HUMAN EVOLUTION 5.0

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The inconvenient truth on energy transition: an evolutionary and ecological viewpoint

The evolution of our species required increasing energy to support practices that contribute to hypersociality. This was crucial to the success of *Homo sapiens* and eventually led to the formation of our global superorganism. An autocatalytic process between human biology and culture started in the Pleistocene, accelerated in the Holocene and became paroxysmal in the Anthropocene, thanks to the access to fossil fuels. Today we seem blind to the contribution of this pulse of energy to our way of life. However, the impact of fossil fuels on the atmospheric greenhouse gases and on local air pollution is now forcing our industrial economies to plan a transition to renewables, such as solar and wind energy, buffered with battery and hydrogen systems. Recent evaluations suggest that this task is much more difficult than predicted. The availability of minerals, technological innovation and economic viability will put serious constraint to the effort. Furthermore, new energy sources with a suitable energy return on energy invested will not be available soon enough. Meanwhile, finance is decoupling from the real gross world product and allows our energy obligations to the future to grow faster than we are growing our economies. The only alternative is a plan for a sustainable and less energy intensive way of life. This is still feasible, but it is hindered by our neurohistory and addiction to energy. A detox therapy is urgent but fiercely resisted. On top of the most evident vested interest, this may also depend on our behavioural traits, inherited from our deep past.

Introduction

In considering the possible paths towards a suitable future for humanity, we are mainly inspired by specialists who study only a fraction of the system at a time. So, when ideas turn into actions, tunnel vision and an overlapping set of measures are bound to emerge. Politics is often subject to the people's scrutiny and when leadership is short, contestable, and accountable (as it should be in a democracy) urgent and weak measures tend to prevail over visions and long-term sustainability. Eventually the compatibility between unregulated global markets and national institutions nurtured by the illusion of an everlasting economic growth and infinite energy supply will end. We will argue that to defuse these problems we need an evolutionary perspective on human nature based on a more ecologically oriented approach. Much attention was paid to capital and labour, and the long struggle between them, in the last two centuries. Today, a new economic vision needs to enter energy consumption and resource depletion as a key component of human predicament. Ecological economics is set to perform this task and will probably take centre stage in the years to come. In what follows we will provide further arguments to the recent idea that we are both energy blind and minerals blind (Hagen, 2020; Michaux, 2021).

In *From Apes to Cyborg. New Perspectives on Human Evolution* (Tuniz & Tiberi Vipraio, 2020) we took a journey into our past and glimpsed into the future according to a vast array of scientific evidence and some speculation. Both hard and soft science were sourced and selected to try and fill the void between them. A plausible story came out of this effort. We claimed that the ability of *H. sapiens* to form vast social organisms was key for their success over all other human species and for their inexorable spread over the planet. After forming a variety of dispersed societies, operating to different norms, we are now part of a global superorganism that keeps threatening major life cycles and perhaps our own survival. Easily disregarded in the past, this attitude has now reached a critical point. At its dawn, the formation of social organisms – we argued – required a certain degree of self-domestication that lowered aggressiveness and put belligerence under a chain of top-down command. This helped establish social hierarchies bound by cultures, symbols, language, and a common vision of the world. In a realm of abundance and freedom of movements a top-down pattern was far from necessary and in fact was an exception among hunters and gatherers, for whom the interest of sharing the “catch of the day” is a social advantage, as it reduces the risk to starve in bad times. But when resources become abundant for some and scarce for others, or when, for some reason, they become unevenly distributed among the population, hierarchical societies develop, overlap and often conflict with each other. A distinction between “us” and “them” appears. Looking ahead, if we keep behaving this way (as we claimed then) there is no guarantee for a better future, despite our technological advances and the possible benefit emerging from global digital networks and artificial intelligence.

The book was published in March 2020. We were just on the verge of three major shocks: a global pandemic, a wave of environmental disasters (linked to climate change) and a near-nuclear war in the heart of Europe. These events were immediately faced with contingent and highly debated countermeasures. In the medium and long term, a transition into renewables was much talked about and little implemented. In any case, it wasn’t until war broke out in Europe that we started to consider energy consumption as fundamental to our troubles at large. Extending our book’s consideration and referring to some crucial passages, we can now envisage some reasons why our species has always disregarded the possibility that energy consumption and natural resources are so pervasive and could come to an end. Mainstream thinking holds that the Market (as an institution) would take care of shortages via higher prices, which will reduce consumption. In addition, or alternatively, the State could allow the financial system to expand the supply of money (via an increase in global debts) to accommodate for the less fortunate or to promote energy growth and national champions. Very little attention is paid to the consequences of each solution, and who will pay the bills. In fact, resources would be accessed either selectively (giving precedence to rich people and countries, via market forces) or by probing into the future, penalizing new generations or foreign competitors. Considering our taste for material goods and services, wrongly interpreted as a proxy for happiness, a double blindness on energy and minerals is now leading us to a further increase in world inequalities both domestically and internationally. It's worthwhile to consider whether we are still in time to prevent a dramatic showdown.

Internal and external human energy

Our body uses chemical energy from food for a wide range of functions: to support the basal metabolism of organs and tissues, to maintain the internal body temperature, to exert muscular force and keep posture, to produce movement and interact with the environment. With proper physical activity, one needs about 2,500 kilocalories per day to perform these tasks (Pontzer, 2014). To our purpose, it is convenient to turn kilocalories into kilowatt hours (kWh) so that we can compare our body energy consumption (~ 1,000 kWh per year) to: i) the muscular energy used for our external interactions (~ 300 kWh per year); ii) the basal metabolism (~ 700 kWh per year) and iii) the extra-metabolic energy that we extract from external sources (~ 20,000 kWh per year). Today, body energy is subject to global food availability and local self-sufficiency is scarce. A quick check of the literature suggests that phosphorus (a fertiliser derived from non-renewable phosphate rock) will be one of the first resources to disappear from the planet and thus would present a major pending threat (Nature Plants, 2022). While keeping this in mind, we will focus on extra-metabolic energy, as it has become truly macroscopic. Let's look at its origins in the context of human evolution.

Our first hominin ancestors, at the end of the Miocene, probably extracted energy from food for less than 1,000 kWh/year per capita, which corresponds to that of an extant chimpanzee (Pontzer et al., 2014). It was used only for foraging, mating and socializing in small groups. They did not need extrasomatic energy. At the beginning of the Pleistocene the first humans began to use body energy to build lithic tools, which allowed for the consumption of more digestible and energetic food (Carmody, 2009). They also discovered how to control fire, an external energy source, which they used to warm up, see in the dark, attack and defend, socialise and further increase the digestibility of food. This new way of life supported a virtuous cycle of cultural and biological evolution that promoted the growth of the brain (an organ with a very high metabolic energy cost). The last human species with augmented brains, *H. Sapiens* and the Neanderthals, expanded further the exploitation of external energy, using fire to modify materials (pyrotechnology) (Wertime, 1973). More efficient stone tools emerged and new materials were derived from chemical synthesis. Key was the discovery of birch tar, as it could be used as a glue for the construction of composite tools (Blessing, 2021). The evolution of technology promoted the increase of external energy consumption and ever more complex social organisms. Ironically, technological innovations only served to increase energy requirements.

Between 150,000 and 50,000 years ago new traits emerged in *H. sapiens*. They were compatible with a self-domestication syndrome (Hare, 2017) and associated with major changes in anatomy, hormonal functions, social behaviour and the time spent to reach adulthood (which stretched ahead to an age never experienced by any other species). Anatomically, we developed a less aggressive appearance and, by rearranging our brain structure, we became extremely pro-social: just like eternal juveniles. It was thus easier to form ever larger groups. But there is a catch. Though the organisation of ever larger bands can be more efficient in many aspects (i.e., for foraging and sheltering) thanks to economies of scale and scope, more energy will become essential to organise and control larger groups, especially when endowed – as was the case – with increasing societal expectations of fitness. Eventually energy requirements were destined to rise.

Complex language and symbolic thinking extended the ability to learn and collaborate. We began to engage in activities far beyond our basic needs and to use a lot of energy to feed our extended mind: a world in which we are deeply embedded in our environment and our social life, via technology and culture. The smart phone is but the latest instrument by which we extend our mind into the world, and vice versa. Archaeological evidence suggests that an embryo of a superorganism with the first hierarchies and symbols was already in existence in Eurasia as long ago as 40,000 years ago when an economy based on mammoth hunting emerged, providing a bounty of food and materials, long before agriculture. People adorned their bodies, painted their skin and produced music and artistic images. More energy was required to perform and climb the social ladder. Several new technological innovations emerged, initially supported by body energy only. For example, the construction of shelters made of mammoth bones and covered with animal skins or the invention of needles and other haberdashery to make clothes, shoes and garments in general.

A first division of labour certainly emerged, as it was calculated that many years of skilled and specialised work were necessary to forge all the jewels and donations that were found in the ceremonial burials of some important deceased.

Given that self-domestication strengthens the predisposition to produce neurotransmitters of pleasure, such as serotonin and dopamine, larger societies were formed by seemingly meeker individuals, who extended their juvenile appearance and behaviours into adulthood. Unfortunately, this phase was also associated with an increasing impact on the environment. We had to wait until the end of the last Ice Age, and less adverse and variable climate conditions, to allow agriculture and animal breeding to build up large surpluses and witness a huge population increase. A higher energy production (and consumption) came with it, both to sustain the basic needs of the lower classes and to supply for the superior needs of the upper classes. More energy and more complex social structures kept increasing hand in hand.

In the following millennia the energy of flowing water and blowing wind could be transformed into mechanical energy (by watermills and windmills). The energy of the first machines could produce up to 10,000 kWh/year per capita. Around 300 years ago, fossil fuels were discovered and burned; first coal, then oil and gas. More innovations in energy management and manipulation arose. We developed steam engines and then internal combustion engines. Thermal energy was also transformed into mechanical energy and electricity, which could drive other complex machines. Industrial revolutions nurtured the well-being of a new society but also perpetuated and amplified social inequality (Stilwell, 2019). Eventually, the concentration of greenhouse gases in the atmosphere soared, changing the global climate. In the more developed regions of the planet tens of thousands of kWh per capita are consumed each year. In the US, the average per capita energy consumption was about 30,000 kWh/year in 1875. In 2021 it has scaled up to 101,000 kWh/year.

Energy addiction

We can argue that we swim in a sea of energy, mostly unaware of it, like fish in the water. We are energy blind and addicted to it. Energy consumption follows the same trend of psychotropic practices associated with social activities (Smail, 2007). A brain scanner is now able to detect every single *like* we obtain from a social network as a kick of pleasure. To deal with addiction in general, we either scale down the intake of the *substance* (via a painful process) or scale it up (to maintain the same psychotropic effect). The search for new energy sources, including nuclear energy, accepts the inevitability of our growing energy voracity.

The psychotropic rewards emerging from our social interactions have accompanied us for thousands of years. They have helped us build an energy hungry superorganism, now interlaced by billions of economic transactions at different levels. Indeed, we are both psychologically and economically addicted to energy. If this holds true, a scarcity of energy would soon bring about a withdrawal crisis.

If we want to reverse course, and start an energy detox therapy, we must seriously consider a major shift in our economic paradigm. This is going to be very difficult. First, we need to defend the vital circuits of the Earth as if they were our own (as they are indeed) (Latour, 2017). Second, we should shift the search for pleasure from excess consumption (beyond a threshold of socially agreed basic and not so basic needs) towards personal and social well-being and satisfaction on a wider sense, including (and accounting for) many non-material goods and services currently excluded or downsized by standard statistics. These would include clean air and water, emphatic and enriching social relations and mental health, just to name a few. It is ironic that, when we lack these precious environmental conditions and ask the Market to provide for them, the gross world product increases statistically but well-being remains (at best) the same and certainly deteriorates for those who cannot afford them. In any case, there are many obstacles, along this way, from an evolutionary perspective. Here is a brief list.

A first obstacle regards status and social comparison. Biologically, we care more about *relative* rather than *absolute* status. Economically, we are subject to a strong imitation effect (Duesenberry, 1951). In the past, status depended on providing resources to the community and was based on respect, storytelling, ethics and sharing. In modern times we compete for status with resource-intensive goods that project our image of economic fitness far beyond the needs they were supposed to meet (think of the designer watches that some people flash out despite being so easy to know exactly what time it is). In any case, the standard of living of the poorest fifth of the population is comparable, in the most advanced economies, with that of the middle class of last century. Nevertheless, one's income *rank* is what really matters. In other words, once basic needs are met, we are more sensitive to *better vs worse* – in comparison with the people we chose to refer to – rather than to *more vs less* in absolute terms. This attitude is typical of hierarchical species and it is enhanced by self-domestication. In *From Apes to Cyborgs* we argued that we seduce, and are seduced, by a vast array of status symbols, which make us admire the upper classes and despise the lower classes, according to an arbitrary set of rules and symbols. Social status is both economical and psychological. A lack of perceived status is linked upstream to poverty and downstream to misery, in the form of depression, addiction and harmful behaviour. If we were to make sacrifices in terms of energy consumption, we must keep this in mind and try not to spread the burden too unevenly.

A second obstacle emerges from our primitive stimulus for action. In our ancestral world, the dopamine pathways that dominate our behaviours were associated with motivation and reward. Skill, patience and ingenuity (but also good luck) were required to bring supper home. The discovery of a bush of berries or a bunch of eggs in a bird's nest was able to kick a sudden flash of joy in our ancestors' brain. The same applies to modern life when we get a job we like, win the contract for a large order, trade in the stock market or indulge in a shopping frenzy. Success leads to a rush of pleasure. However, there is no embedded signal of full satisfaction in our modern brain. Instinctually we become addicted to the next opportunity, the next encounter, the next reward. As in nineteenth century love stories, *desire* provides stronger emotions than *fulfilment*. Turning to our matters, when we ask people to save energy, we are stealing their sweetest dreams. To come to terms with reality, one must acknowledge the possibility of a real danger. Otherwise, a denial procedure could develop.

A third obstacle arises from our cognitive biases. A vast set of circumstances induces human behaviour to depart from economic rationality such as conditioned reasoning, authority biases, imitation effects, peer pressure, group thinking, etc. By developing symbolic thought, we imagine a reality that seems much more real than the reality we live in; a reality held together by myths, religions, ideologies and idealistic constructions. These imaginary worlds are often more powerful than facts. Failure to believe in them may lead to ostracism or death. Neoclassical economics insists that human conduct revolves around rationality, leaving behavioural economics the burden of explaining how and why people act the way they do. Without entering those issues, we must admit that – at least in part – contemporary humans are still driven by the intuitive and emotional brain structure of the limbic system, the same as our ancestors. It is thus understandable that our tribal nature, now enhanced by digital social networks, resists uncomfortable notions involving energy scarcity and climate change. There is no such a thing as a happy degrowth. Like juveniles, we want to keep partying and forget about hangovers.

A fourth obstacle comprises a strong time bias against the future. In the reality of our ancestors this makes sense, as the risk of food expropriation, unstable environment and a short life span all play in favour of the present. An overvalued present is deep-rooted to communicate urgency to better survive in tough times. Economists measure such bias via a discount rate: the more people value the present versus the future, the higher the discount rate and the steeper the relation between present and future. A theory of discounted utility is generally used for analysing intertemporal choices, both to describe actual behaviour (positive economics) and to prescribe optimal behaviour from a social point of view (normative economics). Efforts abound to distinguish time preferences among individuals. Empirically, the discount rate appears steeper in drinkers, smokers, drug addicts, gamblers, risk takers and people with low I.Q. scores (Chabris et al., 2010). Perhaps it is no coincidence that addiction characterises all such activities. As far as gender is concerned, and focusing on risk preferences, a recent study finds no evidence of a difference between men and women in this respect, though women are more prone to face the consequences of their behaviours (Morgenroth, 2022). Unfortunately, our present challenges belong more to the future than to the present. And though we can now imagine them thanks to the recent development of our neocortex, we are emotionally insensitive to long term issues.

Finally, if we define a superorganism as a collection of agents who act in concert to produce phenomena that need to be governed collectively (Kelly, 1994), the economic organisation of societies must be consistent with technology, scale and impact. In the last millennia, such superorganisms took various forms such as nations, empires and alliances, often armed against each other. In the last century, a global superorganism took over and stratified on top of all previous forms without destroying them (globalisation). It was made by an increasing interdependence of trade and investments, people's movements and technological transfer across the globe. A fragmentation of this superorganism is now appearing before our eyes due to a revamp of nationalism and populism and the consequent creation of material and immaterial barriers to slow down (but hardly hinder) a traffic that some hold unbearable. This does not help solve the problems we shall encounter as governance is split, and solutions are not in the common interest. To see why we must turn to energy proper.

Energy as fossil labour

The world annual consumption of energy is a mind-blowing figure. In 2021 it amounted to 159,001 TWh (Our World in Data, 2022), corresponding to a power of 18.5 TW. Divided by the world population, it accounts, on average, for 20,126 kWh/year per capita. Of course, energy consumption is very unevenly distributed. Industrialised countries consume more than developing countries, high density settlements consume more than small villages and modern high-tech cities certainly the most. The average modern house has a vast number of electrical items constantly plugged in. In the United States, the electricity consumption of the residential sector was 1.5 trillion kWh in 2021, corresponding to 38% of domestic electricity (EIA, 2022). The rest was consumed in the commercial, industrial and transportation sectors, the latter mostly to support the public transport system. To move around all the people and the items we enjoy globally we also use fossil fuels for a fleet of 55,000 large ships, 26,000 airplanes, 29 million trucks, 29 million buses, 600 million commercial vans, 700 million passenger cars, and 600 million motorcycles. All together those vehicles travelled 16 trillion km in 2018 (Michaux, 2021).

About 85% of the energy that sustains our way of life derives from fossil carbon and hydrocarbons. To get a feeling of its contribution to our living standards, let us translate it into a proxy for human labour. In 2021 our global fossil fuel consumption amounted to 136,111 TWh (Our World in Data). Considering that a modern human, performing manual work for 8 hours per day, could provide ~ 250 kWh/year, that figure would correspond to the energy provided by 544 billion workers on top of the 4 billion currently available in person. In practice, fossil fuels substitute for about 68 hypothetical workers per capita for the entire population of the globe. Without detracting from technological advances and organisational gains, one must recognize that in the last 100 years "fossil workers" performed a huge number of industrial functions and countless tasks to support our way of life. This advantage is very unevenly distributed across the planet. A single average American, for example, can enjoy the energy equivalent to 400 such workers, while a single average African must be content with less than 8 of them.

With rising gas prices and a war going on among a local and two global superpowers, we need to rapidly shift away from fossil fuels. Besides this, as we must limit carbon dioxide emissions, we need new ways of producing and storing renewable energy. Having dragged our feet for decades, we need a transition, and we need it now. Science shows unequivocally that in order to avert severe impacts of climate change and preserve a livable planet, global temperature increase needs to remain below 1.5°C above pre-industrial levels. Currently, the Earth is already about 1.1°C warmer than it was in the late 1800s, and emissions continue to rise. To keep global warming to no more than 1.5°C (UN Climate Change, 2022), greenhouse gas emissions need to be reduced by 45% by 2030 and reach net zero by 2050 (UN Climate Action, 2022).

Unfortunately, this is not an easy task. We have already touched upon psychological and social hinderances. Some distinguished thinktanks suggest that the main barriers to move away from the use of fossil fuels are only political (EU Thinktank, 2022). However, recent studies reveal that the replacement of all the fossil fuel powered systems of the world with renewable energy is also facing a mineral scarcity problem.

The illusion of a full transition to renewables

There are also other reasons why we tend to downplay the enormous difficulties in replacing existing fossil fuels with renewable energy (Michaux, 2021). First, one must keep in mind that what we call *renewable* energy is only *rebuildable* energy. Solar and wind energies are renewable, solar panels and wind powers stations are not. We must replace and dispose of them after about 20 years. We also must design components in order to recycle them (a novelty for our system of production). We need additional energy and materials to construct them. By disregarding such concerns, we are not only energy blind, we are also minerals and technology blind. Such evaluations are confirmed by a recent bottom-up approach, based on detailed data on energy use. According to this view, there has been little or no accounting of the resources that the earth can deliver for our energy requirements. True, if energy or materials will be lacking, some say, a bottleneck could emerge. But then we could reduce consumption and recycle materials enhancing the benefits of a circular economy. Unfortunately, calculations show that if we were to proceed to a full substitution, circularity will not be sufficient to overcome the overall scarcity of minerals.

In 2018, the global electrical power production amounted to 26,614 TWh, 17,086 of which derived from fossil fuels (Michaux, 2021). As electrical sources present a lower energy return over energy invested, to phase out the contribution of fossil fuels we would have to install a much higher electrical power system up to an annual capacity of 36,000 TWh. A thorough calculation shows that we would need 56 TWh to replace coal fired steel manufacture, 2,816 TWh to replace gas building heating and 17,000 TWh to replace coal, gas and oil for electrical power generation. Then, we would have to charge the batteries of light electric vehicles (with 4,500 TWh) and produce hydrogen for heavy transport with trucks, rail, and ships (with 11,500 TWh). Summing up, to get rid of fossil fuels and provide the same energy we will need much more electrical power capacity in 2050 than today.

It has been calculated that, after total replacement, the proposed global energy supply would then be split between 34,50% of solar photovoltaic, 3,83% of solar thermal, 26,83% of wind onshore, 11,50% of wind offshore, 13,36% of hydroelectric, 7,5% of nuclear, 1,73% of bio waste and 0.74% of geothermal energy [Irena, 2022; Michaux, 2021]. This variety of energy sources accommodates for a reasonable increase of nuclear, geothermal and hydroelectric power stations. Given their discontinuities, the balance between energy generation and energy demand needs a buffer which is mainly provided by gas as of today. Given that solar and wind electrical power make up a substantial proportion of the expected energy mix, and that these sources have a strong production variability, we shall need a 4-week buffer power storage based on the use of batteries to provide a total energy of 549 TWh (Michaux, 2021).

Turning to technologies, the extra annual capacity needed to phase out fossil fuels will require the construction of 586,000 new power plants: a mind-blowing figure compared with the 46,500 in operation in 2018. The global reserves available in 2022 can deliver only a fraction of the metals required to build one generation of new power plants. Indeed, given existing reserves and our current extraction capacity, we can only obtain 20,16% of copper, 10,57% of nickel, 2,45% of lithium, 3,65% of cobalt, just to name a few (Michaux, 2021; 2022). Nobody knows how to source the rest of it. Finally, many of the essential rare earth metals (neodymium, germanium, lanthanum, etc.) will be available only at less than 1-2% of their future requirement.

An objection to resource scarcity calls the Market back in. Some economists may think that the laws of supply and demand are still relevant to the location, extraction and recovery of dwindling supplies of minerals and will help save the planet. Minerals that are uneconomic to mine now could become viable for the future, if their prices will rise to compensate for higher costs of extraction or if new technologies appeared. This is a bet that many of us are prepared to make. But we must suppose that all the minerals we need will be there in the first place. This is far from ascertained. And if only some minerals would be available, bottleneck would appear, and their access would be restricted to the ones who could afford them. This is an issue that deserves particular attention, in our opinion, especially if resources will be geographically concentrated and free trade is under threat.

Perhaps we could introduce a new character into the plot, such as artificial intelligence (AI). So far it has been employed both for peaceful endeavours (i.e., medicine, transport and communications) and in warfare (i.e., via drones). Should we entrust it as a problem solver for matters that humanity alone can hardly acknowledge and manage? In particular, should we delegate AI to plan our transition from fossil fuels to renewable energy and perhaps arrange sustainable food production for nine billion humans? These are open matters. They provide more questions than answers over finalities, direction and control. Without entering such issues, it will suffice to note that AI requires huge amounts of energy and rare minerals. Intelligence emerges from artificial neural networks that are trained by Big Data, which are stored in the Cloud and processed by High-Performance Computers. But the Cloud is far from immaterial. It includes 600 hyperscale data centres, spread around the world, with a power consumption of more than 0.6 TW. This is more than 3% of the total energy consumed by our superorganism as a whole [Sustainability in Business, 2022] and is expected to rise to 8% by the end of the 2020s [IEEE Spectrum, 2021]. It is unclear how much electricity is required for the global use of intelligent technologies, but the figure must be astonishing.

In any case, a full energy transition will entail decades to finalise. Therefore, should we include the extra energy and minerals necessary to meet the demand of a growing population at a positive rate of economic growth, there is no way we can do that with only one planet at our disposal. And let us not forget that, as we write, about 760 milion people have no access to electricity yet. As a result, energy transition will be only viable for the very top of the most fortunate in society.

Energy, human development and inequality

As a rule of thumb, the quality of life is said to increase with the consumption of electricity. This is statistically confirmed, as the two trends basically grow in the same proportion. Combining average individual income, life expectancy and the level of education, the United Nations calculate a Human Development Index (HDI) ranging between zero and one that grows according to the average consumption of energy (UNDP, 1997). Initially proposed in the early 1990s, this index was an important step toward a more sensible measure of progress, one defined less by GDP growth and more by social goals. HDI is presently calculated as the geometric mean of three indicators: life expectancy at birth; education and per capita income in purchasing power parity (PPP). The principles behind HDI informed the Millennium Development Goals, which were launched in 2000.

HDI increases rapidly at low levels of electrical energy consumption and flattens in the vicinity of 8,000 kWh per capita per year. This means that the marginal utility of energy consumption decreases when income increases, suggesting that additional energy is better allocated when assessed to *less*, rather than *more*, developed countries. Obviously, this new parameter has many flaws: it does not consider domestic inequalities, for example, between classes or gender. Nevertheless, it is certainly better than GDP, as an indicator of well-being. Turning to energy requirements, it seems that 3,000 kWh per capita of electricity per year is sufficient to have a good quality of life, with a human development index of 0.8. But of course, this is an arbitrary measure that can be adjusted according to habits, culture, climate etc.

Currently, the United States and Canada consume more than 12,000 kWh a year of electricity per capita. European countries consume "only" up to 8,000 kWh, but that is still a high figure. About 70% of humanity remains below 3,000 kWh per capita per year. So, while in the richer countries a small increase in energy availability produces very little improvement in the quality of life (if any), quite the opposite holds for the poorer ones. However, in our present conditions, rather than talking about further increases in goods and services, and therefore in energy requirements, we should be talking about policies to save, and possibly allocate energy more fairly to achieve the greatest benefits. This is particularly advisable if we want to address, beyond energy scarcity, the huge problem of ecological deterioration and green-house emissions.

A Sustainable Development Index (SDI) has been recently proposed to consider the limitations of the HDI emerging from a growing crisis of climate change and ecological breakdown (Hickel, 2020). HDI pays no attention to ecology and maintains an emphasis on high levels of income that, being correlated with ecological impact, violates sustainability principles. The SDI starts from the same formula of HDI but places a threshold on per capita income, and divides by two indicators of ecological impact: CO_2 emissions and material footprint. Both indicators are calculated in terms of per capita consumption and rendered vis-à-vis planetary boundaries. The SDI is thus an indicator that measures nations' ecological efficiency in delivering human development.

When adjusted for ecological impact, the top 10 SDI performers ranked as follows, in 2019: Costa Rica, Sri Lanka, Georgia, Panama, Cuba, Dominican Republic, Peru, Armenia, Albania, Moldova (Sustainable Development Index, 2022). Of course, these top 10 champions may provide a model for poorer countries to follow, in the vicinity of their GDP, but they certainly cannot constitute a viable example for richer countries. SDI ranking indicates position 100 for China and 159 for USA. For these countries, and their industrial akin and income neighbours, adjustment to sustainable development is subject, among other things, to most of what said above.

Conclusions

This brief review of the ability of our species to face current ecological challenges and the desire to transition away from fossil fuels does not provide us with a comforting picture. Yet, one must proceed to diagnose before therapy. Once ascertained that we strongly prefer business as usual over painful changes to our way of life, particularly in developed countries, we must recognise interdependence as a basic component of our overall well-being. Interdependence can be scaled down by assessing more value to local vs global value chains, to national vs international supply, to quality vs quantity, just to name a few examples. But a global superorganism is not destined to die. Our societies are far more complex than those of only a century ago and there is no way ahead alone. The increase of our liabilities into the future via a decoupling of debts over the availability of natural resources is a reality that we must acknowledge and address. It is a time to think of more fairness, and a more sober life, not as a penalty but as an opportunity. Unfortunately, a glimpse at our inner nature suggests that we shall need an even bigger shock than pandemics, wars, and environmental disasters before embarking on such a cultural revolution. A sudden realisation that energy transition will be only available for the very top of the most fortunate will certainly wreak greater havoc in the near future. Our world is already plagued with economic, political and climate migrations. We are also in the middle of major geo-political disturbances. There is no space for improvisation. Planning for the future is imperative. However, a glimpse to the views of energy experts (e.g., those who provide the energy strategy for governments) is not reassuring. All too often they seem caught in the discussion between the costs and benefits of renewables vs not renewables according to the constituencies (and the vested interests) of their political mandates. Besides, the political discourse often revolves around ideological reasoning and is rarely based on a thorough assessment of sustainability, all things considered. Nonetheless, a new global governance for energy and minerals is desperately needed, if we want our superorganism to keep delivering.

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