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Sustainability: Quo Vadis?

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ABSTRACT

Humanity's over-reliance on fossil fuels has pushed the planet to a critical tipping point, resulting in environmental crises, including the sixth mass extinction and escalating extreme weather events. A landmark Sino-European forum emphasized the need for global cooperation, innovation, and societal transformation to achieve sustainability. Discussions highlighted innovations in materials science, such as bio-based and biodegradable materials, sustainable construction, and the growing importance of a circular economy. The forum stressed that sustainability is not just a technological challenge but requires systemic changes in production, consumption, waste management, and societal awarness and attitude shift. The shift towards a sustainable future also requires addressing energy needs, resource use, and fostering education to raise awareness. Despite challenges, the forum underscored the urgency of collective action, advocating for a balance between human progress and environmental health. Global collaboration is essential to creating a future that prioritizes planetary restoration and responsible stewardship.

1. Introduction

After centuries of over-reliance on fossil fuels, humanity has pushed the planet to a critical threshold. The Earth's atmosphere is thick with pollutants, the oceans are burdened by vast amounts of plastic waste, and ecosystems that once thrived are now fragile and fading. Scientific studies and mounting evidence reveal that we are in the midst of the sixth mass extinction, a phenomenon primarily triggered by human activity. These alarming indicators make it abundantly clear: the trajectory we have pursued over the past three centuries is unsustainable.

Over the past two decades, the reality of the environmental crisis has become impossible to ignore. The frequency and intensity of extreme weather events—hurricanes, floods, droughts, and wildfires—have risen dramatically, with devastating consequences for communities, livelihoods, and ecosystems. These events have caused the extinction of many animal species and claimed countless human lives. They are not isolated incidents but clear signals of the rapid destabilization of the Earth's

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climate system. Although scientists predicted this scenario as early as the 1980s, it is unfolding faster than anticipated.

Humanity stands at a crossroads, and the word 'crisis' feels more relevant than ever. While in English, the term often carries a negative connotation, its original Greek meaning conveys a sense of judgment or a decisive turning point—an apt description of our current situation. Similarly, the Chinese word for crisis, 危机 (Wei Ji), combines 'Wei (危)' meaning danger and 'Ji (机)' meaning opportunity. This duality underscores that the challenge we face is both perilous and promising. The choices we make today will determine whether we remain on a path toward environmental collapse or embrace a future that prioritizes the health of our planet and all its lifeforms.

2. A call for unified action

On July 8th, 2024, a landmark Sino-European forum held at South China University of Technology in Guangzhou convened about 25 members of the Chinese Academy of Sciences, the Chinese Academy of Engineering, the European Academy of Sciences, representatives from the European Materials Research Society, and European industrial leaders to address the interconnected crises of energy, resource depletion, and environmental degradation. The forum was synthesized by participants, taking into account the coverage of different disciplines and the track record of the participants in sustainability related studies and projects.

The discussions emphasized that achieving sustainability will require unprecedented levels of global cooperation, investment in innovation, and societal transformation.

The forum emphasized that sustainability is not merely a technological challenge but a global and societal endeavor. Achieving it requires fundamentally rethinking how we produce and consume, manage waste, and use natural resources—prioritizing reuse over exploitation. The transition to a sustainable future hinges on embracing systemic changes across multiple sectors, from energy production to consumer goods. Accordingly, discussions focused on the United Nations' Sustainable Development Goals (SDGs), particularly SDG 7 (clean and affordable energy), SDG 12 (responsible production and consumption), and SDG 13 (climate action). Fig. 1 illustrates indicative pieces of the sustainability puzzle that should all be addressed in a significant degree, implying also the multidisciplinarity of the problem and the cooperation and cross-fertilization between different fields.

2.1. Innovations and challenges in sustainable materials science

Discussions at the forum underscore significant advancements in the development of materials aimed at minimizing waste and optimizing resource efficiency. A key focus has been the exploration of bio-based and biodegradable materials as alternatives to traditional plastics. Notable innovations include the use of renewable resources, such as dandelion rubber, to develop biodegradable tires. These bio-sourced materials offer promising solutions to reduce environmental pollution from tire waste, decrease reliance on finite resources, and mitigate overall ecological impact (Guicherd et al., 2024).

Similarly, agricultural byproducts are being repurposed into high-value materials. For instance, activated carbon derived from agricultural waste is increasingly used in energy storage systems and environmental remediation efforts (Sagadevan et al., 2024). These applications highlight the growing potential of waste-to-resource technologies in promoting sustainability.

In the construction industry, cutting-edge technologies such as self-healing materials (Gerlinde et al., 2022), active curing control (Korda et al., 2025), and smart monitoring systems (Shiotani et al., 2024) show promise in enhancing the longevity and resilience of infrastructure. These innovations help reduce waste, minimize the need for energy-intensive repairs, and improve long-term sustainability (Han et al., 2019; Ye et al., 2025). Moreover, the healthcare sector is seeing a revolution in regenerative medicine, where functional biomaterials are being developed with smaller ecological footprints (Soriente et al., 2021; Bigham et al., 2024).

2.2. Living materials and sustainable construction

A particularly promising area in sustainable materials science is the development of living materials, which integrate biological functions into non-living substrates. For example, concrete surfaces designed to support plant growth represent an innovative approach to sustainable construction. The fusion of engineering and biological sciences allows for the creation of multifunctional building materials with environmental benefits. Living walls, for instance, act as natural air filters by absorbing carbon dioxide and trapping airborne pollutants, thereby improving urban air quality. These green structures also help mitigate the urban heat island effect, reducing the energy needed for air conditioning (Jimenez et al., 2024). In addition, bacteria doped concrete can heal cracks by precipitation of calcium carbonate and enhance durability of structures, while composites incorporating algae or microbes allow to biodegrade naturally, while maintaining a sufficient level of mechanical properties. Such innovations exemplify how materials science can contribute to planetary restoration by addressing critical environmental challenges (Vieira et al., 2018; Jia et al., 2024).

Fig. 1. Critical pieces of the sustainability puzzle, as emerged in the Sino-European Forum.

2.3. Towards a circular economy

The concept of a circular economy, where waste is minimized and resources are continuously reused, is widely regarded as essential for a sustainable future. However, achieving 100 % circularity remains unrealistic due to the fundamental limitations of the second law of thermodynamics. Nonetheless, progress can be achieved by reimagining production systems to facilitate material reuse and recycling. This includes recycling construction materials and reusing entire components which, after serving their lifespan in one design, can be disassembled and integrated into new applications if their structural capacity remains adequate. Similarly, reusable formworks are increasingly employed in construction to reduce waste (Oval et al., 2023; Zhan et al., 2020).

Advances in metal recycling and low-carbon metallurgy are already enabling the reclamation of valuable metals like copper and aluminum, reducing the need for destructive mining practices (Wei et al., 2024). These developments play a crucial role in promoting sustainability and reducing the environmental impact of resource extraction.

2.4. Reconciling energy needs and resource use

The pursuit of a sustainable future also requires addressing the dual challenges of clean energy and responsible resource consumption. Although renewable energy technologies, such as solar panels and wind turbines, offer promising solutions, they often rely on materials and designs that prioritize efficiency and performance over recyclability. Consequently, the end-of-life disposal of these technologies presents its own environmental challenges.

This dilemma is not only limited to large-scale energy systems but also extends to everyday devices, such as smartphones, appliances, and vehicles. These products are typically optimized for performance and convenience, but are not designed for efficient disassembly and recycling. Shifting toward a model where recycling is prioritized will likely require rethinking device architecture, potentially at the expense of performance. This raises a critical societal question: Are we prepared to embrace technologies that may be slower or less efficient if they ensure a healthier planet for future generations?

Such a shift demands not only advances in engineering but also a fundamental cultural transformation. Societal acceptance of trade-offs in performance, coupled with a rethinking of consumption patterns, will be essential. Reducing consumption and enhancing energy efficiency will be core components of this transition, which may require a reevaluation of our current economic models.

3. Education and cultural transformation

While technological advancements are critical, education and public awareness are equally vital. Sustainability must become a guiding principle in curricula, empowering future generations to make informed decisions about resource use, waste reduction, and energy consumption.

A key aspect of this educational effort consists in fostering an understanding of interconnected global challenges. Climate change, resource scarcity, and social inequality are not isolated issues—they are deeply intertwined. Encouraging a sense of shared responsibility and collective action will be essential in overcoming these challenges (Tilman, 2023).

4. The road ahead

The Sino-European forum underscored the urgent need for international collaboration in addressing the global sustainability crisis. It is important to acknowledge that international politics responded to the climate crisis over 30 years ago with the establishment of the Intergovernmental Panel on Climate Change (IPCC), the convening of annual climate conferences, and the adoption of far-reaching decisions. However, these measures are often not implemented. Moreover, the international political framework has grown increasingly fragile, strained by a multitude of crises. Diverse forms of resistance—including misinformation, complacency, lobbying, and personal financial interests—continue to obstruct decisive global action.

Therefore, important steps in the forward direction include:

i) the responsibility of the scientific community is to provide clear, actionable evidence to counter misinformation, fostering collaboration across disciplines, and actively supporting the implementation of evidence-based policies to overcome resistance and promote global climate and environmental action.
ii) Governments, industries, and citizens must come together to prioritize research, innovation, and scaling of technologies that can deliver meaningful change. This will require not only scientific breakthroughs but also significant shifts in societal attitudes and behaviour.
iii) Apart from scientific breakthroughs, significant shifts in societal awareness and attitude should be encouraged, with society being ready to embrace technologies that may be less efficient but contribute to a more sustainable planet.

The transition to sustainability will not be easy, and will not happen overnight. Yet the urgency to act is undeniable. By rethinking how we design and use materials, adopting cleaner energy systems, and fostering an economy based on optimized production, reduced consumption and where possible recycling, we can chart a path toward a future that harmonizes human progress with environmental stewardship.

Now is the time to embrace this opportunity and act decisively. Together, we can reshape our world into one that values balance, responsibility, and the enduring health of our planet. The stakes are high, yet so are the possibilities. We need to come together and act, before it is too late.

CRediT authorship contribution statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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