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IMPLEMENTATION OF METHODS AIMED AT SUSTAINABLE DEVELOPMENT THROUGH BIONICS

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Abstract

Given the significance of the concept of sustainability and the methods used to fulfil its objectives, the paper aims to highlight the possibility of utilizing Bionics to find and implement methods aimed at sustainable development.
In the authors' opinion, the mentioned methods and means can be complemented by using Bionics as a source of documentation and implicitly applying models aimed at increasing sustainability.
Considering the specificity of this science to decode the "inventions of living nature" by observing natural phenomena, mathematical modelling, prototyping, and verifying theoretical results with practical outcomes, the paper presents several classic examples that contribute to the effort for sustainable development: the drag reduction effect in all fluid flows, based on the shark skin model, used in creating a coating for aircraft to reduce energy consumption, or swarm intelligence of bees and ant algorithms that transfer the behaviour of insects and other animals living in larger communities into technical areas.

Key words*: Bionics, sustainable development, method, biological models.*

INTRODUCTION

The introduction is based mainly on four paper s (European Commission, 2019; European Commission, 2021; European Commission, 2023; European Environment Agency, 2023). Accordingly, sustainability is a highly relevant concept in contemporary society and broadly refers to the ability to perpetuate a process continuously over a defined period.
In the context of business policies and practices, sustainability denotes the capacity to operate and produce without depleting the planet's resources, with the intent of preserving them for as long as possible.
Sustainability, or sustainable development, was first defined by the United Nations in the Brundtland Report over 30 years ago as the capacity to exist and progress without exhausting natural resources. Consequently, sustainability involves meeting humanity's present needs without compromising the resources designated for future generations.
The concept of sustainable development originates from the understanding that Earth's resources are finite, thus limited, and must be utilized responsibly and conservatively to mitigate the negative effects that could adversely affect the environment. The sustainability concept is built upon three pillars: environmental, economic, and social—colloquially referred to as planet, profit, and people.
Currently, there are two principal categories of sustainability: economic sustainability and financial sustainability.
Economic sustainability refers to growth based on well-structured plans and projects, in which medium- and long-term resources intended for core activities are clearly delineated. Additionally, these plans detail the manner in which resources will be utilized, as well as how waste will be collected, stored, transported, and reused, ensuring these operations contribute to the economic prosperity of the business and align with sustainable development goals.
Financial sustainability is closely related to economic sustainability, in that all projects for sustainable development can attract various funding sources and financial instruments. Simultaneously, financial sustainability leads to

reduced raw material costs by optimizing production or service expenditures.

The concept of sustainable development encompasses all forms and methodologies available to both the general population and businesses for utilizing natural resources, aiming to establish a balance between social, economic, and environmental considerations, with a focus on environmental protection.

A developed society must exhibit a high degree of sustainability to achieve harmonious development. Sustainable behaviour is characterized by efforts to protect the environment and the incorporation of ecosystem-friendly practices into daily life.

The notion of sustainable development is supported by current legislation, which has been aligned with the latest European regulations in this field. These regulations pertain to environmental monitoring, selective collection and recycling of resources, environmental legislation, and the adoption of green energy technologies.

The United Nations has outlined sustainable development goals (SDGs) aimed at ensuring a better and more sustainable future. These seventeens goals tackle global challenges related to sustainability, including poverty eradication, zero hunger, clean water and sanitation, affordable and clean energy, and responsible consumption and production. The objective is to achieve these targets by 2030.

In 2018, the European Commission introduced six key transformations, which, if properly implemented, will enable improved sustainability by 2050:

- Enhancing education and healthcare to achieve higher income levels and make more informed environmental decisions.
- Responsible consumption and production, emphasizing doing more with fewer resources to support the adoption of a circular economy and reduce demand.
- Decarbonising the energy industry through the use of clean and renewable energy resources to provide affordable and sustainable energy.
- Ensuring clean food and water through the protection of the biosphere and oceans by fostering efficient and sustainable food systems. This can be achieved by increasing agricultural productivity and reducing meat consumption.
- Developing smart cities through intelligent infrastructure and internet connectivity.
- Promoting a digital revolution in science, technology, and innovation to support sustainable development.

In conclusion, a sustainable society must be socially responsible, focusing on environmental protection and maintaining a dynamic equilibrium between human and natural systems.

MEANS OF ACHIEVING PROPOSED OBJECTIVES

Considering a recent work (Ioniţă, 2023) and common knowledge popularised on several media channels (twi-global.com, 2023; spotmedia.ro, 2023; ecosynergy.ro, 2023) we may describe the means of achieving proposed objectives as follows.

In the last decade, several methods have been analyzed for society to achieve sustainability, ensuring that the environment is adequately protected. Humanity can develop without depleting or excessively exploiting planetary resources, nor should they be degraded or destroyed.

One of the most salient examples involves the ever-increasing quantity of waste, which affects both terrestrial and aquatic environments, significantly impacting the quality of life for humans and animals and contributing to pollution. Thus, a business can become economically sustainable in terms of waste collection by devising a sustainable development plan, which ensures compliance with reporting, collection, and valorisation obligations for packaging waste until legal requirements are met. These obligations may also attract financial support.

When addressing waste collection, economic sustainability can be achieved by creating short- and medium-term plans that implement various recycling solutions for packaging. The ultimate goal is to reduce costs associated with collecting, sorting, storing, and transporting waste to specialized companies that can transform it into reusable resources.

Selective collection and the reuse of packaging and waste represent some of the most effective concepts of sustainability, enabling companies to contribute to sustainable development. Waste collection and transformation should form the foundation of all societies aiming to achieve prosperity and healthy development. By expanding the process of waste collection and recycling, pollution levels can be reduced.

In many regions of the world, massive pollution causes numerous problems. *Factories release chemicals into the air or discharge pollutants into rivers, seas, and oceans,* affecting both flora and fauna, as well as human health. It is crucial *to reduce pollution levels* in order to safeguard public health and secure a future that is not jeopardized by more severe environmental problems.

In addition to air pollution, there are other pressing environmental challenges. For instance, *waste that enters rivers, lakes, seas, and oceans* severely impacts aquatic flora and fauna, leading to ecological imbalances. Aquatic life is endangered, and *many plant and fish species are on the brink of extinction*. Moreover, *chemical spills into the soil* compromise the quality of agricultural crops, leading to poor crop development.

To mitigate these challenges, humanity must turn toward methods to prevent and combat pollution in these environments. In addition to *proper waste collection and secure storage that minimizes environmental impact, waste must also be recycled*. Furthermore, citizens can support sustainable businesses that utilize *biodegradable products or packaging*, cloth bags that can be washed and reused, and *eco-friendly cutlery*. Additionally, clothing made *from eco-friendly materials* should be adopted.

Waste must be disposed of in specially designated bins in central or residential areas, which are equipped with separate compartments for plastic, paper, glass, and metal. Food waste should be disposed of in spaces reserved for organic waste.

A sustainable lifestyle can be adopted at both the individual and corporate level by engaging in selective waste collection and the valorisation of all waste that can generate reusable raw materials, by conserving resources, and by using clean energy wherever possible. It is widely recognized that *fossil fuels take significantly longer to regenerate than the time it takes for humans to consume them*, which means they are not a sustainable energy source. Solar and wind energy, by contrast, are renewable resources available almost continuously, depending on the region, making them viable for indefinite energy supply.

Sustainability is a vital component of any economic activity, as it involves reintegrating primary resources and raw materials obtained from recovered elements through selective collection. This leads to sustainable development, and natural resources can thus be protected, conserved, or preserved for future generations. Sustainable development also involves a commitment to reducing the negative environmental impacts, particularly through the extensive use of renewable energy sources.

Significant financial savings can be achieved, and these savings can be reinvested in modernizing equipment, production facilities, and logistics, or even transitioning to a more advanced level through automation or robotic systems, improving overall labour efficiency.

By considering *tidal and wave energy*, we already possess enough renewable resources to achieve global energy independence.

With *the ongoing climate crisis*, sustainability is increasingly becoming a priority for businesses, as people are becoming more aware of these phenomena and adapting their lives to align with legislative standards. It is likely that in the future, the positive impact on the climate throughout the entire value chain, the enhanced impact on the environment, the improvement in human health, and the productive contribution to society will become the responsibility of companies across all industrial sectors. Environmental damage and harmful emissions must be either reduced or eliminated from production processes.

Moreover, there is a focus on reusing resources to accommodate the global population growth through the implementation of a *circular economy*, allowing one person's waste to become another person's resource. This would drastically reduce waste and create a more efficient supply chain.

By recycling old products—such as aluminium, gold, or copper, which cannot be replaced with alternative materials—we can extend the lifespan of these resources, contributing to sustainability.

Reducing the carbon footprint across all sectors, better water resource management, and even developing solutions to create new potable water reserves for vulnerable areas are essential. Meeting energy demands without releasing harmful emissions is crucial to achieving healthy living, energy independence, and ecosystem preservation.

In the authors' view, the aforementioned methods and solutions can be supplemented through the use of Bionics as a documentation source and implicitly applying models aimed at enhancing sustainability.

PRINCIPLES OF BIONICS

Speaking about Bionics (Rechenberg, 1973; Schwessinger, 1994) we may say that Bionics - alternatively termed biomimetic or biomimesis - is the discipline concerned with the systematic deconstruction of the "inventions" of living nature and their innovative implementation into technological applications. The foundational premise is that natural structures, processes, and systems have been (relatively) optimized through evolutionary mechanisms.

Bionics operates as an interdisciplinary field, where researchers from diverse domains such as biology, engineering, and, when necessary, architecture, philosophy, and design collaborate to develop novel solutions.

The term BIONIK (originating from the German language) is derived from a combination of the words "biology" and "technology." This reflects the discipline's central objective - harnessing principles derived from biological systems and applying them to technical challenges. Bionics goes beyond mere natural inspiration by systematically identifying and decoding these principles for direct technological implementation.

There are two primary pathways in bionics:

Analogical Bionics (a "top-down" approach), where solutions to engineering problems are specifically sought within biological systems. This method involves identifying biological analogies, analyzing them, and utilizing these insights to solve technical challenges. In this case, the biological model is retained and applied to the design or problem in question.

Abstraction Bionics (a "bottom-up" approach), where biological principles are abstracted and detached from their natural context. These principles are then used as templates to conceptualize solutions for technological issues that may not have a clear biological counterpart. This involves recognizing a fundamental principle within a biological model, abstracting it into general scientific terms, and then developing applications in collaboration with engineers, designers, and other technical experts.

Bionics is a highly interdisciplinary field, enriched by new and enhanced investigative methodologies, including advanced computing, modern manufacturing processes, and cross-disciplinary input. While engineers developing functional technical elements were not always aware of corresponding biological solutions, bionics explicitly searches for structures, processes, and systems within nature that are potentially significant from a technical perspective.

This search for biological analogies is not an accidental discovery, but a systematic and intentional exploration.

Bionic’s *main domains of application*:

- Bionics has found utility across a wide spectrum of domains, each reflecting the versatility and applicability of biological solutions.
- Construction Bionics: Investigates biological structural elements and compares them with engineering constructions to optimize load distribution, stability, and material efficiency.
- Sensor Bionics: Examines biological sensor systems for the reception and processing of stimuli, such as vision, olfaction, or auditory systems, and applies these principles to improve technological sensors.
- Motion Bionics: Focuses on the study of locomotive systems in nature, such as propulsion mechanisms and flow control in animals. For instance, studying the surface structures and flow regulation mechanisms of marine animals can lead to advancements in aerodynamics and hydrodynamics.
- Neurobionics: Investigates the natural transfer and processing of information in biological neural systems, translating these mechanisms into information systems and robotics.

- Process Bionics: Analyzes biological processes, such as photosynthesis, with the goal of optimizing energy transfer, resource utilization, and efficiency in industrial processes.
- Anthropobionics: Studies biological movement—particularly in animals—for applications in robotics and artificial intelligence. This includes replicating animal behaviours or movement mechanics in machines and automation systems.
- Climatic Bionics: Engages with natural systems for ventilation, cooling, and heating, using biological models to develop passive and efficient systems in architecture and climate control technologies.

Bionic approaches can be categorized into two methods for addressing technical problems. First we mention *Bionics as a "Top-Down" Process (Analogical Bionics)*: In this approach, biological analogies are sought in nature, thoroughly analyzed, and then applied to technical challenges. By leveraging biological knowledge, this method mirrors the principles observed in nature within technical contexts.
Examples:

- Bird flight: The vortex structures observed at the tips of bird wings, such as those of condors and vultures, have led to the design of winglets on aircraft. These winglets reduce the large vortices created at the wingtips, which are responsible for significant fuel consumption. By mimicking the multi-vortex structure of bird wings, engineers achieved a reduction in aircraft fuel consumption by 5-6%.
- Cat paw biomechanics: When changing direction, the cat's paws expand, increasing the contact area with the ground, thus improving stability. This observation inspired the development of advanced tire profiles that improve vehicle grip, stability, and safety in various driving conditions.
- Spider leg mechanics: Autonomous control mechanisms observed in spider legs have led to the creation of spider-like robots, which exhibit greater productivity and efficiency compared to centrally controlled robots.

Secondly, *Bionics as a "Bottom-Up" Process (Abstraction Bionics)*: This method starts with fundamental biological research, identifying underlying principles in biological systems, abstracting them, and then seeking possible technical applications.
Examples:

- Lotus leaf effect: The water-repellent and self-cleaning properties of lotus leaves—where water droplets roll off without adhering—have inspired patented technologies for non-wettable and self-cleaning surfaces. These are now used in products such as facade paints that remain clean over time by mimicking the lotus effect.
- Shark skin structure: The study of shark skin, which consists of tiny, closely packed scales with fine grooves aligned parallel to the flow of water, has led to the development of riblet films. These films, applied to the surface of aircraft, reduce drag by minimizing air resistance and thus lead to significant reductions in fuel consumption.
- Swarm intelligence: The behaviour of bee swarms and ant colonies - specifically how they self-organize and solve complex problems - has been transferred into technical systems such as information processing algorithms. These swarm-based models are used to optimize various technical applications, including distributed computing and network management.

A possible conclusion: Bionics reflects the study of the biologic evolution results from the engineer perspective.

CLASSICAL APPLICATIONS OF BIONICS RELATED TO SUSTAINABILITY IN TECHNICAL FIELD

Discoveries derived from observing nature (Rechenberg, 1973; Schwessinger, 1994; Niedner, 2017), which are subsequently transformed into technical solutions, align with the strategic objectives of sustainable development, regardless of the methods employed.
The following section reviews various technical applications that illustrate the significance of bionics, particularly from the perspective of sustainability.

In the materials science domain, several notable advancements have been made such as:

- Solar Paint (BRESOPAN): A novel material used in the production of energy through photovoltaic processes, contributing to cleaner energy solutions.
- Self-structuring bridges (Ossit): Inspired by biological systems, the structural design of bridges can adaptively reinforce itself, enhancing load-bearing capacity. This increases durability and promotes material efficiency, thus contributing to sustainability by reducing the amount of material needed.
- Self-healing materials (NovoOssit): Drawing on biological mechanisms, these materials have the ability to automatically repair damage, such as filling potholes in roads. This innovation not only extends the lifespan of infrastructure but also reduces the demand for new material production, which is energy-intensive. Additionally, the decrease in infrastructure failures contributes to accident prevention, further emphasizing its importance in the sustainable development context.
- Resilin-based rubber (Resilinex): Inspired by resilin, a highly elastic protein found in the joints of insect wings, this nearly perfect synthetic rubber offers superior resilience and energy efficiency. Its application in various mechanical systems reduces energy loss and increases overall durability.

In the transportation sector, innovations stemming from biological observations have led to significant advances in energy efficiency:

- Shark-inspired micro-longitudinal grooves: The development of specialized surface textures mimicking the dermal denticles of shark skin has resulted in a reduction of drag, significantly improving the aerodynamic performance of aircraft. These grooves help to streamline airflow, contributing to a reduction in fuel consumption by up to 80%.
- Flexible surfaces and dolphin-like propulsion: Borrowing from the hydrodynamic efficiency of dolphins, flexible surfaces that mimic their skin dynamics are applied in aircraft and submarines to further enhance energy efficiency. This innovation leads to a 90% reduction in fuel consumption for submarines by utilizing biologically inspired damping properties.
- Medusa-inspired propulsion: Mimicking the motion of jellyfish, this system offers efficient propulsion for submarines by reducing energy losses and improving underwater manoeuvrability.

In the domain of waste management, the implementation of protein-based mechanisms (PROMIM) offers a biologically inspired solution for waste reduction and material recovery. Regarding neuro-bionic applications, the coupling of artificial sensory organs with parallel neural networks (PNN) presents groundbreaking advancements in neural systems, contributing to enhanced sensor technology and neural communication.

In the field of agriculture, innovative bionic applications offer biological pest control solutions. For instance, the bionic cleaning beetle and dragonfly-based models are employed to eliminate agricultural pests, such as the Colorado potato beetle, reducing the need for harmful chemical pesticides.

Swarm engineering draws inspiration from the behaviour of bees, utilizing their collective intelligence in various technical domains, including construction and distributed system management. This bio mimetic approach allows for optimized structural designs and resource-efficient construction techniques.

The key to these bionic applications lies in their energy-saving potential, enhanced material longevity, and reduction of resource consumption. By adopting nature’s optimized strategies, technological developments benefit from increased sustainability, which aligns with long-term economic efficiency and environmental protection goals.

These examples underscore the transformative potential of bionics in driving sustainable innovation. By reducing the reliance on non-renewable resources, enhancing energy efficiency, and creating systems that can self-repair or self-regulate, bionic applications contribute significantly to minimizing environmental impact while maximizing technological performance.

CLASSICAL APPLICATIONS OF BIONICS RELATED TO SUSTAINABILITY IN ECONOMIC AND MANAGEMENT FIELDS

Nature serves as a model for management systems, particularly in the optimization of process flows and communication between organizations (Niedner, 2017; Futur, 2022; Futur, 2023). A classic example lies in the behaviour of ants, which locate food sources efficiently because ants that have already found the food leave a pheromone trail behind. Other ants can then follow these trails, ensuring a highly efficient process for locating resources. This biological behaviour has been replicated in logistics, where companies utilize algorithmic models based on the ants' pheromone tracking system to design optimal transport routes, thereby reducing transit times, lowering costs, and minimizing carbon dioxide emissions.

Researchers working within the domain of economic bionics also study the communication strategies of colony-forming insects, seeking insights that can be applied to team management and organizational behaviour. In this context, swarm intelligence offers a model for solving complex problems through decentralized interaction. Just as individual ants or bees contribute to the collective decision-making process, companies can emulate this model by encouraging collaborative problem-solving, where new ideas are pursued and developed through group participation. This also suggests that managers should be willing to invest time in exploring and implementing innovative concepts, much as nature optimizes survival through gradual adaptations and mutations.

In the realm of evolutionary economics, it becomes evident that companies should not seek to impose constant technological progress by force, but rather engage in a more adaptive approach, akin to natural selection processes. In nature, mutations and variations arise organically, leading to breakthroughs in survival and efficiency. Similarly, companies should not only focus on generating new products but also revisit and refine existing solutions that have proven effective. This evolutionary perspective on management supports the idea that businesses must be agile and responsive to external changes, avoiding a linear or rigid trajectory.

The field of evolutionary economics proposes techniques that assist organizations in preventing and managing future economic crises, drawing on the premise that companies are dynamic and complex systems rather than mechanistic and predictable entities. One key insight from this field is that the complexity and unpredictability of a company's growth mirrors the fluctuating patterns seen in nature. Much like the evolutionary process, businesses experience phases of expansion and contraction, and these cycles of growth and crisis are inherent to their development. Consequently, economic bionics suggests that crises are not abnormal phenomena but are part of the natural lifecycle of organizations. The focus should be on developing adaptive strategies to manage these crises, rather than attempting to prevent them entirely.

Biological systems in nature are well-equipped to handle adverse conditions by evolving over time. Plants and animals anticipate challenges, developing traits that enable rapid adaptation. Similarly, companies need to have robust early warning systems in place to detect and respond to impending crises. In this context, corporate strategy should prioritize long-term sustainability rather than short-term profit margins, as relying solely on quarterly financial results is an insufficient measure of corporate health. For organizations to grow sustainably, they must continuously adapt to evolving external conditions, not just when they face immediate threats. This concept is mirrored in natural ecosystems, where organisms are in a constant state of adaptation to ensure survival. Similarly, companies should embrace evolutionary strategies that allow them to shift business models as needed, which is often essential for long-term viability.

Furthermore, each organization must develop its own tailored solutions for the challenges it faces, rather than focusing solely on eliminating competitors. Internal cooperation among departments should be encouraged, rather than fostering internal competition, just as cooperation within natural communities - such as those in bee hives or ant colonies - leads to increased productivity and survival. In such biological systems, the collective effort is always greater than the sum of individual actions.

In responding to crises, companies should not limit their strategies to cost-cutting, restructuring, or process optimization. These measures are often insufficient on their own. Instead, what is required are soft management skills, such as leadership, the development of cooperative abilities, and the flexibility to embrace change within an organization.

In summary, the bionic approach in economics emphasizes that recurring crises and periods of change are an inherent part of organizational growth. Thus, companies must develop the flexibility to leverage both opportunities and risks, using evolutionary principles to manage periods of turbulence effectively.

Nature, while not inherently more equitable or just, does provide an invaluable framework of flexibility and innovation from which organizations can learn. Nature's adaptive processes, honed over millions of years, offer a blueprint for understanding how complex systems survive and thrive. By adopting these strategies, companies can enhance their sustainability, resilience, and long-term success.

Biological diversity, with its millions of species, ecosystems, and landscapes, represents a vast repository of natural wealth that has direct implications for human existence. However, in national budgets and corporate balance sheets, the conservation of nature is often seen primarily as a cost, rather than as an investment that yields economic returns. The role of nature as a productive force - one that contributes to economic growth, value creation, and job markets - is systematically undervalued. Yet, biodiversity provides solutions to nearly every imaginable problem, and while precise quantitative data on its benefits may not yet be available, numerous applications of biological models have demonstrated innovative and economic advantages.

One of the fastest-growing sectors globally is ecotourism, which includes travel and recreation based on experiencing nature. This vast industry, encompassing a wide range of activities, engages nearly the entire population. Ecotourism responds to diverse individual lifestyle preferences, from tranquil forest retreats to the appreciation of unique landscapes, encounters with wilderness, and outdoor sporting activities. In this context, the economic necessity of nature conservation becomes particularly evident, as it provides direct economic benefits. The revenues of private tourism companies and related industries often depend on maintaining intact natural environments, and any tourism model that disregards environmental concerns runs the risk of self-destruction.

CONCLUSIONS

For these paper we intentionally used more open bibliographic sources in order to show that sustainable development using bionics is at hand with huge potential to boost the sustainability because nature is the most efficient developer and manager.

This paper seeks to underscore the pivotal role that Bionics currently plays, and can continue to play, in fostering sustainable development, as articulated by contemporary legislative frameworks.

Bionics leverages scientific methodologies to "learn from nature" in the pursuit of solving both technical and economic problems. It represents a comprehensive approach to research and development, where solutions, inventions, and innovations are derived from the observation and analysis of biological systems and subsequently transferred to technical systems and economic models.

By conceptualizing living organisms as highly advanced technological systems, bionics enables a paradigm shift that resolves the perceived dichotomy between nature and technology. This suggests that a technology more in harmony with nature - or more efficiently adapted to natural cycles - can be realized through bionic approaches. Such an approach would yield technologies characterized by enhanced properties, improved adaptation to ecological cycles, lower risk profiles, higher tolerance for errors, and greater environmental compatibility.

This paper, through a review of pertinent literature, highlights the potential for applying bionic principles across a wide range of disciplines, including but not limited to construction, device engineering, process optimization, material sciences, locomotion systems, and management strategies. Bionics, thus, provides a promising avenue for innovation and sustainable development across diverse fields of human activity.

Nevertheless, there are considerable barriers hindering the broader integration of bionics within current innovation ecosystems. These include extended development timelines for bionic products and processes, resistance from industrial sectors, disparities between academic and industrial stakeholders, limited but increasing funding for research, the absence of bionics from formal educational curricula, and communication gaps between key sectors.

Despite these obstacles, the successful application of bionic innovations in a range of technical fields, combined with the existence of management frameworks inspired by natural systems and the growing academic interest in this domain (universities started to introduce bionics in the curricula, i.e. National University of Science and Technology POLITEHNICA Bucharest), strongly supports the notion that Bionics offers the tools and perspectives necessary for achieving sustainable development.

By providing actionable solutions for implementing the concept of sustainability across various industries, Bionics emerges as an essential instrument in the realization of environmentally sound, economically viable, and socially equitable practices.

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