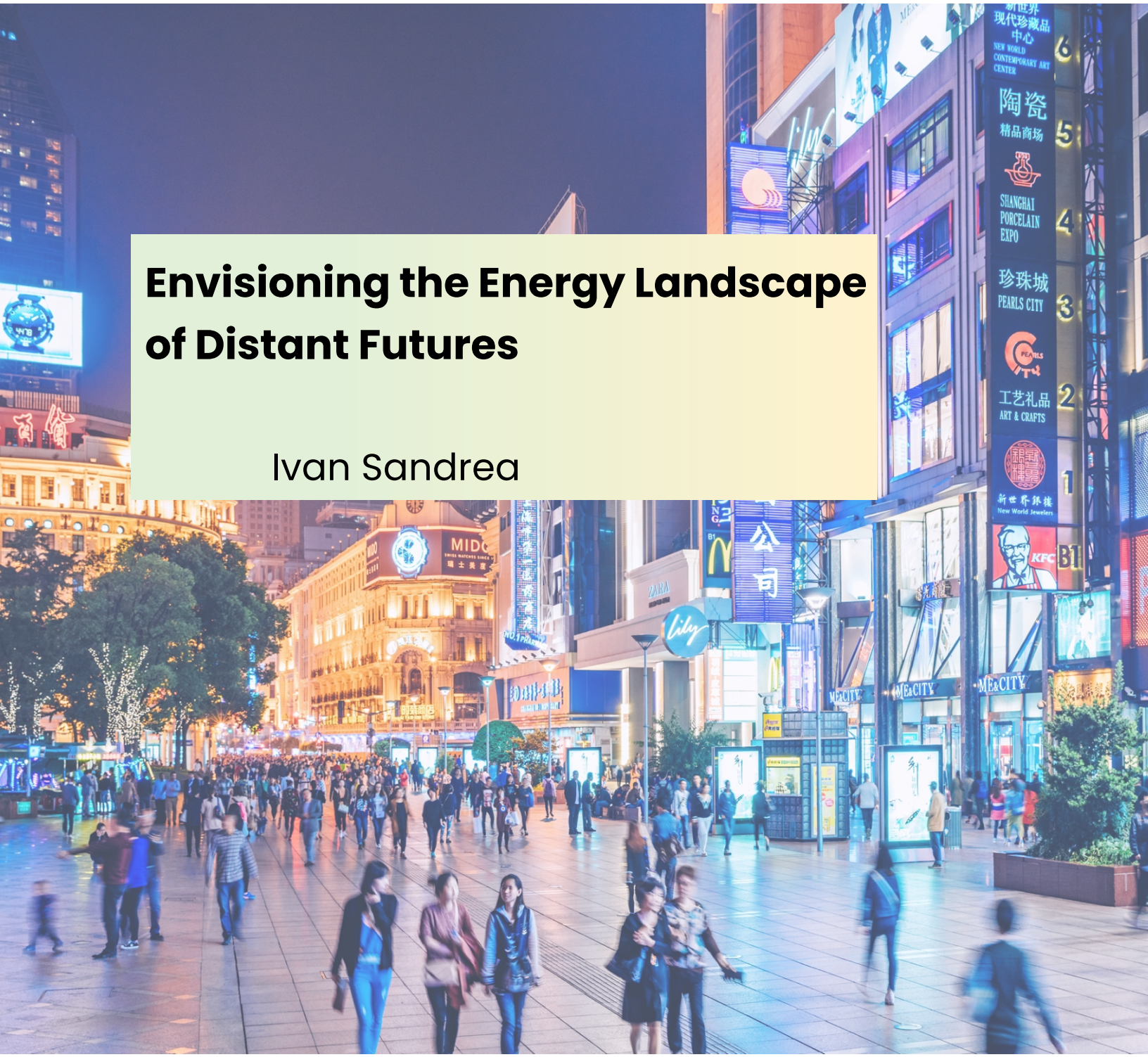

Envisioning the Energy Landscape of Distant Futures

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In contemplating the energy system's distant future, we encounter a range of outcomes that require a paradigm shift, if not a quantum leap, to satisfy future energy needs. In this concise essay, I invite exploration into the potential visage of energy demand and supply – be it a century or even half a millennium from now. As Nils Bohr aptly put it, predicting the future is an intricate endeavor, particularly when it pertains to what lies ahead. So, I am not predicting the future.

Before delving into this exploration, it's vital to acknowledge energy's pivotal role as the cornerstone of human progress. Remarkably, some of the same energy sources that fueled ancient civilizations such as wood and coal are still in use today and growing. Over the eons, humanity has cultivated and developed a spectrum of energy resources, giving rise to a pertinent query: what becomes of ancient, existing, nascent, and yet-to-be-conceived sources of energy in the times ahead?

Throughout history and into the present, a civilization's technological advancement is discernible by the quantum of energy it harnesses. It stands to reason that this correlation will persist. Our society's trajectory, technological development, and economic growth entails continual problem-solving and innovation. A delicate equilibrium with nature remains imperative, and undoubtedly, energy – in copious quantities – remains an intrinsic facet of our foreseeable futures.

Foremost, technologically advanced countries are likely to continue to use vast amounts of energy, but the new shift taking place is whether these will reorganize around energy sources with low emissions, decentralized energy systems, and renewable electricity. The conundrum lies in estimating the number of people for whom this will become reality – 500 million, a billion, two billion, three? The success of this and associated uncertainty carries monumental ramifications for energy needs and how these societies will function. In terms of costs, this shift, which is just two decades in, has already required over US$2 trillion in government spending and subsidies and US$5 trillion from the private sector, and is likely to continue beyond decades.

Furthermore, unless an unprecedented leap eradicates poverty which would allow billons to access the same energy sources as the technologically advanced countries, energy insufficiency is likely to endure, anchoring many to the allure of cost-efficient, high-energy-density, accessible sources. Just as the enduring use of wood for at least three millennia and counting, it's highly plausible that oil, gas, and coal, potentially considered ancient sources of energy in the distant future, could remain essential for billions of people. Technological advances in extraction and processing of those energy sources are likely to continue, but by then society could have solved and moved on from many of the challenges we see today and would be dealing with new ones. What are those new challenges and opportunities going to be?

In a future where societal standards demand ethical sourcing and environmental leadership, the prospect of consuming anything, including critical minerals for future technologies, associated with inhumane standards seems implausible. Quality of life aspirations and technological innovation is likely to drive the demand for superior products. This appetite for advancement, however, is likely to coexist with escalating energy consumption. Innovations could enable us to manage waste streams more efficiently, employing more advanced recycling techniques. The concept of waste disposal might be relegated to history as waste could become one of the top sources of energy and superior products around the world.

Construction materials and homes may not change radically in the future. Bricks and wood have been used for over 5000 years, so any future society that does not depend on these would be a radical shift. Mobility could undergo massive changes, but the bicycle and low-cost combustion cars and motorcycles could continue to move billions of people around the world. Industry, a major consumer of energy and essential sector of the global economy, would not exist in the future without energy feedstock.

Environmental stewardship will continue to flourish. While achieving absolute net-zero is likely to elude us, a trajectory of reduced emissions per capita, per GDP, and per unit of energy produced or consumed may be more realistic. Moreover, our comprehension of Earth's intricate mechanisms will undoubtedly deepen and help us reorder our priorities. However, wars, bacteria,

and natural events, all major contributors to emissions, are likely to be part of our future.

Returning to the link between civilization and energy demand and what the distant future could look like, at least for the technologically advanced countries, some revolutionary work has been done in this regard. According to Kardashev, there are three types of civilizations: Type I civilizations can access all the energy available on its planet and store it for consumption, Type II civilizations can directly consume the energy of a star, Type III civilizations can capture all the energy emitted by its galaxy. To reach a Type I civilization energy consumption must be 10^{16} watts (a lot more than today), Type II must be 10^{26} watts and Type III must be 10^{46} watts. Leading futurologists Sagan and Kaku have translated his work in time for us. According to work conducted by Kaku, if we maintain a 3% energy consumption growth per year, we may attain Type I status in about 100 – 200 years; Type II status in a few thousand years, and Type III status in 100,000 to a million years.

Could billions of people in the next two or three centuries continue to use some of the same enduring energy types that we have been using for more than a millennium, including those that gave rise to modern society? Innovation will ensure that there will not be a shortage of energy sources, that new types of energy will be adopted more widely, and superior products will continue to be available. Energy security is likely to evolve, but its high importance may not change much over time.

In the distant future our fundamental concerns could be centered around other issues that only very few are currently working to understand, such as planetary astrophysics. However, in terms of energy, it is almost certain that our society will be using much more than we are today. Energy and environmental leadership will be one.