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Opinion

Perspectives on the pervasive energy-systems transformations

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Abstract

Energy is central for the global decarbonization and the achievement of a sustainable future for all. This calls for a fundamental energy-systems transformation that would bring multiple co-benefits for health, climate and other challenges facing humanity and especially those without access to affordable and clean energy services. Pervasive transformation toward zero-carbon electricity and electrification of energy end use are central to achieving higher efficiencies, decarbonization and net-zero emissions. This is not merely a technical and economic issue. It is about people, about societies and about values and behaviors. Technology is an integral part of the society and an expression of collective intentionality through aggregation of sundry individual choices. The next disruptive transformation toward a sustainable future may indeed be powered by the digital revolution. It poses dangers for privacy, dissemination of alternative realities and erosion of evidence-based information but it also offers a great promise of catalyzing the emergence of a sustainable future by augmenting human capabilities by new, more convenient, more efficient and decarbonized goods and services. The key question is whether humanity will have the political will to collectively achieve the energy-systems transformation toward a sustainable future and net-zero emissions in merely three decades.

Keywords: decarbonization, climate change, energy-systems transformation, energy transition

The United Nations Framework Convention on Climate Change Conference of the Parties 26 in Glasgow took place during the first 2 weeks of November 2021 [1]. Important progress has been made especially on quantitative targets like the 1.5°C limit on global temperature increase compared to 1.1°C that has already been achieved through human sources of greenhouse gases [2]. At the same time, commitments made at COP26 fall short of the Herculean efforts needed over the next three decades and especially by 2030 to achieve the 1.5°C target. There is strong scientific evidence that emissions need to be halved every decade and approach net-zero by mid-century [3, 4]. Some of us refer to this as the 'carbon law'. The reason is that the global temperature increase is in the zero-approximation a linear function of cumulative emissions, meaning emission must reach net-zero if temperature increase is to be limited. The COP26 commitments translate into emissions reduction by 2030 of a quarter rather of current levels than half that is needed.

In other words, humanity is at a crossroads. The possibility is in reach to increase the ambition and reach Paris agreement, but this also has to result in immediate action. We need to make 'peace with nature' [5] to assure a safe, resilient and sustainable future for all in accordance with the United Nations 2030 Agenda [7] with its 17 Sustainable Development Goals (SDGs). The other possibility is ever-increasing pressure on the Earth systems eroding the essential base for human existence. The danger is that even the Paris agreement target may not avoid tipping elements in the Earth systems such as destabilization of the West Antarctic Ice Sheet, Greenland, Alpine glaciers, Amazon or coral reefs [6]. Especially, a cascade of tipping and extreme events can erode and destabilize social systems and provisioning of basic human needs. Risks of droughts or floods come to mind that are disastrous for all affected and especially those in danger of poverty.

Energy is central for the global decarbonization and the achievement of all SDGs. This is even more essential given the confluence of multiple crises, from the tragic and immediate danger of COVID-19 pandemic, the climate crisis and digital revolution, are here as well as injustice, inequity and ever-increasing pressure on Earth systems [8]. A fundamental energy-systems transformation would bring multiple co-benefits for health, climate and other challenges facing humanity and especially those without access to affordable and clean energy services [8, 9].

What needs to be done has been assessed multiple times over the past decades [4, 10–12]. Priority is to invest in decarbonization and efficiency. This is the

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key because investments in renewables have peaked in 2017 even though new renewables like wind and photovoltaics can be cheaper compared with fossil alternatives. In fact, the investment costs of photovoltaic cells have declined by three orders of magnitude and are now lower than one US dollar per Watt peak [11, 12]. Pervasive transformation toward zero-carbon electricity and electrification of energy end use are central to achieving higher efficiencies, decarbonization and net-zero emissions. This should be complemented by low and zero carbon energy carriers such as hydrogen and carbon capture and removal from sustainable biomass. Major challenges of the needed pervasive transformation of the energy systems are mobility, which can be electrified through electric and plug-in vehicles, heating and cooling through heat pumps and especially freight transport, aviation and shipping. Here, blue hydrogen in conjunction with carbon capture and storage and later green hydrogen and decarbonized synthetic fuels could bring viable solutions.

But this grand transformation toward full decarbonization of energy systems is not merely a technical and economic issue. It is about people, about societies and about values and behaviors. Technology is an integral part of the society and an expression of collective intentionality through aggregation of sundry individual choices. Two historical examples of disruptive change serve to illustrate the challenges ahead during the next three decades to the middle of the century.

First is the replacement of horses and carriages by motor vehicles, a process ignited around the turn of the past century some 120 years ago that in the industrialized parts of the world like in the USA or UK lasted some 30 years until most of the horses and carriages disappeared from the streets. Multiple benefits emerged from the senescence of the horse economy including importantly disappearance of the manure from the streets, a serious health hazard and nuisance of the horse age. Automobiles are not only more convenient but also about five times more energy-efficient compared with horses and emit hundred times less gaseous emissions compared with the solid and liquid waste of horses [13]. Oil, petrochemicals, combustion engines and electricity became the new paradigm of human development and wellbeing.

Second example is the pervasive diffusion of mobile phones in the world during the past three decades essentially at the same time in the Global North and South. There are about ten billion phones for just under 8 billion people in the world. This means that even close to a billion people in the world who do not have affordable access to electricity have a phone. Especially, smart phones in conjunction with the internet provide many more services compared with the copper-wire technology. In fact, a smart phone is a hundred times more efficient compared with devices it replaces and requires some 25 times less materials and gray energy to be produced [14]. A mobile phone is an early sign of the power of digital technologies that created many new opportunities and has improved human wellbeing throughout the world.

The next disruptive transformation toward a sustainable future for all and making peace with nature may indeed be powered by the digital revolution. Convergence of digital technologies poses dangers for privacy, dissemination of alternative realities and erosion of evidence-based information but it also offers a great promise of catalyzing the emergence of a sustainable future by augmenting human capabilities by new, more convenient and decarbonized goods and services [8].

Digital technologies are examples of innovations with exceedingly rapid diffusion and cost reductions because they are granular, even though they are embedded in large and complex infrastructures and systems. They may catalyze the disruptive and transformational changes that need to be achieved within three decades. Artificial intelligence, connectivity (the internet of things), digitalization of information, additive manufacturing (such as 3D printing), virtual or augmented reality, machine learning, blockchain, robotics, quantum computing and synthetic biology are all examples of granular innovations that are characterized by rapid learning and diffusion.

Digital systems can be a powerful influence in helping overcome social inequalities, but they are also characterized by inequalities themselves. Large disparities in access to, usage of and skills relevant for digital innovations such as Internet exist, which are summarized as the 'digital divide'. Even more importantly, gaps also exist in the broader development benefits from using digital innovations. Digitalization has often boosted growth, expanded opportunities and improved service delivery, yet the aggregate impact has fallen short of being inclusive and is thus unevenly distributed. Because of its generally granular nature and fast diffusion and learning rates, digitalization is reshaping work, leisure, behavior, education, health and governance and can facilitate the achievement of the SDGs [8].

However, initiating transformation is difficult due to institutional inertia by incumbent actors with vested interests and consumers/users with habits of following routines. In addition, the globalization of economic and social activities that has occurred over the past decades has created intricate webs of activities, making transformation a complex process. Furthermore, existing studies indicate that the current policy instruments are either absent or ineffective for achieving the magnitude of transformation needed in the expected timeframe [8]. This means that unless there are substantially advantageous (simple, low cost, superior and universal) alternatives offered to individuals, achieving change will continue to be difficult [14].

The full unfolding of the 'Digital Revolution' will have even deeper impacts on our societies compared with smart phones and the internet, creating a next generation of sustainability challenges. Moreover, the

digital transformation may redefine our concept of us as humans. In the Anthropocene humans became the main drivers of Earth-systems changes. In the digital Anthropocene humans will also start to transform themselves, enhancing cognitive capacities into what can be called 'Homo digitalis'. This could be the next disruptive innovation to transform humanity by 2050 and beyond for the benefit of all and the nature.

The challenge is huge. Three decades are left for the fundamental energy-systems transformation, a time comparable to the diffusion of mobile phones and motor vehicles a century ago. Three decades have passed since the first COP that took place during the Earth Summit in Rio. This all indicates that the time is a precious resource.

The Scientific Opinion of the Group of Chief Scientific Advisors to the European Commission [9] that is based on the Evidence Review Report of the European Academies [12] puts people at the center of the energy transition. It recognizes the essential roles of all actors and stakeholders in creating an inclusive and participatory environment that incentivizes and supports low-carbon energy choices that need to become the preferred choices of all to achieve a sustainable and decarbonized future. This should be catalyzed by a support of coordinated combination of policies, measures and instruments, including carbon pricing as a driving force, to shape an effective, consistent and just regulatory systems. It is essential, however, that the revenues from auction of tradable permits or carbon tax be used to support those at the risk of energy poverty as well as to support energy innovation and investments toward efficiency and decarbonization.

The key question is whether humanity will have the political will to collectively achieve the essential transformation and avoid pitfalls of my-country-first or my-region-first logic that is spreading throughout the world. It is for us all to choose which direction to go because a sustainable future for all is within reach if we act decisively and in unison [15]. Time is a precious resource for achieving this disruptive and transformational change in just three decades by 2050.

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