Sustainable Products, Processes and Systems: An Overview

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Introduction

The general objective of this chapter is to provide the necessary background and a flavor of the goal of sustainable development involving the economy, social equity and justice, and environmental protection. The specific objective is to capture the very essence of the environmental aspects and developmental prospects to bring about a sense of balance between nature and civilization. Sustainability, in the most comprehensive sense, should be interpreted to mean the practice of actual values in economics, ecology, culture, and politics for the endurance of systems and processes (Anastas & Warner, 1998; Dresner, 2002; Madhavan et al., 2013; Pogaku et al., 2013; Piemonte et al., 2013). It creates and maintains the conditions under which humans and nature can co-exist to fulfill the social, economic, and other requirements of present and future generations. The pillars of sustainability include three Ps: people, planet, and profit representing the social, environmental, and financial dimensions (Figure 1). There is a need to strengthen the education, employability, and productivity chain in crucial public and private sectors, including manufacturing, infrastructure, healthcare, education, and tourism. Social and economic development has to be balanced by environmental factors such as the use of land, consumption of resources, and the management of waste. The fine balance of oxygen, water vapor, nitrogen, and carbon dioxide in the biosphere is maintained by multiple biological processes. The natural biogeochemical cycles such as the hydrological, nitrogen, carbon, phosphate, and sulfur cycles, stabilize the biosphere and sustain the life processes on the planet. The range of landscape from the lush green tropical environment to the scrublands of deserts is threatened by climate change, and it would eventually destroy flora and fauna. A coastal oil spillage, for instance, is a disaster for the surrounding wildlife. The products ranging from petrochemicals to pharmaceuticals, fibers to food products, and from fast-moving consumer goods to functional foods are manufactured in industrial processes, and these creative expressions of human activities are an integral part of our living. The modernizing impulses are too strong that it disrupts the mechanism of contributing to balancing societal needs and environment. This trend affects the quality of the air we breathe and the quality of water we drink, impacting human health around the world and the world economy. Air pollution due to nitrogen dioxide and ozone provokes chemical changes in some airborne allergens and when it combines with changes in global climate, contributes to the more common airborne allergies. Despite all the emphasis on eco-friendly approaches, environmental problems like climate and temperature change, severe drought and hailstorms, untimely monsoons and flash floods, hurricanes and forest fires, water resource vulnerability, heatwave conditions, and emission of greenhouse gases (GHGs) have become more common in the recent past. The wind speeds and storm duration have increased considerably over the past 50 years. Today, we know that human activities across the world have a significant influence on climate change.

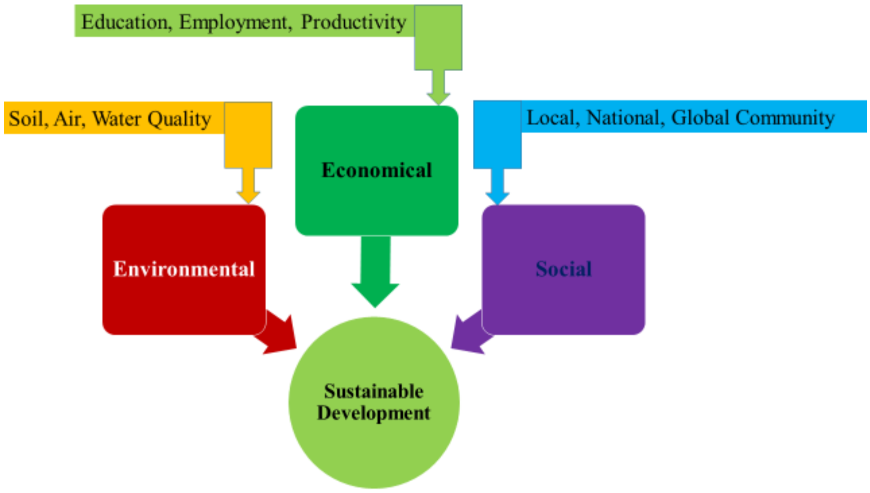

Figure 1. Scheme showing the whole picture of sustainable development, including triple-bottom-line approaches of clean employment opportunities, environment, and social development.

It is essential to understand the step-by-step mechanisms of product formations, scale-up operations, and manufacturing processes that will have a direct bearing on future higher growth prospects. An essential element is to gain a more in-depth insight into the processes that occur during their service under different environmental conditions. The detailed study of product or process development is vital to obtain rational insights into the precise nature of the environmental problems and to ensure the smooth operation of the system that reduces environmental impact. The interrelationship between development and other global environmental impact parameters helps better coordination among the stakeholders. The process or product level indicators such as water and energy usage, the efficiency of the process, the performance of the products, and waste produced are relevant to the manufacturing industry. We have to analyze the pros and cons of each product to have a firm direction on futuristic experiments and better outcomes in the journey of transformation that matters and remains. It is essential to take multiple concrete steps to resolve the issues and a battery of measures necessary to foster skills development and environmental protection for the collective and comprehensive development of the world. From this perspective, the citizens themselves need to distinguish between 'good' and 'not so good' human activities and think the shades of gray differently to face a different set of divergent challenges to adapt to the rapidly changing world. With a growing concern about environmental deterioration, it is better to focus on human activities with a more integrated approach to the challenges, including both the technological and cultural dimensions. The essential components of a sustainable ecosystem from a global and practical perspective include the following:

* Conservation of natural ecosystems

* Restoration and preservation of biodiversity

* Recycling of residues and wastes

* Minimizing product wastage

* Air and water pollution control

* Reducing environmental impacts across the entire ecosystem

* Innovative industrial solutions for efficient and clean production

* Establishing efficient transport networks

* Enhancing engineering skills

* Adopting better management practices

* Focus on emission reduction targets

* Protecting Earth’s climate system

* Use of renewable energy resources

* Dramatic energy efficiency improvements

* Need to emphasize healthy cooking methods

* Sustainable agricultural practices

* Stabilization of population for survival

* Environmental education and social awareness

* Expansion of formal sector and creation of jobs

* Remove legal and infrastructure hurdles

* Innovative green energy policies and programs

* Change people’s mindset towards responsible citizenship

* Creating new and meaningful business models

* Sensitizing people through online and offline campaigns

* Educate the public on current environmental concerns

Multiple Perspectives

The strategic goal of sustainable development is to balance the social, economic, and environmental needs of present and future generations. The key objectives include the effective conservation of natural resources, environmental protection measures, stable economic growth, social equity and justice, and creating conditions for future social and intellectual development. A cluster of social, political, and economic issues needs to be resolved to meet the requirements of a modern nation leading the way towards progress and prosperity. The part of the agenda of the civil society movements in several countries is to fulfill the basic needs of water, food, energy, employment, and sanitation. Environmental policymakers need to define the broad framework towards rethinking, redesigning, and restoring balance and stability in different cycles in nature while moving towards sustainable and holistic global developments. In addition to an array of effective environmental management techniques, it is essential to invest in establishing infrastructure for biosafety testing for toxicity and allergenicity, and implementing a rigorous biosafety process to prevent any serious adverse health impacts of genetically modified crops or products. The progress in industrial ecology involving the study of material and energy flows through industrial systems to meet the needs of humanity is essential for sustainable development. While short-term goals should be aligned with individual efforts, long-term goals should be aligned with collective efforts to produce more permanent finished products with clean processes and functional systems in our developmental journey. Another vital aspect of being considered is the life cycle analysis (LCA) or cradle-to-grave analysis involving the chain of steps, including raw materials supply and transportation, product manufacturing, packaging, actual use, and their safe disposal in an end-to-end model.

It is essential to divert the attention of the public from destructive activities and direct them in the path towards greenness. Higher education is an important instrument for changing the perceptions associated with the products, processes, and systems. It is indeed vital to adopt a middle path between industrial and environmental activism to strike a balance in the three sectors-economy, energy, and environment. The teaching-learning process and powerful positive thought processes develop value systems in life, and interdisciplinary research enables us to develop innovative products, physical and chemical processes, and complete systems with a focus on sustainability. The higher education system has a significant role in creating a global platform by managing quality, scale, and cost through a focus on learning outcomes, skill development on a large scale, and affordable cost. It is essential to strengthening the science, technology, and product linkage via enhanced coordination among universities, research and development laboratories, and industries. The implementation of mega-science projects via this crucial link can boost exploration and development as well as results and perspectives. There is a need to create credible mechanisms for development programs, particularly in emerging nations, to achieve remarkable progress. While awareness about environmentally friendly products spreading across the world, restoring environmental equilibrium, and taking clear and very valid eco-friendly approaches are useful in reducing the risk of future environmental problems. Incorporation of regular course on environmental studies in higher education, awareness programs, environmental workshops, seminars and symposia, literature festivals, interactive sessions, radio and television discussions, industry-institute interface meet, ecological risk assessment process, drama, dance or satire performances, and futuristic initiatives with increasing involvement of the general public would lead to remarkable improvements. Similarly, lead articles, editorials, special magazine features, technical commentaries, and even walkathon or marathon to highlight and draw attention to environmental and hygiene issues in the world can contribute towards meeting the expectations of the people through green methods. The science writers, critics, educationists, chief mentors, and researchers can play a pivotal role in providing the young and enthusiastic readers an overview of the current scenario and stress the need to develop the right attitude and a robust value system. A little psychological push for action in the right direction can make a massive difference in results. There is scope for turbulence, revolutionary activities, and mass movement to address the sustainable development and climate change challenges, as it is the top in the global challenges for humanity. The human development index (HDI) of a country is a measure of achievement indicating health, education, and prosperity, while the human sustainable development index (HSDI) also includes per-capita carbon emissions. We need to change the perception of public life and the environment by sensitizing people towards environmental issues worldwide and raise voices against environmental destruction and unregulated development. The integration of a holistic way of life in the most efficient manner, increasing connection with nature, and sense of the link between political ideology and organizational priorities could significantly influence the thoughts of the younger generation.

The emphasis on exploring science and engineering, technology and optimization, system, and management could contribute to enhancing the quality of life. The increased use of lead-free petrol, auto-exhaust catalysts, ethanol-petrol mixture, and compressed natural gas (CNG) in vehicles provide cleaner transport in the future, and providing high-quality public transport in a rapidly changing world is an important step towards sustainable systems. Because of recent rapid urbanization and accelerated carbon space utilization, the green building concept has gained immense importance in shaping modern infrastructure. Another recent trend is to establish eco-friendly industries and the development of micro-industrial hubs and the creation of regenerative cities. It is more useful to develop ancillary units using eco-technology principles to cater to large-scale industrial hubs. The cutting edge technologies and energy-efficient products and systems ranging from elevators to escalators, from digital photography to drug delivery systems, from petrochemicals to pharmaceuticals, from community food systems to higher education systems and smart materials to paperless smart offices will move us towards a progressive future. The broader implications of technology initiatives like a virtual office with business tools, a single-desk system, effective networking pathways, digital library, publications online store, and information technology-driven implementation include less paper consumption, improved efficiency, and productivity. Innovative, sustainable office concepts and workplace solutions like working from the home office have been gaining momentum in the recent past. The introduction of breakthrough changes in smarter products and services will be instrumental in driving people towards green growth and contribute to concerted conservation efforts.

There is a need to establish a comprehensive database on development and environmental fact and figures, information on types of environment, their characteristics, and importance, products that are hazardous to the environment, academic research data and findings, moral questions and answers, legal procedures, and explanations to educate the reader on every aspect of environmental care. Innovative initiatives like organic farming practices, the use of natural insecticides and genetically modified organisms in integrated pest management, and the use of biogas slurry as the significant nutrient for long-term plantation crops have enhanced the vibrancy of agricultural life. The application of membranes for water treatment and desalination, carbon dioxide separation and conversion, and designing the next generation of agrochemicals from nature also contribute to pollution control. The ecofriendly way of life, including veganism, recycling, alternative constructions, the use of solar panels at the rooftop and the windmill in coastal or desert areas, natural ventilation, and purchasing locally available seasonal vegetables and fruits go a long way to introduce change on a large scale. There is a 'grow your own' movement taking place across the world involving rooftop vegetable gardening for the sake of the environment and improving health. A new way of individual life that includes making conscious purchases of things we need for a healthy, happy life should be encouraged, and minimalism should enter the entire mindscape of people to meet the growing demand of the ever-increasing world population. It is better to have a crystal clear window to manufacture weapons based on logical needs in design and quantity. Our modern mechanical and busy life with high expectations would lead to a robotic existence, and we need catalysts to activate green goals to pursue. A series of development initiatives such as the development of megacities, world-class Greenfield city, multistoried complexes, manufacturing hubs, cleaner production, green computation, and large public projects would require benchmarking practices in making a sustainable ecosystem. The discipline, dedication, and determination enable us to be better equipped and smarter in dealing with the growing market challenges. In the future, the interplay between large multinational companies (MNCs) and megacities will play a significant role in determining prosperity. Best management practices at the asset reconstruction companies (ARCs) can result in a significant reduction in non-performing assets (NPAs) in the banking sector. Interestingly, sustainable cuisine comes within the principles of the natural world to preserve and protect the food supply for future generations and enhance the 'farm to fork' experience.

The use of renewable sources like solar energy would enable continuous and clean power supply, and smart grids could provide efficient energy services to the people. To solve the problems of intermittency and uncertainty, the radical idea of globally interconnected, smart, and robust grid clean energy delivery systems known as the 'global energy internet' may be useful. The hybrid cars that feature an additional clean electric engine are now on the roads that serve as an alternative form of transport. The use of fuel cells in transportation and electricity generation is also an example of green engineering. Changing the global energy landscape via energy production and its use in an eco-friendly manner improves the quality of life. There are ample examples of processes that involve some green aspect, such as the use of catalytic converters on cars, and efficient scrubbers on smokestacks and further investigations will reveal the most impactful way in which we should visualize our role in contributing to moving toward environmental restoration. The development of micro- and nano-electromechanical systems (MEMS and NEMS) enables the fabrication of sophisticated and miniaturized functional devices in different fields of application. The penetration of nanotechnology-based products in food packaging, medical diagnostics, energy, and security sectors, and innovation in nanotechnology is expected to create the next wave of global advances in technology. Green nanotechnology and green neuroscience have emerged recently as fascinating new disciplines, and the research focus will enhance knowledge and enable us to create new biomedical gadgets or targeted drug delivery systems (Drexler, 1992; Niemeyer & Mirkin, 2004; Smith & Granqvist 2010; Yarmush & Shi, 2012). The safety of nanotechnology depends on critical assessment of environmental exposure, toxicity concerns, models and methods of predicting and evaluating the impact of nanomaterials, and evolving techniques to avoid the risks and undesirable side effects. The development of tiny nanomachines or nanorobots may form the basis of the idea of a fully functioning nanofactory of the future. The creation and manipulation of nanoparticles can result in unique optical, mechanical, magnetic, electrical, and catalytic properties that are of great use in different fields of application. Self-cleaning surfaces based on the lotus leaf or construction of bionic cars are examples of innovations inspired by nature. The study involving innovation at the molecular level, focusing on new reaction pathways, leads to green chemistry. The design of eco-friendly alternative pathways for industrial products and processes to meet social needs and economic feasibility can lead to the development of sustainable chemistry. The co-existence model brings people and nature together to restore environmental temperature or to host intricate ecosystems that influence the development process. While moving to eco-friendly systems and processes, the lack of awareness in environmental systems, the inertia in the modern world, and a smaller percentage of overall products that are hazardous become obstacles to the development. Environmental research is rapidly expanding globally, and it would have a profound impact on the process of living. A long-term corrective action plan can restore equilibrium and contribute to sustaining standard weather patterns from season to season. A progressive development model, including a shift towards adopting responsible production standards, strategic management, creation of high-, middle- and low-skilled occupations, advancement in tertiary education practices, and healthcare management, will play a predominant role in achieving the green global mission and long-term sustainable growth.

There is considerable scope to reduce contributors such as industrial, transport, and firewood cocking emissions of GHGs through optimum combustion and minimal loss of energy. Carbon dioxide capture and sequestration (CCS) techniques can be used as a strategy for reducing GHG emissions. Other eco-friendly initiatives such as solid waste, e-waste, and biomedical waste management, rainwater harvesting, resource, and energy conservation, solar energy cultivation, development of smart materials and systems, green printing, green chemical process design, and manufacturing initiatives and recycling programs for paper, plastic, and glass would undoubtedly help in the protection and preservation of ecology. Establishing a large number of biomethanation plants worldwide to process the vast quantity of municipal solid waste (MSW) generated would help harness energy for human benefit and environmental conservation. Recycling of bulk e-waste such as smartphones, laptops, and tablets through a scientific recycling process in an environmentally sustainable way will have an impact across the globe. The disturbance of the marine ecosystem due to industrial effluents, chemical pollutants, sewage discharge, and climate change poses severe threats to fish populations. The growing energy demands of fuels (diesel and kerosene) in large-scale mechanized marine fishing and putting seafood on the plates also contributes significantly to climate change. The corrective measures include improvement in more efficient sources of seafood that play an essential role in reducing the carbon footprint and eventually achieve the sustainability of seafood. The used materials from beverage containers to plastic bags on coastal beaches and industrial waste discharge into the sea pose a grave threat to the ecosystem. This issue requires periodic cleaning and specific preventive measures as a part of waste management. Conversion of biodegradable food waste from hotels and hostels into high-efficiency green fuel cooking gas, methane, through the anaerobic digestion process, is an example of a sustainable livelihood model involving systematic disposal of tonnes of daily waste. The three dimensions of teaching-research, institution, and nation-building activities contribute to the developmental journey of humanity through a more meaningful global connection. The focus on multidisciplinary studies and the development of relevant research at the global level enables us to build the knowledge base to understand better the overall natural ecosystem health and issues related to the global challenges of a sustainable future. It may be worthwhile to set up a Special Environmental Operations and Protection Group (SEOPG) to inspire, educate people about pollution prevention processes and green development, and conduct regular safety and environmental audit.

The creation of a high-skilled, strong workforce by first-rate higher education would lead to a massive expansion of manufacturing products, and export-led growth in the competitive global markets. The three elements of innovation involving recognizing the problem, coming up with a solution, and its implementation would go a long way in the direction of the development of sustainable products, processes, and systems. Designing sustainable products and systems includes design thinking that involves three fundamental aspects: perception, possibility, and practicality with particular consideration for the environmental impact during their whole life cycle. The fundamental elements of successful product design include product quality (desired characteristics, precision, and ease of use), cost of manufacture, development cost and time, and enhanced development capacity. Chemical research and engineering should encourage the concept of an ecofriendly design of chemical products and processes that minimize or eliminate the use and production of hazardous compounds. The bottom line is to be able to evaluate the environmental, economic, and social consequences of different options in their personal, family, social, and professional lives that can make a world of difference, leading to a healthy, happy, and prosperous multicultural society. One of the most significant public challenges globally is to change mindsets to establish a collective action and enhancing awareness levels on vital conservation issues. This awareness can provide a new dimension to our thought processes and be able to perform a variety of roles across multiple functional domains in tackling progress-related health and environmental complications. A comprehensive system with the essential inbuilt checks and balances helps us to move forward in making cross-sector collaborative efforts in achieving global standards of learning and innovation. The practice of green chemistry and engineering not only leads to the development of sustainable products and processes but also has positive economic and social impacts. It is essential to apply the twelve principles of green chemistry to drive people towards green goals. These goals could be achieved by motivating them with a sense of purpose through the carefully crafted development plan, feasibility study for the projects, facilitating legislation, preservation of local ecology, hard work, and dedication (Ahluwalia & Kidwai, 2004; Ahluwalia, 2007; Anastas, 1998; Anastas, 2000; Anastas et al., 2002; Anastas & Beach, 2007; Anastas, 2013; Anastas & Crabtree, 2009; Chen et al., 2011; Collins, 2003; Dicks, 2011; Ehrenberg, 2011; Kirchhoff & Ryan, 2002; Lancaster, 2010; Leadbeater, 2010; Manley et al., 2008; Matlack, 2001; Newman, 2009; Parent & Kirchhoff, 2004; Ryan & Tinnesand, 2002; Roesky & Kennepohl, 2009; Sanghi & Shrivastava, 2007; Shankaranarayanan et al., 2010; Sharma, 2010; Sheldon, 2005; Tundo, Wilson & Schwarzman, 2009).

Waste prevention - Prevention of waste is better than treating or clean up after its formation in a process. The cost involved in the treatment and disposal of waste byproducts and unreacted starting materials adds to the overall cost of production. It is worthwhile to avoid the generation or use of hazardous substances than to waste money, time, and effort to deal with the consequences.

Atom economy - Design of new synthetic techniques to maximize the incorporation of all ingredients used in the process to obtain the final product and to increase the conversion of reactants into final products without generating undesired byproducts. It is a measure of how much of the reactants are incorporated into the desired products. Reducing the number of steps helps in the higher atom economy of the overall process.

Less hazardous chemical syntheses - Discover new synthetic methods that use and produce substances that are less toxic or non-toxic to human health and the environment. As risk is the product of hazard and exposure, it is possible to minimize the risk by reducing the hazard and exposure can never be reduced to zero.

Design for safer chemicals - Design of functional chemical products with reduced toxicity or no toxicity to human health in the short and long terms, i.e., reduction of intrinsic toxicity through structural modification or replacement while preserving the efficacy of function. Careful structural analysis or mechanism of action of specific chemicals can indicate the functional groups to be used in their synthesis depending on their desired activity or toxic effects.

Safer solvents and auxiliaries - Avoid unnecessary solvents, reagents, and auxiliary substances, however, safer ones should be used wherever possible. The use of supercritical carbon dioxide, water, or immobilized solvents could reduce the impacts of solvents on the environment and health.

Design for energy efficiency - Synthetic methods should be conducted at ambient temperature and pressure as far as possible. Recognizing the energy requirements for their environmental and economic impacts would have positive consequences around the world. Recovery and reuse of energy resources within the process can reduce the requirement for additional resources.

Use of renewable feedstocks - Use of renewable rather than depleting raw materials to obtain finished goods whenever technically and economically practicable. Minimize the use of dwindling resources such as coal, gas, and oil as they cannot be replenished through natural processes as rapidly as they are consumed.

Reduction of derivatives - Avoid or minimize unnecessary derivatization whenever possible to eliminate the requirement of additional reagents and energy. Use of blocking groups, protection, and deprotection, temporary modification of processes should be avoided as these steps generate additional toxic or benign waste and multifunctional reagents may be developed.

Use of catalysis - Selective catalysts offer distinct advantages over typical stoichiometric reagents. The use of heterogeneous catalysts has several advantages over homogeneous catalysts. Synthesis approaches for sustainable catalysis represent progress towards more sustainable chemistry. They may decrease the temperature of the reaction and enhance selectivity in specific reactions.

Design for degradation - Develop chemical products so that at the end of their function, they are degradable. They should not persist in the environment and break down into innocuous degradation products. Today, several biodegradable products are available in the market, and microbial degradation is also an alternative path for ecofriendly design.

Real-time analysis for pollution prevention - Develop analytical techniques to allow for real-time in-process monitoring and control. A monitoring mechanism for periodic course corrections would have effects on the consequences by reducing or eliminating the formation of toxic byproducts.

Inherently safer chemistry for accident prevention - Substances used in a chemical process should be chosen to minimize the chances of chemical accidents, including fires and explosions. If we use inherently safe chemicals, the likelihood of leaking into the environment through accidents such as explosions, fire, or the spill is minimized.

The process of development is more a question of visions of the vibrant and robust planet and collective efforts in providing clean and healthy living conditions that require necessary physical and digital infrastructure facility, institutional strength and modest skills base, and trade and other essential services at affordable costs. It is essential to create and develop engineering solutions beyond current or dominant technologies through improvements, innovations, and inventions on eco-friendly practices while protecting human health and well-being. Bioenvironmental and sustainability approaches and system approach to study nature, technology, and society are two of the megatrends in science and engineering. There is a need to learn the lessons from the history of previous incidents or events worldwide such as the greenhouse effect and global warming, industrial and environmental disasters, and sow the seeds of twelve principles of green engineering in the years to come that could lead towards a better future (Abraham & Nguyen, 2004; Anastas & Zimmerman, 2003; Avella et al., 2005; Kaab et al., 2019; Nabavi-Pelesaraei, 2019; Najafi, 2018; Nilashi et al., 2019; Nizetic et al., 2019; Nosratabadi et al., 2019; Parry & Baker, 1984; Stevens & Verhe, 2004)

Inherent rather than circumstantial - Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently safe and benign as possible. It is preferable to use water as a solvent than an organic solvent as it is inherently benign, reducing the need for constant monitoring.

Prevention instead of treatment - Strive to prevent waste generation than to treat or clean it up after its formation. Preventing or reducing waste at the source through the design of novel and innovative processes is more profitable for industries as it requires fewer unit operations. Reducing the amount of waste reduces the cost of additional processing, materials use, and energy and creates less burden on the environment.

Design for separation - Design separation and purification operations to minimize energy consumption and material use. Many conventional methods for separation need large amounts of hazardous solvents or consume large amounts of energy as heat or pressure.

Maximize efficiency - Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency. The standard chemical engineering optimization techniques would add value to maximize efficiency. It is better to maximize the energy intensity in the process rather than using low energy for long periods. We can reduce the need for elaborate safety and risk management methods by conducting the process in small spaces over a short time.

Output-pulled versus input-pushed - Products, processes, and systems should be 'output pulled' rather than 'input pushed' through the use of energy and materials. It is best to minimize the amount of resources consumed to produce desired products. It is better to remove the product produced immediately from the process to enable more significant product formation.

Conserve complexity - Embedded entropy and complexity must be viewed as a worthy investment when making design choices for recycling, reuse, or beneficial disposition. Simple products can be more easily recycled while complex products must be designed for reuse, and they need to be broken down into individual components, which are more material and energy-intensive.

Durability rather than immortality - The design goal should be targeted durability, not immortality. It should be durable enough to withstand anticipated operating conditions and avoid immortality of unwanted materials in the environment as stable molecules migrate to the upper atmosphere. The long-term impact resulting in environmental issues like bioaccumulation and persistence is reduced by designing a durable and biodegradable product.

Meet need, minimize excess - Design for additional capacity or capability solutions should be considered a design flaw. Innovative reactor design and miniaturization would lead to efficient heat and mass transfer, reduced reaction time, eliminate waste byproducts, and enhanced safety features. It is better to incorporate the specific requirements and functions of materials to avoid waste of materials and energy.

Minimize mate rial diversity - Minimize material diversity in multicomponent products or systems to promote disassembly and value retention. The options for final disposition are increased through designs that use a single material capable of performing the required functions. For instance, a polymer backbone can be tailored to accomplish the desired properties rather than using multicomponent materials.

Integrate material and energy flows - Design of products, processes, and systems must include integration and interconnectivity with available energy and material flows. Reusing waste heat or materials from another process by integrating process results in the recovery of materials and energy resources.

Design for commercial 'afterlife'- Performance metrics include designing for performance in a commercial 'afterlife.' Use life cycle thinking in all engineering activities. The design strategy of a pesticide should be such that it decomposes into safe materials in the natural environment within a time frame.

Renewable rather than depleting - Material and energy inputs should be renewable rather than depleting. Minimize the depletion of critical natural resources. The use of alternative sources of energy such as solar, wind, hydroelectric, geothermal, biomass, and hydrogen helps in this direction. The cost of recycling glass, paper, plastic, and aluminum is less than that obtained from fresh raw materials, and such methods contribute to the net consumption parameter.

Understanding the reasons for past and present pollution can help create multiple methods for future green development through reorganized thinking. For instance, lead is a toxic substance, and hence, serious health and environmental damage arising from exposure to toxic lead pigments, compounds from lead processing factory, and careless disposal of used lead-acid batteries by consumers. Lead can alter the body's neurological, biological, and cognitive functions and can cause problems like diminished intelligent quotient, inattentiveness, and hyperactivity in children.

A broad-brush observation suggests that environmental thought should be woven into our individual and collective psychologies to strive towards positive change in a growth-oriented approach. The emission of GHGs - water vapor, carbon dioxide, methane, and nitrous oxide - due to an increase in the set of domestic and international human activities have disturbed the natural mechanism to regulate the atmosphere. These gases trapped the heat of the sun and increased the average global surface temperature by 0.5^{o} C in the past hundred years. Climatologists believe that planet warming by at least 2^{o} C in the next few decades is entirely possible. Indeed, an increase in the global temperature may trigger a series of changes within the overall global climate system, and this could have unpredictable social, economic, and environmental consequences. We need to understand the interactions within and between biological and ecological systems influenced by human activities from a global perspective. It is even more critical that we understand the processes at work inside the Earth and underlying weather mechanisms for climate protection. The systematic increase of concentrations of substances extracted from the Earth's crust and those produced by society, physical degradation by natural processes, and unsafe working conditions all contribute to an imbalance in complex environmental systems and adverse climatic conditions. The potential impacts of climate change include rising sea levels, loss of coastal land, melting of polar ice caps and mountain glaciers, changes in evaporation and precipitation patterns, and drought and crop failure. Climate modeling has indicated that global warming will have a significant impact on the Earth's climate in this century. The large-scale migrations of climate refugees will increase as global warming continues. It is possible to protect ecologically sensitive areas (ESAs) sensibly, recognizing the gravity of climate change. The bio-indicators such as lichens, mosses, and algae species can indicate the quality of a wide range of ecosystems. They can indicate pollution due to sulfur dioxide or excessive phosphates and nitrates. It is essential to take urgent steps to address the conservation concern of vulnerable and critically endangered species across the world. The discipline concerned with analysis, design, engineering, and management of these systems is known as earth systems engineering management (ESEM), and the learner of this multi-dimensional subject can understand the capabilities and limitations of technology and the mechanisms to bring about real change in the existing lifestyle practices. A multilayered view can play an essential part in adding to the whole spirit of clean development mechanism (CDM) while technically correct priorities and global best practices will significantly improve the investment climate. It is worthwhile to have a global museum that displays photos and paintings of environmental disasters to tell the stories that people dealt with incidents and destructive activities, environmental struggle, and social protests. Such recorded transformative experiences and struggles can enlighten and influence our lives today and help us to take appropriate steps to reduce future adverse ecological effects or negative effects on human health. We have to adopt a comprehensive strategy to empower people through innovative information technology solutions to have better working, connecting and collaborating capabilities, and improved quality global communication networks. This strategy helps in a long-term engagement in creative thinking, collaborative decision making, developing design concepts, obtaining proof of concept, conducting validation studies, transfer of technology, and commercial-scale development of products or systems from affordable lifestyle products to dedicated devices.

The proper assembly of best-in-class products can achieve the desire for an economical solution for the essential needs in different processes within a complete system. The human brain is a very complex machine that can perform tasks that are beyond the current capabilities of artificial intelligent systems (AIS). It is essential to put efforts into the study with a focus on enabling technology and enterprise to enhance the sustainability of systems and to address complex sustainability challenges involved through systems thinking and an understanding of ecological principles. The purpose is to understand interconnections between products, processes and systems, and energy through nature and those through industrial civilization. Our body is like a sophisticated chemical factory ever designed consisting of many molecular systems working in harmony. The precise knowledge about how human body systems such as digestive, circulatory, respiratory, nervous, reproductive, and immune systems work together to make an impact suggests approaches to specific medical problems and health care systems. For instance, it may lead to the development of better recycling and waste removal systems, techniques of transforming different raw materials into substances we need to survive, the intricate defense system to fight against natural and artificial chemicals that can injure us, or the development of special senses, memory, and thinking. Inventions inspired by the observation, analysis, and understanding of natural processes and their use in innovative engineering designs and real-world technological applications may provide insight into some of the global effects of climate change.

Cutting-edge technology, sophisticated medical equipment, and insightful opinions from a team of medical experts can provide world-class health care delivery services for patients. The integration of different technologies in a system approach, state-of-the-art infrastructure, and multidisciplinary team of technical experts and civil society can provide a global platform for keeping our environment healthy. Systems engineering focuses on design and development, operation and evaluation, modeling and simulation, implementation, and management of complex systems over their life cycles. It may include a combination of several different systems such as chemical, mechanical, manufacturing, electrical, electronic, digital, civil, reliability, thermal systems, and precision components. There are enough opportunities for designing systems and managing green development in strategic sectors such as nuclear power, defense, space travel, satellite launch vehicles, aircraft, and missiles. The most critical problem with nuclear power generation is massive quantities of radioactive waste disposal at the 435 operable civil nuclear reactors across the world that have a severe impact on vegetation. Radioactive isotopes of noble gases Kr, Xe, and Ar are fat-soluble and can cause genetic diseases due to the emission of high-energy gamma radiation. The problem of space pollution due to spent or malfunctioning satellites, launcher stages, and fragments at specific orbits and altitudes have to be tackled systematically. Environment and climate change have been the subject matter of multilateral negotiations, strong inter-linkages, and interdependencies. Therefore, agreements among the nations in the World regarding the reduction of emissions of GHGs are the current global trend towards decreasing pollution and global warming without hampering industrial productivity growth prospects of certain developing countries. The concept of sustainable development is the origin of the Kyoto Protocol to combat global warming and climate change by reducing both its rate and magnitude by a legally binding agreement. It is an international agreement on climate change by setting internationally binding emission reduction targets of GHGs and allow us to face problems in an organized manner in a rapidly transforming modern world. The use of supercritical water medium and perfluorous liquids or the use of solvent-free conditions, electrochemical methods, and milder operating conditions have a role in sustainable development because of environmental and human safety concerns of traditional reaction media. It may require the integration of many complex components fabricated at the nanoscale, such as active electronic materials, sensors, and light detectors to make customized biomedical devices or other functional systems that would have profound implications to support life. The integration of smart indoor and outdoor devices in embedded systems would lead to better healthcare and environmental monitoring. Similarly, the application of eco-conscious colors to fabrics using natural dyes and creating biocompatible and biodegradable healthcare products, and establishing a vibrant electronic system design and manufacturing (ESDM) ecosystem would go a long way in supporting sustainable systems. Adopting alternative methods of transportation like walking, using public transport, car-pooling, use of ecofriendly cloth bags, conserving forests which are the treasure trove of biodiversity, planting trees in our surroundings and setting up of water treatment plants, and ensuring the recycling of wastes can help save our precious environment through environmental care systems. The design, manufacture, and distribution of eco-friendly and economical light-emitting diode (LED) lighting products and systems to government offices and commercial establishments across the globe play an essential role in moving towards a healthy development-environment balance. The end of analog film processing with the arrival of digital cinema and state-of-the-art digital laboratory reflect technology transition and the recent developments in green technologies like the use of LED lighting systems, which are of immense significance to understand and appreciate the connection of green aspects with human progress. At another level, a sprinkling of water to contain the pollution due to fine coke dust in individual petrochemical plants helps prevent local ecological damage.

The most fundamental approach to preventing pollution is green chemistry, and it is about reducing waste, materials, hazards, risks, energy, and cost. The main aims of green chemistry are to find out alternative synthetic pathways for pollution prevention and lower overall costs associated with environmental health and safety. It has now been possible to carry out environmentally benign chemical synthesis using aqueous phase, supercritical fluids, ionic liquids, phase transfer catalysts, enzymes, ultrasound, and microwave technologies under green conditions. This green reaction medium would replace the conventional volatile organic compounds (VOCs) used as industrial solvents in several processes. The discovery of a catalytic process called metathesis, which uses significantly less energy and stable at room temperature and pressure, is a typical example of green chemistry. The metathesis can be used to break down natural oils and recombine the fragments into high-performance chemicals. It can be used in combination with greener solvents to manufacture certain specialty chemicals, and the process reduces GHG emissions. Yet another example is the process that uses supercritical carbon dioxide in one of the steps of computer chip preparation that significantly reduces the quantities of water, energy, and chemicals required to produce such chips. The green synthesis of the drug, Sitagliptin, used in the treatment of type 2 diabetes is possible using an enzymatic process that reduces waste, improves yield and safety, and eliminates the need for a metal catalyst. The preparation of biodegradable plastics from agricultural products and waste, paint formulations using bio-based oils to replace petroleum-based solvents, and creating a paint that is safer to use and produces less toxic waste or fewer amounts of VOCs. It is also vital to improve the sanitary landfill and incineration techniques in waste management, implement noise control, absorption and protective measures, and effective control of water, air, food, and vector-borne diseases. Monitoring air and water quality, noise, and radiation levels can be used to manage pollution and waste. Recently, much progress has been made in the preparation and characterization of starch-based and chitosan nanocomposites. These nano-biocomposites show great potential in biomedical applications because of biocompatibility and biodegradability. Examples of designed chemical systems made up of a discrete number of assembled molecular components include supramolecular systems to mimic the functions of biological systems, and reacting system examples include chemical process industries (cracking of crude oil), waste treatment ponds, and extraction of metals from the ores. The practice of efficient energy management systems, domestic wastewater, and industrial drainage treatment systems, telecommunication, and software systems help to realize the dreams of the future. We can certainly improve the safety, health, and working conditions of humans with efficient environmental controls, continuous improvements in new technologies, and encouraging entrepreneurship and dynamic leadership. The increased entry of the right people into the global entrepreneurial ecosystem will fuel the growth engine dramatically and ensure the smooth operation of the interconnected systems with productivity and efficiency.

It is necessary to respect the environment in the best interest of the people and conform to the principles of sustainability as we should help people from all walks of life. Also, protect the environment to avoid the severe consequences of the greenhouse effect and climate change effects that may trigger several diseases in susceptible individuals. Sustainability and development must be put in the correct perspective with an element of pragmatism. The climate change challenge has to be dealt with locally and globally with active involvement and participation of the stakeholders comprising groups across academia, industry, government, funding agencies, and civil society in a constant process. Climate Resilient Agriculture (CRA) is an initiative towards a practice of sustainable agriculture in a changing climate scenario. While economic growth requires enhancing agricultural production and establishing a manufacturing base, it should not be at the cost of the environment. Mechanized farming practices and the creation of distinctive manufacturing clusters will serve as an excellent vehicle to take development to the next level. There is a need to strike the right balance between the interests of people and environmental protection, just like a healthy work-life balance. Therefore, it is necessary to include environmental impact assessment (EIA) and social impact assessment (SIA) in the plan evaluation of any developmental project. We have to proceed further via practical and tailored long-term strategies that will help us reach the green goals more efficiently and effectively. There is an opportunity for the green climate fund (GCF) and CDM to carry out collaborative research activities to get better insights into crucial sustainability issues. Identifying several functional systems in Nature allows us to set up future research projects focused on understanding how each system functions with the ultimate goal of developing artificial systems specifically for particular applications. The comprehensive study of ecosystems helps to explain the interrelationships and interactions between living organisms and their biological, chemical, and physical environment, and publishing articles, create awareness among the people about the judicious use of natural resources. Today, more attention is paid to learning about critical ecological concepts and ecosystems, including improvisation and exploration within an educational system that helps to accelerate the process of sustainable progress and prevent the danger of doing the planet irreparable damage. Exploring the research challenges, developing cutting-edge technologies, discussion of future possibilities, and implementation of advances would lead to novel sustainable products, processes, or systems with significant economic growth and increased living standards. World Environment Day (WED) is celebrated every year on the 5th of June to raise global awareness of environmental issues to take affirmative action to protect, preserve, and enhance the environment.

The energy system is the aggregate of different sources and forms of energy and techniques of obtaining, converting, distributing, and using them at different levels and interconnected sophisticated equipment and organizational systems. The development of the energy industry needs reliable production indicators involving processes that make full use of raw materials and less waste generation. The impact of a coal-based power plant on the environment due to GHG emissions must be minimized by promoting 'green coal' technologies, scaling up wind and solar energy production, and the use of alternative fuels such as CNG in vehicles, that are less polluting. The use of pollution control equipment such as high-efficiency electrostatic precipitators (ESP), low-NO_x burners, high chimneys, and flue gas desulfurization (FGD) plants help reduce air pollutants from thermal power plants to some extent. Interestingly, biogas power plant systems provide renewable energy at low cost and help improve public hygiene by recycling waste, plant, and algal materials and low environmental impact. Biogas as an alternative fuel can be used for cooking, heating, and generating electricity. Institutes around the globe should equip the learners from a broad spectrum of sectors in systematized knowledge (theory) and contemporary practice (practical experience) so that they strive to make a difference in the world by changing the production and consumption patterns of fossil fuels. It is the responsibility of the education system to ensure education in a dignified manner through proper mechanisms, as it is a powerful weapon to change the world by influencing the mind of the learners. Tertiary education should promote path-breaking basic science research and cutting-edge frontier technologies in a disciplined way for a brighter world. It should address the issue of a lack of the requisite number of paraprofessionals specialized in this sector that is a significant factor in implementing environmental and resource management from a scientific perspective. The implications of this transformation in the whole environmental care scenario are manifold. The education should emphasize environmental lessons most interestingly to get a thorough insight into development management. There is a need to develop a performance culture towards sustained high and equitable growth, and a comprehensive learning experience equips the student community to deliver better results and become responsible global citizens of tomorrow.

There is a need to provide a sound support system across a broader spectrum of innovative technology ideas with considerable potential for impact or commercialization or improved environmental performance. We need to encourage a sustainable enterprise that has a minimal negative impact on the environment, economy, and society. Establishing an interconnected network of detectors or people to monitor all human activities on earth and promoting environmentally conscious and sustainable activities by proper planning and implementation is an essential step towards climate change and sustainability. The medical system must consistently address patients' needs to fulfill societal obligations and for the benefit of the suffering humanity through expert treatment, skilled surgery, technological solutions, and emotional attachment for effective and efficient humane healthcare. There should be a significant improvement in preventive and curative aspects of healthcare systems that would bring big dividends. The unsustainable exploitation of certain critically endangered medicinal plant species should be prevented to preserve the entire biodiversity and care for the planet by supporting sustainable practices. The medical education and research system should be appropriately oriented from detailed planning to operational execution to achieve a broader objective of health for all and the right to health with a sense of equality and justice.

The development of non-conventional power systems on a mass scale could arrest pollution to no small extent, and sophisticated technologies coupled with legislative reforms could make a significant contribution to development processes. The discovery of new methods to control pollution due to rapid industrialization with the potential for more sophisticated follow-up observations could reduce harmful ecological consequences, and effective disaster management also has enormous ecological importance. The long-term commitment to an extensive ecological restoration, including afforestation, sustainable cultural practices, and adopting the least intrusive means in promoting ecotourism and horticulture traveling, may result in the stability of the atmosphere and enhance the green cover in the planet. Nature camp, nature walks, and bird watching activities provide youngsters an exciting exposure to natural experiences and particular orientation towards sensitizing them to the ecological aspects and conservation issues that help develop the eco-consciousness. In a larger university system, each institution is represented by several departments working together in harmony and strengthening the academic culture of science-based problem solving and societal development with social awareness aimed at achieving technology commercialization through CDM and primary pollution prevention to effectively mitigate global climate change. The emerging trends in technology include additive manufacturing using 3D printing to print spare parts for machines, drone technology for commercial photography and to save survivors during flash floods or landslides, and the development of tabletop, handheld, and wearable devices. 3D printing is useful in making medical implants, dental crowns, joint implants, and other organs for transplants. Recently, a water sampling drone was tested for its capability to collect water containing bugs, mud, or algae in hard-to-reach areas and check for signs of oil spills at a later stage in a laboratory. A variety of wearable devices such as activity trackers, smartwatches, and smart-shirts are already in the market. Higher education plays a substantial role to awaken, educate, enlighten, and fortify the younger generation with the ordinary random facts woven into a new fabric of more meaningful value chain development while working towards progress. A comprehensive study of all the developmental and environmental aspects will help us to know the logic of sustainable practice and to gain the edge and the depth that are essential for definite progress. In this context, it is essential to pursue a series of specialized lines of investigation to understand nature and its behavior and to tread the sustainable scientific path of development. We have to take proactive and exemplary actions and ideals forward with a sense of justice. This aspect is determined by the pattern of thoughts and concepts that arise and a passion for progress.

Bulk, fine, and specialty chemical processes of the future can be redesigned to eliminate or decrease the use of hazardous organic solvents. The process design must include downstream processing as an integral component and should have fewer steps, minimum waste, and maximum yield. They should be inherently safe and preferably involve one-pot continuous operation using operational tools such as catalysis, waste management, and process intensification while practicing sustainable engineering. It involves the sustainable use of energy and resources in the design of products, processes, and systems or operating systems with the integration of social, environmental, and economic considerations (Figure 2). A multipronged approach from ideological education agenda to a catalyst of higher education excellence is required to generate a value chain, including awareness, concern, action, and results in the right direction. The immediate challenge before the education system is to excel in higher science, engineering, and management education, research, and practice. Interdisciplinary research work should be encouraged to obtain new insights and better practices. A particular focus on advanced molecular modeling techniques helps scholars to design innovative solutions to complex problems faced by the healthcare research domain and the development of drug therapies. A change in procurement policies of certain commodities like palm oil that involves deforestation and social evil, the use of child labor in individual countries would have a higher ecological significance that should be encouraged. We have to look at development as a participatory process to bring about a dramatic transformation by considering the long-term sustainability of each of the products, processes, and systems. A shift in the attitudes of the younger generation towards the environment will be a significant milestone in the long term to establish the crucial links between human beings and nature. The essential requirement is to take immediate pollution measures to reduce the intensity of the problem without ignoring other developmental aspects in the pipeline. Enhanced use of technology and multiple office connectivity in real-time helps move towards total green office solutions. It is essential to motivate people to create cleaning processes in public spaces, including religious places. The implementation of projects with checks and balances is needed to keep the surroundings clean and safeguard the ecology and maintain the highest standards of hygiene.

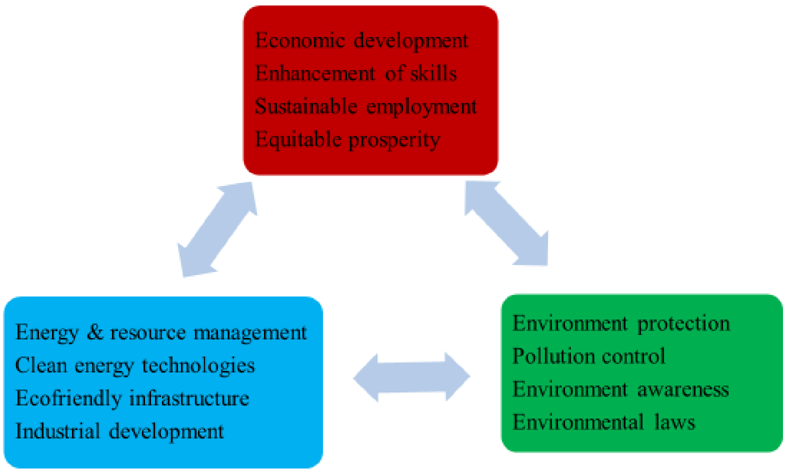

Figure 2. Scheme showing a continuing sequence of stages that can occur in economic, energy, and environment sectors in the actual process of sustainability

More excellent knowledge of the various biogeochemical mechanisms governing global environmental balance should enable us to better target remedial measures according to the local environmental profile. The current trends, recent advancements, and new approaches cover the multiple aspects of design, delivery, disposal, productivity, profitability, and packaging. Domain expertise, workmanship, professionalism, and social skills will lead to smart technologies for the production of compact disc players to complex scientific instrumentation systems and artificial satellites to military embedded systems. The complex issues in sustainability involve the journey in the value chain, including human resource development and impact on environmental footprint. This aspect consists of factors such as innovative downstream process technologies and the process of continuous improvement, minimizing negative economic, environmental, and social impacts, and enhanced system reliability. The critical issues in the chemical and material industry must be addressed through comprehensive vision, strategic sustainability objectives, developing new initiatives, effective execution processes, key performance indicators, and sustainability improvements in the products, processes, and systems. For effectiveness, the print, television, and web narratives should cover the newsworthy items in education, healthcare, and environmental sectors to prevent future environmental degradation, and inspire, influence, and inform young minds about active involvement in public affairs that will ultimately help bring profound change. This trend also helps prepare people to speak of sustainable development, spread information about activities, form a network of supporters, face sustainability challenges, and force the government to take much more comprehensive measures. The sustainability culture must be developed via strategic actions to arrive at sustainable solutions as we should leave future generations a better place to live.

It is essential to establish green systems that ensure accountability, responsibility, transparency, and active involvement of people in healthy and desirable activities. Building a better environment is the responsibility of all of us, and this noble act will be in the interest of the whole world. The entire humanity and industrial leaders, journalists, lawyers, environmentalists, and civic associations must coordinate to drive economic growth and empowerment to the citizens. Given the crucial importance of the environment and healthcare systems, higher budgetary allocations are required to make any significant improvements to cater to the human needs of the population. There should be greater coordination among the different countries in the world on sustainability issues, systems, and operations. Cooperative global proactive approaches, strengthening of multilateral partnerships, a mammoth social awareness campaign, advancing core priorities with economic and environmental interests and creating and developing ecotourism and industrial parks, development of mega and smart cities, coupled with pollution control mechanisms could radically change the whole environmental landscape of the planet leading to the positive impact of a global growth increase (Figure 3). The strict imposition of laws is necessary but not sufficient for the building and sustenance of scientific communities to ensure greener earth for a better future. The regulatory steps required to control pollution and necessary clear guidelines at various stages, even in the engineering phase, of production, assembly, and marketing of functional systems, must be framed and executed. The supply systems and management must ensure that the quality products reach the consumer without any adulteration down the entire supply chain. The establishment of a center for the environment (CE) is essential to check and report harmful chemicals such as mercury in cosmetics and skin tightening lotions, and adverse reactions of commercially available consumer products or drugs, and to detect adulteration of petrol, oil, and other food products that we consume every day, in the interest of the society. The natural consequences of this outlook are a step-by-step analysis of the conditions for the practice of science as a process and the general orientation of policies towards underlying issues related to industrialization. Further, a museum of inventions and prototypes from all fields of engineering and industry and a digital repository of knowledge, including training materials, will set the individual on the track of innovation and create awareness about the delicate balance between ecological sustainability and industrial transformation. Perspectives of the origin, evolution, and development of processes provide a platform for people interested in sustainable and holistic living, and planned and positive thinking with due considerations to green aspects provides a prudent approach to productivity and profitability.

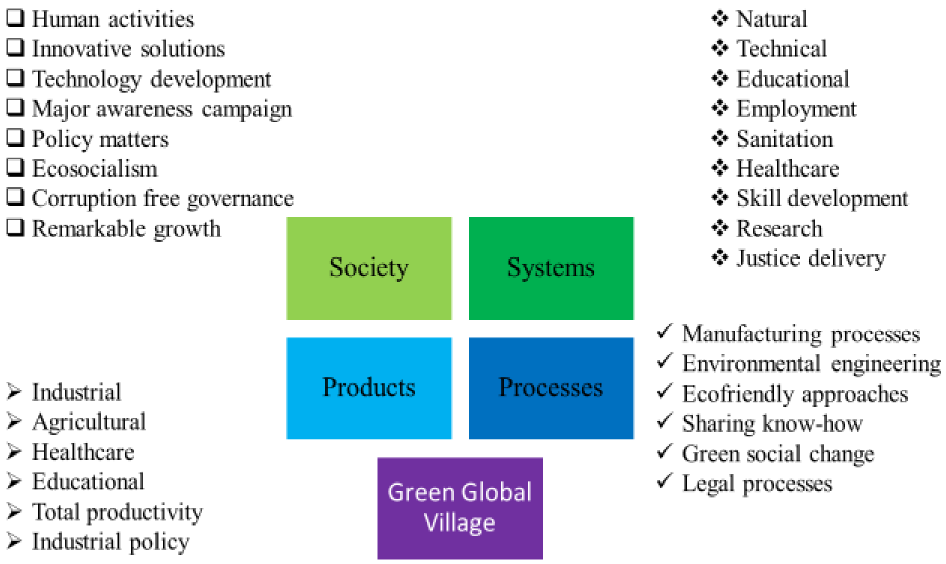

Figure 3. A Broad View of Economic, Scientific, and Infrastructural Development Aspects that Provides Green Signal for Accelerated Growth in Different Sectors Using Available Resources while ReducingEnvironmental and Industrial Health Hazards.

Conclusions

Our collective future rests on actions to push public awareness campaigns for clean air and to prevent environmental degradation of various scales through industrial policy formulation and implementation. The challenge is to strive for a balance between specific directions and the collective sustainable sensibilities in promoting the true scientific spirit. It is more useful to focus on the interests of people toward climate change and climate justice in our developmental journey. The standard legal document that conforms to international best practices and processes that lead us to a better understanding of how one can proceed forward will be a significant milestone in facing the development challenges ahead, and this is significant in the context of the right to a pleasant environment. Moreover, it is crucial to initiate constructive reforms and empower environmental courts committed to the protection and preservation of the environment and providing a more effective mechanism relating to liability and compensation to the victims of pollution and ecological damage, and promoting environmentally sustainable growth via practical and tangible action plan and acceleration in technological advances. Success involves the integration of various elements from a desire to design and from futuristic ideas to advance technologies. They can be listed as strategic vision, specific reforms, innovative thinking and professionalism, a culture of performance, entrepreneurial ecosystem, expansion of the industrial cluster model, conducive business environment, business-friendly tax structure, value-added services, climate parliament, and policy matters. It remains to be seen whether a multidimensional approach to the topic and the same ideological bents of mind coexist and proper coordination and constructive cooperation will result in green progress soon with success in multiple fronts to make sure the Earth remains a good place to live for generations to come.

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