Energy Abundance: Curse or Blessing?

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Abstract. Abundance of scarce resources is always an exciting prospect and if that resource is Energy, it can't get better. In this study, we attempt to visualize future scenario, year 2065, when the energy abundance will be a daily life reality. We look into the road to such abundance through the lens of framework that characterizes impact of energy abundance. We believe best case scenario will be driven by fission technology. Such future will also be accompanied by high level of automation, robotics, advanced transportations, and post scarcity economies based on resources abundance. However, the major challenge will be managing heat emitted from extensive use of energy.

Keywords: Energy abundance, abundance implications.

1 Introduction

"Free energy will promulgate a forward leap in human progress akin to the discovery of fire. It will bring the dawn of an entirely new civilization—one based on freedom and abundance." —Sterling D. Allan (Feb. 2003)

Among various natural resources, energy has been integral to human society. The availability of usable energy has had both accelerating and hindering effects in growth and development of economies. On one hand, energy has been fueling growth and development to transform societies into modern, wealthy economies. On the other hand, limited supplies have been slowing the pace of growth and development for the least developing nations. Energy consumption per capita has a strong positive correlation with human development indices (Figure 1), and especially with economic indices (such as gross domestic product [GDP] per capita). Increasing electricity consumption per capita can directly stimulate faster economic growth and indirectly achieve enhanced social development [1].

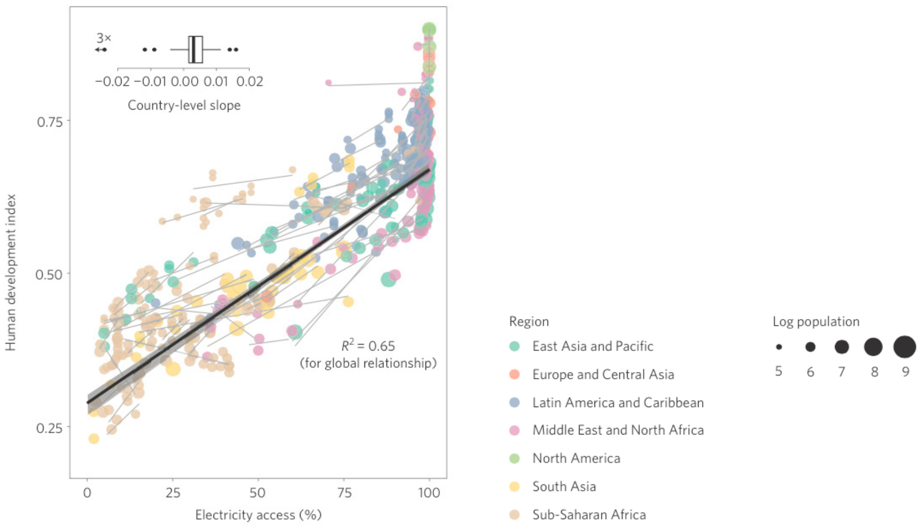

Figure 1. ***Relationship between electricity access and human development index in different populations [1].***

The world has been striving toward uncovering abundant energy supplies. Substantial investment in developing and improving the efficiency of renewable energy technology and diligent explorations to unearth more fossil fuels are significant steps toward achieving abundant energy supplies. Further, there has been continuous emphasis on energy efficiency in terms of energy production technology, energy-efficient product design, and smart energy consumption. All of these steps point toward a future world that will be blessed with abundant energy supplies. Further, a positive relationship between energy and development sets a sound foundation for the belief that a future world with abundant energy will be lit up by explosive growth and development.

The future of a world with energy abundance and subsequent technological advancement makes an interesting case to ponder. Will the impact of such a leap be positive or negative? Before getting much deeper into implications of energy abundance, we start by conceptualizing the abundance of energy and briefly examining how we achieve this abundance.

1.1 Energy Abundance

Imagine what the world might be like if we could produce energy cleanly, inexpensively, and on a global scale. What if ultra-efficient solar arrays cost no more to make than cardboard? Now add ultra-efficient vehicles, lighting, and the entire infrastructure of an industrial civilization, all made at low cost and delivered and operated with a zero carbon footprint. Then the global prospect would be not scarcity, but unprecedented abundance—radical, transformative, and sustainable abundance. We would be able to produce much more of what people want and at a radically lower cost—both economic and environmental. This isn't the future most people expect [2].

One can always argue that energy has always been abundant in nature. However, availability itself alone does not guarantee abundance. Rather, it is the ability to utilize this energy that characterizes abundance. Thus, we define abundance of energy as adequate production of useable energy, which is available, accessible, cheap, transportable, transferable, and scalable.

The transferability of energy would lead to a global scenario that ensures that energy can be evenly distributed. The scalability would lead to a scenario where energy can be utilized from small-scale application to large space exploration. These assumptions serve as the foundation for the further analysis.

1.2 Road to Abundance

How do we achieve this radical abundance of energy? We can view economic history as a series of technological revolutions that each enabled the subsequent revolution. Advances in agriculture allowed a small portion of a population to feed the entire population, thereby enabling urbanization and industrialization. Industrialization allowed the mass production of complex goods, thereby enabling the cheap manufacturing of powerful computers. Computation devices allowed efficient creation, storage, and distribution of information, thereby enabling dramatically more efficient learning, communication, and collaboration (Internet + globalization). Internet and globalization set the stage for energy abundance [3].

The present moment is a tipping point, in which decentralized transmission networks, cheap photovoltaics, sophisticated low-energy appliances, mobile phones, and "virtual" financial services are all merging to create a super-grid that will shift the energy paradigm [1]. These disruptive technologies increase access to basic electricity services. The smart grid will use the Internet as its control location. Like the cloud, it will store energy anywhere in the grid. Energy will become a social phenomenon, as Internet is today [4]. Everybody will be a both a consumer and a supplier of energy. Energy will be stored anywhere in the grid, and energy exchange will happen in a mesh.

The abundance of energy will be a result of the Internet of energy architecture, and a series of technological innovations in different solution areas. The energy efficiency of electrical utilities will increase. The efficiency of solar energy will increase, and cost will decrease. The amount of solar energy we can harvest on Earth is somewhat limited by varying cloud cover and the cycle of night and day. Space-based solar harvesters in orbit, on the Moon, or elsewhere in space will collect solar energy and transmit it back to Earth [5]. In 2065 we will be able to produce hydrogen through the electrolysis of water by overcoming today's problems—today, the process consumes more energy than it supplies.

Although nuclear fission produces a great deal of energy without relying on fossil fuels, it also produces nuclear waste. Nuclear fusion generates significantly less waste without all the radiation. In fusion process, fusing together light atoms into a heavier one at extremely high pressures and temperatures produces energy. Although fusion energy was already achieved even in the early 1970s, only recently did a fusion reaction produce more energy than was needed to start that reaction. A recent experiment at the Joint European Torus fusion reactor in the United Kingdom produced 20 million joules [6]. The ITER Tokamak fusion reactor is designed to produce 500 MW of output power with 50 MW to operate. Construction of the ITER Tokamak complex started in 2013 in Cadarache, southern France, and expected to start plasma experiments in 2020, with full deuterium-tritium fusion experiments starting in 2027 [7]. A Lockheed Martin research team has been working on a scalable compact fusion reactor, which will be small and practical enough for applications ranging from interplanetary spacecraft and commercial ships to city power stations [8].

The fusion reactor is considered very safe, as it requires extremely precise and controlled pressure, temperature, and magnetic field parameters to operate. Any deviation from the optimal condition will render it unable to react or to produce excess heat, consequently requiring no elaborate failsafe mechanism. There is no risk of a runaway reaction, and day-to-day-operation of a fusion power station does not involve the transport of radioactive materials and leave long-lasting radioactive waste to create a burden on future generations [9].

The basic fusion fuels from which deuterium and tritium are extracted and generated are water and lithium. Approximately 70% of the Earth's surface is covered by water. There is enough deuterium for millions of years, and enough easily mined lithium for several hundreds of years [9]. Also, fusion inflicts very low global impact on the environment, as it does not involve the emission of carbon dioxide (CO_2) greenhouse gas. A 1,000-MW electric fusion power plant would consume around 100 kg of deuterium and 3 tons of natural lithium in a year while generating 7 billion kilowatt-hours (kWh) of energy.

As R. P. Siegel puts it, “In many ways, fusion power seems like the perfect energy source. It's clean, it's inexpensive, and it uses seawater as its fuel source. It's the Holy Grail, it's the pot of gold at the end of the energy rainbow, and it has no appreciable side effects, except for one: modern civilization on steroids” [10].

1.3 Dynamics of the Energy Abundance

To examine the impact of the energy abundance on a global scale we look at two interesting restrictions: the nature of ownership and distribution of energy solutions, and the environmental impact such energy solutions create.

How does a future energy solution develop, and what will be the nature of the technology that determines technology ownership and distribution? If the technological breakthrough occurs as a simple and imitable technology, the ownership will be of more decentralized nature. However, if the scale of investment required in developing energy technology and producing energy is substantial, requires high-level operational expertise, and is difficult to imitate, the energy production might be more centralized. In such a case, the energy market might converge toward an oligopoly structure. Energy abundance, cheap unlimited energy, and oligopoly market structure might be against all economics odds.

One needs to add a few facts to reverse such odds. First, unlike in traditional economic theories, the energy producer will be capable of producing energy in unlimited quantities with very low marginal cost. Second, owners of fusion technology would have to dig deep in their pockets to develop it. However, at the beginning phase such technology will be facing stiff competition from alternative energy production from shale gas, other fossil fuels, existing nuclear technology, and improved renewable technologies. In such circumstances, to wipe out and win the competition, owners of fusion technology will have incentive to provide energy at cheaper price. Further, such endeavors will be favored by very low marginal costs of production. Third, owners of such technology will be able to create very strong barriers to market entry when they couple huge upfront investment with lower price. Thus, there will be enough incentives for the fusion technology owners to provide abundant energy.

On the other extreme, such energy technology might be developed as simple technology that does not require massive investment and is easy to imitate. Under such circumstances more entities would be able to develop and implement energy technology. This would also lead to a more decentralized and distributed market structure. We believe that development of this nature will provide an ideal platform for the favorable energy abundance scenario.

A decentralized market structure provides more safety from market collusion and other forms of market irregularities. In this study, we depict centralized energy technology distribution as unfavorable and decentralized technology distribution as favorable variables of the future scenario.

Energy has not only fueled the advancement and amenities of modern life but also brought some serious environmental consequences. Extensive use of fossil fuels as source for energy production has escalated greenhouse emission and also global warming. Since the Industrial Revolution in 1790, and accelerating since the mid-20th century, the burning of fossil fuels has caused Earth's surface temperature to rise. The combined effect has led to the climate change. What ever the energy production technology is, there is always a possibility of negative environmental impacts. Currently, the renewable energy source of hydropower is examined for its negative impact on water ecology, and nuclear energy sources are criticized for nuclear waste.

To achieve maximum benefits from the energy abundance, the future technology should have minimum environmental burden or the environmental impacts should be well negotiated. The environmental impacts from the use of resources place restriction on the abundance and its potential benefits [11].

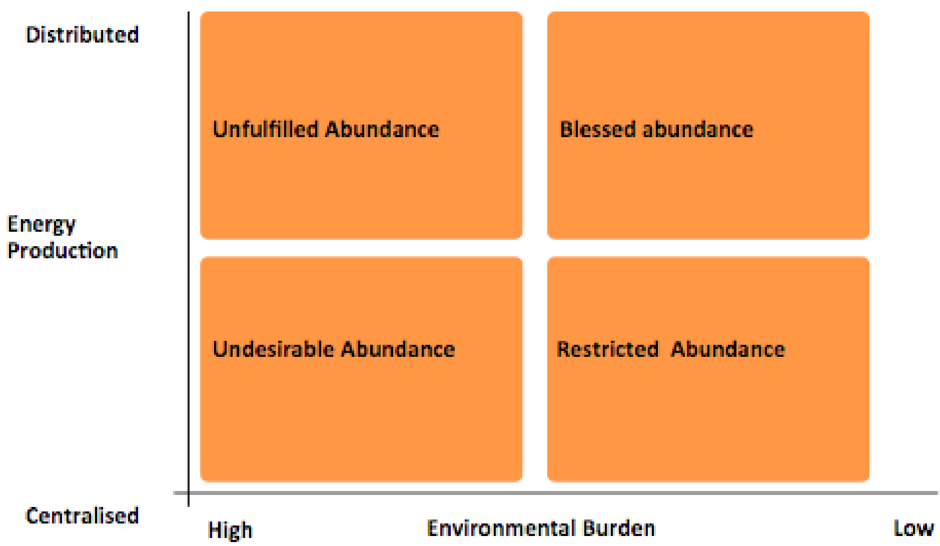

Figure 2. ***Future energy abundance scenarios.***

Considering these two dimensions of technological distribution and environmental burden from energy production and use, we visualize four alternative scenarios (Figure 2). In an ideal world, the energy production capabilities are not centralized and distributed. Further, the production and consumption of energy is not constrained by environmental consideration. We call this case *blessed abundance*. On the other extreme, the least desirable scenario, the energy production technology is centralized such that it poses looming political and economical threat to sustainable and full-fledged abundance. Further, use of energy abundance also has negative impact. This is called *undesirable abundance*. In other alternative scenarios, either the technological distribution is restricted (*restricted abundance*) or the use of energy is cursed by environmental implications (*cursed abundance*).

In this article we have a closer look at the scenario of blessed abundance. We picture the world 50 years from now, in 2065. The world will be blessed with the abundance of energy supplies and advanced technological development. We call this state, according to Bob Metcalfe, “squanderable abundance,” because we will have more energy than we need. What happens to humanity when we have hundreds of thousands of terawatts of energy available? In the words of Sterling D. Allan, “Free energy will promulgate a forward leap in human progress akin to the discovery of fire. It will bring the dawn of an entirely new civilization—one based on freedom and abundance” (Feb. 2003).

2 *Squanderable Abundance*

With squanderable abundance, energy becomes the fuel that allows us to fulfill almost all of our dreams [12]. We start looking at those dreams by analyzing the direct implications of the energy abundance.

2.1 Water

The water crisis is the number one global risk based on impact to society (as a measure of devastation), and the number eight global risk based on likelihood (likelihood of occurring within 10 years) as announced by the World Economic Forum in January 2015 [13]. Although water is abundant almost everywhere, clean, drinkable water from natural sources is shrinking drastically. However, if cheap technology is available in order to purify water from available sources, the water problem will be resolved. Due to cheap transportation cost, water plants can be established near or at the sea and clean water can be transported in any part of the world. Abundance of energy can easily mitigate shortage of clean water, as simple solutions can be devised to desalinate seawater with abundant energy [14].

Groundwater is another vast source of clean water. In the post–energy scarce world, this huge source of water will be in use with ease. Availability of abundant clear water will bring great positive change to the ways life is lived, especially in the developing countries [15,16].

2.2 Food

Accordng to Food and Agriculture Organization (FAO) of the United Nations, energy is closely related to food security, poverty eradication, and better nutrition. Food systems consume 30% of the world’s total consumed energy; hence, energy is a very important factor in determining food price [17]. Cheap and abundant energy directly affects the food price. Until now food production was heavily dependent on the weather, for example, the position of the sun and amount of rainfall. As a result, throughout the year a big part of the world was unavailable to be used for food production. For example, the Nordic land was arable only during a very short summer. And the agricultural systems in the developing countries near the equator also depended greatly on the amount of natural rain.

Abundance of energy nullifies these dependencies and makes it possible to produce food anywhere throughout the year, disregarding the weather. As a result, food can be produced not only in the traditional arable land throughout the year, disregarding the harsh weather, but also in the harsh environments, such as a plateau or desert, or even in riverbeds, seafloors, and underneath the Earth's surface. It requires initial investment to build the infrastructure. However, low production cost, cheap transportation, and robotic labor reduce the cost significantly.

Abundance of energy also brings down the cost of harvesting and post-harvest technology, for example, solar crop driers and refrigerators. Availability of such machineries reduces huge food waste by enabling efficient crop collection, safe storage, and affordable transportation. This not only increases food volume but also improves food quality.

2.3 Transportation

Commercial transportation takes 27% of total energy consumption of the world [18]. Energy abundance will reduce the transportation cost significantly. This significant reduction in transportation cost will bring successive reductions in all walks of life. For example, the reduction in transportation cost will reduce production cost of transportation vehicles by reducing the transportation cost of raw materials that will in turn reduce transportation cost further. With great reduction in transportation cost, the transportation system of tomorrow will be redefined. It is more probable that personal aerial vehicle (PAVs) will be used to travel short to medium distances, such as from home to office, and high-speed ground transportation will be used for long-distance travel.

Some revolutionary systems and solutions have already been proposed for high-speed ground transportation. Maglev (derived from magnetic levitation) is a transport method that uses magnetic levitation to move vehicles without them touching the ground. With maglev, a vehicle travels along a guideway using magnets to create both lift and propulsion, thereby reducing friction and allowing higher speeds. A current version of maglev in Japan has already attained a speed of over 600 km/h. ET3, an organization connected to the Venus Project, has been promoting a tube-based maglev that can travel up to 4,000 miles per hour, in a motionless, frictionless tube, which can go over land or underwater. This technology will make it possible to go from Los Angeles to New York for an extended lunch break, or from Washington, D.C., to Beijing, China, in 2 hours. This is the future of continental and intercontinental travel. Elon Musk has come up with a concept of high-speed transportation system called Hyperloop, whereby pressurized capsules ride on a cushion of air that is driven by a combination of linear induction motors and air compressors [19].

With energy abundance, the major constraint of the cost of energy will be out of the play, and availability of cheap vehicles thanks to low production cost will accelerate the advent of a new era for personal transport systems. Already, research on the means to “lift personal transportation into the third dimension” has garnered huge amounts of attention [20,21,22]. MyCopter, a project funded by the European Union (EU), is working on a personal air transport system (PATS) based on low-altitude PAVs envisioned for traveling between homes and working places in urban environments. The Advanced Air Vehicle Program (AAVP) of the National Aeronautics and Space Administration (NASA) is looking into fixed-wing and vertical-lift aircraft as well as exploring far-future concepts that hold promise for revolutionary improvements to air travel [23]. In addition, research on advancing wireless energy transfer technology [24] and low-latency ultra-reliable networks [25] has also garnered much attention, both in academia and industries. The PAVs will be provided with energy from ground wirelessly, and the driving and navigation system will be totally shifted to the next-generation wireless network. Note that the driverless car is already a reality today.

It may not be very far in the future when flying cars/PAVs will be parked in the lower space. Wireless lift will be used to board the vehicles. Once boarded, the passenger(s) will require only giving the location of destination and pay some amount for the trip, without thinking about navigation and refueling. The PAVs will use their own power source to reach highways and then get wireless power from the 3D highway system.

2.4 Labor

Given the pace of current technological advancement, we believe that robotics technologies will accompany the abundant energy scenario. This leads to an optimal production scenario in which availability of unlimited low-cost energy and superior operational efficiency will boost production, transportation, and agricultural efficiency in an unprecedented way. As a result, job markets will see important restructuring. The routine jobs that do not require human judgments and interventions but mostly entail activity to be executed repeatedly will be the first candidate to go to the robots. Again cheap energy will ensure that programmed machines as a workforce come at better price. Thus, for labor-intensive jobs, humans will be set to take a back seat and look for alternative careers.

Jobs that require technical expertise, creativity, and non-routine judgments will be the ones that people might aspire to hold. Further, service-oriented professionals, such as doctors, teachers, and lawyers, would be of increasing importance. Machines doing basic jobs will also mean that many jobs that exist today will be extinct. In such circumstances, a big challenge for economies will be keeping the unemployment rate down. Economies will be required to invest substantially to train and educate people. The countries that train and develop the workforce for skilled jobs, such as designing and maintaining sophisticated machines or writing the code that helps them run, will have substantial competitive advantages over others [26].

3 Impact to Our Society

3.1 Post-Scarcity Economics

There are four kind of costs associated with production: energy, labor, time, and resource costs. Everything that we use consumes energy to be produced and transported. For example, energy represents roughly 50% of ocean shipping costs and 40% of aluminum production costs [27]. As a result, reduction in energy cost will cause cycles of successive cost reduction. *The Economist* predicts that within the next 20 years, half of all jobs will be taken over by machines. In some highly automated industries, like the automobile industry, it might be even up to 90% [28]. The ability of machines to work even in unfavorable environments for long hours will bring labor and time costs down. A non-human workforce, abundance of energy and raw materials, and the advent of efficient production technology will enable conditions of material abundance, which in turn will enable free distribution and complete a fully developed post-scarcity economics.

When energy is readily and cheaply available, with robots providing a cheap and reliable labor force, one might argue that the natural resources will be depleted at an exponential rate. The future market will be redefined by relentless production and consumption. At the same time, mining and resource exploration will also become more expansive. By the virtue of cheap and abundant energy, governments will be able to deploy more resources to explore new sources of material that otherwise would have been inextricable. Thus, increased consumption will be accompanied by added sources of natural resources from more exploration and new methods of growing foods, as discussed earlier. Reduced transportation cost and reduced lead time will further drive up the urge for sourcing. Increased food and material sourcing will lead to future globe where countries can focus on specializing in certain areas of production or as a source of raw materials.

Overcoming the hurdle of energy limitation would also mean possibility of developing material recycling technologies that otherwise would be far fetched. Material recycling technology could act as a closing loop in production system that injects used material back as raw material. The recycling industry coupled with reverse logistics, enabled by the grace of cheap energy, would be acting as a new source of raw material supplies in the production loop. These recycling businesses will also be a standout for the investors. The resulting consequences will be reduction in waste and also severe penalties on the wasting of resources.

In an alternative scenario, a shift in business model from product ownership to product leasing might emerge in the production system. Currently, consumers own the product. However, pressure to be material-efficient might cause business to shift the business model so that the producing companies own the product and customers use it by making leasing contracts. The company is responsible for maintaining the product and the customer pays leasing fees for the use of the product, thus creating a circular economy. However, the circular economy will still need to integrate recycling in its structure. Further, the resource pressure in the future might lead humans to space exploration in search of resources.

In post-scarcity economies—with diminished energy, labor, and transportation costs; reduced lead time; and better sourcing—the resultant effect would yield very cheap foods and products. Thus, we can visualize a future globe where energy-driven economic sectors such as production and transportation gain enormous production and operational efficiencies. The global food and product markets will be more affordable and accessible than ever. With the falling prices of foods and products, courtesy of the peaking efficiencies, one could rush to the conclusion that future economies will contract due to decreasing prices. Despite the falling prices in food and products, the towering shares of the service and entertainment sectors of the economy will, mostly, compensate the economic growth. Undoubtedly, the economies will be flooded by commoditized products, thanks to the unprecedented efficiency that we will achieve. At the same time, cheaper products will also mean that consumers will have higher discretionary income left to spend. The products that are considered luxurious now will be commoditized. As a result, increased commoditization of product will result in lucrative growth of luxury products, services, and entertainment. Products that are endowed with art, design, and creativity will continue to command luxury position and premium revenue. Entertainment, tourism, and sport industries will flourish to a new height. Thus, as consequences of falling prices of food and products, service sectors will experience explosive growth.

3.2 Liberalization

The energy abundance will lead more countries down the path of economic openness and liberalization. The developing nations that are in dire need of external financial injection in the economy will have to open up and liberalize themselves to benefit from the vast potential of the energy abundance. As present, there lies a wide disparity between countries in terms of economic and financial capacities. The developing countries are still far from achieving the growth and development levels of their Western counterparts. The sluggish economic growth can be partly explained by the fact that these developing countries have failed to meet the energy needs required to the drive up the economy. Maximizing the utilization of energy, to propel the economy, requires substantial investments in building infrastructures and establishing the industries. However, government can break the investment hurdles by opening the market to the private and foreign investors. Further, developing countries are also lagging behind in terms of access to the modern technologies. In such circumstances, foreign direct investment, as always, will act as an important tool to gain access to the technology. Given the robotic revolution and automatization in economics sectors, the stakes for liberalizing economies are set to be even higher. One can only imagine that more economies will be lured into economic openness and liberalization once the abundance of energy rises to the horizon. The outlook of the global economy in the future will be more open and liberal than ever.

3.3 Technological Singularity

"If very complicated chemical molecules can operate in humans to make them intelligent, then equally complicated electronic circuits can also make computers act in an intelligent way" —Stephen W. Hawking, physicist (1998).

Technological singularity has been predicted as early as 2030, when the intelligence of computers, computer networks, or robots would enable them to redesign themselves for self-improvement. Robots operating with such strong artificial intelligence (AI) will not only rival human beings in terms of intelligence and creativity, but the repetition of such cycle—that is, the machine or machine-assisted human being designing further intelligent machines—may result in an intelligence explosion [29]. It is predicted that the end product of such a chain will be something that is unfathomable with current knowledge. Currently, opinions are divided more on the ramifications of the emergence of such super intelligence than on the inevitability of its emergence. If the avoidance of potential hazards and pitfalls can be ensured, this will surely expedite the ongoing journey of technological civilization at an unprecedented pace when coupled with energy abundance.

3.4 Exploring Space

As most of the problems of the current world will be resolved by both the direct and indirect influence of energy abundance except the available space on this planet, it is safe to assume that energy abundance will rejuvenate the race to conquer space. Unfortunately, with the closest star, Proxima Centurai, being 4.24 light years away, the travel time will be enormous unless spaceships attain a travel speed that is at least a significant percentage of that of light. Along with other issues, the requirement of the sheer amount of energy needed for such a voyage and a feasible propulsion system are two major hindrances for interstellar travel. It has been theorized that fusion rocket starships with a large number of stages of nuclear fusion reactions can achieve speed arbitrarily close to that of light [30]. Even if technologies like EmDrive (i.e., radiofrequency resonant cavity thruster) ultimately fail, energy abundance is expected to open the door to a new era of technological excellence. It won't be long after energy abundance when a generation ship with a modern Columbus or an egg ship with frozen early-stage human embryos along with highly intelligent and trained robot parents will leave this planet to find a new home in the heavens. With energy abundance, colonizing the Moon or Mars will be achieved within a reasonable timeframe. In that case, this new land can be used to test the extraterrestrial human civilization and as the center for space exploration.

3.5 Societal and Cultural Implications

According to Pritzker [31], energy enables us to live healthful, fulfilling lives. Energy is used to power our homes, grow our food, and manufacture our clothes and other basic necessities. Energy let us communicate with friends and family, travel abroad, and commute. Energy liberates especially women and children from the drudgery of manual labor. In both the developed and developing worlds, energy is critical for clean water, healthcare, reliable lighting, and transport and telecommunication services. Countries that can meet their energy needs become wealthier, more resilient, and better able to navigate social environmental hazards.

Megatrends affecting future development include the dynamic of technology, the transition of service society, environmental awareness, and the aging population. In addition to this bottom-up approach, peer-to-peer models of organization where individuals organize their joint efforts in open cooperation and *prosumerism* will increase [33,34]. Prosumerism (producer + consumer) refers to consumers and citizens turned to active producers. In practice, peer-to-peer models can mean, for instance, social media networks, open source programming communities, grassroots political movements, consumer movements, and co-working spaces [32,33].

The population is aging rapidly, which increases the need for assistance and care services to support the daily living of the aging population. Not just the elderly but also the younger generations increasingly demand new services to support and ease their everyday living as household demographics change, as urban lifestyles develop, and as the values of service consumption evolve.

We will live longer and stay healthy. The aging of the world's population in developing and developed countries is an indicator of improving global health [34]. However, the main health burdens for older people are from chronic diseases. The need for long-term care increases. Many of the very old lose their ability to live independently because of limited mobility, frailty, or other physical or mental health problems.

In 50 years, family structure may be very different in form than that of the family of 2015. Two adults and children principally form the family structure in 2015. The traditional family of mother, father, and children may vary to include numerous varieties of diverse familial arrangements. Gay-parent, single-parent, and grandparent families will prosper in 2065. Although the members of the 2065 family may differ, the love between the family members will not. Families will adapt and shape society around the needs of the family. Families will make sure the needs of their children are met through community action.

The global learning environment will enhance a student's understanding about the world in 2065. The need for self-education will not diminish even when there is energy abundance. The population will be highly educated, and perhaps the working mode will be different from how it is now. For example, especially for creative workers, where the shift occurs from working mode to leisure time, it will be difficult to determine such mode. As there is no need for mundane work in 2065, because robots are doing the routine jobs, there will be more time for entertainment and intellectual debate.

4 Environmental Implications

Scientists at the Stockholm Resilience Centre have identified nine planetary boundaries (see Figure 3) that define the envelope within which we must conduct our affairs if we are to avoid destroying our very source of sustenance. In addition to climate change, there is also biological diversity, nitrogen and phosphorus consumption and release, ocean acidification, stratospheric ozone, land-use change, freshwater availability, aerosol loading, and chemical pollution [35]. We need to respect all of these boundaries in order to maintain the comfortable living conditions we enjoy now. With fusion energy and provided that we will be able to manage heat economically, the future looks bright. Also, in terms of respecting these environmental boundaries, we will better off than is currently the case.

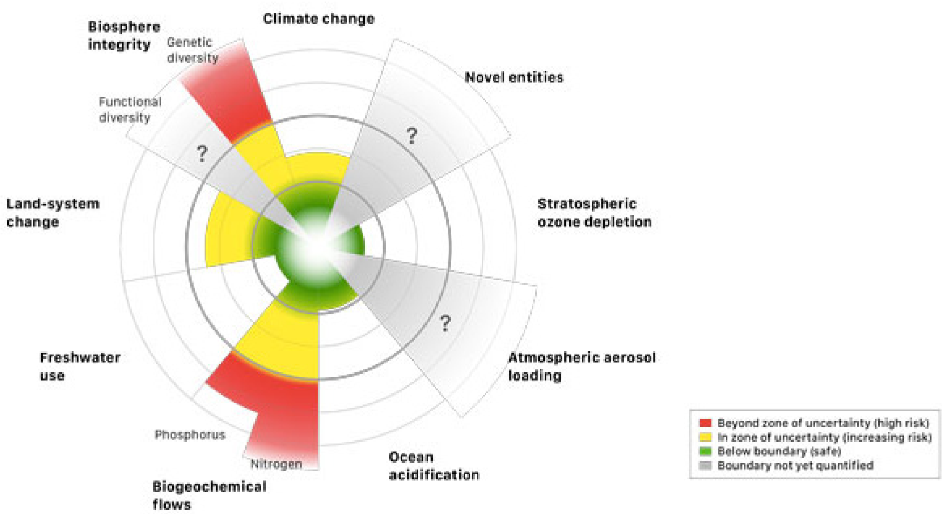

Figure 3. ***Estimates of how the different control variables for seven of the nine planetary boundaries have changed from 1950 to present. The green shaded polygon represents the safe operating space [35].***

Energy consumption has always gone hand in hand with material consumption, resource depletion, and environmental pollution. However, energy abundance occurring via fusion combined with technological advancement will ensure that future will have a different outlook. The fact that use of fusion to produce energy will not emit harmful gases like carbon dioxide and carbon monoxide will be instrumental to controlling air pollution. Transportation and industrial sectors, which have been dependent on fossil fuels, can be greener and cleaner with the use of fusion energy. Further, it would put a brake in further depletion of ozone layer. In fact, fusion energy might be the world's only chance of avoiding catastrophic climate change caused by global warming [36].

The massive jump in consumption patterns in a post-scarcity scenario means materials will be among the valuable resources. Thus, the penalty for wasting materials and resources would be pivotal for controlling material waste at the source. The emergence of a circular economy and pervasive material recycling technology will also equip us with the capability for better material waste management. Better waste management will automatically lead to reduced land and water pollution. Abundance of energy can further lead to development of air and water purification technology.

Along with all the positive environmental implications, energy abundance can still have some serious challenges to overcome. Even with clean technology like fusion, heat emission is likely to be major issue. Given the fact that global warming is already a big challenge, this makes it look like a condemnable threat. The enormous consumption of energy will surely produce a huge amount of heat that needs to be managed. The heat management can have both environmental and economic implication. On one hand, unmanaged heat can lead to severe environmental consequences in terms of global warming and ecological damages; on the other hand, it will require substantial resources. The additional resource requirements will add to the cost of energy production and, ultimately, limit the full-fledged benefits of energy abundance. Thus, the nature of heat management is a critical consideration.

5 Summary

The dawn of human civilization was proclaimed when humans learned how to control fire—that is, use energy. The adoption of better means regarding how to produce and utilize energy have ushered in a human life of comfort, ease, and luxury, and enabled the transformation from a "cave inhabitant" to the one heading for other galaxies. With energy abundance, there will be a tremendous change in the way an individual lives his or her life from the way the world runs today. We will not have scarcity of food, water, shelter, raw materials, manual labor (i.e., robots), or even processing power (i.e., strong, AI-driven supercomputers). The wars over energy sources or trans-river boundaries, that is, water sources, will be no more. As a result, the energy abundance will have an enormous potential to change the world.

However, deliverance of that potential primarily depends on the emergence of humankind as a global community with a global political will. Note that richest 1% now owns more wealth than the bottom 90% in the United States. Even in last 4 years, 80 of the world's top billionaires have doubled their wealth, and currently their wealth equals that of the bottom 50% of the rest of the world [37]. If such a trend continues, or if few countries and corporations manage to control the whole energy system and consequently other production systems, energy abundance itself may not bring any positive change to the world. Rise of machines as workforce may render most people jobless, and the resulting extremely low purchase power may make energy and material abundance irrelevant to a large percentage of people. In short, it depends on the political will of the global body whether the machine will work for humankind, giving them freedom from manual labor, or whether the machine will be used to rule them in the energy-abundance-enabled, post-scarcity world. However, we believe the explosion of social media through the Internet and future versions of such communication systems will not only bring people from different corners of the world closer and make them citizens of a global village, but also empower the masses of people and give them substantial and direct access to policymaking.

Additionally, abundance of energy along with a non-human workforce may spur the indiscriminate and unscrupulous utilization of available resources. If the production of this enormous energy does not come from clean sources or if the use of this energy causes environmental pollution, it may take the planet to the brink of instability and natural calamity. The climate may undergo drastic and irrevocable change; ecosystems of diversified flora and fauna of the planet will be threatened.

In the age of such abundance and prosperity, humankind may not converge on political or economic ideologies, and diversity of thoughts on these aspects may still be considered as beauty. However, consensus on how and at what pace the natural resources will be utilized, how fast the civilization will be allowed to flourish, and what costs will be conceded for such advancements will be mandatory in order to preserve the world as a livable habitat for next generations.

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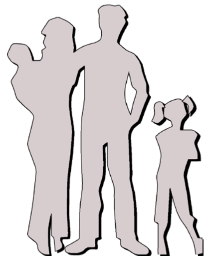
References

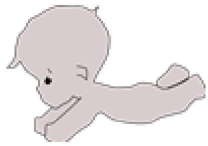
1. Alstone, P., Gershenson, D., Kammen, D. M.: Decentralized Energy Systems for Clean Energy Access. Nature Climate Change, 5, 305--3014 (2015)
2. Drexler, K.E.: Radical Abundance. How a Revolution in Nanotechnology Will Change Civilization. Public Affairs, New York (2013)
3. Rader, G.: If Energy Was Free and Renewable, How Would the Economy Be Fundamentally Different from What It Is Now? Quora (2010)
4. Metcalfe, B.: Squanderable Abundance of Energy. Lecture at the Singularity University (2009), https://www.youtube.com/watch?v=q5f5mHx9g3A
5. Lamb, R.: What Is the Biggest Energy Source of the Future? HowStuffWorks.com (2010), http://science.howstuffworks.com/environmental/energy/biggest-energy-source-future.htm
6. Roudman, S.: The Nuclear Fusion Arms Race Is Underway, http://motherboard.vice.com/blog/the-nuclear-fusion-arms-race-is-underway

7. ITER Organization, https://www.iter.org/proj#itersite
8. Lockheed Martin, http://www.lockheedmartin.com/us/products/compact-fusion.html
9. Fusion for Energy, http://fusionforenergy.europa.eu/understandingfusion/merits.aspx
10. Siegel, R.P.: Fusion Power: Pros and Cons (2012), http://www.triplepundit.com/special/fusion-power-pros-cons/
11. Zinam, O.: The Myth of Absolute Abundance: Economic Development as a Shift in Relative Scarcities. American Journal of Economics and Sociology, 41(1), 61--76 (1982)
12. Diamandis, P.: What If We Had a Squanderable Abundance of Energy? We Do. Big Think, http://bigthink.com/in-their-own-words/what-if-we-had-a-squanderable-abundance-of-energy-we-do
13. World Economic Forum: Global Risks 2015, http://reports.weforum.org/global-risks-2015/#read
14. Fischetti, M.: Fresh from the Sea. Scientific American, 297(3), 118--119 (2007)
15. The Water Project: 10 Ways Clean Water, http://thewaterproject.org/10-ways-clean-water-changes-the-world
16. Lopez-Gunn, E., Llamas, M.R.: Re-thinking Water Scarcity: Can Science and Technology Solve the Global Water Crisis? Natural Resources Forum, 32, 228--238 (2008)
17. Food and Agriculture Organization of the United Nations: The Post-2015 Development Agenda and the Millennium Development Goals, http://www.fao.org/post-2015-mdg/14-themes/energy/en/
18. U.S. Energy Information Administration: International Energy Outlook 2007, http://www.eia.doe.gov/oiaf/ieo/index.html
19. Elon, M.: Hyperloop Alpha. SpaceX (2015), http://www.spacex.com/sites/spacex/files/hyperloop_alpha-20130812.pdf
20. Jump M. et al.: MyCopter—Enabling Technologies for Personal Aerial Transportation Systems. International HELI World Conference, Frankfurt/Main, Germany (2011)
21. Moore, M. D.: NASA Personal Air Transportation Technologies, http://cafefoundation.org/v2/pdf_tech/NASA.Aeronautics/NasaPavTech.pdf
22. Djojodihardjo, H., Thangarajah, N.: Research, Development and Recent Patents on Aerodynamic Surface Circulation Control—A Critical Review. Recent Patents on Mechanical Engineering, 7(1), 1--37 (2014)
23. NASA: Advanced Air Vehicles Program, http://www.aeronautics.nasa.gov/programs-aavp.htm
24. Chaurasia, D., Ahirwar, S.: A Review on Wireless Electricity Transmission Techniques. Current Trends in Technology and Science, 2(4) (2013)
25. METIS: Mobile and Wireless Communications Enablers for the Twenty-Twenty Information Society, https://www.metis2020.com/
26. Fink, L.: How Will the Sharing Economy Reshape Our Spending? World Economic Forum, https://agenda.weforum.org/2015/02/how-will-the-sharing-economy-reshape-our-spending/ (2015)
27. Gold, D.M.: If Energy Were Free and Unlimited… GreenGold (2011), http://www.greengoldblog.com/2011_05_01_archive.html
28. The Economist: The Onrushing Wave (2014), http://www.economist.com/news/briefing/21594264-previous-technological-innovation-has-always-delivered-more-long-run-employment-not-less
29. Chalmers, D.: On Singularity, Intelligence Explosion. Singularity Institute for Artificial Intelligence (2010)
30. Spencer, D. F., Jaffe, L. D.: Feasibility of Interstellar Travel. Astronautica Acta, IX, 49--58 (1963)
31. Pritzker, R.:. The Case for Energy Abundance (2014), http://www.ssireview.org/blog/entry/the_case_for_energy_abundance
32. Heinonen, S., Karjalainen, J., & Ruotsalainen, J.: Introduction to Scenarios FCI (2015)
33. Wikipedia, http://en.wikipedia.org/wiki/Prosumer
34. WHO: 10 Facts on Ageing and the Life Course, http://www.who.int/features/factfiles/ageing/en/
35. Rockström, J., et al.: Planetary Boundaries: Exploring the Safe Operating Space for Humanity. Ecology and Society, 14(2), Art. 32 (2009)
36. LENR & Cold Fusion News: Climate Change: LENR Could Be Our Last Best Hope (2014), http://coldfusion3.com/blog/climate-change-lenr-could-be-our-last-best-hope
37. BBC News: Richest 1% to Own More Than Rest of World, Oxfam Says (2015), http://www.bbc.com/news/business-30875633

Appendix: Scenario in 2065



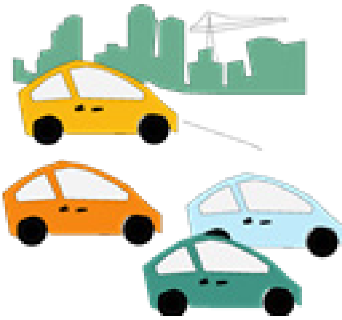
In 2015, Maija, 35, lives with her husband Esko, 34, and their newborn child Samuel, 6 months, in Töölö. Apart from his new family, Esko has a daughter Milla, 8, from a former relationship. Milla stays every other week at her father's in Töölö and every other week at her mother's in Sipoo, where she goes to school. Thus, during every other week, Maija and Esko have to transport her to school in Sipoo, taking much time. The family keeps contact with Milla through Skype, and from time to time they play hide and seek through Skype connection. Maija and Esko and their children spend time in their summer cottage in Kemiö; this summer cottage has belonged to Maija's family since 1900 and they have had solar panels for some years now.



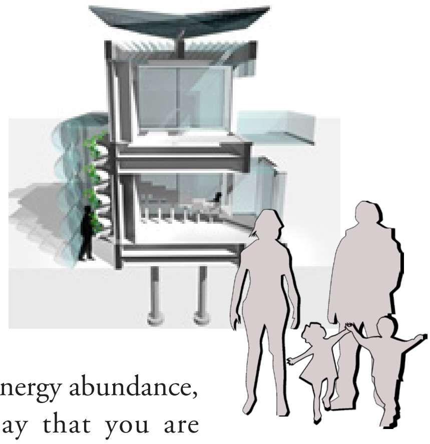
Communication today is mostly through social media with digital and electrical devices. It depends your age whether you use WhatsApp or Facebook or SMS for sending updates of your life and for capturing the moment and sharing—you might use Instagram for ad hoc picture delivery and/or get inspired by Pinterest. Maija is on motherly leave and spends most of her time at home with baby Samuel. At the moment, Samuel is spending most of his time sleeping and eating. His mother has time to update the blog she started to keep since she found out that she was having a baby. This is something she wants to share later with her son. She has learned from Milla how to use WhatsApp and Instagram, which are free to use. Besides that, Maija is keen on tracking energy consumption at home and at the summer cottage, and from time to time she changes the consumption pattern accordingly as needed.

When the family spends time at the summer cottage, they treasure family traditions such as growing their own food, picking berries, fishing, and sometimes hunting. Maija has increased her interest in where the family's food comes from, and today she prefers to eat local food that is most often produced, processed, distributed, and consumed within a smaller, defined area. She even has her own vegetable patches. She is considered self-sufficient for necessity items, as it was a hundred years ago.

In comparison to life more than a hundred years ago, our lives now are delightfully luxurious. Those born during the last century were more concerned with survival than living standards. There was constant lack of necessities and hardly any leisure time, except Sundays. Individuals worked to meet basic needs like those for food and shelter, and families and neighbors provided tight-knit communities filled with work and belongingness. Education was entirely dictated by the social class you had been born into.



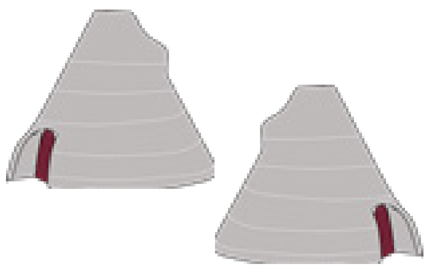
Today, Esko is working for the advanced Company Z. The company offers good benefits, and a company car is included. This car uses electricity. Shared transportation gives a good option for Maija to travel short distances, as they have only one car, and it provides a good opportunity to reduce the reasonable expenses of traveling. Shared transportation is a demand-driven vehicle-sharing arrangement, in which travelers share a vehicle either simultaneously (e.g., ride sharing) or over time (e.g., car sharing or bike sharing), and in the process share the cost of the journey, thereby creating a hybrid between private vehicle use and mass or public transport.



Meanwhile, when the family is not at home the Hoover robot is chasing after the dust on the floor.

In 2065 Samuel is now 50 years old and he has his own family—his wife Sofia and their twins Ariel and Amos. The twins have moved from home to live abroad in order to have new kind of perspective on life, where they will nourish their intellectual curiosity. Actually, after the energy abundance, you can't really say that you are traveling because everything seems to be so near.

Samuel travels short to medium distances with a personal aerial vehicle (PAV) similar to MyCopter, and if he has to travel long distances he uses the high-speed ground transportation system, which is similar to Hyperloop. The roads and streets expanded vertically and the low-altitude space has routes to follow.



The family lives at the same place where they used to have the summer cottage when Samuel was still a child. People have started to escape back to the countryside, where they have fresh air and enough space to express themselves. There each family member has his or her own cabin, and the cabins are linked together. They have very lively social circles, a kind of "MyTribe."

Samuels's family eats fewer processed foods and eats food grown closer to where they live. Abundance of energy ensures the availability of required water throughout the year. As a result, food can be produced not only in the traditional arable land throughout year, disregarding the harsh weather, but also opens up the door to new and exciting ways of doing this.