacity worldwide continues to grow, driven by investments in technology and innovation.
2. **Wind energy:** Energy captures the power of moving air to spin turbines and produce electricity. Like solar power, it is a clean and inexhaustible alternative to fossil fuels. Onshore and offshore wind farms are rapidly expanding across the globe, with wind energy representing an increasingly important share of the global energy mix (Boyle, 2012; REN21, 2021; IEA, 2023; IRENA, 2025).
3. **Water and hydrological cycle:** It is another essential renewable resource, continuously replenished through its natural cycle. However, freshwater availability is limited and must be managed sustainably to prevent water scarcity. Efficient management practices, such as treated water reuse and harvesting rainwater, are vital for maintaining long-term access. Water is also used to produce hydroelectric power, a renewable source that converts the kinetic energy of flowing rivers into electricity. While it is a clean form of energy, large dams can have negative environmental impacts, including community displacement and habitat loss.
4. **Forests:** Forests are renewable resources that can provide timber, fibers, and other plant-based products sustainably. Proper management practices, including reforestation and selective logging, allow for resource use without causing deforestation or degradation. Additionally, forests play a critical role in climate regulation, functioning as carbon sinks that help mitigate global warming (Bach, 2020; Jaiswal *et al.*, 2022; Tze-Zhang *et al.*, 2022; Osman *et al.*, 2023; Kafumu and Ojija, 2025).
5. **Biomass:** Refers to organic materials, such as agricultural residues, wood, and forestry by-products that can be converted into energy. Burning biomass for heat or electricity is a sustainable alternative to fossil fuels when managed responsibly. Biofuels, such as ethanol and biodiesel, are other forms of energy derived from biomass.
6. **Soil:** Fertile soil is a renewable resource essential for agriculture. However, it is only truly renewable if managed properly. Practices such as crop rotation, conservation agriculture, and the use of natural fertilizers help maintain soil productivity and nutrient availability. Poor management can lead to erosion and soil degradation, threatening agricultural output.
7. **Biodiversity:** Including plants, animals, and microorganisms, is considered renewable when ecosystems are conserved and restored. Protecting natural areas and managing biodiversity sustainably are essential for maintaining ecological balance. Beyond providing food and medicine, biodiversity underpins critical ecosystem services such as

pollination and pest control (Bach, 2020; Jaiswal *et al.*, 2022; Tze-Zhang *et al.*, 2022; Osman *et al.*, 2023; Kafumu and Ojija, 2025).

The adoption of renewable resources contributes to climate change mitigation, rural development, and energy diversification. Technological innovation, supportive public policies, and global investment have accelerated their implementation. In 2025, breakthroughs in energy storage, efficiency, and smart grid integration have enhanced the reliability of renewable energy systems. Hydrogen-based storage and advanced photovoltaic materials enable a continuous and scalable supply, even in regions with variable renewable potential (Figure 6) (Jacobson and Delucchi, 2011; IEA, 2023; Taps, 2025).

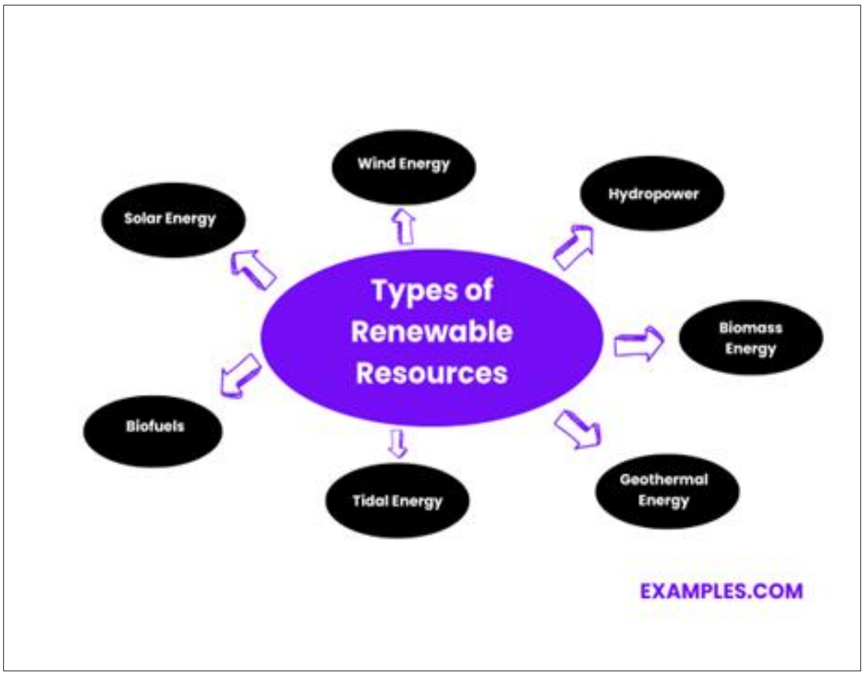

Figure 6: Different types of renewable resources provide a range of sustainable energy options, each with unique applications and benefits

Sources: ©2025 Examples.com and https://www.examples.com/physics/renewable-resources.html#google_vignette

3.3.2. Benefits of the Sustainable Use of Renewable Resources

The sustainable use of renewable resources brings a wide range of economic, environmental, and social benefits.

1. **Reduction of carbon emissions:** Renewable resources, particularly in the energy sector, are essential for reducing greenhouse gas emissions, which are directly linked to climate change. Replacing fossil fuels with solar, wind, and hydropower can help mitigate global warming.
2. **Preservation of natural resources:** Resources such as water, soil, and forests can be maintained over the long term if used responsibly. This ensures that future generations will also have access to these resources for their well-being, reflecting the importance of integrating economic development with environmental stewardship.
3. **Energy and food security:** Greater reliance on renewable resources can strengthen a country's energy security by reducing the need for fossil fuel imports. Similarly, effective management of resources such as water and soil ensures food security and helps prevent scarcity crises. The transition to a green economy, based on renewable resources, can generate millions of green jobs from solar panel installation to sustainable forest management and the application of innovative agricultural technologies (Kelman *et al.*, 2022; Sher *et al.*, 2024; Delgado-Baquerizo *et al.*, 2025).

3.3.3. Importance of Renewable Resources

Renewable resources are essential for ensuring planetary sustainability because they naturally regenerate, allowing continuous use without depleting available reserves. They play a key role in reducing greenhouse gas emissions, a fundamental step in combating climate change, while also promoting energy and food security. Furthermore, the sustainable use of resources such as solar energy, water, and biomass helps preserve ecosystems, drives green economic growth, creates jobs, and fosters technological innovation (Figure 7) (Kelman *et al.*, 2022; Sher *et al.*, 2024; Delgado-Baquerizo *et al.*, 2025).

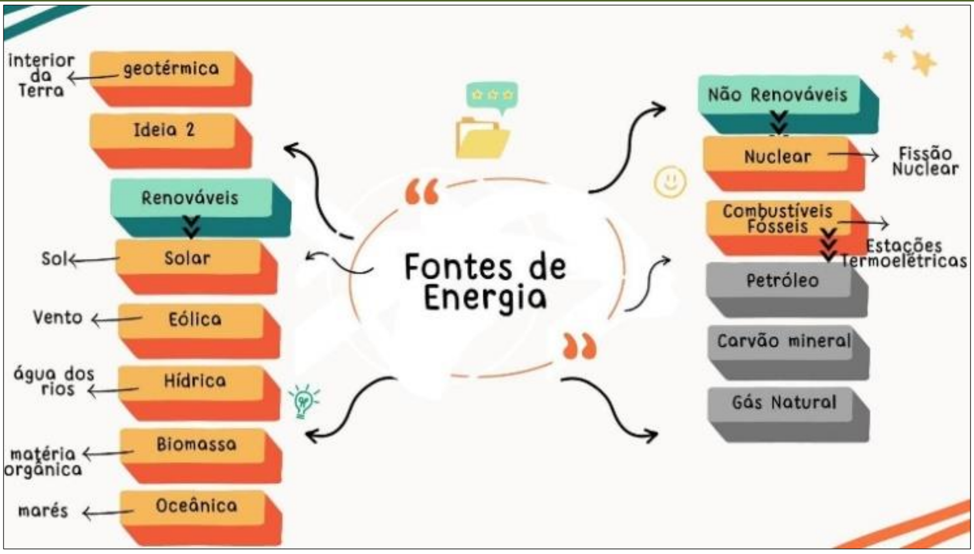

Figure 7: Renewable and non-renewable energy sources
Sources: FDPLEARN and https://fdp.aau.edu.et/ipa/mapa-mental-energias-renovaveis.html

3.3.4. Challenges in the use of Renewable Resources
While renewable resources provide numerous benefits, their use presents certain challenges:

1. **Intermittency**: Some renewable energy sources, such as solar and wind, are intermittent, meaning their production depends on climatic conditions. Implementing energy storage systems can help address this issue.
2. **Initial costs**: In some cases, the initial installation costs of renewable technologies such as solar panels and wind turbines are still high. However, low operating costs can offset these expenses over the long term.
3. **Local environmental impacts**: Improper use of certain renewable resources, such as the construction of large dams for hydropower, can cause significant environmental impacts, including biodiversity loss and the displacement of communities (Kelman *et al.,* 2022; Sher *et al.,* 2024; Delgado-Baquerizo *et al.,* 2025).

3.3.5. Why renewable resources are essential for our future

1. **Climate change mitigation:** One of the greatest challenges facing humanity is climate change, largely driven by the burning of fossil fuels such as oil, coal, and natural gas. Transitioning to renewable energy sources, including solar and wind power, can significantly reduce greenhouse gas emissions and slow global warming.
2. **Conservation of natural resources:** Non-renewable resources, such as oil and gas, are finite and depleting rapidly. The adoption of renewable resources reduces pressure on these scarce and valuable resources, enabling a more sustainable approach to managing the planet's natural wealth.
3. **Diversification of the energy mix:** Excessive dependence on a single energy source, such as oil, can make an economy vulnerable to market price fluctuations and supply disruptions. Integrating renewable resources into the energy mix diversifies energy sources and reduces this vulnerability.
4. **Job Creation and economic development:** The shift toward renewable energy creates significant economic opportunities. Investment in the renewable energy sector generates jobs in manufacturing, installation, maintenance, and operation of renewable energy systems. It also fosters technological innovation and strengthens global market competitiveness.
5. **Reduction of greenhouse gas emissions:** Generating electricity from renewable sources, such as solar and wind, produces minimal or zero greenhouse gas emissions, helping to mitigate climate change and reduce atmospheric Carbon Dioxide (CO_2) levels (Kelman *et al.,* 2022; Tze-Zhang *et al.*, 2022; Sher *et al.,* 2024; Delgado-Baquerizo *et al.,* 2025).
6. **Improved air quality:** Burning fossil fuels for energy and transportation releases harmful air pollutants, including fine particulate matter and nitrogen oxides. Renewable energy use reduces these emissions, improving air quality and public health.
7. **Biodiversity conservation:** Fossil fuel extraction and large hydropower dams can negatively affect ecosystems and biodiversity. In contrast, many renewable energy sources, such as solar and wind, have relatively low environmental impacts when properly implemented.
8. **Access to energy in remote areas:** Renewable energy technologies, such as solar panels and small wind turbines, can be deployed in remote regions

without access to traditional power grids. This improves the quality of life in rural communities and helps bridge the energy access gap.

9. **Energy price stability:** Unlike fossil fuels, whose prices are volatile and susceptible to geopolitical crises Rene renewable energy sources generally have low and stable operating and maintenance costs, contributing to long-term price stability (Kelman *et al.,* 2022; Sher *et al.,* 2024; UNEP, 2024; Delgado-Baquerizo *et al.,* 2025).

3.3.6. Challenges and Barriers

1. **Intermittency and storage:** Some renewable energy sources, like solar and wind, are intermittent and weather-dependent. To overcome this limitation, effective and scalable energy storage technologies must be developed and deployed.
2. **Infrastructure and initial costs:** Transitioning to renewable energy requires substantial investments in infrastructure, including solar farms and wind parks. Although costs have decreased significantly in recent years, initial expenses remain a barrier for some countries and communities.
3. **Resistance from the fossil fuel industry:** The fossil fuel industry has a strong vested interest in maintaining its market dominance, which can lead to political opposition and lobbying efforts aimed at slowing the transition to renewable resources (Kelman *et al.,* 2022; Tze-Zhang *et al*., 2022; Sher *et al.,* 2024; Delgado-Baquerizo *et al.,* 2025).

Renewable resources go far beyond energy generation and play a vital role across multiple sectors, from agriculture to ecosystem conservation. The adoption of sustainable practices in the use of water, forests, soils, and biodiversity alongside the transition to renewable energy is essential to ensuring planetary sustainability and the well-being of future generations. In conclusion, despite the challenges, the responsible management of these resources can deliver significant environmental and economic benefits while helping to combat climate change and protect the environment (Sher *et al.,* 2024; Delgado-Baquerizo *et al.,* 2025).

3.4. Differences between Human Development, Epigenetics, and Renewable Resources

To better understand the scope and unique characteristics of each subject, it is useful to compare their main features side by side. The following table outlines the key differences between human development, epigenetics, and renewable resources, detailing their definitions, objectives, areas of application, and contributions to sustainability. This comparative approach not only clarifies how each concept operates independently but also sets the stage for identifying its points of convergence. Understanding these intersections is essential, as human development depends on both the sustainable use of renewable resources and the health outcomes influenced by epigenetic processes together (Table 3) (World Commission on Environment and Development, 1987; FAO, 2017; National Geographic Society, 2023).

Table 3: Renewable energy adoption in relation to human development indicators, including the Human Development Index (HDI), education, health, and inequality. It illustrates how energy transitions reshape social and economic conditions, ultimately influencing population well-being

Aspect	Human Development	Epigenetics	Renewable Resources
Definition	Process of expanding freedoms and capabilities to improve the quality of life.	Study of heritable changes in gene expression without altering the DNA sequence.	Resources are naturally replenished within human timescales.
Importance	Promotes well-being, equity, and sustainable progress.	Key to understanding diseases and developing targeted therapies.	Reduces environmental impact and ensures long-term energy security.
Advances 2025	Inclusion of digital inclusion and climate resilience in HDI/MPI.	CRISPR-based tools for targeted epigenome editing.	Hydrogen storage and next-gen solar technologies.

The interconnected cycle between renewable resources, epigenetic mechanisms, and human development. Sustainable management of natural resources influences environmental conditions that can modify gene expression without altering DNA, shaping health, cognitive abilities, and overall well-being. In turn, human development and societal choices directly impact how resources are used and preserved, creating a feedback loop that affects both environmental sustainability and future generations (World Commission on Environment and Development, 1987; FAO, 2017; National Geographic Society, 2023).

3.5. Interrelationship between Human Development, Epigenetics, and Renewable Resources

1. **Human development and epigenetics:** Human development encompasses health, education, and living standards, all of which are influenced by biological and environmental factors. Epigenetics explains how environmental exposure, such as nutrition, pollution, and stress, can modify gene expression without altering DNA sequences. These changes can directly affect life expectancy, cognitive capacity, and disease susceptibility, thereby influencing human development indicators.

2. **Renewable resources and human development:** Access to sustainably managed renewable resources supports essential components of human development, including clean energy, water, food security, and ecosystem services. Renewable resources contribute to higher Human Development Index (HDI) scores by promoting economic opportunities, environmental quality, and improved public health.
3. **Epigenetics and renewable resources:** Sustainable use of renewable resources helps protect environmental quality, thereby reducing human exposure to pollutants and toxins that can trigger harmful epigenetic modifications. Clean energy adoption, for example, can decrease air pollution-related epigenetic changes linked to respiratory and cardiovascular diseases.
4. **Central connection:** Together, these three dimensions form an integrated framework: renewable resources preserve environmental health, which reduces negative epigenetic impacts, ultimately fostering conditions that enhance human development (Table 4) (Figure 8) (Bird, 2007.).

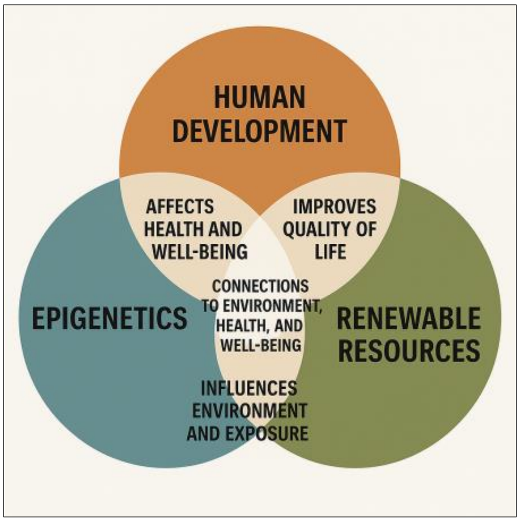

Figure 8: The interconnected relationship between human development, epigenetics, and renewable resources. Human development relies on health, education, and environmental quality, which are influenced by epigenetic mechanisms shaped by environmental factors. Sustainable use of renewable resources helps maintain ecological balance, reducing harmful exposures and fostering conditions that enhance well-being and long-term societal progress

Source: United Nations Development Programme (UNDP)

Table 4: Emerging studies reveal that exposure to pollutants and unsustainable resource use can induce epigenetic changes with downstream effects on cognitive development, disease susceptibility, and life expectancy

Environmental Stressor	Epigenetic Modification	Cognitive/Health Outcome
Air pollution (PM2.5, heavy metals)	DNA methylation changes in neural development genes	Cognitive deficits, increased risk of neurodevelopmental disorders
Pesticide exposure	Histone acetylation alterations	Immune dysfunction, higher cancer risk
Nutrient deficiency (e.g., folate, vitamin D)	Altered DNA methylation and RNA regulation	Impaired learning, shorter life expectancy
Urban stress and noise	miRNA dysregulation in stress-response pathways	Anxiety, sleep disturbances, reduced resilience

The integration of renewable resources, epigenetics, and human development highlights how sustainability, biological adaptation, and social progress are interconnected. Renewable resources ensure ecological balance and economic stability, epigenetic mechanisms regulate how environmental factors shape human health and development, and human development provides the framework of equity and well-being that sustains societies. Together, these themes reinforce the importance of adopting responsible management practices that protect nature, enhance human potential, and foster a more sustainable and inclusive future (World Commission on Environment and Development, 1987; FAO, 2017; National Geographic Society, 2023).

3.6. Sustainability

Sustainability refers to the capacity to meet present needs without compromising the ability of future generations to meet their own. It integrates environmental, social, and economic dimensions, aiming to maintain ecological balance, protect natural resources, and promote long-term human well-being. In practice, sustainability involves adopting strategies and technologies that minimize environmental impact, reduce waste, and ensure responsible use of renewable and non-renewable resources (Figure 9) (World Commission on Environment and Development, 1987).

Figure 9: Represents the conceptual connection between sustainability and management. Sustainability involves meeting present needs without compromising the ability of future generations to meet their own, while management refers to the planning, organizing, monitoring, and controlling of resources to ensure their efficient and responsible use. Together, these concepts provide a framework for maintaining ecological balance, supporting economic stability, and promoting social well-being

Source: FAO (2017)

3.7. Management in the Context of Natural Resources

Management refers to the process of planning, organizing, monitoring, and controlling the use of resources to achieve specific objectives efficiently and responsibly. In the context of natural resources, management encompasses the strategies and practices used to ensure that resources such as water, forests, soil, biodiversity, and energy are used in a way that maintains their availability, quality, and ecological functions over time. This includes sustainable harvesting, conservation measures, restoration initiatives, and policy development to balance human needs with environmental protection (FAO, 2017).

3.8. Conservation VS Preservation

1. **Conservation:** Conservation is the responsible management and sustainable use of natural resources, such as water, soil, forests, and biodiversity, ensuring their long-term availability for both present and future generations. It accepts human use of nature but seeks to balance this use with practices that maintain ecological integrity. Examples include reforestation, selective logging, and sustainable agriculture (World Commission on Environment and Development, 1987).
2. **Preservation:** Preservation emphasizes protecting nature in its original state, with minimal or no human interference. The goal is to maintain ecosystems, landscapes, or species in their pristine condition. National parks and natural reserves often adopt preservationist principles, limiting activities such as logging, hunting, or construction to safeguard biodiversity and natural heritage (Table 5) (Figure 10) (World Commission on Environment and Development,1987; FAO, 2017; National Geographic Society, 2023).

Table 5: Emerging studies reveal that exposure to pollutants and unsustainable resource use can induce epigenetic modifications, with downstream effects on cognitive development, disease susceptibility, and life expectancy

Policy Strategy	Integration with Epigenetics	Expected Developmental Impact
Renewable energy adoption	Reduces pollutant-related epigenetic disruptions	Improved population health, longer life expectancy
Clean technology investment	Minimizes industrial toxins affecting gene regulation	Lower incidence of chronic diseases
Health–environment monitoring programs	Tracks biomarkers of epigenetic change	Early prevention of cognitive decline and disease

Figure 10: Conservation refers to the sustainable use and responsible management of natural resources, ensuring that ecosystems remain productive for current and future generations. Preservation, on the other hand, emphasizes protecting nature in its original state, minimizing human interference to maintain ecosystems intact
Source: National Geographic Society (2023)

3.8.1 Key Difference

A. **Conservation**: Use with responsibility (sustainable exploitation + protection).
B. **Preservation**: Non-use, protection from interference (keeping ecosystems intact) (World Commission on Environment and Development,1987; FAO, 2017; National Geographic Society, 2023).

3.9. Renewable Resources and Climate Change

1. Role of renewable resources in mitigating climate change: Renewable resources, such as solar, wind, biomass, hydro, and geothermal energy, play a crucial role in reducing greenhouse gas emissions. Unlike fossil fuels (coal, oil, and natural gas), renewables produce little to no carbon dioxide (CO_2) during energy generation. By replacing fossil-based energy with renewable energy, societies can significantly lower their carbon footprint and slow down global warming.
2. Energy transition and sustainability: The transition to renewable resources supports sustainable development by reducing dependency on finite, polluting fuels. Solar panels, wind turbines, and hydroelectric systems enable clean and consistent energy production. However, challenges such as intermittency (e.g., no sun at night, variable wind) require complementary technologies, such as energy storage systems and smart grids (Intergovernmental Panel on Climate Change, 2011; Devadasa and Laxminarayana, 2023; Osman *et al.*, 2023; Shang, 2024; Shrestha *et al.*, 2024; United Nations, 2025).
3. Impacts beyond energy: Renewable resources are not limited to electricity generation.

They Also Influence Agriculture, Forestry, and Water Management, All of Which Are Deeply Linked to Climate Resilience. For Example:

A. Forests, when managed sustainably, act as carbon sinks, absorbing CO_2.
B. Soil conservation practices improve fertility and reduce erosion caused by climate extremes.
C. Water cycle regulation through sustainable hydropower and rainwater management supports ecosystems in adapting to changing climates.

4. Benefits for Climate and Society

A. **Carbon reduction:** Mitigates global warming.
B. **Air quality:** Reduces pollutants from fossil fuels, improving health.
C. **Energy security:** Diversifies energy sources and reduces vulnerability to oil price fluctuations.
D. **Economic development:** Creates green jobs in renewable energy industries.

5. The relationship between renewable resources and climate change (Figure 11) (Intergovernmental Panel on Climate Change, 2011; Devadasa and Laxminarayana, 2023; Osman *et al.*, 2023; Shang, 2024; Shrestha *et al.*, 2024; United Nations, 2025).

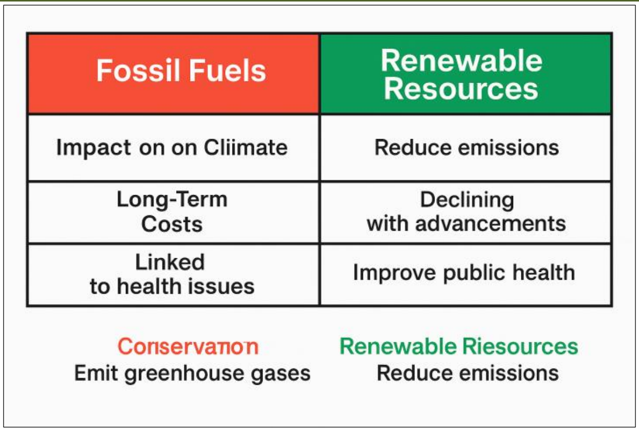

Figure 11: Relationship between renewable resources and climate change. Sustainable use of resources helps reduce greenhouse gas emissions, preserve ecosystems, and promote long-term resilience to climate change
Source: IPCC (2023)

The relationship between renewable resources and climate change is central to building sustainable societies. By replacing fossil fuels with renewable energy sources such as solar, wind, and biomass, countries can reduce greenhouse gas emissions and slow global warming. Furthermore, the responsible management of water, forests, and biodiversity ensures ecosystem resilience, preventing further degradation and supporting climate adaptation. This integrated approach demonstrates that renewable resources are not only vital for energy security but also for maintaining ecological balance and safeguarding human well-being in the face of climate change (IPCC, 2023).

Renewable resources are crucial in addressing climate change, as they reduce greenhouse gas emissions, promote sustainability, and enhance global climate resilience. Their responsible management can ensure both environmental protection and long-term social well-being (IPCC, 2023).

1. Policy and Governance Dimension

The successful integration of renewable resources into global energy systems depends heavily on policy frameworks and governance mechanisms. International agreements, such as the Paris Agreement, emphasize the urgent need to expand renewable energy deployment while ensuring equity between developed and developing nations. National policies that incentivize investments in solar, wind, and bioenergy, combined with subsidies for energy storage and grid modernization, play a critical role in accelerating the transition (United Nations, 2022; IRENA, 2023; World Bank, 2024).

2. Co-Benefits for Public Health and Social Equity

Renewable resources also generate co-benefits that extend beyond climate mitigation. By reducing reliance on fossil fuels, they improve air quality, lowering the incidence of respiratory and cardiovascular diseases. Additionally, decentralized renewable solutions, such as solar microgrids, enhance access to energy in rural and marginalized communities, thereby supporting social equity and advancing the United Nations Sustainable Development Goals (United Nations, 2022; UNEP, 2024; World Economic Forum, 2024).

3.10. Renewable Resources as a Pathway to Climate Resilience and Human Development

Renewable resources represent a cornerstone for addressing climate change while simultaneously advancing human development. By replacing fossil fuels, they significantly reduce greenhouse gas emissions and foster climate resilience. Their sustainable management not only ensures long-term ecological balance but also secures essential elements for food, water, and energy security. Furthermore, the equitable distribution of renewable energy solutions empowers vulnerable communities, promotes social justice, and enhances public health. When aligned with global policies and human rights principles, renewable resources become a driver of inclusive growth, technological innovation, and intergenerational sustainability. Ultimately, the nexus between renewable resources, climate action, and human development is indispensable for building a more equitable, resilient, and sustainable future (Figure 12) (Padilla *et al.*, 2023; UNEP, 2024; World Economic Forum, 2024).

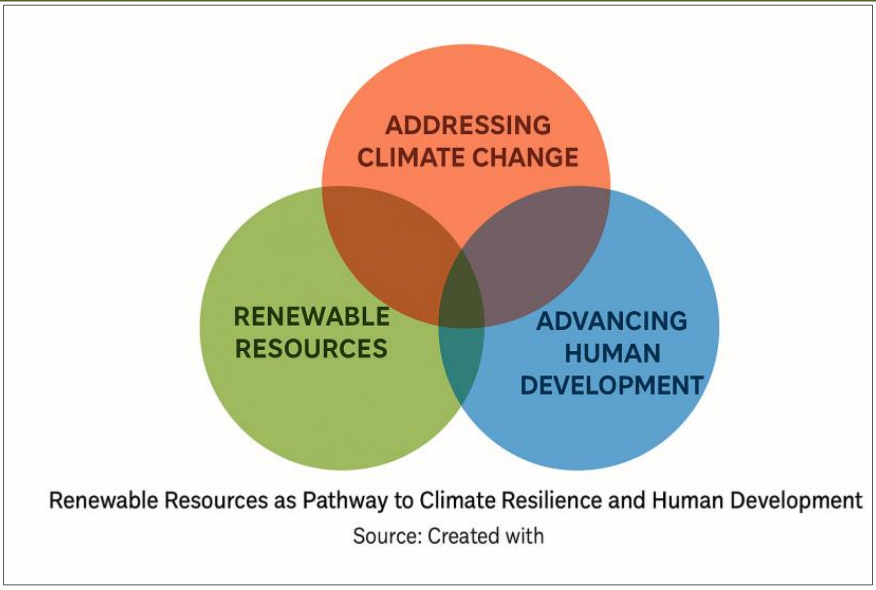

Figure 12: Connections between renewable resources, epigenetics, and human development. The three areas interact and complement each other, emphasizing their integrated role in building more sustainable and inclusive societies
Source: Marco Santan Institute

4.0. CONCLUSION

The interplay between human development, epigenetics, and renewable resources forms a multidimensional framework for advancing global sustainability. Human development provides the societal and economic goals, while epigenetics offers insight into how environmental and social conditions influence health and long-term potential. Renewable resources supply the ecological foundation necessary for sustaining life. When these dimensions are addressed collectively through equitable policies, responsible environmental stewardship, and science-based health strategies, they reinforce one another, creating conditions where social well-being, environmental resilience, and economic stability can coexist. This integrated approach is crucial for creating a future where progress is both inclusive and sustainable for generations to come.

REFERENCES

- 123 Ecos Editorial. (2025). Renewable resources: Definition, types, and importance. *123 Ecos Magazine*, *12*(3), 45–49.
- Alkire, S., & Santos, M. E. (2010). Acute multidimensional poverty: A new index for developing countries. *Journal of Human Development and Capabilities*, *11*(2), 243–276.
- Bach, E. M. (2020). Soil biodiversity supports broader ecosystem services and resilience. *Sustainability*, *12*(7), 2662.
- Bekdash, R. A. (2023). Methyl donors, epigenetic alterations, and brain health: Understanding the connection. *International Journal of Molecular Sciences*, *24*(3), 2346.
- Benhacene H. L. M., & Hussien, A. M. (2025). The impact of adopting renewable energy resources on sustainable development in Saudi Arabia: A qualitative view. *Sustainability*, *17*(2), 768.
- Bird, A. (2007). Perceptions of epigenetics. *Nature*, *447*(7143), 396–398.
- Boyle, G. (2012). Renewable energy: Power for a sustainable future. Oxford: Oxford University Press.
- Chakrabarti, S. K. (2024). Expanding role of epigenetics in human health and aging. *Environmental and Human Health and Medicine*, *29*(3), 221-235. Delgado-Baquerizo, M. *et al.* (2025). Soil biodiversity and function under global change. *PLoS Biology*, *23*(3), e3003093.
- Devadasa, K. D., & Laxminarayana, N. H. (2023). The role of renewable energy in mitigating climate change. *Journal of Visual and Performing Arts*, *4*(1), 1015–1022.
- Egger, G., Liang, G., Aparicio, A., & Jones, P. A. (2004). Epigenetics in human disease and prospects for epigenetic therapy. *Nature*, *429*(6990), 457–463.
- Epigenome editing. (2025). Wikipedia. Retrieved Mar, 18, 2025, from https://en.wikipedia.org/wiki/Epigenome_editing
- Extrapolate. (2025). Top-10 trends redefining the epigenetics market 2025. Extrapolate.com. Retrieved Aug, 5, 2025, from https://www.extrapolate.com/blog/top-10-trends-epigenetics-market-2025
- FAO. (2017). Sustainable management of natural resources for resilience and productivity. Rome: Food and Agriculture Organization of the United Nations.

- Feil, R., & Fraga, M. F. (2012). Epigenetics and the environment: Emerging patterns and implications. *Nature Reviews Genetics*, *13*(2), 97–109.
- Feinberg, A. P., & Tycko, B. (2004). The history of cancer epigenetics. *Nature Reviews Cancer*, *4*(2), 143–153.
- Fuks, F. *et al*. (2025). DNA and RNA epigenetics: Complementary regulation systems. Retrieved Mar, 15, 2025, from https://www.sciencenewstoday.org/dna-and-rna-epigenetics-work-together
- Han, S. *et al*. (2025). Harnessing technological innovation and renewable energy consumption to reduce CO_2 emissions in G-20 countries. *Scientific Reports*, *15*, 2236.
- Holliday, R. (1987). The inheritance of epigenetic defects. *Science, 238*(4824), 163–170.
- Intergovernmental Panel on Climate Change. (2011). Special report on renewable energy sources and climate change mitigation (SRREN). Cambridge: Cambridge University Press.
- Intergovernmental Panel on Climate Change. (2023). Climate change 2023: Mitigation of climate change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.
- International Energy Agency (IEA). (2023). World Energy Outlook. Retrieved Aug 15, 2025, from https://www.iea.org/reports/world-energy-outlook-2023
- International Renewable Energy Agency (IRENA). (2023). Renewable energy and jobs: Annual review 2024. Abu Dhabi: IRENA.
- International Renewable Energy Agency (IRENA). (2025). Global renewables outlook: Energy transformation. Retrieved Aug 15, 2025, from https://www.irena.org/Publications/2025/Jul/Renewable-energy-statistics-2025
- Investopedia. (2013). Human development index (HDI). Retrieved Aug, 15, 2025, from https://www.investopedia.com/terms/h/hdi.asp
  IPCC (2023). Climate Change 2023: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.
- Jacobson, M. Z., & Delucchi, M. A. (2011). Providing all global energy with wind, water, and solar power. *Energy Policy, 39*(3), 1154–1169.
- Jaiswal, K. K. *et al.* (2022). Renewable and sustainable clean energy development and its impact on social, economic, and environmental health. *Energy Nexus, 7*, 100118.
- Johns Hopkins School of Advanced International Studies (SAIS). (2025). Renewable energy vs sustainable energy: What's the difference? *Energy Policy Journal* (Online).
- Kafumu, D. W., & Ojija, F. (2025). Biodiversity and renewable energy in a warming world. *Sustainable Social Development*, *3*(1), 3228.
- Kelman, R. *et al.* (2022). Sustainable hydropower planning in Gabon: The HERA approach. *Journal of Sustainable Water and Energy*, *HERA Project*, 19.
- Klasen, S. (2016). Human development reports: A critical evaluation. *Journal of International Development*, *28*(3), 409–425.
- Lee, K.-J., Sampath, D., & Mavrommatis, K. (2025). A DNA methylation classification model predicts organ and disease site. *ArXiv, 1*, 2506.00146v1.
- Li, Y., Zhang, X., & Chen, H. (2025). Precision epigenome editing: Therapeutic potential and challenges. *Trends in Genetics*, *41*(4), 299–312.
- Lucidarium. (2025). The concept of human development: origin, definition, and meaning. Retrieved Feb, 15, 2025, from https://lucidarium.com.br/conceito-de-desenvolvimento-humano-origem-definicao-e-significado/
- Mahajan, A., Navarro, E. J., Poole, W., & Lopez, C. F. (2025). Multiscale modeling: Chromatin and epigenetics. *ArXiv, 1*, 2504.03876v1.
- Marei, H. E. (2025). Epigenetic regulators in cancer therapy and progression. *NPJ Precision Oncolog, 9*, 206.
- Meadows, D. H., Meadows, D. L., Randers, J., & Behrens III, W. W. (1972). The limits to growth. New York: Universe Books.
- Men, J. *et al.* (2025). Neurodegenerative diseases: Epigenetic regulatory mechanisms and therapeutic potential. *Cell Signal*, *131*, 111715.
- Moore, L. D., Le, T., & Fan, G. (2013). DNA methylation and its basic function. *Neuropsychopharmacology*, *38*(1), 23–38.
- Morse, S. (2023). Quality of life, well-being, and the Human Development Index: A media narrative for the developed world? *Social Indicators Research, 170*(3), 1035–1058.
- National Geographic Society. (2023). Conservation and preservation: Approaches to protecting nature. National Geographic. Retrieved Aug, 20, 2025, from https://education.nationalgeographic.org/resource/conservation/
- National Institute of Environmental Health Sciences (NIEHS). (2025). Strategic plan 2025-2029. Retrieved Aug, 18, 2025, from https://www.niehs.nih.gov/about/strategicplan
- Nature Cancer. (2025). An AI model uses epigenetics to identify 170+ tumor types. *Nature Cancer, 2025*, 1-12.

- Nature Subjects: Epigenetics. (2025). Retrieved Aug, 15, 2025, from https://www.nature.com/subjects/epigenetics/nature
- Nussbaum, M. C. (2011). Creating capabilities: The human development approach. Harvard University Press.
  Plutus Education. (2024). Importance of Human Development Index. Retrieved from https://plutuseducation.com/human-development-index
  Osman, A. I. *et al.* (2023). Cost, environmental impact, and resilience of renewable energy under a changing climate: a review. *Environmental Science and Pollution Research, 21*, 741–764.
- Padilla, M. F. C., Melanie K., & Smith, M. K. (2023). Technology acceptance and readiness among different generations of urban tourists. *Marketing & Management, 1*, 37-48.
- Panwar, N. L., Kaushik, S. C., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: A review. *Renewable and Sustainable Energy Reviews*, *15*(3), 1513–1524.
- Ren21. (2021). Renewables 2021 global status report. REN21 Secretariat. Retrieved Aug, 15, 2025, from https://www.ren21.net/gsr-2021/
- Quarto, G. *et al*. (2025). Fine-tuning of gene expression through the Mettl3-Mettl14-Dnmt1 axis controls ESC differentiation. *Cell*, *188*(4), 998-1018.e26.
- Sen, A. (1999). Development as freedom. New York: United Nations Development.
- Shang, Y. (2024). Impacts of renewable energy on climate risk: A global analysis. *Energy Research & Social Science*, *362*,122994.
- Sher, A. *et al.* (2024). Importance of regenerative agriculture: climate, soil health, biodiversity, and its socioecological impact. *Discover* Sustainability, *5*, 462.
- Shrestha, P. *et al.* (2024). The co-benefits of renewable energy on cardiovascular health. *Environmental Health Perspectives*, *48*, 101098.
- Skinner, M. K. (2025). Environmental epigenetics 2025 update. *Environmental Epigenetics*, *11*(1), dvaf004.
- Stanford Encyclopedia of Philosophy. (2011). The Capability approach. Retrieved Aug, 18, from https://plato.stanford.edu/entries/capability-approach/
- Swedish Development Research Network. (SweDev). (2025). Leadership transition and strategic focus at Swedev's June 2025 Steering Committee Meeting. Retrieved Aug, 18, 2025, from https://swedev.dev/leadership-transition-and-strategic-focus-at-swedevs-june-2025-steering-committee-meeting/
- Tahir, M., Norouzi, M., Khan, S. S., Davie, J. R., Yamanaka, S., & Ashraf, A. (2025). Artificial intelligence and deep learning algorithms for epigenetic sequence analysis. *Computers in Biology and Medicine, 183*,109302.
- Taps. (2025). TET-assisted pyridine borane sequencing for DNA methylation profiling. Wikipedia. Retrieved Jul, 20, 2025, from https://en.wikipedia.org/wiki/TET-assisted_pyridine_borane_sequencing
- Tiffon, C. (2018). The impact of nutrition and environmental epigenetics on human health and disease. *International Journal of Molecular Sciences*, *19*(11), 3425.
- Tze-Zhang, A. *et al*. (2022). Comprehensive study of renewable energy sources: Classifications, challenges, and suggestions. *Energy Strategy Reviews, 43*, 100939.
- United Nations Development Programme (UNDP). (1990). Human development report 1997: Human development to eradicate poverty. Oxford: Oxford University Press.
- United Nations Development Programme (UNDP). (1997). Human Development Report 1997: Human development to eradicate poverty. New York: University Press.
- United Nations Development Programme (UNDP). (2019). Human development and the SDGs. Human development report. Oxford: Oxford University Press.
- United Nations Development Programme (UNDP). (2023). Global Multidimensional Poverty Index (MPI): Unstacking global poverty: Data for high-impact action. Oxford: Oxford University Press.
- United Nations Development Programme (UNDP). (2024a). Human Development Report 2023-24. Breaking the gridlock: Reimagining cooperation in a polarized world. New York: UNDP.
- United Nations Development Programme (UNDP). (2024b). Global Multidimensional Poverty Index (MPI): Poverty. Oxford: University Press.
- United Nations Development Programme (UNDP). (2025). Global Multidimensional Poverty Index (MPI): Poverty. Oxford: University Press.
- United Nations Development Programme. (2025). Human Development Index (HDI). Retrieved Aug, 17, 2025, from https://hdr.undp.org/data-center/human-development-index#/indicies/HDI
- United Nations Environment Programme (UNEP). (2024). Critical transitions: Circularity, equity, and responsibility in the quest for energy transition minerals. Nairobi: UNEP.
- United Nations. (1948). Universal declaration of human rights. United Nations. Retrieved Aug, 16, 2025, from https://www.un.org/en/about-us/universal-declaration-of-human-rights
- United Nations. (2022). Renewable energy and climate action: Accelerating a sustainable future. New York: United Nations Publications.

- United Nations. (2025). Renewable energy: Powering a safer future. New York: Nações Unidas.
- WHO. (2025). Global report on epigenetics in health. World Health Organization. Retrieved Aug, 15, 2025, from https://www.who.int/publications/b/78420
- World Bank. (2024). Energy transition and climate resilience: Strategies for sustainable development. Washington: World Bank Group.
- World Commission on Environment and Development. (1987). Our common future. Oxford: Oxford University Press.
- World Economic Forum. (2024). How renewable energy serves as a catalyst for broader social change. Davos: Solutions, Insights, Laboratory Solutions, Journalism Network.
- Wu, Y. L. *et al.* (2023). Epigenetic regulation in metabolic diseases: Mechanisms and clinical applications. *Signal Transduction and Targeted Therapy, 8*(1), 98.
- Xu, R. *et al.* (2025). Epigenetic regulation in early embryo development: from zygotic genome activation to the first lineage specification. *Trends in Genetics, S0168-9525(25)*, 00112-X.