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THE WORLD IN 2050 AND THE SIX GRAND TRANSFORMATIONS TOWARDS SUSTAINABLE DEVELOPMENT GOALS

1. INTRODUCTION

Humanity is at the crossroads. One possibility is the transformation toward sustainable future for all and the other fundamentally different alternative is continued transgression of planetary boundaries with affluence for a few while billions are left behind (TWI2050 2018) In other words, this would mean to continue current, unsustainable development patterns.

Transformation toward sustainable future for all is in principal reachable (TWI2050 2018) especially after the world community adopted the 17 Sustainable development goals of the 2030 Agenda (UN 2015) and the Paris Climate Agreement in 2015 (UNFCCC 2015). This could be the third revolution in human development to be compared in significance and fundamental changes that occurred during the Neolithic Revolutions some 10,000 years ago and the Industrial Revolution some two centuries ago with truly explosive developments. For example, life expectancy doubled during the last century to over 70 years. This is due to a whole host of achievements from education, food and health to better working and living conditions. Really impressive is the decline of war and violence and yet more people die by suicides than war and violence together. Thus, the impressive achievements are interlaced with inequities and deep inequalities and concerning developments. Still today almost a billion people go hungry every night while nearly two billion are overweight. So, on average enough food is produces but this achievement is not shared by all. There are more telephones in

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the world than people meaning that everyone has access, and this is close to the factual reality, but one billion do not have electricity at their homes to charge the phone.

2. NEOLITHIC AND INDUSTRIAL REVOLUTIONS

Early humans lived as hunters and gathers but this all changed with the two major transformations — the Neolithic and Industrial Revolutions. They were possible because the Earth support systems were kind to humanity. Figure 1 shows the climate during the last 120,000 years. Time before present is on the horizontal scale and average global temperature on the vertical. Some 120,000 years ago the last interglacial period was over and was followed by a continued cooling accompanied with significant variability. This ended with the last ice age some 20,000 years ago. Thereafter, Earth warmed very, very rapidly in terms of geological scales and then something unique happened. The period of the last ten thousand years, called the Holocene, brought very stable and warm temperatures, almost 8oC above the ice-age lows. Homo sapiens developed agriculture settled down and first civilizations emerged. This development period is called the Neolithic Revolution and was the "cradle" of modern civilizations.

During the Neolithic revolution global population increased 100-fold to about billion by the onset of the Industrial Revolution. The relatively benign changes in the global mean temperature are shown in Figure 2. Also, shown are future possibilities assessed by the Intergovernmental Panel on Climate Change in its Fifth Assessment Report (2014) based on the scenarios in the

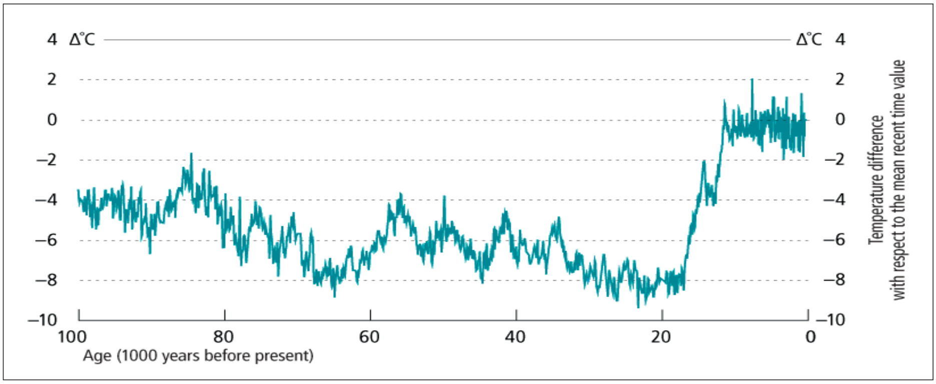

Fig. 1. Shown is the mean global temperature of the Earth during the last 120 thousand years. Time before present is on the horizontal scale and the temperature on the vertical scale. Source: Data from Petit et al. 1999, labeled as in Young and Steffen 2009.

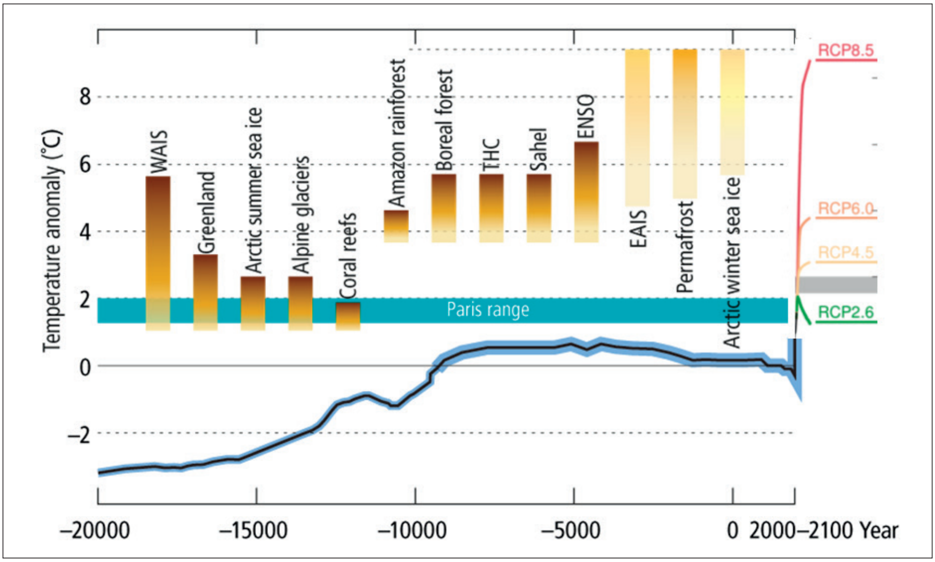

Fig. 2. Shown are the global mean temperatures during the last 20 thousand years together with the range agreed during the Paris Conference of the Parties to the Climate Convention of below 2°C and down to 1.5°C if possible. Also shown are possible tipping points of the Earth system as a function of the increasing temperatures together with pathways developed for the IPCC by the scientific communities. Source: Adapted from Schellnhuber et al. 2016.

literature (Nakicenovic et al. 2000, IPCC 2014, Riahi et al. 2017, van Vuuren et al. 2017). Only the so called RCP2.6 pathway that stabilizes global mean temperature at below two degrees Celsius (corresponding to radiative forcing of 2.6 W/m^2, thus the name) is consistent with the range agreed 2015 at the Paris Conference of the Parties to the Climate Convention, namely to stabilize global mean temperature blow 2°C and if possible down to 1.5°C (UNFCCC 2015). Also shown are possible tipping points of the Earth systems as the "amber" colors, much like a thermometer that gets redder the higher the danger is. In particular, West Antarctic Ice Sheet, Greenland, Artic summer sea ice, Alpine glaciers and coral reefs are already endangered because global meant temperature has exceeded 1oC above the pre-industrial levels.

3. SUSTAINABLE DEVELOPMENT GOALS

The world is at cross-roads. Current development trends are endangering Earth systems on which humanity depends while inequities and inequalities are increasing so that billions are left behind with least capability to adapt and mitigate the adverse developments.

Fig. 3. 17 Sustainable Development Goals adopted by all nations during the 2015 United Nations General Assembly. They represent an aspirational vision and a transformational agenda for a sustainable future for all. Source: UN DESA (2015)

In this sense, the 2030 Agenda and its 17 Sustainable Development Goals (SDGs) that were adopted by all nations of the world in 2015 (UN 2015) are an aspirational vision of how to achieve sustainability for all and avoid the continuation of current unsustainable direction of development. SDGs are shown in Figure 3 and represent a holistic agenda in the sense that all 17 SDGs need to be achieved simultaneously. The relationships among the SDGs have been studied extensively including tradeoffs and synergies (TWI2050, 2018 and 2019, Miola 2018). For example, a potential tradeoff exists regarding possible land-use to produce food (SDG2) or biomass for energy purposes (SDG7). A good example of synergies is that if energy systems is transformed towards decarbonization (SDG7) there would be multiple benefits for climate (SDG13). The emphasis needs to be on the multiple benefits minimizing the costs of implementing 2013 Agenda and avoiding conflicts associated with tradeoffs.

Achieving the 17 SDGs is a transformational agenda. Incremental change will be not enough. Figure 4 illustrates how such transformational and deep change could be achieved. There are growing number of actors of change from science and civil society to private sector and government. They operate from local to global level and will help make it clear to all that pervasive and urgent action is needed to implement 2030 Agenda. The metaphor of cross-roads means in this context that the humanity would take a turn from business-as-usual toward the vision of a sustainable future for all. This implies eventual emergence of new values and norms, new morality and new ethics. The SDGs would become thereby the new “social contract.”

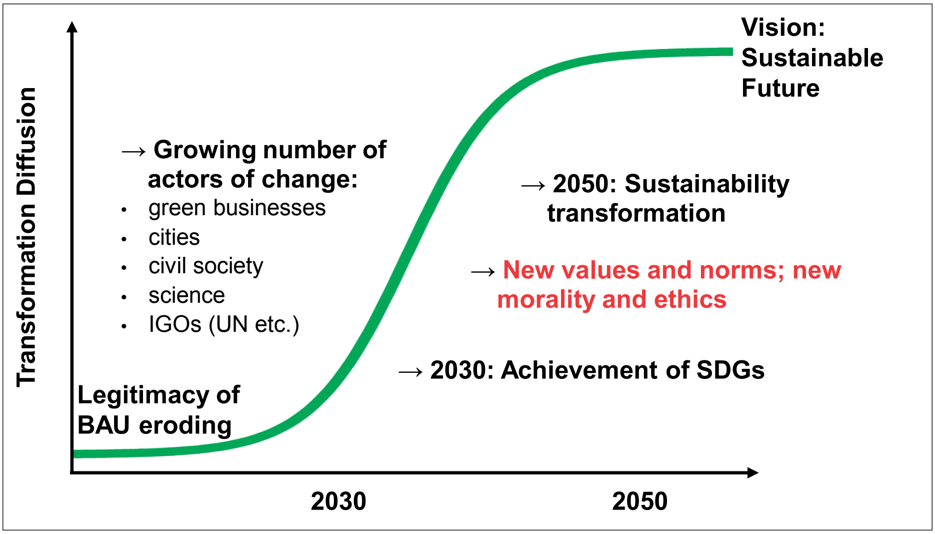

Fig. 4. Illustration of The World in 2050 conceptual framework. Legitimacy of business-as-usual (BAU) is eroding because major actors of change see a major transformation toward achievement of the Sustainable Development Goals (SDGs) as a vision for humanity's future. Source: TWI2050 (2018, 2019)

4. SIX MAJOR TRANSFORMATIONS

The 17 SDGs of the 2030 Agenda and their 169 Targets are comprehensive but thus also very complex. Communicating how synergies leading to multiple benefits can be achieved is thus non-trivial given the complexity. The World in 2050 (TWI2050 2018) identified Six Major Transformations necessary to achieve the 17 Sustainable Development Goals (SDGs). The Six Transformations help realize synergies among the SDGs. They are shown in Figure 5 and are: (i) Human capacity and demography; (ii) Consumption and production; (iii) Decarbonization and energy; (iv) Food, biosphere and water; (v) Smart cities; and (vi) the Digital Revolution. Together, they provide a people-centered perspective, enabling the building of local, national, and global societies and economies that secure the wealth creation, poverty reduction, fair distribution, and inclusiveness necessary for human prosperity. They are necessary and potentially sufficient to achieve the 17 SDGs if addressed holistically and in unison (TWI2050 2018, 2019).

All Six Major Transformations are needed for achieving SDGs. Here we will focus on three exemplary illustrations only, but the full descriptions and evidence is given in TWI2050 (2018, 2019).

Fig. 5. TWI2050 focuses on Six Transformations that capture much of the global, regional, and local dynamics and encompass major drivers of future changes: (i) Human capacity & demography; (ii) Consumption & production; (iii) Decarbonization & energy; (iv) Food, biosphere & water; (v) Smart cities; and (vi) the Digital Revolution. Source: TWI2050 (2018, 2019)

5. HUMAN CAPACITY AND EDUCATION

The first exemplary case is education. It is self-evident that human capacity and knowledge are the key for achieving sustainability for all. One measure is education. Today, about 80% of the global population over the age of 15 have at least primary education, up from just over 56% in 1970 and 43% in 1950. The shared socioeconomic pathways (SSP) developed for the IPCC by the scientific communities indicate future developments, only some of which are consistent with the Six Major Transformations (Riahi et al 2017, van Vuuren et al 2017, TWI2050 2018). In particular the SSP1 is an ambitious pathway and a proxy for a sustainable development futures. SSP2 is the current-trends scenario and in many ways the future that has to be avoided in the sense of the crossroads. In SSP1 and SSP2, the historical trend continues toward almost universal primary education, but the sustainable development for all calls for universal secondary education. SSP3 portrays little improvement and is the least desirable future development.

The share of the world's population over 15 years of age with at least a secondary education attainment has doubled from some 30% to 60%.

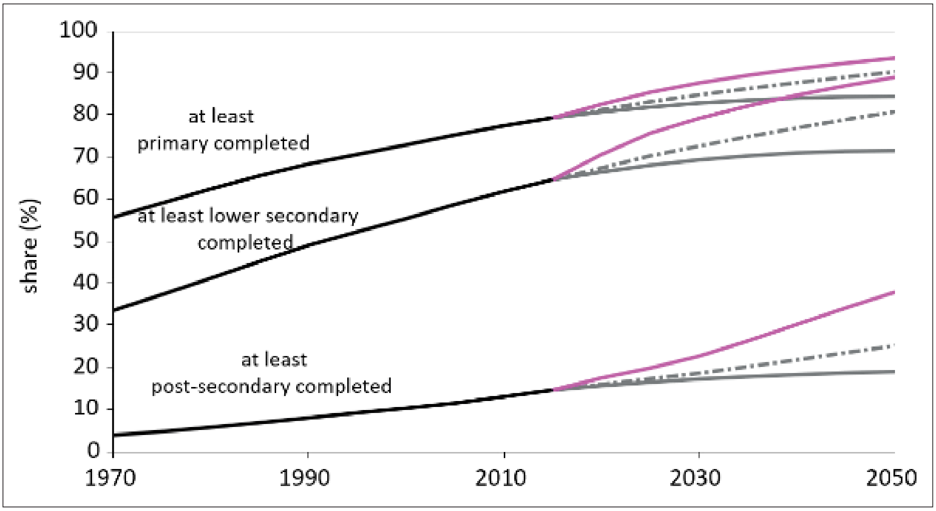

Fig. 6. About 80% of the global population over the age of 15 have at least primary education, up from just over 56% in 1970 and 43% in 1950. Three shared socioeconomic pathways (SSP) developed for the IPCC by the scientific communities are shown: SSP1 is an ambitious pathway and a proxy for a sustainable development for all. SSP2 is the current-trends scenario. In SSP1 and SSP2, the historical trend continues toward almost universal primary education, but the sustainable development for all calls for universal secondary education. SSP3 portrays little improvement.
Source: Data from Wittgenstein Centre for Demography and Global Human Capital (2018) and Lutz et al. (2018)

SSP1 portrays a significant acceleration reaching over 85% by mid-century. In contrast, SSP3 portrays a deterioration leading to higher birth rates and global population. Most importantly, post-secondary attainment increases in SSP1 and nearly stagnates in SSP3. Even in SSP1, the mid-century level is just over 30% and not that much different from secondary education attainment in 1970. This is a huge challenge for knowledge societies in times of digitalization. Achievement of sustainable development for all would definitely need a higher educational attainment if no one is to be left behind (Lutz et al. 2018, TWI2050 2018, 2019)

6. DEEP DECARBONIZATION TOWARD NET-ZERO BY MIDCENTURY

Another exemplary case considered here is the need for deep decarbonization of all human activities. Cumulative and annual emissions and sinks of CO2 are exceedingly limiting about possible future emissions given that the globally they are still increasing at historical rates of more than 2% per

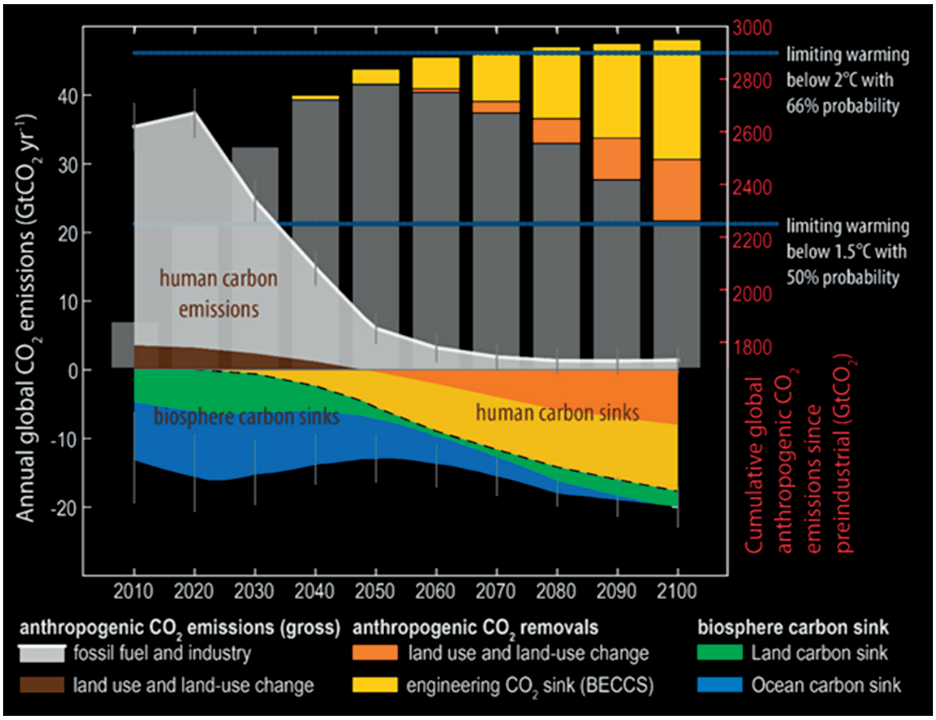

Fig. 7. Cumulative and annual emissions and sinks of CO_2 are shown for stabilizing global climate at below 2°C and 1.5°C. Energy-related and land-use emissions need to decline toward zero by midcentury. The figure is called "Carbon Law" as a metaphor to Moore's Law of semiconductors where a number of transistors on a chip doubled every 2.5 years. Essentially, emissions need to be halved every decade. In addition, human carbon sinks need to increase to almost half the magnitude of current positive emissions: Third, biosphere carbon sinks need to be maintained as atmospheric concentrations decline. The vertical grey bars show cumulative emissions since the beginning of the industrial revolution of some 2,000 billion tons CO_2. Net negative emissions are needed to stay within 1.5°C stabilization budget. The remaining budget for stabilizing at 2°C is a bit more generous so that the demand on net-negative emissions can be significantly reduced. Source: After Rockström et al. (2017).

year. In comparison, stabilizing global climate at below 2°C and 1.5°C means immediate emissions peak and decline to net-zero emissions by midcentury. Most of carbon emissions shown in Figure 7 in grey are energy-related. Together with land-use emissions they need to decline toward zero by midcentury from the current level of some 40 billion tons of carbon dioxide ($GtCO_2$) per year. Deep decarbonization is called for as an essential process for achieving the 17 SDGs and the Paris Agreement.

The illustration in Figure 7 is called "Carbon Law" as a metaphor to Moore's Law of semiconductors where a number of transistors on a chip doubled every

2.5 years (Rockström et al. 2017). Carbon Law indicates that global emissions need to be halved every decade to achieve net-zero by midcentury. In addition, human carbon sinks need to increase to almost half the magnitude of current positive emissions: A tall order. Carbon capture from biomass (BECCS) and land-use change are here the key. Third, biosphere carbon sinks need to be maintained as atmospheric concentrations decline.

The vertical grey bars in Figure 7 show cumulative emissions since the beginning of the industrial revolution of some 2,000 $GtCO_2$. This budget, or carbon endowment of humanity, will be exhausted shortly as the remaining emissions for achieving stabilization at below 1.5°C are essentially nil while we still as mentioned emit some 40 $GtCO_2$ per year. Net-negative emissions are needed to stay within this budget. The remaining budget for stabilizing at 2°C is a bit more generous so that the demand on net-negative emissions can be significantly reduced. The Carbon Law can be seen as roadmap towards making the Paris Agreement and the SDGs a reality. In 2018, IPCC confirmed this result in its Special Report on 1.5°C (IPCC 2018) based on a comprehensive review of the scientific literature. This all exemplifies the urgency of immediate and deep decarbonization of all human activities as an integral part of achieving sustainable future for all.

7. DIGITAL REVOLUTION AND HOMO DIGITALIS

The third exemplary Major Transformation discussed here and perhaps most challenging one is the Digital Revolution. After the Neolithic and the Industrial Revolutions it could indeed be the third in human history. Neolithic Revolution brought agriculture and early civilizations, the Industrial let to explosive development of humanity and by replacing human labor by machines also ended the slavery and created wealth for many but did leave billions behind. The Digital revolution could "liberate" humanity from many cognitive functions through digital enhancement, but it is also challenging the absorptive capacity of our societies — it is by no means clear that it will amiable to social steering toward sustainability for all.

It could be said that the digital age began some three decades ago with the introduction of the mobile (cellular) phones. The first GSM phone was Motorola 3200 introduced in 1992 and as mentioned today there are more phones in the world than people. The change was disruptive in the sense that the "copper wire" phones were abruptly replaced especially as smart phones started providing many services from banking and access to internet-related information replacing many other digital and analogue devices. Figure 8 compares some 50 devices that used to provide services now offered by smart phones.

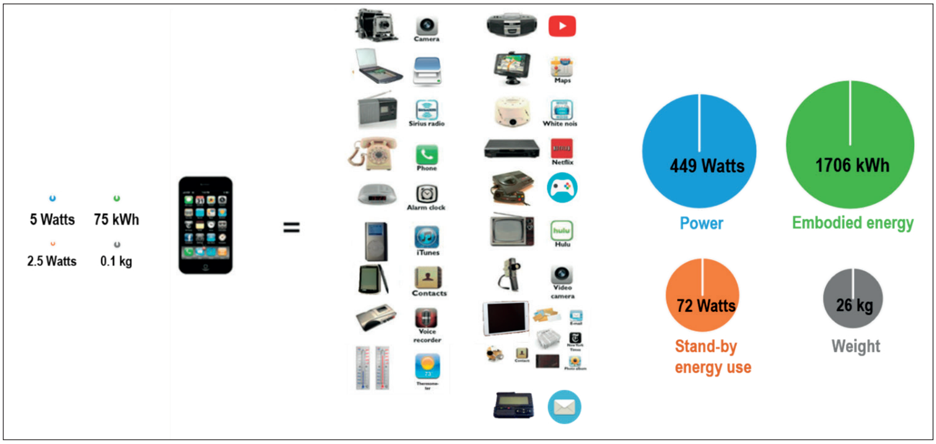

Fig. 8. Rapid progress of information and telecommunication technologies is illustrated by an enormous efficiency potential offered compared with traditional alternatives. A smartphone needs between 2.2 Watts in standby to some 5 Watts in use, while the numerous devices portrayed in the figure that it replaces need up to a hundred times more power. There is about a factor 25 reduction of embedded energy required to produce the devices and a proportional reduction in emissions. Bundling of services from various devices in the smartphone can be regarded as an example of the power of the Digital Revolution and its huge potential to increase resource efficiencies through new technologies and behaviors. Source: Nuno Bento, based on data in Grubler et al, (2018) and visualization of Tupy (2012).

The rapid progress of information and telecommunication technologies shown in Figure 8 could be an indication of the path-breaking potential of next-generation digital technologies, the clustering in new activities and associated behaviors. The efficiency improvement of potential of smart phones compared to the traditional devices it potentially replaces is hundred-fold and the reduction of embedded energy and emissions needed for the production is about 25-fold.

TWI2050 report summarizes the positive impacts of digitalization on the SDGs as follows: "better and lower cost services improve access and affordability and hence contribute toward reduction of poverty and inequality. Better asset utilization and virtualization increase resource efficiency and can reduce the resource and ecological footprint of human activities, thus positively contributing to a range of SDGs" (TWI2050 2019).

Potential negative effects are grouped in TWI2050 (2019) into four clusters:

"Lack of access to digital infrastructure and services compounds the negative impacts of the digital divide, potentially opening up a digital consumption divide. For example, someone who does not own a smartphone could no longer use public transport options organized under a pervasive shared mobility model.

Big data applications centered on private consumption and services raise data privacy concerns and present risks of social control by governments and/or large multinational firms. Also, the fundamental nature of network externalities (benefits grow exponentially with the degree of interconnectedness and information sharing) almost automatically lead to natural monopolies.

Cost reductions in services could lead to "take-back" (or economic "rebound") effects in which cost savings lead to further increases in the same or substitute demands. For example, cost reductions from shared mobility models for urban commuting to work could lead to increased demands for (long-distance) recreational travel trips on weekends and during holidays.

Negative impacts on employment: Better asset utilization in a sharing economy and increasing virtualization, despite reducing resource use and waste, will impact manufacturing through lower demand for devices, vehicles, and physical goods, and hence negatively impact employment. Moreover, increasing digitalization of service provision, such as autonomous vehicles in public transport fleets, reduces the need for human labor, again negatively impacting employment. Concerns are also voiced that continued digitalization in manufacturing could render the traditional comparative advantage of emerging economies in manufacturing (lower labor costs) increasingly obsolete. This could lead to a relocation of industrial and manufacturing activities back to industrialized countries, or it could create an additional entry barrier for resource-based economies that currently benefit from the international division of labor in their efforts to industrialize" (TWI2050 2019).

Figure 9 offers an additional perspective of the digitalization challenges in the short and long term. It focuses on the artificial intelligence, but the wider convergence of digital technologies would involve deep learning, big data, additive manufacturing, robotics and blockchain to mention a few. In the short term, structural unemployment is perhaps the biggest challenge. However, all are relevant. For example, proliferation of autonomous weapons is a huge danger for the world as it would expand the portfolio of possibilities from cruise missiles and drones to weapons with enhanced analytic and cognitive characteristics. The manufacture of 'home-made' weapons with additive (3d) manufacturing is already a deplorable reality. Suffice it here to also mention the legal challenges of autonomous systems like self-driving cars.

In the long term, challenges become even more pronounced ranging from the question of human enhancement to status of humanity in a world

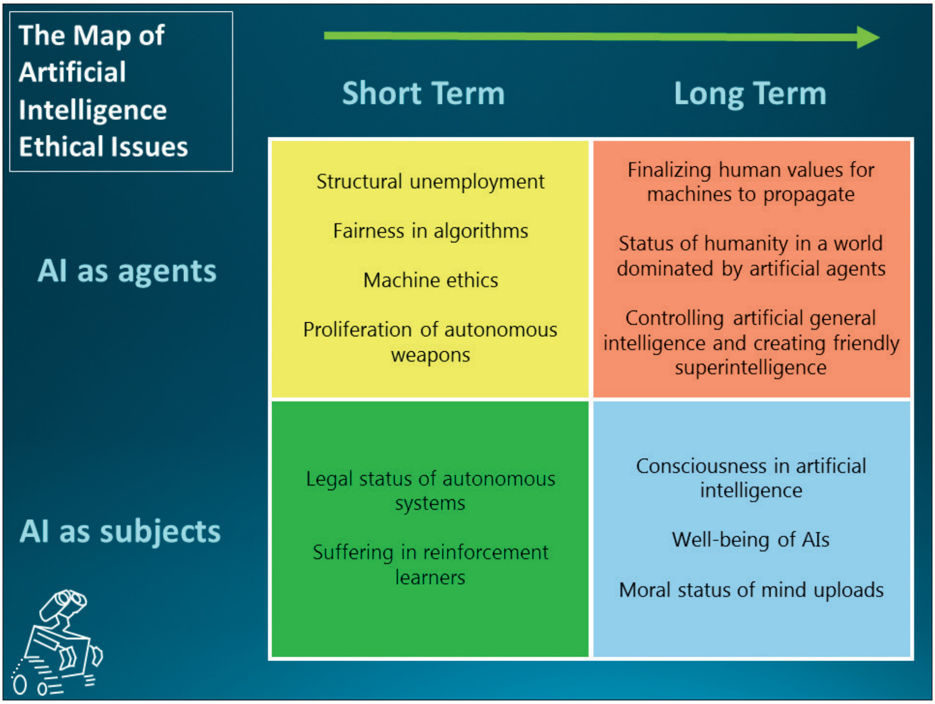

Fig. 9. Major ethical challenges of artificial intelligence in the short and long term. Source: x/Futurology (http://i.imgur.com/13CNnD1.png).

dominated by artificial agents and how to create friendly superintelligence of machines. Finally, perhaps the biggest question is the possibility of consciousness in artificial systems. This question was described in a visionary way by Alan Touring in 1951, almost 70 years ago: "It seems probable that once the machine thinking method had started, it would not take long to outstrip our feeble powers. They would be able to converse with each other to sharpen their wits. At some stage therefore, we should have to expect the machines to take control" (Alan Turing during a lecture on15 May 1951 broadcast by the BBC).

The full consequence of evolutionary process leading the Digital Age that could also be called Digital Anthropocene (WBGU 2019) to signify that one single species, the homo sapiens, is likely to increase its influence on Earth systems and determine the nature of the next era in Earth future after the Holocene. The power of the possible changes would fully emerge through a confluence and co-evolution of whole clusters of digital technologies and human behaviors. Digitally enhanced humans or homo digitalis would have the capacity of directing the Six Major Transformations

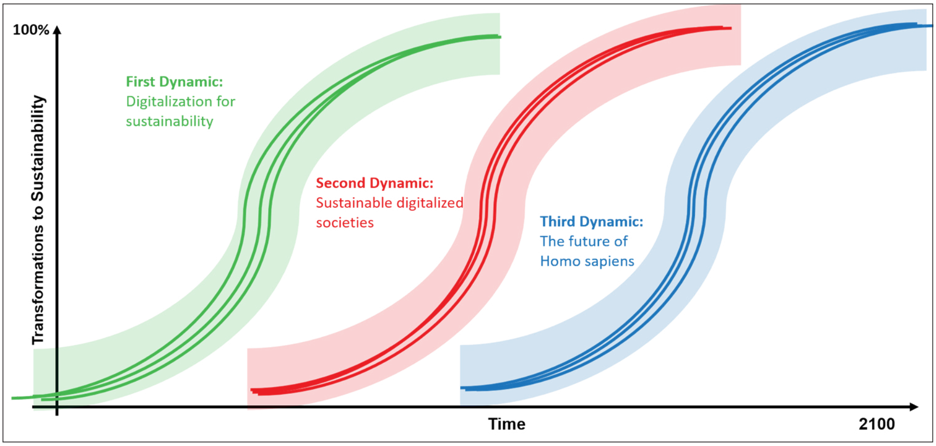

Fig. 10. Three possible Dynamics of the Digital Age. All three are already emerging in parallel, albeit with different levels of intensity, so there is no strict chronological sequence involved. Each dynamic consists of multiple pathways that follow different technology trajectories. The name given to each dynamic reflects the priorities for action required in each case. For illustrative purposes, we show a simplified version that does not cover all emerging technology clusters and possible pathways. Source: TWI2050 (2019) adapted from WBGU (2019).

toward sustainable future for all but also into the undesirable future of inequity and inequality with further dangerous transgression of planetary boundaries.

8. TRANSFORMATIONAL CHALLENGES AND OPPORTUNITIES

The world is at crossroads as we are currently experiencing signs of counter-transformations away from sustainable future for all — for example CO2 emissions and inequality are continuing to increase transcending planetary and human-development boundaries. The transformation toward a sustainable future for all is possible but ambitious and urgent action is needed now and continued people and planet focus beyond 2030. Continuation of incremental change will not be enough. The key would be the Six Major Transformations needed to enable the world to meet the 17 SDGs. For this to become reality, it will be essential to achieve synergies with multiple benefits among the SDGs.

With the Digital Revolution, a new era in human history is emerging after the Neolithic and Industrial Revolutions. Digitalization can enable a disruptive revolution toward a Digital Anthropocene — a quantum leap for civilization. The paradox of the Digital Anthropocene is that digitalization is essential for achieving the Six Major Transformations yet it is also endangering them for example through digital divide and because it is challenging the absorptive capacity of society. Building responsible knowledge societies capable of acting towards sustainability in the Digital Age is essential. Achieving Digital Anthropocene sustainable for all is really the only option especially compared with undesirable futures of inequity and inequality with further dangerous transgression of planetary boundaries.

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