Available online at http://cadmusjournal.org/
Cadmus
Promoting Leadership in Thought that Leads to Action
Volume 5, Issue 4 - July 2025

Securing the Future with Deep Tech, Quantum Information Science, and AI

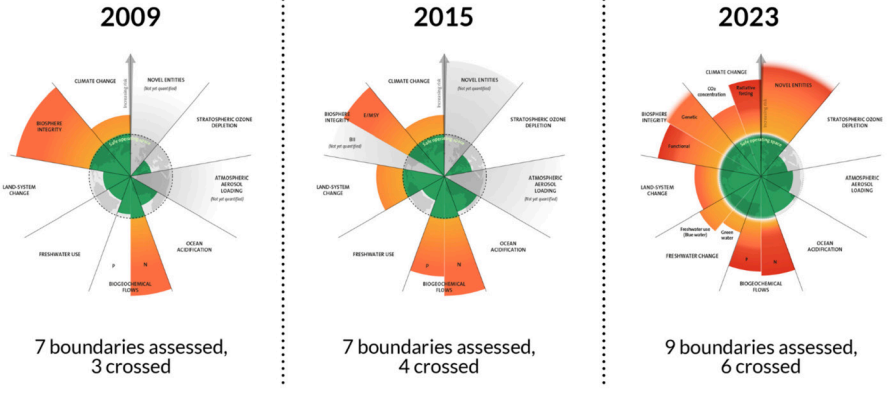
Mariana Bozesan
Fellow, World Academy of Art & Science; Full Member, Club of Rome;
Founder, AQAL Capital & AQAL Foundation, Germany

Abstract

This paper centers on the critical role of deep technologies, Quantum Information Science (QIS), and the often-overlooked potential of artificial intelligence (AI) in ensuring a sustainable future. While public sphere discussions often center on the downsides of artificial intelligence (AI) and the need for regulation, this chapter emphasizes how deep technologies, leveraging AI, are currently driving significant progress across essential sectors of the economy, including energy, food, and transportation. This chapter argues that by harnessing advanced innovations, we can effectively address current crises and disruptions. It makes a compelling case for prosperity rather than austerity and shows the transformative potential of these technologies in achieving net zero goals, positioning deep technologies and Quantum Information Science with AI as essential catalysts in the pursuit of a sustainable future.

1. No Retreat from Climate Change without Prosperity

Figure 1: The evolution of the planetary boundaries framework. Licenced under CC BY-NC-ND 3.0 (Credit: Azote for Stockholm Resilience Centre, Stockholm University. Based on Richardson et al. 2023, Steffen et al. 2015, and Rockström et al. 2009).



The stability of Earth relies on its operating system, specifically its nine Planetary Boundaries (PB) that regulate it and include biosphere integrity, freshwater availability, ocean acidification, biochemical flows, land-system change, ozone depletion, and climate change—please note that climate change is one out of many other planetary boundaries. Unfortunately, six of the nine boundaries have already been breached (Figure 1) and threaten life and human activity as we know them.[*]

Any transformation presupposes a change of mindset—reflecting the highly influential emotional, spiritual, psycho-social, and cultural factors—that must evolve to enable transformation toward sustainability.

Tessa Moeller et al. argue the risks associated with the tipping of safe planetary boundaries in response to overshoots, could be reduced *if* planetary warming is precipitously reversed by decreasing greenhouse gas emissions to net zero or below by 2100.[†] Moeller et al. join other scientists including the director of the Potsdam Institute, Johan Rockström et al., who agree if (1) *all* economic transactions begin to account for the *total cost* of planetary damage, (2) collective planning and global cooperation are increased, (3) cutting-edge technologies such as AI (and I would add Quantum Information Systems) are included, and (4) rapid acting, to name a few major activities.[‡]

It goes without saying that any transformation presupposes a change of *mindset*—reflecting the highly influential emotional, spiritual, psycho-social, and cultural factors—that must evolve to enable transformation toward sustainability.[§] RethinkX founders, Tony Seba and James Arbib view the "reductionist, narrow, linear mindsets" of current incumbents as the main reason that currently prevents transformation.[¶] Continuing to patch up "old systems through 'Band-Aids' solutions which address the symptom not the cause," (p. 56) will only accelerate the collapse they contend. Conventional frameworks, Seba and Arbib argue, are an "extraction-based system of production" driven by zero-sum game trade-offs that fail to appreciate the complex processes of change. Conventional frameworks often fall short to fully understand their own system dynamics leading to an underestimation of both the threat posed by unsafe planetary boundaries and the potential of technology to mitigate them. But there is tremendous hope.

[*] Planetary boundaries, https://www.stockholmresilience.org/research/planetary-boundaries.html

[†] Tessa Moeller, et al, "Achieving net zero greenhouse gas emissions critical to limit climate tipping risks," *Nature Communications* 15 (2024). [DOI: 10.1038/s41467-024-49863-0].

[‡] IPCC, AR6 Synthesis Report (2023) https://www.ipcc.ch/report/ar6/syr; Francesco Fuso Nerini et al., "Extending the Sustainable Development Goals to 2050 — a road map," *Nature* Viewed August 1, 2024 https://www.nature.com/articles/d41586-024-01754-6

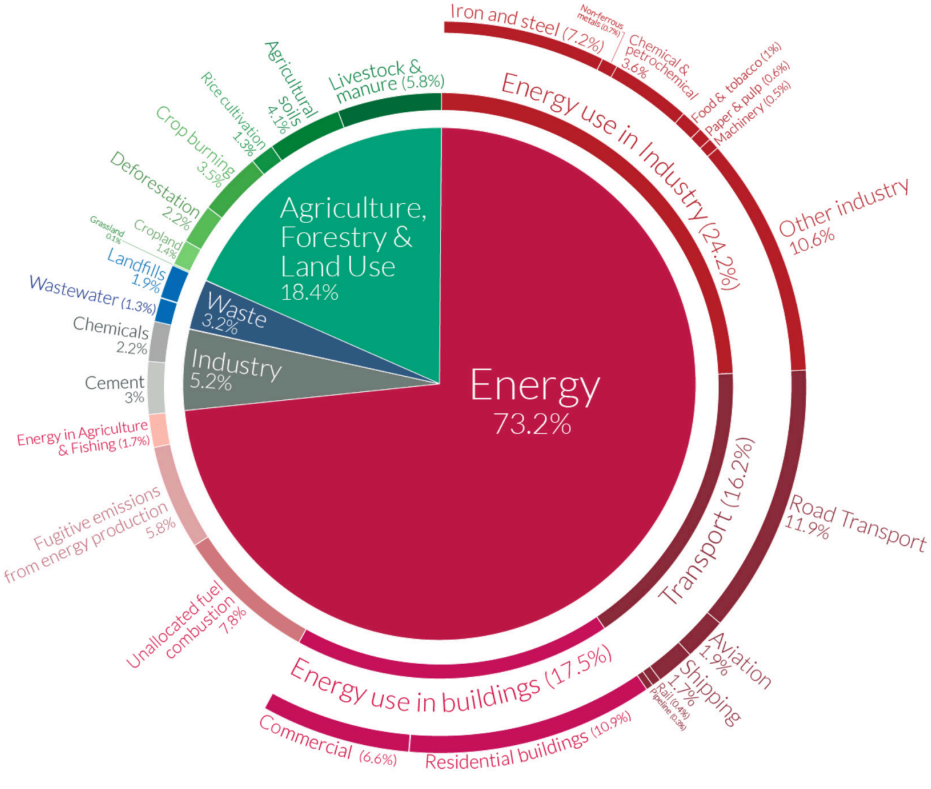
[§] Mariana Bozesan, "Turning Mindshifts into Transformation Leadership," in *Transformation Literacy*, eds. Petra Künkel and Kristín Vala Ragnarsdóttir (Cham: Springer, 2022), 235–253 https://doi.org/10.1007/978-3-030-93254-1_16

[¶] Tony Seba and James Arbib, *Rethinking Climate Change: How Humanity Can Choose to Reduce Emissions 90% by 2035 through the Disruption of Energy, Transportation, and Food with Existing Technologies* (RethinkX, 2021), 56 https://www.rethinkx.com/publications/rethinkingclimatechange2021.en

2. Net Zero is within Reach

More than 90% of greenhouse gas emissions come from three economic sectors, namely energy supply (57 %), food production (18.4 % from agriculture, forestry and land use) and the transport sector (16.2 % from road transport, aviation and shipping) (Figure 2).[1]

Figure 2: Global greenhouse emissions by sector in 2016 – Source: Climate Watch, the World Resources Institute (2020). Licenced under CC-BY by the author Hannah Ritchie (2020)[*]



The technologies required for transformation are already here or will be available before 2035. However, these are leading to massive disruption because they now offer superior capabilities at significantly lower costs compared to older technologies.[†]

In addition, AI today is perceived by many as a *seemingly* new phenomenon, especially since the emergence of Large Language Models (LLMs) such as ChatGPT in 2022. However,

* Hannah Ritchie, "Sector by Sector: Where Do Global Greenhouse Gas Emissions Come From?" *Our World in Data* (2020) https://ourworldindata.org/ghg-emissions-by-sector

† Seba and Arbib, *Rethinking Climate Change*

those of us with several decades of experience in this field know that AI has been developing continuously, but *exponentially*, for over 70 (!) years. Alan Turing's famous paper on the so-called imitation game, the "Turing Test", was published in 1950, and the Dartmouth AI Conference took place in 1956. The "sudden" appearance of LLMs is therefore the result of a long and ongoing development, and it represents only a small part of AI. This also means that we are only at the beginning of a new era that promises a wealth of opportunities if pursued in a sustainable way.

Without advanced tech, the pace of innovation towards net zero emissions in most sectors of the economy would be slower, less efficient, and potentially more expensive.

3. There is Hope

Deep tech and especially quantum information science (QIS), which we will discuss briefly later, are not yet on most people's radar but will play a key role in shaping our sustainable future. They aim to deliver technological solutions based on significant scientific and engineering challenges and not only provide the tools needed to innovate but dramatically accelerate the pace of development and transformation of critical infrastructures. Without advanced tech, the pace of innovation towards net zero emissions in most sectors of the economy would be slower, less efficient, and potentially more expensive. The level of automation, precision, and effectiveness that these technologies offer is crucial for critical infrastructure such as energy, transportation, and food, but also healthcare, medical technology, robotics, IoT/IoE sensor industry, global gigabit connectivity, high-bandwidth brain-computer interfaces (BCI), AR/VR, etc.

In his book *Brighter*, Adam Dorr argued:*

- The technologies to address climate change and reduce the 90% of Greenhouse gas emissions are available today. Technology "disruption is coming and cannot be stopped" (p. 154). Below, we will discuss in more detail what technologies and how they are being applied. They will also help withdraw excess carbon dioxide from the atmosphere to go below net zero and restore planetary boundaries and planetary damage.
- It can be done before 2040 and much faster than is generally believed.
- It is financially viable and can be achieved through prosperity and not austerity, which would condemn billions of people to poverty. In fact, Dorr argues against conventional thinking including that of climate emergence activists who propose degrowth to address climate change. In his view, the degrowth theory fails to understand the whole complexity of climate change and compares it with bloodletting in the Middle Ages before the existence of modern medicine.

* Adam Dorr, *Brighter: Optimism, Progress, and the Future of Environmentalism* (San Francisco: RethinkX, 2023)

> *Technology development is the apex of the human capacity to impact the world through collective intelligence and, despite its failures, it may be our only chance to address climate change in time.*

- It can be achieved within the current economic and market environment, but it must be done in a sustainable and focused manner, through a timely approach, and by keeping the cost down.
- The transition will not happen without massive disruptions in the major sectors of the economy namely energy, transportation, and food, which means people must brace for the negative impact of that transformation.

Technology development is the apex of the human capacity to impact the world through collective intelligence and, despite its failures, it may be our only chance to address climate change in time. Whereas biological evolution took 3.5 billion years to develop cells from the onset of the first life-form, it took technological evolution only 14 years to move from the invention of the first personal computer in 1975 to the World Wide Web when global collective intelligence began to come online. Tech development is a function of the *exponentially growing complexity*, a concept many find difficult to grasp due to our innate tendency to think *linearly*. Nevertheless, our future depends on our ability to understand complexity to shape our future, to adapt, and to act in a timely manner.

3.1. Transformation of the Energy Sector

The truth about the energy transition is simple: the old, fossil fuel-based technologies are less and less able to compete economically with the new ones. The transformation in the energy sector is being driven by the cost-effective use of solar panels, wind turbines, batteries, and their convergence, even if we continue to use energy from fossil fuels (coal, gas, oil) or nuclear energy in the transition phase. Despite initial challenges, sustainable technologies have seen significant price reductions since 2010: The cost of photovoltaics has fallen more than 20-fold, the cost of offshore wind capacity has fallen more than 3-fold and the cost of lithium-ion battery capacity has fallen almost 45-fold.* In the first half of 2024, wind and solar generated more energy than fossil fuels and have overtaken fossil fuels in the EU for the first time in a half year period according to think-tank Ember.† Wind and solar grew to an all-time high of 30% of the EU's electricity in the first half year of 2024 compared to 27% from fossil fuels that fell by 17% according to the same source.

Deep tech with the support of AI is contributing significantly to advances in the development of fusion reactors, which promise an almost unlimited and clean energy supply.

* Tony Seba and James Arbib, "Switching to Clean Technologies," *RethinkX*, https://www.rethinkx.com/faq-and-mythbusting/switching-to-clean-technologies

† E. Graham and N. Fulghum, "Wind and Solar Overtake EU Fossil Fuels in the first half of 2024" *Ember Climate*, July 30, 2024, https://ember-climate.org/latest-insights/eu-wind-and-solar-overtake-fossil-fuels/

They rely on advanced fields such as advanced materials science and plasma physics. These technologies are critical for optimizing plasma confinement in stellarators and tokamaks and are essential for maintaining stable fusion reactions. One deep tech investment example is Proxima Fusion, a Munich-based start-up developing the first generation of fusion reactors based on quasi-isodynamic stellarators with high-temperature superconductors to lead the world into a new era of clean energy. It is important to recognize that the use and especially the convergence of these new technologies heralds the end of the fossil fuel era. It is essential not to get caught up in the stranded assets of traditional energy sources.

3.2. Transformation of the Transportation Sector

Like energy, the transportation sector is complex but equally important in reaching net zero. Technological, economic, and social forces are creating feedback loops and destabilizing today's transportation sector, primarily for economic reasons. The transformation is being driven by advances in electric vehicles, improved batteries, autonomous driving, ride-sharing, and ride-hailing.

Autonomous vehicles (AV) and ride-hailing platforms, for example, represent the application of AI in transportation. Here, AI is used for various important functions such as image recognition, decision-making, and navigation. Similarly, ride-hailing platforms such as Uber and Lyft rely heavily on sophisticated AI algorithms. These platforms use AI to efficiently manage logistics, predict demand, introduce dynamic pricing, and optimize routes.

In particular, the convergence of these technologies is reshaping the new industry. "Transport as a Service" (TaaS) will eventually relieve the roads of parking spaces, the planet of unnecessary greenhouse gas emissions, and, especially, people of the cost and burden of unwanted car ownership.

3.3. Disruption and Transformation of the Food Sector

Imagine obtaining your food, especially proteins, without animal husbandry or slaughter, while significantly reducing greenhouse gas emissions during its production. And without antibiotics, pathogens, or parasites. Agriculture, forestry, and land use are responsible for 18.4% of global greenhouse gas emissions. The dynamic transformation currently taking place in the food sector will bring significant positive changes by 2030 and open exciting opportunities while significantly reducing greenhouse gases. This anticipated paradigm shift will be driven by the economic benefits of precision fermentation and cellular agriculture, ushering in a new era of innovation and sustainability.

Precision Fermentation (PF) and Cellular Agriculture (CA)

Fermentation has been part of human culture for centuries and is used in beer brewing, bread making, and food preservation. Since the early 1980s, precision fermentation has also played a key role in the pharmaceutical industry. It helps in the production of drugs such as human insulin, growth hormones, and vaccines. It makes it possible to genetically modify microorganisms such as bacteria, yeast, or algae using techniques such as CRISPR-Cas9 to produce desired molecules through fermentation. These are then purified and used for food production.

Like precision fermentation, cellular agriculture is revolutionizing food production by culturing animal cells outside the animal to produce meat or dairy products without livestock. This offers benefits for animal welfare, reduces environmental impact, and mimics conventional animal products, but still has challenges in production costs and scaling.

AI plays a key role in both these deep technologies to increase productivity and efficiency and ensure quality. In precision fermentation, AI analyzes sensor data such as temperature and growth rates to create optimal conditions, detect anomalies early on, and scale up production. In cellular agriculture, AI optimizes the control of bioprocesses and the development of cell lines. It also helps with the structural composition of cells to replicate the texture of conventional meat products. Both technologies are considered "deep tech" as they involve complex biological and technical processes based on advanced science.

Humanity is expected to experience the greatest change in food and agricultural production since the dawn of agriculture 10,000 years ago. This economically driven disruption is primarily focused on proteins. By 2030, modern proteins could cost five times less than animal proteins, and by 2035, ten times less—competing with sugar. These proteins will surpass traditional proteins in nutritional value, health benefits, taste, and variety. Cellular agriculture will further revolutionize the sector so that by 2030, modern foods will not only be of higher quality, but also over 50% cheaper to produce than animal products.

A significant environmental benefit of food production through precision fermentation and cellular agriculture is the drastic reduction in the amount of land required for animal husbandry. This change could lead to significant environmental benefits. The oceans will also benefit, as reduced commercial fishing and the availability of seafood from precision fermentation and cellular agriculture will allow marine ecosystems to recover.

4. Quantum Information Science (QIS)

Given the current preoccupation with AI, it would be easy to miss the extraordinary importance of Quantum Information Science (QIS), a cutting-edge field that combines the principles of quantum mechanics with information science, including AI, and is pioneering in several areas:

- *Quantum sensors* use quantum properties to measure physical quantities with extreme accuracy. The enhanced sensitivity of quantum sensors can lead to significant improvements in fields such as navigation, medical imaging, biomedical research, and geological surveying. Emerging prototype quantum sensors are diamond nitrogen-vacancy (NV) color sensors and optically pumped magnetometers (OPMs). They are shown to have improved stability, accuracy, precision, and ultra-sensitivity, and can be used at reduced costs compared to current methods using classical physics. Other encouraging technologies are quantum sensors based on entangled photonics. This light-based quantum technology could make communication networks and computers nearly unhackable, and can be produced entirely on a chip.
- *Quantum communication and quantum cryptography* use quantum states to enable extremely secure data transmission that protects against eavesdropping and cyber

threats. This ultra-secure method of encryption is crucial for protecting sensitive information in an increasingly digital world threatened by AI-driven cyber security attacks.

- *Quantum security* uses quantum algorithms and principles to better protect data against AI-based cyber threats.
- *Quantum algorithms* have been specially developed for quantum computers and enable calculations to be carried out at unprecedented speeds thanks to quantum superposition and entanglement. Notably, software-based products powered by quantum algorithms such as those developed for example by Kipu Quantum can significantly reduce the number of physical qubits required—by several orders of magnitude.* This makes it feasible to solve relevant problems much earlier in the quantum technology lifecycle. Starting from about 1,000 moderately noisy qubits, which characterize the current Noisy Intermediate-Scale Quantum (NISQ) era of hardware development, these algorithms can already achieve commercial usefulness for certain applications including the development of new materials, drug research, or protein folding.
- *Quantum computers*: Perhaps the best-known application of QIS: Quantum computers work with quantum bits (qubits) and can perform complex calculations at high speed, including in drug research, materials science and the modeling of complex systems.

At a time when exponential innovation in deep tech, amplified by AI is rapidly accelerating productivity, unprecedented opportunities are coming online that help address the great global challenges including climate change. Disruptions in critical infrastructure sectors such as energy, life sciences, transportation and food production are the key levers. Technologies such as quantum information science and AI are driving the transformation towards a sustainable economy and setting new benchmarks for the pace of progress. This should give us tremendous hope. Despite the major challenges, these technological breakthroughs offer us unique opportunities to shape a sustainable future for humanity. This marks the beginning of a new era of prosperity where integral sustainability is the key to making transformation to a sustainable future feasible.

Author's Contact Information
Email: mbozesan@AQALfoundation.org

References

1. Hannah Ritchie, "Sector by Sector: Where Do Global Greenhouse Gas Emissions Come From?" *Our World in Data* (2020), accessed August 4, 2024, https://ourworldindata.org/ghg-emissions-by-sector

* https://kipu-quantum.com/