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Perspective

On *Energy and Environment Nexus*: balancing economic development, social well-being, and ecological sustainability with science

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Abstract

This opinion piece is the Author's contribution to the inaugural issue of *Energy & Environment Nexus* (EEN), drawing on his 40+ years of learned experience in thermodynamics, engineering, energy science, techno-economics, and sustainability. It is intended to systematically expound the core concept of the 'Energy and Environment Nexus', and call for a science-based approach to balancing economic development, social well-being, and ecological sustainability. By no means is the author arguing for the opinion piece to be a definitive conclusion, but to serve as a means of introducing the EEN journal.

Keywords: Energy, Environment, Climate, Sustainability, Science, Economics

Born in the 1960s', rural China with lingering childhood memory of persistent hunger[1–3], growing up in the 1970s' 'cold war' era of a world filled with energy crisis fear[4–9], studying Engineering Thermophysics[10–14], energy science, and combustion technology courses[12–14] in the 1980s when the world awoke to fossil fuel burning caused global warming scare[15–19] (yes, 'global warming' was the narrative before the current 'climate change'[20,21]) , and having devoted my professional life to *energy for today and tomorrow* and true social and environmental sustainability since the 1990s[22–30], I have long been immensely intrigued by the interdependence, i.e., *nexus*, amongst energy services, societal well-being, and environmental health[26–28]. While energy is vital for human progress, civilisation, economic growth, and social well-being, its extraction, conversion, and use have profound environmental impacts, necessitating a shift towards sustainable solutions[25,29–31]. Since the early 2000s, I have advocated cross-discipline discussion, collaboration and debate within the learned academy that I am a fellow of, the Australian Academy of Technological Sciences and Engineering (i.e., Australia's Academy of Engineering or ATSE), on this both scientifically and morally important subject of energy and environment nexus, and launched my own studies into the relevant themes[26,27], teaching the topics in classrooms, and sharing my learnings and wisdom at various forums and seminar tours[26,27].

I realised that *energy* is such a widely and wildly misunderstood term that literally a vast majority of us confuse it with *power*[26,27]. While energy refers to the potential or ability to do work, power is the time flow of energy, or work being done, for a better explanation[27–34]. The energy–power relation is very much the same as the 'cash and cash–flow' relationship in the business world. As much as companies care more about cash-flow, people who say they want energy actually want power[27]. It is *power* that enables us to do things, including conquering nature (e.g., extracting materials from the environment), influencing others (e.g., teaching and education), and/or controlling society (e.g., running an institution or governing a country). In this sense, we the people, constantly seek power, use power, and are being subjected to exploitation by power. Inspired by the fact that energy is a mass commodity—very much like food, water, and air on which lives depend—I conceptualised the governing principles of energy services and coined the term 'Zhang's four imperatives of energy'[27], namely, in the order of importance, Power Intensity, Energy Density, Cost, and Scale. Power Intensity refers to the amount of power generated from a given primary energy source per unit of area of land in units of W (energy/time). The land taken into account is the total area used in the entire process or the whole life cycle, from energy resource extraction, through conversion, power generation and use, to final waste disposal, aka the footprint of the process on the Earth's surface. I emphasise the importance of considering the planet's surface, which is finite and confines human livelihood and social activities, including energy resource harvesting, conversion, and use. This definition of power intensity also signifies the intimate relationship between energy and the earth environment. For example, the production of 20 tonnes of coal in a typical open-cut mine takes several minutes over a land area of several tens of square metres. In contrast, the production of 20 tonnes of dry biomass requires more than one hectare (10,000 m^2), and an entire year to grow. Energy

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Density refers to the amount of energy per unit of mass or volume of an energy source or carrier, measured in units of MJ/kg or MJ/litre for liquid fuel, or MJ/m^3 for gaseous fuel. Higher energy density fuels are more advantageous because they are easier to transport, store, and handle. This explains why the transport sector uniquely favours liquid fuels, as the energy source has to be carried on board. It also explains why the hydrogen energy concept is difficult to find commercial reality, and why energy storage, in the forms of batteries, compressed air, pumped hydro, raising and dropping weights, or spinning wheels, cannot serve as solutions to clean energy challenges. Cost includes both capital expenditure (or Capex) and operating expenditure (or Opex). Put simply, no one wishes to pay more for the same goods or services, including energy, unless charity or philanthropy is involved. Cheap energy is fundamental to accessibility and, in my view, crucial to improving the living standards of poor people. Note that cheaper energy also encourages consumption, as more people have access to more and better energy services, which naturally imposes a greater impact on the environment for both resource extraction and waste disposal. Scale refers to the (large or small) capacity of a power generation or energy conversion installation. From a process engineering or energy systems viewpoint, larger energy installations are not only always more efficient but also facilitate better pollution control and waste management as they are confined in one place. Besides, urbanisation has been an unstoppable phenomenon in the developing world where people move from rural areas (countryside) to urban areas (towns and cities). Large-scale energy infrastructures match this trend of socio-demographic change.

Energy professionals are certainly aware that energy resources are extracted from the *environment*, processed and converted in the *environment,* and, that throughout the entire process—from extraction to end use—waste, including waste heat and pollutants, is generated and ultimately released back into or dispersed in and dissipated through the *environment*[26,27,35]. Thus, they are acutely mindful of the dependence of *energy* on the *environment*[35], though not necessarily in a scholarly position to fully embrace the scientific depth and engineering breadth of the environment—energy interdependence, aka, the *energy and environment nexus*.

On the other hand, the *environment*, in its narrow-scope definition, refers to the surroundings or conditions in which living things—whether human, animal, or plant—operate[29,30], including during energy conversion and power generation. In a slightly broader scope definition, the environment is considered the sum of all the living and non-living things and their effects that influence human life[35]. While all biotic living things include animals, fish, and plants, abiotic beings include air, water, and soil. In a scholarly context, the 'environment' broadly refers to the totality of all external conditions, both living and non-living, that influence an organism or groups of organisms. This includes physical, chemical, biological, social, cultural, and political factors. In essence, it encompasses everything that surrounds and affects a system, shaping its form, survival, and behaviour. I think these definitions would need some deeper consideration and reframing. This is because I have always been puzzled by, and have found, two unique peculiarities about the concept of the environment, among other things. The first is that when people talk about the environment, they seem to forget that humans are in fact part of the environment, but think of themselves as something beyond the environment, as if Homo sapiens are superior to the environment. The second is that when discussing environmental protection, many people take the absolute moral high ground, to the extent that any doubt or disagreement about their views on how to protect the environment is considered inimical to ecological sustainability and human existence. Perhaps this is why environmental science and/or environmental engineering courses at universities have been so popular amongst the youths who seek a university degree, but not necessarily the science and scientific principles for their degrees. And, as I see it, and very much like their energy counterparts, the environment professionals do not necessarily fully embrace the true characteristics of energy and the environment, and the nature of their interdependence, making my case for an energy and environment nexus more necessary and perhaps urgent. Perhaps, a good dose of thermodynamics holds the key.

After some two decades of pondering, the opportunity eventually came knocking on my door in January 2025, with the creation of a scholarly journal on energy and environment by my old school, Southeast University (SEU), and an invitation extended to me to serve as a co-Editor-in-Chief, together with Professor Rui Xiao, the Dean of School of Energy and Environment at SEU. While my heart felt splendid about this invitation, my head was conscious of the administrative workload of nursing a newborn and healthy scholarly journal, which would take time away from me, someone who always enjoys scholarly labour and true freedom. Yes, to manage and contain *entropy* increase, or to keep things in good order, is always time-consuming and energy-demanding, and I would have preferred a role as a special adviser to the new journal, which would allow me to enjoy the scholarship without the administrative work (or, should I say, without having to manage and contain entropy increase?). With Professor Xiao's persuasion, however, my heart won over my head in the deliberation—though my head is now satisfied that, finally, the very scholarly platform I have wanted for decades has arrived. Long story short, I have proudly named the new journal *Energy and Environment Nexus* (EEN).

'Nexus' means a connection or a link between things. It is where different things come together and are interconnected. It can be a physical place, a relationship, or an idea that links multiple elements together. Think of a spider web. The centre of the web is the nexus—all the threads (connections) come together there. Alternatively, imagine our kitchen table on Christmas eve. There are all kinds of tasty food, family sitting around it, the drama of kids messing the pudding, politics in conversation, and someone trying to cut the steak with a butter knife. That table? That table is indeed the Nexus—where everything (and everyone) collides. *Energy and Environment Nexus* signifies the importance of the connectedness of Energy and Environment and provides a platform, or a dinner table, for robust and collegial debate on a wide range of topics on the science, technology, engineering, economics, and policies relating to Energy and Environment.

This scholarly journal could not have been more timely, when the world seems to be madly obsessed with fears of climate change, depletion of energy (and other resources whose processing also requires energy), CO_2 emissions, sea level rise, urban air pollution and hazy smog, waterway contamination, pervasive forever chemicals like PFAS, soil degradation, and the perceived increase in the frequency of natural disasters, while the elite classes ignore that nearly one-half of the world's population (approximately 44%) still live under below the poverty line[36]. Indeed, in my view, to lift the poor out of poverty, we must first and foremost afford them easily accessible, cheap, reliable, secure, and clean energy sources, which will naturally be followed by a cleaner environment and a healthier population, who will then become more productive in creating their own economic prosperity[26–28,35–41]. The developing world does not need to repeat the 'development – wealth creation – pollution – clean-up' process that the developed world underwent, but can instead adopt and adapt proven and emerging technologies to their

advantage so that development is not accompanied by pollution and damage to the environment.

With *Energy and Environment Nexus*, I want people to think about the four forms of energy we routinely need: food, heat and cooling, electric power, and transport fuels—along with their respective unique characteristics and interactions with the environment. I want people to collegially discuss that, like any other essential mass commodities, energy services must be affordable, reliable, and secure, and accessible to all. I want people to appreciate that energy follows *Zhang's four imperatives of energy*—namely, power intensity, energy density, scale, and cost[27] —in a manner akin to the basic food we eat, the water we drink, and the air we breathe. I want people to realise that renewable energy sources such as solar and wind may be free and clean, as some politicians and many activists claim, but converting them into useable forms of energy, or power rather, is neither cheap nor clean. Besides, solar and wind are part-time (intermittent), temperamental (weather dependent), and casual (often working when people do not need them and stopping when people are desperately in need). They also require huge amounts of rare minerals and exotic materials, high maintenance, and vast land areas. Furthermore, because of their inherently low reliability, poor availability, and small load factors, solar and wind installations have to be overbuilt by as much as three to four times, incurring excessive costs. Historically, energy transformation has always been a long and gradual process. Renewable energy infrastructures can find their unique places in remote and rural areas where fossil energy services cannot reach or in the distant future when fossil fuels are completely exhausted. Scientific research and technological innovation in the renewable energy space are certainly encouraged, but should not be mandated. To pull up the shoots to help them grow is never a good idea. I want people to be able to differentiate between climate science and climate change ideology. Climate science is a multidisciplinary field studying the Earth's climate system, encompassing its past, present, and future states, as well as the factors and events that influence it, including atmospheric CO_2 concentration. But the Earth's climate is a complex system and has always been changing according to its own course[42,43]. To blame global warming, climate change, and every natural disaster solely on anthropogenic CO_2 emissions is, scientifically speaking, an oversimplification or bias and, morally speaking, an ideological movement. Note that what is called greenhouse gases makes up about 2% of the gases (chiefly, water vapour, CO_2, CH_4, N_2O, O_3, as well as others) in the atmosphere, and of that 2%, 95% is water vapour; the rest consists of trace gases, including CO_2, which makes up about 3.62% of all greenhouse gases. Anthropogenic CO_2 emissions contribute 3.4% to the 3.62% CO_2 in the atmosphere. Taking these factors together, human activities would only contribute 0.28% of the total global warming effect, which is minuscule compared to many natural phenomena and events[43,44]. Climate science should be allowed to evolve at its own pace. Devising global policies for climate change actions based on developing and unproven science is incompatible with science principles and can incur unexpected and dangerous consequences. CO_2 is not a knob that one can just turn down or up to adjust the global temperature. People do not have that ability. To think we do is … hubris! I want people to ask why in the Earth's history, warm periods with high atmospheric CO_2 concentrations, were followed by cool periods or even ice ages, all before the existence of Homo sapiens. Is the current rise in the atmospheric CO_2 concentration driven by a small increase in global temperature, rather than the rising CO_2 concentration driving global warming? I want people to consider why some major human civilisation events coincided with historical warm periods, e.g., the unification of the Six States by Qin Shi Huang in the 3rd century BC to form China, and the Roman Empire reaching its greatest territorial extent under Trajan in AD 98–117, and why the 'Dark Ages' in human history, specifically the Early Middle Ages (roughly 5th to 10th centuries) coincided with a mini-ice age (global cooling). In fact, when the temperature rises, the natural world responds. Plants and oceans release more CO_2 than they otherwise would. Warmer temperatures lead to a thriving environment. I want people to embrace the fact that an increase in the atmospheric CO_2 concentration is actually leading to global greening and has not led to an increasing frequency of natural disasters[43–48]. I think the best option to deal with climate change is to adapt and become more resilient, including lifting the poor out of poverty[46–53], and building better infrastructure. It is hubris to believe that humans can reverse climate change by eliminating fossil fuel burning, or by carbon capture, utilisation and storage (or CCUS), or by geoengineering—any manmade action against the natural course will be met with an opposite and at least equal reaction—whenever an action force exists, there must also be a reaction force of equal strength and in the opposite direction to the action force. This is a fundamental principle of physics, also known as Newton's Third Law of Motion. What is considered a solution to a problem today may well become a problem for tomorrow. I want people to know that the future of the environment is determined by the poor, not the privileged rich elite, because of the golden rule of 'what the few have today, the masses will demand tomorrow'. It is the desire for a better and more secure life that drives human progress and civilisation and, as such, 'if it is not economically feasible, it is not sustainable'[54–55]. I want people to know that I am absolutely against brainwashing our young generations to believe that doomsday is upon them due to anthropogenic CO_2 emissions. Kids should be allowed to be kids, be happy and healthy, be learning literacy and numeracy, and as they grow up, they should study, create, innovate, and build a brighter future for themselves and for generations to come. With this *Energy and Environment Nexus* platform, I place a premium on global conservation, energy equality for all, and a cleaner environment for mankind to enhance our resilience and adaptability to the ever-changing world[56]. And above and beyond all, I want a rational scientific debate amongst people of all walks of life, religions, and ideologies about our shared interest in this *Energy and Environment Nexus*[52–55,57].

Science is a journey of discovery and truth-seeking, but it is not the absolute truth. Science is not always correct—and that is actually one of the greatest strengths of science. Science is a self-correcting process which relies on evidence, testing, and revision. Scientific knowledge is not infallible and must be falsifiable in principle. There is no such thing as settled science. If a theory is not falsifiable, it is not science; it must be a belief, or a religion, or even worse still, a cult. For example, some of us *believe* that God created the world. Because there is no way to falsify that statement or to test and disprove it, it can only be a belief or religion. It is not science[55–58].

Science thrives on robust debate and scrutiny. Let's work together to liberate us from the confinement of ideological belief and embrace a science-based approach to balancing the economic development, social well-being, and ecological sustainability through the *Energy and Environment Nexus*!

Author contributions

The author confirms sole responsibility for all aspects of this study and approved the final version of the manuscript.

Data availability

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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Competing interests

The author declares that there is no conflict of interest.

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