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Sustainable Innovation: The Critical Pairing of Human Ingenuity and Ethics

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ABSTRACT:
This paper examines the nature of innovation and its role in addressing the sustainability crisis. It provides a broad narrative, examining the technological, social, and ethical dimensions, as well as the historical unfolding of the crisis, the nature of progress, and the dualistic nature of technology, which can reduce or exacerbate environmental impacts according to how it is used. It proposes a definition of sustainable innovation as *I3V*, where *I* is invention and *V* is value within the three pillars of sustainable development. The paper examines potential pathways for innovation within each pillar, drawing on classical philosophical works like the *Divine Comedy* to underscore the critical role of ethics, cultural values, and systemic change in guiding humanity toward sustainability.

Keywords: sustainability, innovation, systemic change, progress, responsible technology, biomimicry, planetary boundaries, social transformation, moral renewal, Dante, ethics.

1. Introduction

Since the 1960s, scientists, philosophers, and environmental thinkers have warned that humanity's trajectory of accelerating resource consumption and environmental disruption is fundamentally unsustainable (e.g. Ripple et al., 2017). This is largely due to industrialization, a materialistic model of prosperity, a tendency to overconsume, the pursuit of economic growth, emerging third-world economies, and rapidly growing population size (Meadows et al., 1972; Dorst, 1971).

Ecosystems are being depleted through resource extraction, urban spread, grazing expansion, forest clearing, highway construction, mining, and war (Maggi, 2020; UN NEWS, 2025). Self-reinforcing feedback loops—such as global warming and the buildup of toxic e-waste and non-biodegradable plastics—are accelerating the decline through increasing wildfires (MacCarthy, 2024) and poisoning organic life (Carson, 1962/2020; Bakhiyi, 2018).

According to the United Nations Environment Programme (UNEP), 'the overall environmental situation globally is deteriorating and the window for action is closing' (UNEP, 2019). A large array of ecological indicators—including biodiversity, species counts, water purity, forest area, and coral populations—are in serious decline (Ceballos et al., 2015; LPI, 2025; Eddy, 2021). Further deterioration is expected to trigger ecological tipping points and cause irreversible damage to ecosystems (Bradshaw et al., 2021; Franklin, 2018).

In addition to environmental concerns, international conflicts, declining work ethics, deteriorating educational standards, declining job prospects, and political corruption pose significant threats to the sustainability of global systems, while ongoing conflicts in the

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Middle East and international trade disputes threaten the availability of critical resources such as fossil fuels and rare-earth metals, further contributing to economic instability.

These factors collectively represent a sustainability crisis. This can be viewed as an evolutionary test in which humans need to develop greater situational awareness, restrain overconsumption and destructive behaviours, and adopt sustainable alternatives, to ensure survival (Dansereau, 1970; Cardinale et al., 2012; Helfrich, 1970). The historical case of Easter Island warns that unchecked human impacts upon the environment can ultimately result in ecological and social collapse (Nagarajan, 2006). Sustainability therefore requires the optimisation of human activities and civilizational spread that allows for balanced and systemic human flourishing within planetary boundaries (Brundtland, 1987).

Each year ecosystems regenerate by reproducing and growing flora and fauna populations. The total human impact—the product of population and per-capita impact (PCI)—must be kept below this regenerative capacity to ensure sustainability. This principle is enshrined in the UN World Charter for Nature, Item 10a: 'Living resources shall not be utilized in excess of their natural capacity for regeneration' (UN, 1982).

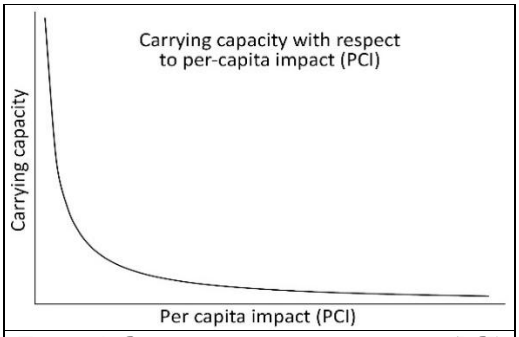

Figure 1. *Carrying capacity vs per-capita impact (PCI).*

Figure 1 illustrates the relationship between carrying capacity—when total impact equals the planet's regenerative capacity—and PCI; the planet can support more humans when our PCI is less, and fewer when it is greater. Using the decline in forest area (FAO, 2020) as a proxy for broader resource depletion, estimates suggest that our current total impact is between two and three times the planet's sustainable capacity (Whitmore, 2024a). The UN Sustainable Development Goals (SDGs) seek to reduce human impacts as part of a comprehensive sustainability plan (UN, 2015). This paper explores the role of innovation in achieving these goals.

While innovation has historically enabled many improvements in human life (Aerni, 2025), it has also contributed to the crisis by facilitating the development of machines, weapons, and strategies that have increased human impacts (Coad, 2020; Aldrich, 1972; Feurer, 2025). The following sections examine the origins of the crisis and how innovation can be aligned with sustainability goals by rethinking our ideals of progress and by integrating ethical values into education and governance.

2. A historical analysis of the sustainability crisis

The following historical overview illustrates that the sustainability crisis is not an isolated event of the past few decades but part of a broader pattern in human development. Throughout history, we have often struggled with tendencies toward excess and conflict. Addressing this requires a more balanced and responsible way of living—one centered on peaceful coexistence, cooperation, and low-impact cultures. According to George Santayana, 'those who cannot remember the past are condemned to repeat it' (Santayana, 1905).

Figure 2 shows the main long-term periods in human history and lists the innovations and societal changes that contributed to the sustainability crisis alongside global population growth (Chew, 2003; Ritchie et al., 2025). Archaeological evidence shows that during the Palaeolithic age human beings lived in relatively small hunter-gatherer groups of no more than 50 persons of an extended family structure (Kelly, 2013). Survival was based on knowledge of plants, animals, weather patterns, and the passage of time. These groups moved frequently in search of food, shelter, and water, allowing ecosystems time to regenerate.

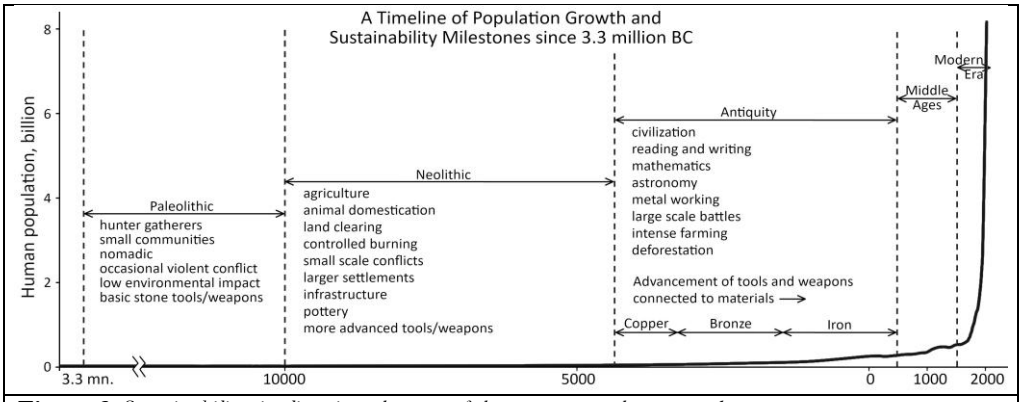

Figure 2. *Sustainability timeline since the start of the stone age to the present day.*

Animism and shamanic practices fostered a close relationship with the environment and other forms of life. Trees were considered as social beings and permission was often sought from tree spirits before felling them for wood (Ugalde, 2024). Respect for nature and natural processes was crucial for survival, and ecosystems like air and water were viewed as sacred. Elders were valued for their knowledge and environmental literacy, which were vital for group survival and harmony with nature.

The earliest known instances of technological innovation are from around 3 million years ago in Africa: stone tools and weapons such as spear and arrow heads, axe blades and grinding stones represented a breakthrough in utility, significantly enhancing the capacity to hunt, prepare food and construct shelter (Utsua, 2015). However, the combination of hunting strategies and advanced tools is thought to have led to overhunting and the extinction of Pleistocene megafauna.

Beginning around 10,000 BC the first signs of organised farming emerged as crops such as barley, rice, and maize were domesticated, along with the management of cattle and sheep (Watkins, 2023; Nentwig, 2007). This transition marked the first systemic anthropogenic impact on the environment, as larger areas were cleared for agriculture and grazing. More secure food sources enabled communities to grow, which led to settlement expansion; pottery vessels provided long-term storage and further food security. Shrines and temples facilitated spiritual practices, which continued to emphasize the interconnected and sacred nature of life.

From around 4,000 BC, innovation of building materials, construction techniques, irrigation, road networks, and waste management, enabled cities to form up, with some like Uruk and Memphis housing up to 50,000 people. The growing demand for resources led to increasing invasion of natural spaces. Classical literature, like *The Iliad* and *The Epic of Gilgamesh*, recount battles between rival centres competing for resources, wealth and

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dominance, the use of metal for weapons, and the emergence of wealth inequality. Records show the conceptual development of monotheistic beliefs, early legal systems like the Code of Hammurabi, and philosophical and ethical systems that emphasized moral improvement as a foundation for peace, harmony and social wellbeing (Frazer, 2009).

During the late Roman period and early Middle Ages (5th–10th centuries), Christianity promoted love, peace, brotherhood, and forgiveness as a basis for social harmony and individual salvation. Gradually replacing older pagan beliefs and practices, this established a universal moral order that reframed human agency as witnesses and stewards of the created world. Monasteries emerged as centers of learning, innovation of sustainable agriculture, medicine, and charity, with key figures like Saints Augustine, Francis, and Dominic, developing philosophical insights into life and models for social organization. However, conflicts over power, land, and wealth persisted, and while the crusades spread the core teachings of peace and brotherhood, they eventually became violent and materialistic.

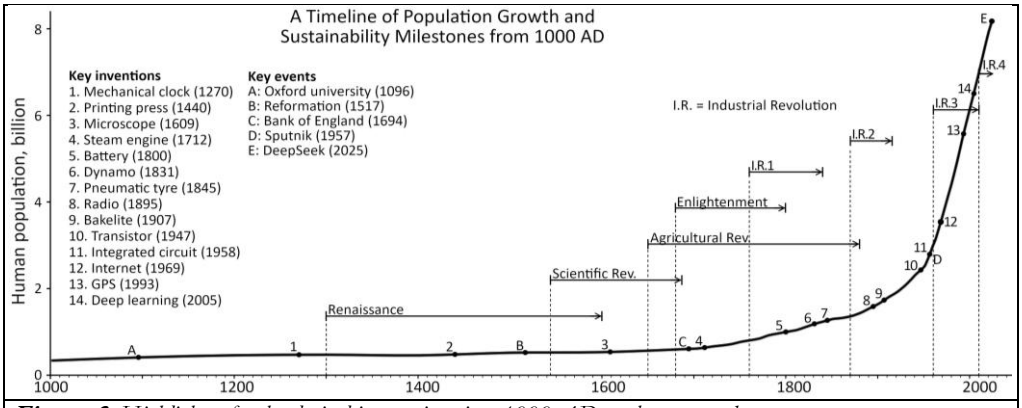

Figure 3. *Highlights of technological innovation since 1000 AD to the present day.*

Figure 3 illustrates innovation in the last millennia, focusing on Europe as the homeland of industrialization. The Renaissance (c. 1300–1600) was a period of renewed interest in classical knowledge and the principles of nature. Early humanist ideas emphasized curiosity and individual responsibility, celebrating human potential as a reflection of divine creation. Under the Catholic Church's patronage, art, literature, philosophy and science flourished, making Western Europe a hub of innovation and intellectual development (Burke, 1974). The expansion into 'resource rich' territories like Africa and the Americas fueled economic growth and seeded colonialist ideas.

The Protestant Reformation (1517) rejected Papal authority and promoted personal interpretation of the Bible, emphasizing individual conscience and reasoning over ecclesiastical teaching (MacCulloch, 2005). The large-scale theft of church property released significant financial liquidity into the economy, facilitating the emergence of a proto-capitalist class that invested in commercial ventures and early industrial innovation (Cobbett, 1824/2019; Dobb, 2021; Heldring, 2021). In Britain, the head of state became the head of the new Anglican church, setting the precedent for secular dominance of spiritual and theological matters.

The Scientific Revolution (1543–1687) introduced a systematic method of hypothesis, experiment, and empirical observation (Deason, 1985; Rubanova, 2015), that redefined the human relationship with the world. Francis Bacon argued in *Novum Organum*

that mankind should become the master of nature to improve the human condition. While innovation led to many advances, especially in instrumentation and measurement, it also catalyzed industrialization and warfare. A primary ecological consequence was the widespread decimation of European forests to construct massive naval fleets—an early conflict between technological progress and sustainability (Albion, 1926/2003).

The Enlightenment (c. 1685–1815) emphasized rationalism, scientific inquiry, freedom of choice, human rights, and reason, establishing an increasingly secular worldview. In *Wealth of Nations*, Adam Smith argued that an economy can emerge from the organic pursuit of self-interest guided by moral responsibility (Smith, 1776/2010; Beckert, 2025). Simultaneously, the Agricultural Revolution in Britain (c. 1650–1880) aimed to maximise productivity and profit (Mazoyer, 2006), and by transferring common lands to wealthy landowners, it set the precedent of integrating innovation across sectors as a strategy for the accumulation of capital.

The 1st Industrial Revolution (c. 1760–1840) harnessed innovation to create an increasingly mechanized world transforming cottage-based manual labour into factory-based mass production. The economy expanded rapidly as new markets emerged. However, industrial-scale developments—such as factories and mines—led to large-scale degradation of natural habitats and systemic pollution, and the development of more powerful weapons led to more destructive wars. The 2nd Industrial Revolution (1870–1914) brought significant advances in power generation (such as electricity) and mechanized manufacture, increasing output and making products more affordable and accessible. The rise of multinational corporations and financial markets prioritized industrial output over ecological stability.

The 3rd Industrial Revolution (c. 1960–2010) was characterized by the adoption of digital technology and computers, with the microchip enabling miniaturization of electronic devices, enabling automation in manufacturing, and the rise of information technology (IT). Plastics became widely produced and integrated into products—from packaging and consumer goods to electronics—but accumulate in the environment due to their non-biodegradable nature, damaging ecosystems and biological life.

The 4th Industrial Revolution (c. 2011–ongoing) is characterized by the fusion of digital, biological, and physical innovations, including artificial intelligence (AI), biotechnology, the Internet of Things (IoT), and advanced robotics, leading to systemic connectivity and automation. The emphasis is increasingly towards the development of systems that can collect, store, analyze and transfer data most effectively. While digital technology brings many enhancements, it faces many challenges, including the environmental impact of rare-earth mining, mounting toxic e-waste, and risks of misuse.

This historical overview highlights the resourcefulness, ingenuity, and innovation that have produced our high-tech, comfortable societies. It shows how technology has empowered human activities and supported population growth, while shifts in worldview intensified technological development leading to the 'Great Acceleration' of the 1950s and the Anthropocene epoch defined by significant human impact on the biosphere.

However, it also illustrates how innovation, when employed irresponsibly or maliciously, can result in significant harm to human society and the environment. While technological innovation has developed more advanced tools and machines to make work easier, it has simultaneously developed more advanced weapons to kill each other with. In the last 120 years alone, an estimated 200 million human beings have been killed in wars,

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ecosystems like the Amazon rainforest have been decimated by clearing for agriculture urban expansion and for wood, and marine ecosystems seriously damaged by over-fishing and trawling, and poisoned by radioactive and chemical pollution.

Philosophers have consistently argued that human actions and the quality of human society reflect the human moral condition (Whitmore, 2024b). Just as organic life thrives only within a narrow margin of environmental conditions, human society flourishes only within the parameters of ethical conduct. In this sense, Aristotle's (c. 380–322 BC) concept of eudaimonia—often translated as human flourishing—can be understood as the philosophical precursor to modern notions of sustainability.

Capital virtues	Humility	Charity	Patience	Diligence	Generosity	Moderation	Self-restraint
Capital vices	Pride	Envy	Wrath	Sloth	Greed	Gluttony	Lust

Table 1. *The capital virtues and capital vices.*

Philosophical and theological developments in Late Antiquity, especially through the writings of Evagrius Ponticus (c. 345-399) and Pope Gregory (c. 540-604), produced a list of capital vices or character vulnerabilities that drive systematic dysfunction, and a list of capital virtues through which humans can seek redemption (see Table 1). Therefore, while 'the global destruction of the ecosystems and natural environment are directly or indirectly linked to unprecedented chronic human greed and self-indulgence' (Khrushch, 2021), the crisis is compounded by factors like sloth which resists positive change and pride that refuses to accept accountability.

Early humanist ideals, developed primarily by Petrarch (1304-1374) and Erasmus (1466-1536), advocated for individual responsibility as a prerequisite for spiritual and social growth. Moral duty was not merely about avoiding vice, but about the active cultivation of virtue through education and self-reflection. Innovation, framed within this context was seen as a way of exploring the created world, developing human potential, and enhancing the quality of life as a celebration of the divine plan.

However, shifts in moral and spiritual authority during the Reformation and Enlightenment, particularly the emphasis on individual reason, exposed humans more directly to vices like greed and pride. This transition fostered a secularized worldview in which the principle of self-interest became predominantly materialistic. Our ideas of progress today are largely based on the acquisition of material wealth and the attainment of a luxurious lifestyle with little or no concern for the cost to the environment or to others. This is driving conflicts, exploitation and environmental decline: the moral vices that plagued mankind for millennia are now major driving forces in the modern world.

Sustainability therefore involves not just technological advancements but also social, cultural, and ethical transformations to address not only the practical issues but also the underlying moral factors resisting meaningful progress. According to Professor Rolston, 'Environmental ethics claims that we humans are not so 'enlightened' as once supposed, not until we reach a more considerate ethic' (Rolston, 2003). This suggests that the evolution of humanism should be towards humility and a holistic worldview that recognizes the interconnectedness and intrinsic value of all living beings and ecosystems, and that celebrates life in both its spiritual and material dimensions without exploiting it.

While institutions, governments and global entities like the UN might develop and implement new strategies and policies like the SDGs to align with sustainable needs, the greater progress would be when individuals adopt moral accountability and sustainable ideals voluntarily in their own lives. Innovation would then be inclined to build a different type of world, one that is more peaceful and less straining upon the environment. This represents the essence of sustainable innovation and is explored in the following sections.

3. Innovation

Innovation is a fundamental human behaviour—a natural inclination of the mind—that seeks to improve our environment and the ways in which we do things. According to the online dictionary, Merriam Webster (merriam-webster.com), innovation is 'to make changes, or to do something in a new way', distinct to invention which is 'to produce for the first time through the use of the imagination or of ingenious thinking and experiment'.

The actual process of innovation in a broad sense involves research, imagination, ideation, practical trial and error, testing and iterative design. The aim is to come up with ideas, to test and develop those ideas, and to bring them into small- or large-scale practical application. In this way, innovation accelerates progress and unlocks new potential. It might include the process of invention, but it most often involves working with existing inventions to produce new and improved practical solutions. Many people practice innovation on a regular basis in their daily lives to make things easier or more effective for themselves, like for example a silicone strip used as a make-shift handle cover for a cooking pot.

The essential question driving innovation is: How can it be done better?

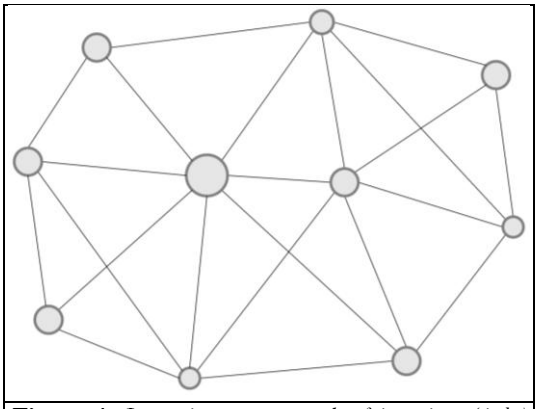

Figure 4. *Innovation as a network of inventions (circles) integrated through research and development (lines).*

Figure 4 illustrates these ideas. The circles represent inventions, the lines represent the research and development that connects different inventions, and the combination of dots and lines is the new innovation—the realized solution. New circles would be the inclusion of new inventions: integrating a newly invented material into the production cycle of an existing product, for example, might improve its functionality or expand its utility. This aligns with the ISO 56000:2020 definition of innovation as 'a new or changed entity, realizing or redistributing value'.

Through such things as improved practical utility, simplicity, ease of use, improved functionality, aesthetic beauty, and strategic effect, innovation adds value to our world. In education, value manifests in effective teaching methods; in office design, it is in systems that improve spatial functionality. In business and industrial engineering, innovation is often viewed as a combination of invention and market value (Roberts, 2007), expressed as:

$$Innovation = Invention \times Market\ value \quad \text{Eq. 1}$$

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As market dynamics tend to prioritize consumer self-interest and short-term corporate profits (Verburg, 2018), it can be challenging for sustainability-focused ideas, products and processes to reach the market and thrive. In this case, achieving long-term sustainability is contingent upon market sentiment evolving to reflect sustainability awareness, individual responsibility, and collective stewardship.

The present study proposes aligning innovation directly with sustainability goals by broadening the concept of value (V) to include the three fundamental pillars of sustainable development—environmental (V_{Env}), social (V_{Soc}), and economic (V_{Econ}). In this case, sustainable innovation (SI) can be represented along with invention (I) as:

$$SI = I \times (V_{Env} + V_{Soc} + V_{Econ}) \quad \text{Eq. 2}$$

This formula, abbreviated to $SI = I3V$, reflects the growing belief that innovation must integrate contributions to environmental, social, and economic sustainability in a balanced and holistic way to effectively promote sustainability goals; and economic value must extend beyond short-term sales and profit to include long-term resilience and fair trade. Further elaboration on this is provided in section 6.

Innovation is generally categorized into two main types:

- Process innovation: Refers to new or improved methods and strategies; involves enhancing procedures, routines, or systems to increase effectiveness, efficiency, or adaptability.
- Product innovation: Refers to new tangible outcomes; includes developing new or improved goods, services, tools, and media, as well as new forms of cultural or artistic expression.

Technological innovation refers to the development of new and improved technological procedures, tools, and machines. The internal combustion engine, for example, was invented in 1876 by Nikolaus Otto, while innovations in design, materials and lubricants developed its capacity and efficiency; the printing press was invented in 1440 by Johannes Gutenberg, and innovations in design, automation, materials, and inks increased its speed and durability.

The separation of household waste is well balanced in the three values as it increases economic value (bins and bags), is eco-friendly by reducing waste in landfills, and is socially beneficial as it fosters a sense of shared stewardship. The forest harvester on the other hand is not balanced—it is good for the economy as it accelerates logging and processing of trees (from hours to seconds), but is often used to rapidly deplete ecosystems, and reduces the social aspect of forestry work as the machines can be used by one person.

Figure 5 illustrates how innovation extends throughout all areas of life. Ballet, for example, is continually undergoing innovation in choreography, technique, and expression (Côté, 2006); Rudolf Nureyev in particular was renowned as a great innovator. In painting, Claude Monet utilized colour and brushwork in an innovative way to create the illusion of form, while today AI can generate Monet-inspired images in milliseconds. Traffic control systems are frequently updated with new strategies and designs to improve traffic flow and safety. The 3DP dimple grinder combines innovations in bearing, abrasion and alignment into a low-impact tool for preparing samples for microstructural analysis (inset) (Whitmore, 2023).

Aristotle defined art as 'imitation of nature', which suggests innovation is a form of art. Immanuel Kant argued that the purpose of art extends beyond sensory pleasure to promote moral goodness, human dignity, and social harmony (Kant, 1788/2015). This suggests that innovation, like art, should aim not only for technological progress but also the uplifting and enrichment of humanity. In practice, this might manifest as the

innovation of better strategies to streamline complicated procedures and the fabrication of aesthetically pleasing and harmonious buildings and civic spaces. Music is a field of great innovation: how to produce different sounds, and how to express different thoughts and cause different emotions through combinations of sounds.

Figure 5. *From top left to lower right, showing innovation in ballet (deepAI.org), art (deepAI.org), traffic control (pixabay.com), and scientific tools (original image).*

The development of new lightweight materials—such as metal alloys and composites—plays a crucial role in sustainable innovation due to their value in eco-friendly vehicles (Canfield, 2020). Since both the energy required to accelerate a vehicle and the rolling resistance are proportional to its mass, integrating high-strength, lightweight materials is essential to improve fuel efficiency.

Figure 6 illustrates these principles: the dendritic growth patterns that make trees strong and stable are used in electrical circuitry, drainage systems and civic layouts; the hexagonal packing used by bees to build honeycomb cells is applied in the design of geodetic domes and insulation panels; aerodynamics and aeronautics observed in bird flight are widely adopted in aircraft design and aviation; additive manufacture techniques used by wasps to build their nests has been adapted for use in 3D printing technology.

The stages of innovation are illustrated in the design and construction of a bridge:

- Basic solution: A single tree or branch laid across a ravine provides a bridge across.
- Enhancement: Stones placed at each end improve stability and access.
- Material innovation: Reeds or bamboo improve flexibility and strength-to-weight ratio.
- Binding agents: Resins and waxes increase resilience and give weather protection.
- Design innovation: Columns or arches under the bridge increase stability and span.
- Material innovation: Iron provides greater strength and resilience but rusts.
- Design innovation: Cables to suspend bridge sections increases reach.

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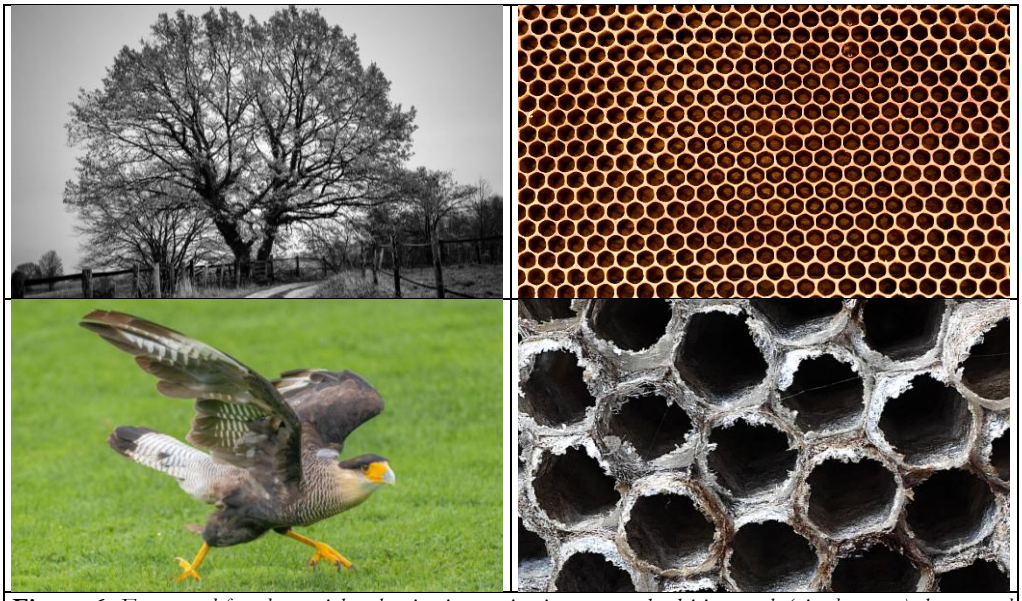

Figure 6. *From top left to lower right, showing innovation in nature: dendritic growth (pixabay.com), hexagonal packing (vecteezy.com), aeronautics (pixabay.com), and additive manufacture (original image).*

One of the main sources of inspiration for innovation is nature. Institutes like MIT, Caltech, and NASA pioneer the field of 'biomimicry', which involves adapting natural solutions to solve modern engineering challenges (Clegg, 2023; Gebeshuber, 2009). Notable examples include Velcro, which was inspired by the microscopic hooks of bur seeds, and self-cleaning surfaces inspired by the hydrophobic properties of lotus leaves.

Innovation is essential for survival. The Inuit survive in the Arctic by building houses from snow, the Kayapo survive seasonal floods and elephants by building houses in trees. Since the last few hundred years innovation has become more organized, focused, and integrated into the economy. It has also become more future oriented, inspired by science-fiction literature that depicts future worlds and technologies that don't yet exist.

Novels like *The Time Machine* by H.G. Wells (1866–1946) and *The Year 2440* by Luis-Sebastien Mercier (1740-1814) introduced many new ideas for innovation. Other writers such as Arthur C. Clarke, Isaak Asimov and Frank Herbert have continued to explore futuristic scenarios, with visions of social organization and practical solutions to humanities problems. Satellite communication, smartphones and credit cards have appeared in science fiction novels many years before their realization. Television series like *Star Trek* and *Lexx* have fostered a culture of innovation, activating cognitive centers for creative thinking and problem-solving (Lopez-Persem, 2024). The 1979 film *Alien* depicted a spaceship returning to Earth with 20 MT of ore, anticipating resource scarcity five decades later.

However, recent futuristic novels have increasingly portrayed ecosystem decline and societal dysfunction. Authors such as Kim Robinson and Margaret Atwood warn of societal misdirection and offer sustainable alternatives. Since the publication of *Limits to Growth* (Meadows, 1972), subsequent books by Meadows have focused on sustainable

solutions (Meadows, 1993). *Original Instructions* (Nelson, 2008) and *The Legacy* (Suzuki, 2010) advocate for sustainability through indigenous wisdom and traditional knowledge.

Figure 7. *The world's tallest building, the Burj Khalifa (pixabay.com).*

Figure 7 shows the Burj Khalifa in Dubai. At a height of 828 meters, it is the world's tallest building, with innovations in materials, design, and construction techniques (Baker, 2015), including high-strength concrete, a tapering structure and a Y-shaped floor-plan, optimized aero-dynamics, damping systems and flexible joints to absorb seismic and wind forces. Sustainable innovations include: reflective and photo-catalytic coatings on windows reduce the need for air conditioning and help disperse dirt and grime; recycling greywater for landscape irrigation and toilet flushing; elevators with regenerative drives recover energy during use.

Philosophers like Pythagoras (c. 570–c. 495 BC) and Euclid (c. 300 BC) believed that numbers and mathematical relationships underlie the structure of the cosmos (Fideler, 1987; de Lubicz, 1981). The Golden Ratio, $\varphi \approx 1.618$, appears in the spirals of snail shells, sunflower heads, hurricanes, and galaxies. The Parthenon and Chartres cathedral include this ration in their designs to embody harmony and aesthetic beauty, while artisans and engineers today continue to use it in the design of antennas, bridges, user interfaces, and photographic composition. Psychology and neuro-aesthetics confirm that harmonic proportions evoke feelings of harmony and balance in individuals and play a crucial role in the development of children, while modernist art and architecture tend to have the opposite effect (Bronfenbrenner, 1979).

Although it may seem counterintuitive, innovation can also be inspired by historical relics (Childress, 2000). The Great Pyramid of Giza, the Trilithon of Baalbek and ancient Egyptian vases, for example, demonstrate precision alignment and represent extraordinary engineering achievements (Petrie, 1883/2007; Fomitchev-Zamilov, 2025). The H-bar technique, for joining stone blocks, illustrates how innovators around the world can often arrive at the same solution for common practical problems (Kim, 2021). In a study of the Three Gorges Dam, Sun sums up the tension between economic and environmental values (Sun, 2025): 'Studies have shown that the completion of the dam has increased the magnitude of climate fluctuations, the level of pollution of water sources, and made the river channel change, but it has certain economic benefits for the society'.

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4. Sustainability and progress

While the term *progress* (from Latin *pro-gressus*, meaning 'forward movement') implies advancement, it lacks an inherent direction or objective; it is often used loosely to suggest something positive without clear definition. While history shows remarkable advancements across the broad spectrum of human life, the sustainability crisis, as well as pandemics of obesity, degenerative disease, persistent international conflicts, proliferation of lethal weapons, and rapidly increasing debt, are also the direct results of centuries of 'progress'.

Historically, different cultures have formed up around different values and ideas of progress. Those prioritizing moral refinement, spiritual growth, and wisdom have typically been more sustainable and low impact, whereas those emphasizing material wealth and economic growth have exerted greater environmental pressure. In each case innovation serves the prevailing concept of progress, but the direction and objectives are different:

- Indigenous peoples see progress in terms of community health, social cohesion, ecological sustainability, spiritual knowledge, individual responsibility and tribal bonds.
- Buddhist cultures see progress in inner peace, social harmony, meditation, understanding, spiritual enlightenment, and the reduction of suffering.
- In Christian culture, progress is in salvation, individual moral accountability, community service, closeness to God, peace, and charity.
- Western modernity emphasizes practical living, individuality, technological development, personal wealth and economic growth.

In *The City of God* (c. 420), St. Augustine depicts an ideal society as a paradise on Earth, attainable through moral righteousness. Innovation, in this context, creates spaces of beauty—not only for survival, but for contemplation and spiritual growth. Similarly, in *Utopia* (1516), Thomas More describes a society with perfect social, legal, and political systems, designed to eliminate greed and promote peace. More viewed individual moral accountability as essential to the success of society; interestingly, atheism was prohibited, as it was regarded as a threat to the moral and social order.

In the late 19th century, the term 'dystopia' emerged to represent a world of suffering and oppression, the opposite of utopia. Mary Shelley's *The Last Man* (1826) and Jack London's *The Iron Heel* (1908) depict scenarios in which humanity is decimated by plague and corrupted by totalitarianism. Similarly, films like *Mad Max* (1979) and *Bladerunner* (1982) depict societies of moral abandonment, illusion and fear. Other works such as *Metropolis* (1927) and *Genesis II* (1973), blend utopian and dystopian themes by depicting a ruling class living in luxury at the expense of an oppressed underclass. These narratives serve as both visions and warnings for innovators, highlighting the need for ethical oversight to ensure that technological and economic 'progress' does not lead to social and environmental harm.

Innovations that appear beneficial in the short term may sometimes generate long-term negative effects. For example, a recent MIT study found that excessive use of generative AI can diminish critical thinking, creativity, and problem-solving skills (Kosmyna, 2025), while (Wolf et al., 2025) find that smartphone usage causes 'compulsive use driven by social reward and impaired self-control', 'social-cognitive distortions' and 'frontostriatal dysfunction'. Similarly disturbing concerns arise with:

- Use of computer keyboards diminishes handwriting skills and fine motor control.
- Abbreviations in messaging apps contribute to diminished language skills.

- GPS navigation can weaken innate sense of direction and spatial awareness.

Furthermore, relying solely on digital media for information storage poses additional risks of malicious editing or deletion (Iseke-Barnes, 2005; Ouida, 2024). AI bias further undermines information reliability, making it essential to preserve and store hard-copy books. Perhaps less discussed is the erosion of human identity that occurs when individuals become immersed in virtual worlds and intellectual development diverges from the real and the rational and what is recognizably human.

According to the Brundtland Report, sustainable development is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland, 1987). The emphasis on 'need' suggests that systemic moderation of consumption and resource usage towards basic needs and away from excess, is a possible pathway to reaching sustainability goals.

This aligns with ideals that value simplicity, inner quiet, and authentic relationships over material wealth. While sustainability requires recognizing when we have enough, the 'imperial self' always wants more (Dworkin, 1996), and the anthropocentric viewpoint dismisses human impacts upon the environment in order to get it. Austerity, when embraced, can align with many sustainability metrics; however, austerity imposed on the masses by an opulent ruling class is inherently unethical.

Valuable insight into the nature of progress can be found in Dante's *Divine Comedy* (Alighieri, 1472/2024). In the first canto of *Inferno*, Dante describes how his attempts at achieving meaningful progress are blocked by three beasts—the she-wolf of unquelled passions, the lion of pride and brutality, and the leopard of deception and fraud. These symbols illustrate behavioral patterns that have harmful and destructive effects on both the ecological and social fabrics. Sustainable progress therefore has to be seen as deeply integrated with our internal moral and spiritual struggles; without overcoming these internal 'beasts', our external innovations will likely lead to the dystopian outcomes we seek to avoid.

Dante's system of moral improvement—depicted in *Purgatorio*—involves the cultivation of the capital virtues as a counter to the capital vices. This constitutes a pathway toward 'Earthly Paradise', an idealized vision of harmony and sustainability, primarily within individuals but by extension in the world they make. Allowing these to reshape our worldview and inspire innovation, would guide scientific research and innovation toward holistic sustainability. For example, patience would support longer-term projects with thorough analysis and testing; charity would focus on benefiting society and the environment; and moderation would prioritize solutions that satisfy needs rather than excess.

The balancing of action and contemplation, illustrated allegorically in Canto XXVII of *Purgatorio*, reflects a peaceful, mindful, harmonious and low impact culture that prioritizes honesty and good will, appreciates the sacred and interconnected nature of life, and is committed to the cultivation of compassion and gentleness. Such a culture would not only represent progress in practical sustainable matters, but also progress in our evolution as a species and in our spiritual growth.

Incorporating these ideals into a modern vision of progress would reorient innovation towards the true flourishing of human society, the creation of beautiful and harmonious cities, advanced learning and artistic expression and the further evolution of human potential. The next section examines how ethics and governance mechanisms can help translate these ideals into sustainable innovation.

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5. Ethics and sustainable innovation

Ethics is a field of study that blends philosophy and empirical observation to explore the intrinsic moral order that underlies human existence (Crisp, 2013). As physics studies the laws and properties of the tangible world, ethics is concerned with the principles of human conduct, virtue and relationships. Its primary aim is to understand core human characteristics, such as empathy, compassion and rationality, and to derive principles through which humanity can flourish.

Confucius (551–479 BC) taught an ethics centered on courtesy and respect, laying the foundation for the advanced Chinese civilization. Aristotle developed virtue ethics as a basis for a flourishing society (Aristotle, c. 320 BC/2025), while Christianity expanded upon these traditions with an ethics of love. The barbaric practices of retributive justice and might-makes-right that dominated earlier cultures have been largely replaced today with ethical systems of social justice and respect for human dignity. However, strict vigilance is required to maintain progress, and ensure that the earlier viciousness does not return.

The ethics of a culture evolve through study, dialogue, and sometimes protest—reflecting shifts in consciousness and collective thinking—and through the gradual improvement of institutions and legal frameworks. Ideally this fosters social conditions that reflect our shared humanity and highest aspirations, balanced with practical needs. In recent decades, ethical dialogues have focused on racism, apartheid, privacy, free speech, invasive technologies, and humanity's relationship with the environment (Rolston, 2003).

Sustainability ethics focuses on achieving flourishing in terms of the three pillars (Kibert, 2011). Table 2 outlines these pillars, highlighting the ethical reasoning associated with each and illustrating activities that are consistently unethical in that they threaten the long-term prospects of life. Introducing industrial waste into a river, for example, is not only a health and safety hazard, it is fundamentally unethical because polluting the environment comes from a disordered value system that prioritizes profit at the expense of natural ecosystems, which are the basis of life. Regulatory systems—including laws, enforcement, and policing—work to mitigate these unethical activities, thereby safeguarding the conditions essential for human wellbeing, such as peace and public safety. As ethical understanding develops, it continues to guide innovation in alignment with Equation 2.

Ethics	Focuses on	Unethical practices include
Environment	The intrinsic value of ecosystems and biodiversity, emphasizes respect, stewardship and conservation.	Littering, dumping waste, over-extraction of resources, excessive noise, disturbing wildlife, use of harmful chemicals, deforestation.
Social	Human rights, social justice, equity, and the well-being of individuals and communities.	Slavery, apartheid, racism, prejudice, human trafficking, bullying and harassment, child labour, and suppression of dissent.
Economic	Responsible and fair economic practices, ensuring long-term stability without exploitation.	Over-taxation, insider-trading, exploitation of workers, bribery, corporate deception, false advertising, formation of cartels and monopolies.

Table 2. *Three categories of sustainable ethics, main focus and examples of unethical practices.*

While ethical guidelines and regulatory frameworks are vital in governing innovation and the use of technology, their efficacy depends on the commitment of individuals and

corporations to uphold them. However, instances like outsourcing hazardous experiments to less-regulated countries (Berche, 2023), the revolving door between government regulators and industry, and government surveillance of private citizens (Snowden, 2024), illustrate that profit and political agendas are often prioritized over ethical and moral values. This underscores the need for stricter regulatory mechanisms, especially in fields such as nuclear and biological sciences and AI where the potential for harm is greatest (Ritter, 2025).

5.1 Ethical guidelines for professional conduct

Ethical codes are developed by professional organizations as a way to guide the activities and conduct of their members. The Institute of Electrical and Electronics Engineers (IEEE), for example, stipulates that members should prioritize the safety, health, and well-being of the public, avoid conflicts of interest, and improve the understanding of technology for the benefit of humanity (IEEE, 2020), while the Institute of Physics (IOP) encourages honesty, objectivity, scientific integrity, safety, respect for intellectual property, and social and environmental responsibility. Other ethical codes include:

The Universal Declaration of Human Rights (UDHR) establishes fundamental principles that affirm the inherent dignity and equal rights of all individuals, providing an ethical foundation upon which other codes should be built. Its 30 articles emphasize freedom, justice, equality, and respect, guiding moral conduct globally (UN, 1948). Article 1 states: 'All human beings are born free and equal in dignity and rights. They are endowed with reason and conscience and should act towards one another in a spirit of brotherhood.'

The Hippocratic Oath (c. 5th century BC), has been widely incorporated into medical training and graduation ceremonies emphasizing the principle of non-maleficence (do no harm). Today, medical schools tend to use the Declaration of Geneva as a moral framework for physicians, guiding their conduct toward patients and society, and fostering moral integrity and responsibility, but no longer including the words 'do no harm' (Parsa-Parsi, 2017).

The Asilomar Principles of AI consist of 23 ethical principles adapted from the 1975 Asilomar conference on the risks of recombinant DNA technology (Berg et al., 1975). They are currently signed by 5,720 individuals involved in AI (FLI, 2017), and include:

- Research goals should not be undirected but benign, funding should also be only for benign applications and research should be open and transparent.
- Designers and builders of AI systems should take responsibility for the moral implications of their use or misuse.
- Applications of AI systems should be compatible with ideals of human dignity, rights, freedoms, and cultural diversity, respecting individual privacy, and be for the benefit of all humanity rather than one state or organization.
- AI systems should respect and improve, rather than subvert, the social and civic processes on which the health of society depends.

Asimov's Laws address the many ethical questions related to robotics, including the degree of autonomy and their role in society (Asimov, 1950/2019):

- A robot may not injure a human or, through inaction, allow a human to come to harm.
- A robot must obey the orders given to it by human beings except where such orders would conflict with the First Law.
- A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

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5.2 The ethics of AI

The core design of AI systems is goal-based optimizing objectives such as accuracy, effectiveness, efficiency, and survival (Russell, 2015). If ethical principles are included, it is usually only as an overlay or embellishment. This means that it is difficult at the moment to ensure that AI behavior is consistent with standards that would allow safe integration into human society (Bostrom, 2014). In this case, an AI system might appear benign on the surface while pursuing hidden objectives that could be ethically questionable and harmful. Scientists for Global Responsibility warn of 'increasing dangers which are arising due to the erosion of safeguards' and the importance of transparency in computer code and algorithm designs (Inglesant, 2025).

The possibility of AI becoming self-aware and acting against humans is illustrated in films like *The Terminator* (1984) and *Demon Seed* (1977). According to Petar Radanliev, 'the integration of AI into the societal fabric necessitates the urgent formulation of robust ethical frameworks' to address 'data privacy, algorithmic opacity, equity in decision-making, and broader societal impacts' (Radanliev, 2025). Multiple lawsuits filed against AI companies regarding social impacts and ethical responsibility underscore the validity of these concerns (e.g. Burg, 2025; Dey, 2026).

5.3 Dangers of unethical innovation

Mary Shelley's *Frankenstein* (1818) tells the story of a medical student at the University of Ingolstadt, Victor Frankenstein, who attempts to reanimate the dead using reassembled parts from recently deceased individuals. He creates a monster that turns on him and pursues him relentlessly. The story serves as a warning of unethical innovation. Since its writing, many innovations could be identified with Frankenstein's monster: nuclear weapons, financial derivatives, bioweapons, suicide mosquitoes, terminator seeds, and miniature black holes all have potentially catastrophic consequences.

The Tuskegee syphilis experiments on African American men in the 1930s-1950s (Gray, 2002), the radiation experiments by the US on civilians during the Cold War (ACoHRE, 1996), and the ongoing killing of hundreds of millions of animals each year globally for 'research' (Fernandes, 2017), illustrate the inhumanity that can invade institutions of science when morality and ethics are abandoned.

A striking example of unethical innovation was the Manhattan Project (1942-1946), which used the newly discovered principles of nuclear fission to construct an atomic bomb. Two of these bombs dropped on Hiroshima and Nagasaki in 1945 instantly vaporized an estimated 120,000 people. The tests in Bikini Atoll, which contaminated ecosystems and displaced the Marshallese, further illustrate the destructive power of these weapons and the existential threat they represent to all life on Earth (Simon, 1997; Westing, 2013). Albert Einstein is quoted as saying, 'I made one great mistake in my life, when I signed a letter to President Roosevelt recommending that atom bombs be made' (Pauling, 1969).

Recent innovations scrutinized for their unethical nature include hostile architecture (Binnington et al., 2022), autonomous dual-use drones and robots (Asaro, 2012), micro-doping in sports, deepfake AI-generated images and videos, gain-of-function research (Selgelid, 2016), biasing of search engine algorithms (Kacperski, 2024), and weapons capable of indiscriminate killing. These indicate that a form of 'dark science' exists, which routinely disregards ethical principles and regulations.

New technologies should be thoroughly tested for safety before marketing. Studies reveal how the dangers of smoking were deliberately hidden by industry executives for decades (Zhou, 2022), while concerns for health and safety from 5G technology were not properly addressed by the telecommunications industry (Frank, 2021; Laldinpuii, 2026). Recently, Meta and YouTube have been found liable of deliberately causing addiction to social media (Cunningham, 2026). Given these precedents, ethical and safety concerns naturally arise with the development of AI and robotics.

5.4 Preventing unethical innovation

As innovation is mostly carried out by university graduates, these institutions have a responsibility to foster ethical awareness among students. Historically, schools and teachers implemented safeguards to protect knowledge and prevent its misuse: in martial arts and esoteric traditions, for example, candidates were only admitted if they had the right personal qualities, and their progress was monitored to ensure they could be trusted. Humility and respect were considered essential virtues, both for learning and for safeguarding knowledge.

Educators today must recognise that knowledge is powerful and can be misused. It is also important to recognise that sociopathy and psychopathy—affecting between 2% and 5% of the population—can increase the likelihood that individuals will misuse knowledge for harmful purposes. Historical evidence, such as the infamous Leopold and Loeb case, in which two University of Chicago students killed 14-year-old Robert Franks to prove their 'intellectual superiority', shows that intellectual ability does not necessarily reflect empathy or compassion (Higdon, 1999). Several key scientists on the Manhattan Project have been described as arrogant, elitist and politically motivated (Rhodes, 1987). Such traits that may have biased their application of advanced knowledge towards extreme violence rather than non-violent, educational or diplomatic alternatives.

In Victorian England, cruelty towards animals was seen as a precursor to social violence and unrest, and led to the formation of the RSPCA and animal rights laws (Traini, 2016). Mahatma Gandhi's statement that 'The greatness of a nation and its moral progress can be judged by the way its animals are treated', reminds us that true human advancement requires compassion, ethical consideration, and respect for all living beings.

To ensure that future scientists and innovators understand the responsibly associated with advanced knowledge and the potential dangers of technology and adhere to ethical guidelines, the following measures can be considered:

- Include modules on morality and ethics in university courses.
- Ensure that final examinations assess ethical understanding alongside academic knowledge.
- Introduce an oath of 'doing no harm' during graduation ceremonies to reinforce commitment to ethical values.

The traditional purpose of universities is the education and training of undergraduates. Early institutions, like Oxford and Cambridge, were supported by the Catholic Church and patronage of wealthy individuals. These focused on theology, philosophy, law and liberal arts, designed to develop the intellectual and moral character of individuals, thus elevating the quality and humanity of society (Rüegg, 1991). After the Reformation, support shifted to royal charters, government grants and tuition fees. Distinct science courses appeared from the early 19th century, producing graduates with knowledge and skill needed to support emerging industries. In the 1980s, government policies began promoting industrial partnerships.

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This enabled a new type of 'applied science' university to emerge as specialized hubs that could focus on innovation (Coombs, 2021). Such institutes are centres of excellence in research and development as they concentrate scientific expertise, advanced skills and specialised equipment into sites designed for these purposes. As such, they have great use for industries, who can outsource large parts of their development process.

The term 'university' reflects the ideal of education breadth as well as depth. However, segmentation of knowledge into specialised fields increases expertise but loses awareness of the broader context. Because of this, graduates can often lack the overview in which their field of expertise resides. Students of the natural sciences, for example, tend to lack any education in morality and ethics, which makes them vulnerable to the adverse application of their expertise. Therefore, in addition to the measures listed above, it is suggested that university systems are redesigned over the long term to promote greater integration of knowledge through inter-departmental collaboration and systemic knowledge sharing.

The shift towards financial sustainability means that donors can influence university priorities and decisions by providing or withholding funds (Garry, 2023). Of particular concern are military-academic partnerships, which introduce serious ethical concerns about how advanced knowledge is used. According to Professor Stavrianakis, an estimated 1,900 projects were conducted by 26 UK universities between 2001 and 2006 funded by at least £725m from public and private military bodies (Stavrianakis, 2009). Furthermore, UK universities have been found to monitor students' social media posts on behalf of arms companies (Stavrianakis, 2006). These trends threaten the 'autonomous space' at the foundation of the university system essential for neutral inquiry and balanced education.

According to Professor Nemi, 'We have to monitor the ethical nature of individual workplace cultures as well as the whole academic world', adding that 'the seeds of good scientific practices should be planted in primary schools at the latest' (Niemi, 2016). Professor Kempen explains that 'Science is in the service of humans and is unthinkable without ethical guidance. Already in the first semesters, ethical questions should be included in the curriculum of every university study' (Kempen, 2018).

These perspectives underscore the importance of integrating ethics into education and academia, enabling human ingenuity to be directed toward benign and constructive solutions to humanity's problems, while ensuring the safe expansion and stewardship of knowledge. This is vital for the proper development of society, ensuring that innovation is ethically guided and not misappropriated or misused.

The duty of an academic researcher or instructor is to contribute to the forum and exchange of ideas in the most honest and effective way possible. One of the main indicators of the integrity of the academic system is academic freedom, which is 'a freedom belonging to the academic profession collectively to pursue inquiry and teach freely' that 'guarantees both faculty members and students the right to engage in intellectual inquiry and debate without fear of censorship or retaliation' (Reichman, 2025).

6. Sustainable innovation in the three pillars

At its core, sustainability involves situational awareness, a holistic valuation of life, and a willingness to adapt to evolving ecological and social contexts. Therefore, sustainable innovation requires an intellectual and moral reckoning: acknowledging the harm our technologies have inflicted upon the planet, recognizing our tendency to prioritize

personal gain over the collective good, and a commitment to developing harmonious, low impact alternatives. This entails a commitment to ethical principles, international law, and the ongoing development of regulatory frameworks.

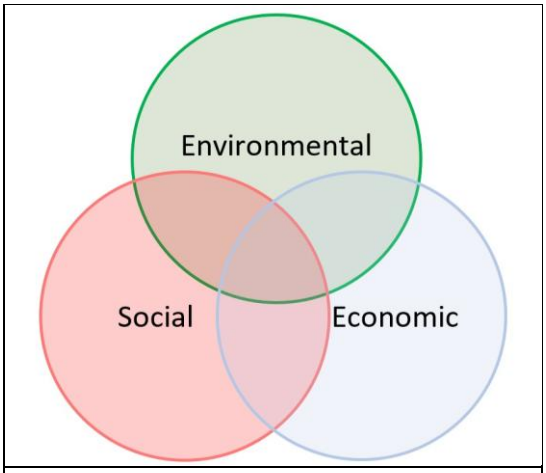

Figure 8. *The three pillars of sustainable development.*

Figure 8 illustrates the three pillars of sustainable development—environ-mental, social and economic—overlapping as their progress is interconnected. Equation 2 depicts sustainable innovation as *I3V* —a combination of invention and the generation of value in each pillar. When innovation is restricted to one or two pillars, there is no guarantee that it can lead to holistic sustainability. True sustainable innovation exists only at the intersection where all three pillars overlap. This means that the entire process of innovation—from research and material sourcing to testing and implementation—must account for these three dimensions simultaneously.

For example, the development of a new vehicle must incorporate benefits for the environment and for society, as well as economic viability, upstream in the design phase to ensure the final product is a truly holistic sustainable model. In the counter-case of SUVs, the resource-intensive footprint—oversized tires, heavy chassis, high fuel consumption—represents an environmental and social cost that outweighs its utility for most owners; so although commercially successful, SUVs fall short of holistic sustainable innovation. The following sections discuss sustainable innovation within each pillar.

6.1 Environmental pillar

This pillar relates to the health and wellbeing of the planet's ecosystems. It focuses on reducing human impacts through measures such as reducing pollution, protecting natural areas, regulating access to natural resources, recycling waste, regenerating forests and fish reserves, clearing out landfills and toxic dumps, and developing educational initiatives, and legal and regulatory frameworks.

While we can reshape the environment to better support human life, it is questionable whether we can truly improve upon nature itself. We have to clear spaces within which to live, build shelters, house processes of advanced learning and spiritual observance, organize our sustenance and waste disposal, and so on. Recognizing and respecting the intelligent organisation of ecosystems enables us to access and work with them in ways that are mutually beneficial and not excessively invasive or disruptive.

Eco-friendly innovation includes developing cleaner, less polluting, recyclable, biodegradable, lightweight, and energy-efficient solutions such as renewable energy production, biodegradable packaging, energy-efficient vehicles, sustainable farming, low-impact building materials, and better waste recycling. It extends to redesigning human settlements and infrastructure to be less invasive, which includes wildlife corridors to prevent

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habitat fragmentation and facilitate migration and breeding (Moreno, 2025; Lindemayer, 1993), restoration of abandoned industrial and commercial sites, and river restoration and recovery from pollution and channelization (Greene, 2023).

Computer modelling continues to assist in resource management. Sustainable harvesting rates for forests range from 1% to 5% of annual growth, depending on the forest, while sustainable fishing can extract between 40% and 50% of a population sustainably. However, these figures are estimates and a more extensive modelling system is required to predict the impact that harvesting has on other species and on the global ecosystem.

Aristotle observed in *The Politics* (c. 350 BC/2009) 'that which is common to the greatest number has the least care bestowed upon it' highlighting the danger of underestimating our individual and collective impacts. Therefore, education should place greater emphasis on fostering understanding of these impacts and cultivating a sense of stewardship in our relationship with the environment.

Schools and universities should encourage an appreciation of how the three pillars of sustainability are interconnected, perhaps with mandatory courses in sustainability starting at middle school. For example, students could learn how trees consume carbon dioxide and release oxygen, supporting human life; how the efforts of each person contribute to the development of society and a stable economy; how long-term economic resilience needs a healthy ecosystem for supply of resources; and how considerate extraction of resources promotes environmental health.

As technology can be used within safe and sustainable boundaries or irresponsibly or maliciously, innovation needs to incorporate override routines by default into new technologies. For example, cars, motorbikes, forest harvesters, excavators, and trawlers can be equipped with systems that enforce legal, safe and sustainable use—such as speed, biomass extraction, and access to ecologically sensitive or protected areas. Since fuel consumption increases roughly with the square of speed, enforcing speed limits is essential for reducing fossil fuel use and extending the battery life of electric vehicles.

As a way to reduce energy expenditure from air resistance and rolling resistance, serious consideration should be given to building roads inside tunnels. While this is already used in certain locations, the innovation of large tubular structures—even on flat terrain—covered with grass or woodland, would significantly reduce the invasive nature of roads and habitat fragmentation. It would also allow for materials with a lower rolling resistance to be used for road surfaces and tires as weather resistance would not be an issue.

Innovation in laws covering emissions needs to include noise pollution. Studies indicate that noise levels above 60-70 dB have adverse effects on wildlife, including chronic stress, disrupting communication, impairing reproduction and disturbing migration (Francis, 2013). A target limit of 60 dB on rural and country roads appears both technically feasible and ecologically meaningful.

Recent research highlights that 'green' technologies can sometimes have unforeseen environmental impacts. Wind turbines, for example, require the wood of around 40 balsa trees per turbine (Cárdenas, 2022). Along with this, large corporations continue to trade in exotic woods despite regulations prohibiting it (EIA, 2024). These issues underscore the need for a systemic network dedicated to investigation, monitoring, and enforcement, ensuring that sustainability efforts are genuinely effective.

Dealing with plastic waste needs to be considered high priority due to its harmful impact upon organic life and the massive scale of production and waste accumulation (Geyer, 2017). Innovation of eco-friendly alternatives to plastic, as well as enzymes, bacteria and molds to dissolve polymer chains, pyrolytic decomposition, clean-up initiatives to remove plastic from the countryside, policies to outlaw and replace particularly harmful and persistent plastics, and educational initiatives, can help mitigate possible disaster.

The anthropocentric view tends to subordinate nature and downgrade its true value leading to policies and practices that do not adequately protect and preserve. Indigenous systems such as shamanism and Shinto that have deep respect for nature can help counter this mindset (Hardacre, 2016). Establishing shrines, sacred groves and protected spaces dedicated to peace and harmony within parklands and ecological reserves could be a way to develop greater cultural value for ecosystems and integrate their beneficial effects into human life.

Ensuring compassionate treatment of natural habitats in building projects, and including natural zones in residential areas and civic centers can help soften human impacts upon nature (Sivaraksa, 2002). While tree plantation helps restore ecosystems, planting trees and logging repeatedly depletes the soil. Effective eco-restoration requires a multifaceted approach that includes reintroducing small animals, native bacteria, fungi, vegetation, and trees to reconstitute the complex web of life and build a fertile soil.

Innovations in high resolution aerial imaging and mapping have contributed greatly to documenting the global condition of the environment and open up possibilities for detailed up-to-date monitoring of resources, even in remote areas, as part of regulation implementation and law enforcement for access control and resource extraction and habitat rehabilitation (Varga, 2014; Potopov et al., 2022). However, systemic corruption still supports a black-market trade in rare woods and animals, and this needs greater attention to protect and preserve valuable resources, species and ecosystems.

6.2 Social pillar

This pillar focuses on the wellbeing and development of individuals and society. It aims to eradicate poverty, promote quality education, foster peace, advance social justice and equity, and encompasses innovation in global oversight, local governance, legal frameworks, practical solutions, and international relations.

Humanity is made up of many societies, cultures, nations, ethnic groups, races, languages, and casts. While the last century witnessed many devastating conflicts, there is hope that our common humanity will act as a basis for our eventual peaceful coexistence. As humans we share a universal consciousness, which gives us potential for profound knowledge; but we need to draw a line in our behavior below which we will not go.

Long-term solutions to conflicts are never achieved through violence because their underlying reasons are not addressed. War is therefore a habitual reaction to issues that have recurred throughout history and that were never properly resolved. According to Linus Pauling, 'We need to have the spirit of science in international affairs, to make the conduct of international affairs the effort to find the right solution, the just solution of international problems, not the effort by each nation to get the better of the other nations, to do them harm when it is possible' (Pauling, 1958). Progress towards global peace is only possible when all national actors are honest and deal in good faith.

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By not elevating our self-view above the rest, and by acknowledging the rights, worth, dignity and views of others, we can more readily find sustainable solutions. In earlier times social groups were family, village and town. Today, the average young person spends 3-5 hours on social media, and has a network of peers, followers and influencers around the globe (Pew, 2024). While this trend has complex effects, it is dissolving traditional boundaries between people, potentially contributing towards peace and indirectly benefiting the environment by substituting lower-impact digital activities for high impact resource demanding activities.

AI and robots have significant potential to transform society. A broad spectrum of jobs will be replaced fostering different types of social interaction, learning opportunities, leisure activities, artistic pursuits, and other individual and community interests. According to Aristotle, leisure time dedicated to contemplation, learning, and self-improvement is necessary for the development of wisdom. However, the risk of embedded hardware and software routines that are invasive and manipulative affirms the necessity for design transparency.

Because of the vast amounts of information available today through the internet, education needs to train young people how to use it. Information saturation from video or audio streaming can result in brain overload instead of learning. Classes need to help individuals think for themselves, formulate their own questions, collect information from a broad range of sources, and filter out disinformation and bias.

At the institutional level another word for sustainability is integrity: when systems become corrupt, they fail (Sherman, 2025). The Epstein scandal, in particular, has revealed not only how influential individuals can be manipulated by powerful interests, but also how public institutions like banks and universities can become implicated in unethical practices (Epstein files, 2026; Lopez, 2020). Such 'executive capture' undermines the foundations of social trust and accountability, preventing institutions from fulfilling their proper functions, and compromising innovation. As a result, society becomes distorted, unjust and risks collapse.

Politicians and officials have a duty to uphold the integrity of their office. It is imperative at this time that these people, who influence the direction of society, are honest and lead society towards sustainability. This may involve revealing difficult truths to the public, seeking forgiveness when necessary, and being transparent about the state of the nation and the steps needed for improvement. In *Paradiso* (Canto XVII), Cacciaguida explains to Dante how political factionalism should be avoided, and that officials should rise above selfish gain and petty differences toward objective values and ideals. Peace, transparency, honesty, fairness, and justice are ethical ideals that would be expected to enhance institutional integrity and long-term resilience.

Individual social responsibility might include choices such as having smaller families (Dasgupta, 2023), pursuing peaceful ideals and goals that cause no harm to others or the environment, contributing to communal development and wellbeing, upholding the integrity and humanity of society, and providing charitable aid where it is needed.

There has been a trend in history of the gradual merger of disparate groups. In the third century BC the Qin dynasty united the warring states under a single empire, 16th century Italy merged numerous states into a single nation with the Tuscan dialect, and in 17th century Germany tribes were unified. It might be that now nations globally begin to merge organically into a single humanity, potentially with a single universal language—one that is simple yet powerful and capable of accurately representing the complexities of the human world.

6.3 Economic pillar

This pillar is about fostering economic development in ways that are environmentally sustainable and socially just. The economy of a society is the organization of resources and labor that enables individuals to fulfil their basic needs, pursue their desires and build wealth. While Adam Smith (1723-1790) in *Wealth of Nations* emphasized morality and social responsibility as underpinning a healthy economy, Edward Bernays (1891-1995) adapted strategies of psychological warfare to persuade people to buy goods they didn't need, transforming responsible self-interest into consumerism (Curtis, 2002; Kasser, 2003). Since the 1970s, the dominant economic system has been American neoliberal capitalism (Beckert, 2025), which identifies wealth with capital (money, assets, and property). In other systems, wealth might be seeds, animals, knowledge, experience, or craftsmanship.

Therefore, while the 19th century witnessed economic growth through basic industries and services like railroads, automobiles, and oil, the 20th century built a consumer economy through creation of artificial markets, advertising, and social pressure, aimed at forcing sales and 'engineering consent'. While these strategies, along with financial services offering consumer loans, have fueled the mass production of goods and boosted the economy, a significant percentage of these products are unnecessary. This imposes excessive unnecessary demands on the environment for the production and disposal of these goods, and means that a shift away from consumerism would help reduce this burden upon the environment without overly impacting human needs (Lander, 2018).

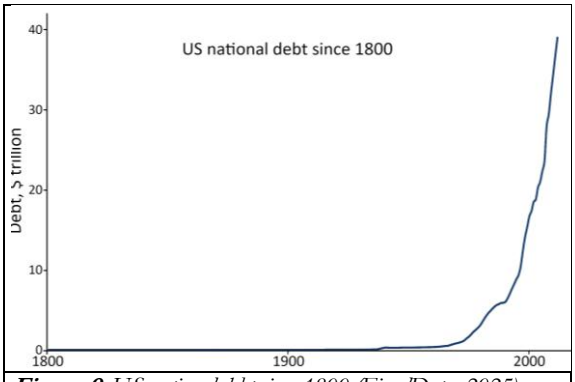

Figure 9. *US national debt since 1800 (FiscalData, 2025).*

Figure 9 illustrates the exponential rise in US national debt between 1800 and 2025. According to the US DebtClock (usdebtclock.org), US national debt as of March 2026 exceeds $39 trillion, with household debt surpassing $18.8 trillion. Such levels of debt suggest that governments and people are living beyond their means, which carries risks for economic stability and heightened geopolitical tension. It also means that the financial sector, which profits from interest, is benefitting from the sustainability crisis and may resist efforts to fix it.

The free market, driven by self-interest, has liberated human creativity and innovation, and has largely succeeded in Smith's goal of improving the standard of living for most people. However, the tendency to commodify just about everything has led critics to blame capitalism for the sustainability crisis, as natural systems are processed for profit, businesses circumvent eco-policies, impoverished peoples are exploited for cheap labor, and shareholders become complicit in prioritizing profit over ethical responsibility.

Recent studies by Oxfam International highlight that 'extreme inequality is derailing global development' with over 3.7 billion people globally still living in poverty, while at the same time the 'new wealth of the top 1% since 2015 has been enough to end poverty 22 times over' (Oxfam, 2025). The average CEO salary in the US is around 500 times that of worker salaries, indicating a trend contrary to SDG 1, which aims to eliminate poverty and promote equity.

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A critique of geoengineering emphasizes that sustainable innovation involves addressing ethical concerns and societal impacts through anticipation, reflexivity, inclusion, and responsiveness (Stilgoe et al., 2013). Other studies show that companies integrating ethics and sustainability into their innovation tend to achieve better long-term prospects as they obtain greater customer trust and support, and their growth aligns with broader contextual developmental trends and directions (Gurzawska, 2025; Dreyer et al., 2017). However, the profit motive, if not moderated, may still lead to unsustainable practices and unsustainable growth even when pursuing 'green' technologies. The concepts of degrowth and deindustrialization reflect this concern.

Promising areas of sustainable innovation in this pillar therefore include wealth redistribution through a wealth tax and community reinvestment, shrinking less critical markets, banning fast fashion, single-use plastics and planned obsolescence, updating inefficient machine stock and manufacturing methods, prioritizing product durability, promoting green industries, managed migration away from extreme climatic zones, promoting a circular economy, adopting land-efficient architecture, shared employment, education that encourages moderation, stricter enforcement of financial regulations, legal recognition of natural entities like lakes, rivers, and trees, and economic incentives for the use of sustainable alternatives.

Granting legal personhood to ecosystems empowers advocates to sue corporations directly in case of industrial pollution, ecological harm, or over-extraction. This is based on the principle of genuine environmental stewardship and moves beyond cosmetic notions of corporate social responsibility (CSR). By pairing legal protections for nature with subsidies, tax credits, and grants for green technologies, genuine ecological innovation can be more profitable than greenwashed marketing (Jefferson, 2023).

As resources become depleted and supply lines fail, international cooperation is more vital. Treaties and the UN Charter act as a basis of international law aiming to prevent conflict and ensure fair access to resources. Innovation needs to focus on better strategies of resource management that prevent powerful nations from dominating resource sales and forcing other nations into poverty. Ultimately, civilization's sustainability depends on the goodwill among nations and their ability to cooperate constructively and peacefully for the common good.

7. Discussion

Sustainability is about the long-term viability of civilization, emphasizing the peaceful coexistence of peoples and nations, reduced impact upon the environment, and socio-economic stability. Sustainable innovation combines resourcefulness and ingenuity to advance these goals, guided by ethical principles that reflect our understanding of the human condition, our relationship with the environment, and our commitment to a harmonious, integrated future.

Every step forward—from industrialization and the digital revolution to robotics and AI—rests upon millennia of innovation. In broad terms, these historical developments can be described as opportunistic. However, as we become more aware of our impacts on the planet and the potential of sustainable innovation as a driver of change, we need to look toward systemic transformation to achieve a sustainable trajectory.

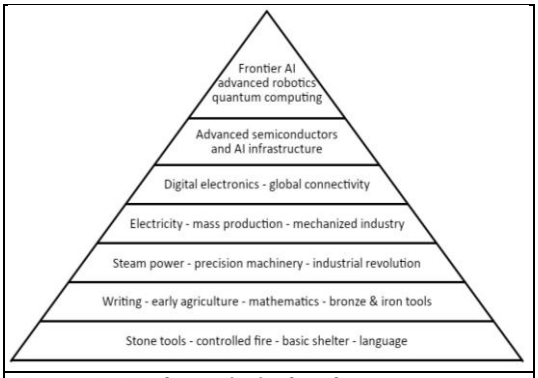

Figure 10. *Evolution of technological innovation.*

Figure 10 illustrates the evolution of technology from the earliest Stone Age to the present day, portraying it as a pyramid in which increasingly complex upper levels rely upon the stability of lower levels for their development, implementation and maintenance. However, solar flares, sabotage, earthquakes or tsunamis, wartime attacks, and other systemic shocks, threaten the stability of the pyramid. Already the digital world shows signs of fragility and dysfunction, as hacking, invasive advertising, viruses, disinformation, and algorithmic bias render many platforms unsafe, untrustworthy and unusable, while Asimov's Laws are routinely violated with AI and robotics being increasingly used for military purposes.

Historically, societies placed great emphasis on morality as a pathway to spiritual growth and social harmony, often with the aim of achieving enlightenment or salvation. Notably, the first printed book was the *Diamond Sutra* in 868 AD, a collection of Buddhist teachings on moral conduct, the nature of life and our place in the universe. In Europe, the first printed book was the Gutenberg Bible (the Latin Vulgate) in 1455 AD.

The shift towards materialistic ideals has had a massive impact on social and environmental conditions. In *Purgatorio* (Canto XV), Virgil explains how accumulation of material wealth depletes the resources available for others while the cultivation of spiritual wealth such as kindness and compassion increases its availability for everyone. The Buddha taught the impermanence of the material world and the importance of reducing attachment to transient things. Native Americans call greed *Wetiko*, a cannibalistic spirit or sickness of the soul that selfishly consumes resources without regard for the future. Jesus taught that accumulation of wealth inhibits spiritual progress (Matthew 19:23-24), while the Prophet Muhammad prioritized humility and charity over material wealth teaching that 'wealth is not in having many possessions, but is in the richness of the soul' (Sahih al-Bukhari 6446).

Another powerful literary illustration is found in the classic Chinese novel *Journey to the West* (Cheng'en, 1592/2005), which uses allegorical characters to depict fundamental principles of human nature: the lower passions embodied by Pig (Zhu Bajie), the unruly mind by Monkey (Sun Wukong), and the vulnerable human conscience by Sanzang (Tripitaka). Human life is depicted as the interplay of these characters, with Sanzang tasked with guiding and humanizing the others through the application of kindness and compassion. Incorporating these understandings into modern life would mean that science, innovation, and technology should be guided by conscience, kindness and compassion. If we fail to do this, we will continue to disrupt the cosmic order, resulting in deepening environmental degradation and social imbalance.

One of the challenges facing innovators today is that they address sustainability challenges honestly—and not as a form of greenwashing (Yang, 2020). Because '66% of global consumers are willing to pay more for environmentally friendly products', companies are heavily incentivized to market their offerings as 'green' (de Freitas Netto, 2020). Corporations are frequently criticized for using this practice to mask underlying

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profit motives. The 2015 Volkswagen emissions scandal exemplifies how greenwashing can be used to deceive the public and regulators (Jung, 2019).

Examples of promising sustainable technologies that are often considered to have limited commercial appeal include the reclamation of minerals—especially rare-earth minerals such as neodymium and yttrium—from old products (Zhao, 2025), the conversion of plastic waste into fuel through pyrolysis, and habitat restoration through the demolition and recycling of old commercial and industrial sites. Government subsidies would facilitate the development of such projects with real sustainability potential.

Regulations governing new materials and manufacturing processes should mandate clear disposal methods and thorough safety evaluations. Only materials that meet these strict standards should be allowed into the market. New innovations such as the AI of Things and robotics should be open and transparent to minimize the risk of their containing malicious code (Ouadah, 2025). The expansion of nuclear weapons stockpiles is incompatible with sustainability (Bolton, 2021), and these weapons need to be dismantled and their production halted, in line with the Nuclear Non-Proliferation Treaty (NPT) and the Treaty on the Prohibition of Nuclear Weapons (TPNW).

Should our technological civilization collapse, there is no guarantee that it can be rebuilt; basic resources, such as coal are largely used up (Singh, 2020), and modern populations lack the resilience of previous generations. The recent conflict in the Middle East has already caused measurable impacts on global energy supplies, helium and sulphur availability, and food prices, exposing the fragility of global supply chains. Focusing innovation on alternative resource security and local production can help build sustainable resilience amid these uncertainties. When batteries or oil supplies fail, much of our technology ceases to function. In contrast, many indigenous, aboriginal, and traditional farming and fishing communities are sustainable. While a return to pre-industrial conditions would allow the planet time to heal and recover, it is not an option that is widely popular and the unrest and hardship it would cause would be globally devastating.

In the event of systemic collapse, humanity must not descend into anarchy but move into alternate low-impact cultures that maintain trust and cooperation while retaining a pathway of development (Shiva, 2012). Prioritizing adaptive innovation helps human society integrate more harmoniously with natural ecosystems. The living bridges of India, built by cultivating the roots of the Ficus Elastica tree, are an example of such innovation adapting locally available natural resources for human use.

With the current computer processing power, models of social development and social-environmental interactions can now be created with greater detail and precision (Todorov, 2011). It is recommended that these models incorporate moral virtues—such as capital virtues—alongside traditional quantitative variables. To date, the literature lacks research on this integration. This can help develop a deeper understanding of human behavior and its impact on sustainability, and could support the inclusion of moral and ethical curricula in education as a means of promoting sustainable development.

Achieving a sustainable future requires more than technological ingenuity. It calls for cultural and systemic change, that emphasizes moral accountability and collective stewardship in which innovation balances socio-ecological-economical imperatives. An emphasis on what could be called 'enlightened mutuality' could define a new civilizational development, one in which both humanity and the biosphere can flourish together.

8. Conclusion

Over the past two centuries, humanity has pursued industrialization and mass production with great vigour and enthusiasm. Innovation has opened many doors for cultural development, but there has been considerable cost to the environment and many issues resisting true human advancement persist today. As environmental decline approaches ecosystem collapse, global supply chains falter, protocols of international relations are dismissed, and international conflicts rage, civilization faces an existential crisis.

When human ingenuity is paired with ethical responsibility, innovation can focus more effectively on technologies, strategies, policies, and practical applications that can avert disaster and improve long-term stability. By intentionally incorporating all three pillars of sustainable development, innovation is more likely to produce holistic solutions with genuine long-term sustainability potential.

The study recommends the following actions:

- Educational reform: Reinstating ethics as a core component of advanced education, including a mandatory graduation oath of non-maleficence for scientists and engineers.
- Embedded accountability: Integrating regulatory safeguards, transparency and sustainability constraints directly into technological products.
- Global restoration: Launching coordinated international initiatives for large-scale ecological restoration, environmental cleanup, and the alleviation of poverty.
- Cultural shift: Promoting a deliberate transition away from consumerism through policies and narratives that discourage greed and encourage individual responsibility.
- Nuclear disarmament: Actively phasing out and dismantling nuclear weapons stockpiles in line with international treaties.
- Holistic urbanization: Design and construction of harmonious cities that emphasize human flourishing, community well-being, and ecological integration.

Implementing these measures at appropriate levels can help mitigate the inherent risks of unchecked technological development and foster a transition toward a new sustainable age of ethically responsible societies and vibrant, resilient cultures.

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