Chapter 1
Bioeconomy as a Driver for the Upcoming Seventh K-Wave (2050–2100)

Markku Wilenius

Abstract This chapter sets out to project the future role of bioeconomy in our socio-economic structure in the light of the so-called Kondratieff long-wave theory. This framework presupposes 40–60 year-long economic cycles, and according to the author's interpretation of the theory, we are now embarking into the sixth wave (2010–2050), followed by the seventh wave 2050–2100. This chapter sets out to understand the development of the waves in the light of the changing relationship of humans with nature. The assumption is that as we move towards mid-century, our relationship with nature will turn into a more collaborative form, away from the extractive practice of current economies. This chapter explores four potential domains for bioeconomy development in this respect: (1) agriculture, turning to more regenerative and becoming a part of the solution to climate problem; (2) forestry, expanding its role as a source of new materials, medicine and well-being; (3) algae production, becoming an essential source of energy and new materials production; and (4) biomimicry, being extensively deployed as a design principle for emerging technologies. All this potential development will signify exponential growth of the impact of bioeconomy for our societies to come.

Keywords Long-wave theory · Seventh Kondratieff wave · Bioeconomy futures · Human relationship with nature

1 Introduction: The Corona Shock and the Fragility of the Planet

As I am writing this chapter, a coronavirus called COVID-19 is ravaging the world economic system, threatening to bring it down. This tiny biological entity is setting the public agenda and determining the actions of societies around the globe. What kind of biofuture does this virus mean for us? What does the virus outbreak tell us about our

M. Wilenius (✉)
Professor of Futures Studies and UNESCO Chair of Learning for Transformation and Planetary Futures, Finland Futures Research Centre, University of Turku, Turku, Finland
e-mail: markku.wilenius@utu.fi

E. Koukios, A. Sacio-Szymańska (eds.), *Bio#Futures*,
https://doi.org/10.1007/978-3-030-64969-2_1

society as a whole? How could societies prepare better for these kinds of unexpected events? What do these events imply in terms of our relationship with nature?

The COVID-19 pandemic has really brought home the utter fragility of our world and our planet. The economic and social havoc wreaked by the crisis goes far beyond anything our global system has experienced in times of peace. There are three specific reasons why this has happened. According to our analysis, the first reason has to do with the nature of our current capitalistic economic model. During the last 40 years, as Jacobs and Mazzucato and others have noted, our economic system in the western world has consistently given precedence to short-term profits over long-term benefits (Jabobs and Mazzucato 2016). There seems to be a strong bias to ramp up income inequality, as clearly shown by Thomas Piketty. In contrast to most of the twentieth century when the trickle-down effect still created a rather equal distribution of wealth among the socio-economic classes, there has been a sharp turnaround from the early 1980s as the uppermost quadrant of earners are now relatively much better off (Piketty 2014).

While social stratification has intensified over the last 40 years, it has also had a natural counterpart. Our natural habitats have become much more fragile, and the ecosystem has lost much of its resilience. The level of biodiversity, one of the ultimate indicators of planetary development, has declined dramatically. According to the WWF Living Planet Index, the population size of vertebrates[1] has declined by 60% from 1970 to 2014. Moreover, measurements show that our ecological footprint – a measure of our consumption of natural resources – has risen by a staggering 190% in the past 50 years.[2] Additionally, recent FAO calculations indicate that we have lost 420 million hectares of forest since 1990. The main cause of deforestation is large-scale commercial agriculture (the cultivation of soya beans and palm oil), accompanied by local subsistence agriculture.[3] Also, our most critical asset of all, the top soil of agricultural lands, is being rapidly depleted. According to FAO estimates, we can look forward, on average, to some 60 years of harvests before the top soil is degraded beyond use.[4] Without the top soil, the capacity of land to filter water, absorb carbon and ultimately produce healthy and nutritious food will be severely limited. All this is due to modern agriculture that relies on intensive tilling and pesticide and fertilizer use.

It is clear, then, that we have created a global economy that is not only socially unjust but is also causing a major ecosystem catastrophe that further amplifies the real pandemic threat to the world: runaway climate change. The Intergovernmental Panel on Climate Change's (IPCC) landmark 1.5 °C report stated convincingly that the current measures taken to avoid breaching the critical 1.5 °C temperature threshold are inadequate. On the other hand, it is known that once the planet warms up by

[1] https://s3.amazonaws.com/wwfassets/downloads/lpr2018_summary_report_spreads.pdf

[2] https://www.footprintnetwork.org/resources/data/

[3] http://www.fao.org/state-of-forests/2020/en/

[4] http://www.fao.org/news/story/en/item/357059/icode/

2°, the world system will enter a whole new stage, a path of extreme events from which there is no return.[5]

Our planetary ecosystem, it seems, is being stripped of its protective, regenerative capacity. But the same has happened to our social systems. Norms, regulations, redundancies, human-made and natural buffers, a whole host of checks and balances that used to be there to ensure the necessary rejuvenation of the system – all this has been brushed aside to give way to short-term profits. As sociologist Ulrich Beck famously stated in his analysis of risk society, these are the globe-wide impacts no one intended (Beck 1992). These unintentional consequences of human action have depleted the resilience of human-built systems, at the same time as we have destroyed the resilience of natural systems.

To oversimplify somewhat, societies are generally speaking run by their intentions. Are these intentions currently leading our systems towards greater resilience and towards building up a capacity to transform, the two critical qualities of any complex system? Let's consider this in the context of the World Economic Forum's Global Competitiveness Report,[6] which ranks the countries of the world on an index that is said to measure the capacity of countries to provide prosperity for their citizens.

In practice, the index consists of 103 indicators. These indicators, however, say very little about things like decarbonization, new energy availability, environmental health or resource security. In other words, the measure of competitiveness in the index effectively excludes consideration of resilience and the capacity of agility and transformation. It ignores the whole idea of long-term sustainability. Current responses to the COVID-19 crisis, for instance, have made clear the failure of the US public health care system to tackle and contain the coronavirus – and yet the United States ranks second in the global competitiveness index. Indeed as we move forward, the increasing complexities and uncertainties faced in future societies will give added weight and importance to two major requisites that human systemns are facing the capacity to be resilient and the capacity to transform.

2 The Long-Term View to the Future

In this chapter, we attempt to project the long-term future based on the K-wave theory of societal development (see Wilenius 2017). We apply a theory of long waves in order to try to understand the evolution of societies from one phase to another as they respond to unfolding challenges. We postulate that bioeconomy will have an increasingly prominent role as societies seek to bring greater well-being to their citizens while struggling to overcome the problems they have accumulated over time. The K-wave theory of societal change posits that the technologies, modes of organization and values that will define a wave are already burgeoning and identifiable from the very start of the previous wave. In other words, what we see now

[5] https://www.ipcc.ch/sr15/

[6] http://www3.weforum.org/docs/WEF_TheGlobalCompetitivenessReport2019.pdf

emerging, even if it still marginal, can potentially grow and evolve into something predominant much later – in our case, in the latter part of this century.

These waves are described and explained in more depth later in the chapter. In the meantime, let us briefly introduce the waves that are now unfolding. Since the birth of industrialization, we can count five waves that have occurred in cycles of 40–60 years. We have currently moved into the sixth wave.

2.1 Sixth Wave (2010–2050)

Having started around 2010, the sixth wave will see the focus of technology development shift towards resource efficiency, the building of a new energy system and a transition to a more digital and circular economy, showing the first real signs of a post-industrial model of material economy. Post-material values and systems thinking, key ideas in circular society, will slowly come to prevail in the cultural domain, marking a departure from the material values derived from previous phases. This shift is well manifested by long-term data from the World Values Survey.[7] In the sixth wave, both the growth rate of the traditional economy and resource use will be challenged as the convergence of world economies continues and large emerging economies decelerate (Guillemette and Turner 2018). Around 2050, climate emissions will overshoot the 1.5 °C limit, as anticipated in the IPCC's business-as-usual scenario (IPPC 2018). This will lead to increasingly dramatic weather phenomena, floods, fires and droughts, extending to areas previously unaffected by such extreme conditions. Furthermore, various irreversible second order changes will make climate patterns increasingly unpredictable.

2.2 Seventh Wave (2050–2100)

Artificial intelligence has become ubiquitous around the world, and together with advanced blockchain systems has helped to create created a new form of global interconnectedness and consciousness. A changing world is moving from climate shocks towards a rebalancing of resource use and resource renewal. Industrial heritage systems have been superseded by biological systems, resulting in a transformation from industrial thinking to full-scale circular economy. Non-renewables are increasingly substituted by biologically manufactured materials, and new resource bases for commercial harvesting have been developed. In the oceans, for example, kelp forests are now exploited for a variety of goods and services. The huge potential of algae to produce food, energy, medicines and a wide array of other products is being fully utilized. People are refining organic materials, and the entire planet

[7] http://www.worldvaluessurvey.org/wvs.jsp

has been turned into a garden that is carefully nurtured and harvested. The massive shocks caused by global warming and changed weather patterns have resulted in a global ban on the use of coal, oil and natural gas for energy production. The bio-economy has become the new economic paradigm, coupled with advanced concepts of circulation and social equality. As global agricultural practices have shifted towards a more regenerative model and large habitats have been reforested, levels of carbon dioxide in the atmosphere have fallen dramatically. The manipulation of natural systems has pushed many species close to extinction, but massive revitalization efforts have been put in place. New forms of cultivating biomaterials are flourishing everywhere, and work is underway to restore the planet's soil and forests, inspired by the new ethos to save the planet and humans as part of the planet.

These condensed images of the future draw attention to the key dynamic of the waves: each phase of growth is fed by a need arising from the previous wave, but as attempts gather momentum to find solutions, so novel issues unfold that begin increasingly to pressure the system as the wave is nearing its end. This type of schematic approach provides a useful heuristic tool for anticipating very long-range futures. At the same time, it helps us break loose from the constraints and lock-ins that tend to tie our thinking to the present reality.

Let us now go back to exploring how human cultures have evolved over time in terms of their relationship with nature.

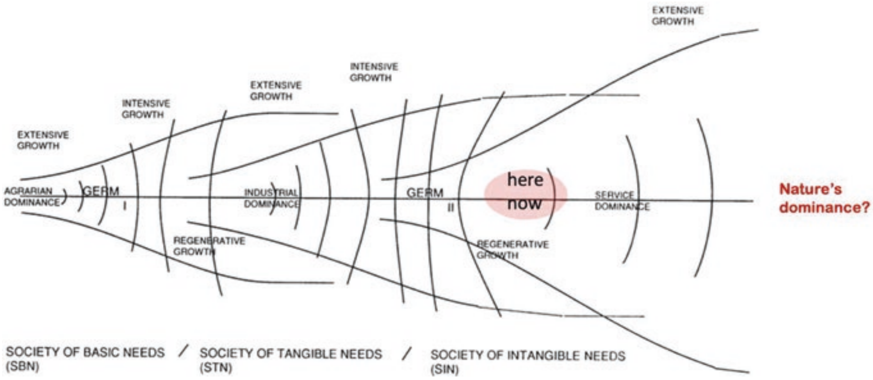
3 From Past to Future: The Development of the Human Relationship with Nature

In order to understand the role of organic life in our cultural systems, we really need to go back all the way to the switch from hunter-gatherer to agriculture. The cultivation of land marked a critical shift indeed in our relationship with nature. As agriculture came to dominate our relationship with nature, it laid the ground for a more structured approach to human collaboration. Compared to hunting, agriculture was a much more predictable and organized pattern of behaviour. It also created a very different kind of social structure: it made possible the creation of institutions such as the church and the army, all because our relationship with nature had changed (see also Laloux 2014).

As this change began to unfold some 10,000 years ago, something very different started to emerge as well. Suddenly, societies found themselves in a position where they were able to grow, even if that growth was still very modest compared to the explosion seen in the last century. Communication with the land through cultivation helped societies grow and expand, and early technologies such as ploughing and harrowing ensured a more stable harvest and paved the way to more intensive agriculture – and ultimately to industrial revolution.

The rise of agricultural society brought stability and organization. At the same time, it marked the beginning of the taming and harnessing of nature for human purposes. As steady seasonal crops provided for a regular food supply, the human relationship with nature became more instrumental. But farmers still had to deal with various fluctuations: in some years the weather could be extremely dry; in others there might be a surplus of tormenting rains. All the work in the fields was done by hand, with simple tools. It was imperative to take good care of the soil since no other fertilizers were available except the manure provided by domesticated animals.

The nature of this society that was being built was, according to the model created by futurist Pentti Malaska, a society of basic needs: it attended to the needs that are quintessential for human life on earth, i.e. food, shelter and clothing. Agriculture provided the food; stable settlements provided the shelter. Malaska's model of socio-economic evolution is well-described in this diagram (Malaska 1999):



Original by Pentti Malaska (1999), further developed by Markku Wilenius

From its modest origins, the agrarian way of life evolved over the millennia by experiment and experience into the dominant form of culture and a source of livelihood to most people. As we approach the industrial turn, something happens that Malaska calls *autopoietic transformation*. That is, societies begin to transform and turn, in a self-organized manner, onto a totally new trajectory. The emergence of industrial society marked a step towards a redefined order of needs (Wilenius 2014). These new emerging needs can best be described as tangible, entailing everything from household wares to skyscrapers. Meeting these needs was supported by a growing range of technologies, all designed to expand the range of human activities. By the early nineteenth century, the march to modern society was truly underway.

The advent of industrial society heralded a very different relationship with nature. Natural resources, particularly everything that could be drilled and extracted from the earth, became the core engine of industrialization (Bardi 2014). The raw materials were needed to build factories in which products were produced for trading. The relationship with nature thus became very utilitarian. If the farmer used to prepare the land with hardly any external inputs, industrialization suddenly provided access to all manner of inputs. Essentially an extended human arm, technology was there to facilitate the extraction process. Financial markets emerged to make the necessary transactions possible.

Industrial development can be seen and understood as a sequence of phases where humans discover needs that have to be met in order to improve the quality of human life create a decent human life. Humans become increasingly creative in building new machinery and in inventing materials and processes that allow them to break from the way of life that is centred around food, shelter and clothing. Meeting multiple tangible needs becomes the lynchpin of human aspiration. Values become more material and whole new social classes are born. Natural resources and trade become a source of wealth accumulation.

At some point, however, Malaska says, industrial dominance begins to give way to service dominance. While industrial dominance brought in its wake its own logic (hierarchically run factories, mass production, etc.), the new service dominance logic is based on tailoring, assisted by new algorithm-based technologies such as artificial intelligence and the Internet of Things. All these new services are now leading to a society that functions in a fundamentally different way. The key motive in service dominance is efficient resource allocation. This is what all these new technologies are geared to: communicating and distributing data and information in a way that allows systems to adapt to take away the word "new" changing circumstances.

But there is more. Malaska's model posits that with services, we also move from tangibles to intangibles. This is a well-known phenomenon, yet still poorly understood (see Haskel and Westlake 2018). At the core of the phenomenon is a shift in investments towards software, design and branding, for example, at the same time as values become more immaterial. Whether in manufacturing or service production, intangibles have gained increasing prominence, and that in itself has given a whole new tone to our economies. It also seems to be leading to new consumption patterns: given the increasing amount of software at our disposal, our consumption of human relations has increased to unprecedented levels. According to US statistics, young people (16–24 years) today spend on average 3 hours on social media every single day.[8] Through social media, social relationships have become consumables that increasingly permeate our behavioural patterns.

In order to deepen our understanding of the transformation we are now witnessing, it is necessary to look at how industrialization itself has developed over time. There is no better way to do that than to examine the long-term waves of socioeconomic development, the so-called Kondratieff waves. The notion of long-term waves was first introduced in the international debate by the Russian economist Nikolai Kondratieff at the beginning of the twentieth century (Kondratieff 1928/1984). The theory postulates that societies develop in cycles of 40–60 years. Each wave begins with a period of growth and ends with a period of decline and depression. In-between each wave there is always a period of crisis that stimulates the birth of a new cycle. Kondratieff himself was a traditional economist who relied

[8] https://review42.com/how-much-time-do-people-spend-on-social-media/

on data describing economic activities, but in his wake economist Joseph Schumpeter gave a somewhat broader interpretation to the theory and incorporated technological cycles into the waves. In this chapter, we offer a much more holistic interpretation of the cycle theory. However, economic data can still be used to illustrate the unfolding of cycles, as is done in the following graph which uses rolling 10-year yields of the Standard & Poor equity index coupled with the notion of technological shifts (Fig. 1.1).

Based on these 40–60 year patterns, it is possible to see how each wave has been driven by the creation of specific technologies and their applications, which in turn have instigated new social behaviours. With the onset of industrialization and the steam engine, the race was on for human invention. The use of steam brought a dramatic increase in labour productivity. The second wave, which brought the age of steel and railroads, contributed to expand the infrastructure and created the first mass transport system. In the third wave, new innovations around electricity use had a tremendous impact on industrial productivity. At the same time, new chemistry came along, paving the way to the production of paper from pulp, for instance. In the fourth wave from the 1930s onwards, automobiles burst onto the scene, accompanied by a sharp rise in the consumption of petrol and other petrochemicals. The last wave, emerging in the early 1970s after the oil crisis, turned out to be a triumphal march for digitalization and the expansion of various communication technologies. That era came to an end with the financial crisis that very nearly brought down the whole global financial system.

Each of these waves has signified brought together human intentions, igniting the creation of new technological fields and aspirations of economic growth with a view to providing material goods and promoting new cultural habits. Industrialization has moulded human life and created ever new ways of harnessing natural resources. All this has created the challenge we are now facing: how to stop the plundering of nature and how to establish a more balanced relationship and interaction with the natural world (Wijkman and Rockström 2011). Indeed, along with rapid industrialization, we have denied our planetary boundaries and brought ourselves to a situa-

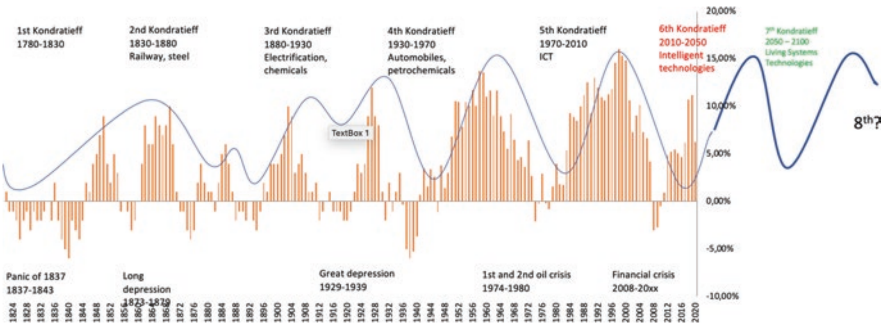


Fig. 1.1 Kondratieff waves. (Rolling 10-year return on the S&P 500 from Jan 1814 to March 2020 (% per year). Source Datastream, Bloomberg, Helsinki Capital partners (illustration), Markku Wilenius)

tion where many ecosystems are being depleted by the intensive extraction of natural resources.

From very early on, the human meaning of industrialization was progress. Its essence was the intention to create a decent human life and a comfortable everyday existence. This was not something that would happen overnight: in early industrialization, conditions in the rising urban developments were miserable. However, modern sewage systems and other new technologies boosted the development of modern urban systems, even though that development was often thwarted by contradictions and challenges. As political scientist Marshall Berman observes, modernization meant empowerment and destruction at one and the same time: it was in the nature of modernism to build cities and industries while tearing down everything representing the old. To be modern was to live in the constant maelstrom of disintegration and renewal in a world where "all that is solid melts into air" (see Berman 1981). As much as human experience has been shaped by modernization, it has also brought new ideas about what the future should look like. The development of industrialization was thus shaped by the human capacity for anticipation.

In the context of the K-waves, my argument is that the anticipatory power of the waves stems from the observation that the technologies adopted cleared the way for the appearance of other technologies. If technology is understood as an extension of human power, then movement in the course of industrialization has meant the process of taming ever new technologies for human good. The following matrix attempts to illustrate the point (Fig. 1.2):

4 The Sixth Wave Revisited

We are currently ploughing ahead at full steam in the sixth wave, which will take us up to the middle of this century (see Wilenius 2017). This wave is characterized by a deepening understanding of the huge inefficiencies and unintended consequences we have been building into our economies. This is particularly true with regard to our energy sources, infrastructure and consumption patterns, all of which suggest some alarming conclusions about our capacity to mitigate climate change. There is overwhelming evidence that this change has already started. Recently NASA reported that average global temperatures over the last 5 years have been the warmest on record, pushing the level of warming beyond 1.1 °C.[9] The 2015 Paris Agreement recommended that warming should not be allowed to exceed 1.5 °C, but signatory countries have been very slow to adopt the agreement as a part of their national policies.[10] The IPCC estimates that hundreds of millions of lives will be at stake if the world exceeds the 1.5 °C warming target and begins to move towards the

[9] https://climate.nasa.gov/news/2945/nasa-noaa-analyses-reveal-2019-second-warmest-year-on-record/

[10] https://www.nationalgeographic.com/science/2019/11/nations-miss-paris-targets-climate-driven-weather-events-cost-billions/

THE SUCCESSION OF DEVELOPMENT WAVES IN INDUSTRIAL SOCIETIES

K-Waves	1st wave	2nd wave	3rd wave	4th wave	5th wave	6th wave
Period	1780–1830	1830–1880	1880–1930	1930–1970	1970–2010	2010–2050
Drivers	Steam Machine	Railroad Steel	Electricity Chemicals	Automobiles, Petrochemicals	Digital communication technologies	Intelligent, resource efficient technologies
Prime field of application	Clothing industry and energy	Transport, infrastructure and cities	Utilities and mass-production	Personal mobility and freight transport	Personal computers and mobile phones	Materials and energy production and distribution
Human interest	New means for decent life	Reaching out and upwards	Building maintenance	Allowing for freedom	Creating new space	Integrating human, nature and technology

Fig. 1.2 Development waves in industrial societies

2 °C level. Beyond 2 °C, the research shows, we will begin to see large chunks of the Antarctic and Arctic ice melt into the sea – something that is in fact already happening.[11,12]

It is estimated that a staggering 70% of all energy production is lost to waste heat.[13] At the same time, we are still hugely dependent on fossil fuels, which account for some 80% of primary energy production.[14] The shift towards cleaner energy has been a painfully slow process, in no small part because of the 5 trillion dollars of subsidies that still go each year to the fossil fuel industry according to IMF estimate.[15] At the same time, it is estimated that under the current baseline scenario regarding the necessary steps to reduce emissions levels, the global economy could benefit up to 26 trillion dollars by 2030 for taking stringent measures.[16]

In other words, it seems that in the current sixth wave, we will inevitably have to focus on addressing the structural inefficiencies inherited from the previous period. The ambitions to achieve such efficiency gains have been there for a long time, yet

[11] https://phys.org/news/2020-02-oceans-antarctic-ice-sheet-collapse.html

[12] https://www.washingtonpost.com/climate-environment/rapid-arctic-meltdown-in-siberia-alarms-scientists/2020/07/03/4c1bd6a6-bbaa-11ea-bdaf-a129f921026f_story.html

[13] https://e360.yale.edu/features/waste-heat-innovators-turn-to-an-overlooked-renewable-resource

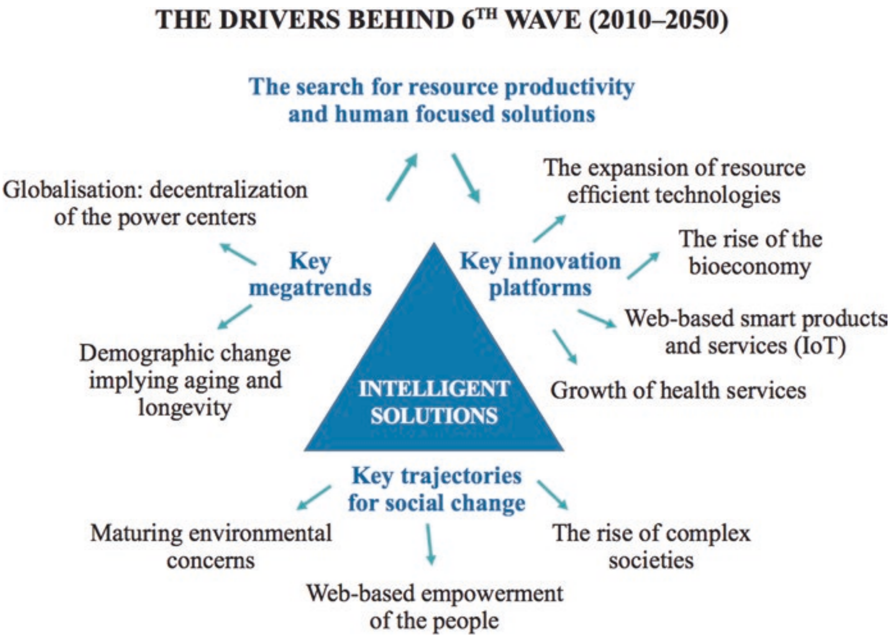
[14] https://www.iea.org/data-and-statistics/charts/global-primary-energy-electricity-generation-final-consumption-and-co2-emissions-by-fuel-2018

[15] https://www.imf.org/en/Publications/WP/Issues/2019/05/02/Global-Fossil-Fuel-Subsidies-Remain-Large-An-Update-Based-on-Country-Level-Estimates-46509

[16] See the report of the Global Commission on the Economy and Climate: https://newclimateeconomy.net/publications

the results so far have been quite disappointing (von Weizsäcker et al. 1998; von Weizsäcker 2009). Even though the price of renewable energy has come down to competitive levels and new energy investments have soared to around 300 billion dollars, we still have a very long way to go before we will see renewables actually replacing fossil fuel-based energy production.

However, productivity gains will certainly be pursued with every technological advance possible. This will involve not only an abundance of new technologies but also new emerging social movements as growing numbers of people, particularly in the younger generation, will seek to find ways to adjust their lifestyles according to the planetary boundaries.[17]



New resource-efficient technologies will come on stream as we move further along the sixth wave. Blockchain and virtual currency will increasingly be adopted by virtue of their capacity to enhance transparency and security in any transactional system and ultimately pave the way to a more neutral global currency. Artificial intelligence and machine learning are also rapidly developing and expanding, helping to speed up communication between machines and humans and to introduce learning in various technological systems. Their growth and expansion is expected to continue over the next decades, which will at once cause much concern about the control-invoking mechanisms embedded in these technologies.

[17] https://www.thenational.ae/uae/young-people-value-environment-over-money-according-to-global-survey-1.190473

Quicker and more immersive learning will be also greatly enhanced in the sixth wave. Augmented and virtual reality technologies will be widely deployed, given their capacity to improve learning through experience and transcend time and place. We will also see the continued spread of Internet of Things (IoT) technologies, enabling the integration and coordination of physical assets and digital systems. Big data technologies will also expand on the strength of their capacity to extract information from large volumes of data. Furthermore, 3D printing technologies will gain greater prominence, allowing for the production of three dimensional objects using digital data – and saving large amounts of materials.

We can also expect to see the growing interest in the secrets of human health materialize in new health technologies and preventive medicine. At the same time as personalized medicine becomes more readily available, new stem cell and nanoscale medicine will also be widely deployed. Digital technologies will be extensively used, and societies strapped by the high costs of running their public health systems will invest heavily in preventive health care in order to cut the costs of treatments for the various ill effects of cardiovascular disease. In the United States alone, cardiovascular diseases are the direct cause of one in three deaths, and the annual cost of treatment is estimated at 316 billion dollars.[18] Globally, according to some estimates, annual health-care costs are projected to rise from the current figure of 4.3 trillion to some 18 trillion dollars by 2040.[19]

In the sixth wave, the bioeconomy will be based on providing solutions to two major and very much interconnected challenges that face humanity as we move on to the next phase. The first set of bioeconomic solutions have to do with new bio-based materials that need to be developed in order to provide a replacement for non-renewable materials that have become increasingly scarce, such as critical and rare metals including lithium, copper, uranium, gold and so-called rare earth elements (REEs). The second set of solutions should arrive in the areas of land degradation, food scarcity and the western dietary bias. As Lester Brown has compellingly stated, providing adequate food supplies could become a weak link for our civilization in the same way as it was for many preceding civilizations, starting from Mesopotamia: many have ultimately perished because of the degradation of their cultivated agricultural land (Brown 2012). All these developments will mature as we move on to the seventh wave of development around the middle of the century.

[18] https://millionhearts.hhs.gov/learn-prevent/cost-consequences.html

[19] https://image.health.allianzcare-emails.com/lib/fe9b12747766047874/m/1/30a0836e-6ce7-4b9c-8b47-99a206299502.pdf

5 The Seventh Wave

As the sixth wave draws to a close by the middle of the century and the population on the planet reaches some 9 billion, the inability of societies to respond adequately and timely to the challenge of climate change will lead to a massive crisis. With ever-stronger storms, enduring droughts and rising sea levels due to the meltdown of large parts of the Antarctic ice bed, decision-makers will finally recognize that the runaway climate change must be stopped at any cost. This will bring in new global policies whose sole aim is to reverse climate change and elicit material and even spiritual revolution on earth as it is dawning upon us that we have persisted too long with our old model of industrial, material intensive development. The awareness of the earth system and the carbon cycle is about to increase radically.

Moreover, there will be wider acknowledgement of the long-term cycles of geological ages, and the present age, aptly named by aquatic ecologist Eugene Stoermer as the Anthropocene, is understood to postpone the next glacial period (Stager 2011). Humans of the twenty-first century have changed forever the deep future of earth, the next thousands or even millions of years. Whatever humans will be able to do in terms of regulating carbon emissions, there is no reversing the systematic changes that have already happened. However, the changes to the climate and indeed to the earth system will bring a huge boost to all efforts to rebalance our skewed relationship with nature. The focus in the latter part of the century will be on gaining a deeper understanding of living systems, and many technologies, both old and new, will be geared to learning from nature. It will be a period of nature-orientated technologies, in the spirit that futurist Pentti Malaska coined the term (Pouru et al. 2018).

So this is the backdrop for the seventh wave. Let us proceed now to look more closely at some of the key fields of operation. My projection is that the notion of bioeconomy will have at least four critical dimensions in the seventh wave:

1. A renaissance of agriculture, which will get underway as agricultural practices are geared towards regenerating the soil, including massive carbon sequestration.
2. Forests will become an extensive source of new materials, but at the same time their role as a promoter of human health and well-being will be fully realized.
3. Algae will be cultivated and used on a grand scale as a source of energy and new materials.
4. Biomimicry will be extensively deployed as a design principle for new technologies, bringing substantial gains in resource efficiency and enabling totally new technologies in all fields of life.

The following explores each of these dimensions in closer detail.

5.1 Soil and Agriculture

The potential of soil for the bioeconomy and its role in addressing climate change has largely been overlooked. The fight against climate change has been dominated by actions aimed at transferring to low carbon renewable energy by increasing resource efficiency and cutting emissions in many sectors of the economy, including buildings, transport and infrastructure. While great advances have been made on many of these fronts, the huge potential for using cultivated agricultural land as a carbon sink has not been considered a major option for carbon storage.

For some time now, it has been known that the agriculture sector as a whole is an important contributor to climate change, accounting for up to 30% of all human emissions (OECD 2015).[20] The potential of carbon sequestration in soil is well known, but as said indicated, the ideas of moving towards more regenerative agricultural practices has been largely dismissed as an overall policy goal (Zomer et al. 2017).

Recent research has shown that agricultural land has been a major anthropogenic source of carbon dioxide and contributed significantly to the atmospheric concentration of CO_2, which has risen from the pre-industrial level of 278 ppm to the current figure of 417 ppm.[21] Today, it is estimated that the soil carbon stock has been depleted by around 133 Pg (petagram, a unit of mass). Since the estimated stock of organic carbon at 2 metre's depth is 2047 Pg and the stock of inorganic carbon 1558 Pg, even minor changes in the organic carbon stock may have a substantial impact on atmospheric concentration levels. In fact, the calculations prove that the technical cumulative potential of carbon sequestration at 178 Pg in soil and 155 Pg in vegetation between 2020 and around 2100 and at the end of seventh wave could cause a massive drawdown of 178 ppm, bringing atmospheric CO_2 back to pre-industrial levels (Lal 2020). Moving organic carbon from the atmosphere to soil and vegetation, all achievable by human activity, could thus have hugely positive effects by creating climate-resilient soils and generating new, post-industrial agricultural practices throughout the world.

Given the current state of the food chain and indeed our food and agricultural policies, it is imperative now to launch a rebalancing act on a planetary scale.[22] Longitudinal studies have hinted that the only viable long-term solution is to combine modern scientific agriculture with selected aspects of small-scale traditional, regenerative agricultural practices. This will balance our biological need for food with the environmental impact of food production while building on those types of cultural, social and psychological needs that are deeply integrated into our societies (Cleveland 2014).

Global agricultural subsidies currently amount to 700 billion dollars a year. It is notable that out of this vast sum, only 1% is spent on pro-environmental purposes.

---

[20] https://www.oecd.org/agriculture/ministerial/background/notes/4_background_note.pdf

[21] https://www.co2.earth/

[22] https://thecarbonunderground.org/

According to a report from the Food and Land Use Coalition, we need to transform our food and land use systems within the next 10 years.[23] By reallocating our subsidies to support sustainable farming, we might be able in the next decade to develop a land use and food production regime that can help safeguard biodiversity, provide a healthy diet, improve food security, create more sustainable methods of agriculture and ensure a better income for farmers. In other words, the global farming community that is currently contributing to global environmental and social destruction could become a key provider of solutions to the problems of global warming and soil degradation. As agriculture covers some 30% of the planet's land surface, the shift from carbon emitter to carbon absorber would critically redefine the role of agriculture in the global economy bioeconomy.

5.2 Forest Sector

The seventh wave will bring a reassessment of the key role of forests in the global ecosystem. According to the Global Forest Watch, which is run by the University of Maryland, we are currently losing primary forest coverage at a rate of over ten million hectares a year. One-third of that destruction is happening in the tropical regions of the world where it is almost impossible to restore the native rainforest. Another source indicates that a forest area equivalent to the size of India will be lost by 2050 if the current rate of deforestation is allowed to continue.[24]

A recent foresight study using the Delphi process and consulting a large number of forest experts explored the future of the forest industry and the bioeconomy and concluded that this sector is highly dependent on the future agenda of international climate and energy policies (Hurmekoski et al. 2019). It was concluded that the forest sector need to invest heavily in developing and widening its concepts, products and services, while the focus for the bioeconomy should be on eco-system services. The assumption, endorsed by the vision of the experts interviewed, was that in the future, the forest sector will be an increasingly strong part of the bioeconomy overall and as such a major component of the sustainability pathway for 2050 and beyond (ibid.). Earlier studies have also suggested that European forests could easily double their carbon sequestration by introducing so-called climate-smart forestry. They suggest that the total mitigating impact of forests and the forest sector up to 2050 could be as high as 20% of total EU emissions and thus represent a significant part of the EU's mitigation strategy (Gert-Jan Nabuurs et al. 2017).

It seems quite probable, then, that forests and the forest industry will have an elevated role in the seventh wave economy, for a number of reasons. The first has to do with the fact that the transformation that started with digitalization around the turn of the millennium – which saw a reduced demand for paper and somewhat later

[23] https://www.foodandlandusecoalition.org/global-report/

[24] https://www.cgdev.org/media/future-forests

a sharp increase in the demand for board and pulp – will finally come to completion. As easily recyclable material from woody biomass will become the norm, substituting plastic-based and other non-renewable materials, the sustainability potential of wood fibre-based materials and products will be fully realized.

The second factor is that we will need a deeper knowledge of the role of forests in working towards a climate balance. The Global Climate Risks Index shows clearly that weather extremes are already affecting many parts of the world, particularly countries in tropical regions.[25] The trend is continuing to gather momentum, and the future outlook is for more extreme weather patterns and for more heat. According to the IPCC's 1.5 °C report, we will be seeing more unusually hot days and weather extremes in the future in many parts of the world, with tropical countries being the hardest hit (IPCC 2018). There is a growing body of evidence that land use strategies will become the hot topic in climate change negotiations in the coming years and decades, surpassing the role of energy, industry and transport. The IPCC Special Report on Land Use observes that there is major potential for carbon sequestration with reforestation and afforestation strategies (IPCC 2019).

The message to the forest sector is this: high-end knowledge about the forestry industry, whether in Finland, Canada or elsewhere, will continue to grow and flourish, partly because a massive reforestation of Earth has already started in the sixth wave. Back in 2006, the United Nations Environmental Program launched its One Billion Trees campaign,[26] which has now spread across the world.[27] In the seventh wave, we will probably see huge reforestation plans all around the globe in a bid to balance the carbon cycle by sequestrating carbon into the soil and trees. A study at the Technical University of Zürich (ETH) showed that there is space available on Earth for about 1 trillion trees that would cover 0.9 billion hectares of land, particularly in Russia, China, Canada and Australia. The combined effect of this forestation exercise would be a drawback of 2005 billion tonnes of carbon, the equivalent of two-thirds of the carbon released into atmosphere since the industrial revolution.[28] There is little doubt that as the climate keeps shifting towards ever more diverse weather patterns, these strategies will be applied in order to save human lives and to prevent infrastructure destruction.

The growing ambitions to save the Earth from runaway climate change will most likely also spur a renaissance of wood construction, which can be thought of as a method of carbon storage. Large timber buildings have been built and tested during the last 20 years, and their future looks very promising as wood-based building materials are stronger and safer than concrete and even steel.[29] As the technology

[25] https://germanwatch.org/sites/germanwatch.org/files/20-2-01e%20Global%20Climate%20Risk%20Index%202020_14.pdf

[26] https://www.unenvironment.org/resources/publication/plant-planet-billion-tree-campaign

[27] https://gulfnews.com/uae/environment/the-billion-tree-campaign-1.130096

[28] https://ethz.ch/en/news-and-events/eth-news/news/2019/07/how-trees-could-save-the-climate.html

[29] https://www.nature.com/news/the-wooden-skyscrapers-that-could-help-to-cool-the-planet-1.21992

continues to evolve and improve and as consumers increasingly turn to ecological options, there is good reason to expect that wooden buildings and structures will be endorsed in the seventh wave.

Furthermore, forest-based textiles and bioplastics have moved to the rapid development phase and are set to grow and expand in the future.[30] Innovations whereby plastic is made from wood, textiles are made from wood-based sources and large buildings are made from timber all open up interesting avenues for the transfer and circulation of consumption onto more sustainable paths (Hetemaki et al. 2017). Bioreactors and refineries are definitively the type of industrial activities that greatly diversifies the output of high-value chemical and pharmaceutical streams as well as biofuel as an energy source. The forest sector itself is a hub for multisector networks that offer diverse outputs ranging from climate regulation and water and soil protection to new schemes of eco-tourism and cultural services. In short, the forest represents a vital source of alternative materials and services for the future, and indeed there are substantial grounds to argue that the maintenance and restoration of forests will be one key element of planetary politics in the seventh wave.

5.3 The Case of Algae

Current UN estimates are that by 2050, the world population will number around 9.7 billion.[31] The world will need new sources of food in order to meet the growing demand. In fact, calculations show that food production will need to be stepped up by 70% in order to meet demand levels in 2050. Algae have a high protein content and are very nutritious. They can be cultivated on non-arable land, and they also grow in sea water, which means they do not compete for resources with other forms of food production. Recently, much research has been done in different parts of the world to understand the potential of algae in food production, materials development and the promotion of human health. Algae have substantial potential to play an important part in reinventing the global food system for the second half of the century.[32]

The reason why algae are attracting such huge interest in research and development has to do with the well-known planetary "hockey curve" problem.[33] The exponential growth of consumption and emissions is creating a very different kind of reality for the second half of the century, and in order to solve the growing problem, we need to reinvent the way we produce food. Algae are one of the most promising

[30] https://arstechnica.com/science/2020/01/are-bioplastics-all-hype-or-the-future-of-textiles/

[31] https://population.un.org/wpp/

[32] https://ethz.ch/en/the-eth-zurich/global/eth-global-news-events/2017/11/eth-meets-you-at-the-aaas-2018-in-austin-texas/AAASAlgae.html

[33] https://openresearch-repository.anu.edu.au/bitstream/1885/13126/3/1259855.full.pdf

avenues to explore, as are certain other biotechniques that will allow us to disconnect food production from traditional agriculture. In the future, we will be making food "from air", simply by adding microbes to the fermentation process. Already there is a food-producing company whose carbon footprint is one-hundredth that of meat production.[34]

For the seventh wave, the critical systems that need to dramatically improve their sustainability performance are food, agriculture and energy. The major issue for our society is how we are going to change our manufacturing and food production systems in order to increase resource efficiency while at the same time reducing emissions to a fraction of what they are today. According to FAO, climate change and warming will contribute to constraining the amount of arable land in many parts of the world.[35] The challenge of how to produce more food on less arable land is acute indeed. By 2050, it is simply imperative that we find new ways of producing food, fuel and some critical materials.

In all these critical sectors, emerging technologies in the area of algae production may become a major industry. In terms of water usage, for instance, algae are 800 times more efficient in producing protein than meat. Moreover, algae have enormous genetic diversity, which means that they have an extremely complex biochemistry and can thus serve as an almost endless source of materials (Fabris et al. 2020). There is a good chance that much of our food in the latter part of the century will come from ponds and vats, with algae serving as a source of food, energy and medicine. Moreover, algal biomass may contain large amounts of oils, and it has the great advantage of being able to convert almost all its energy from feedstock into a source of energy. Instead of using existing precious resources, algal biomass is produced by taking CO_2 from the atmosphere and small quantities of waste water. The technology is already there, ready to go. In other words, scientists seem to agree that algae feedstock is one of the major opportunities for a far more sustainable method of fuel production (Adeniyi et al. 2018). Since algae are plentiful and still a largely untapped opportunity, there is real potential for them to become a commercially attractive product for the global economy.

Algae can be classified into three main groups, i.e. microalgae, algae and macroalgae. Microalgae are single cell organisms that produce sugars using sunlight and carbon dioxide. They are essentially phytoplankton, which produce 50% of the world's oxygen. Macroalgae are multi-cellular tissues that are found in seaweeds, for instance. A good example of an algae product is spirulina, which has a wide range of positive health effects.

Microalgae are very rich in lipids and provide a raw material for biodiesel. They need very little land to grow and therefore do not compete with agricultural crops. It is a highly efficient source of oil compared to other similar sources. Algae are also a source of amino acids and omega 3. Furthermore, microalgae biomass can be used

[34] https://edition.cnn.com/2020/01/20/europe/solar-foods-solein-scn-intl-c2e/index.html

[35] http://www.fao.org/3/I9542EN/i9542en.pdf

to produce carbon-neutral plastics and foams. In terms of food security, algae have another important use in tying up phosphorus, a non-renewable source that is rapidly being depleted as there is only one country in the world, Morocco, with substantial amounts of this feedstock. As some studies suggest, in the process of using phosphate as a fertilizer in agricultural lands, up to 80% is wasted as run-off, causing eutrophication.[36]

In sum then, algae offer major potential in at least three distinct areas: in food security, in addressing global nutritional deficiencies and in producing inexpensive but high-quality protein to feed the growing population of the world. Up to 70% of the dry weight of algae is protein, so it offers a terrific alternative for the world which is now getting much of its protein intake in the form of meat. In algae, we have a non-soya-based vegan alternative that can be used as flour, oil and many other foodstuffs – and even as raw material for beer.[37] Secondly, in the world of chemicals, algae-based biofuels can become a significant replacement for fossil fuels. Thirdly, there are also major uses for algae in the field of medicine. Most synthetic vitamins are currently derived from petroleum. Algae could be a great source for all our vitamins and an important dietary supplement as they contain all the essential vitamins, minerals and amino acids that human beings need. In fact, we can eat the whole algae and have all the benefits of natural vitamins. In countries such as Japan and South Korea, where seaweed is traditionally an important part of the diet, people generally enjoy better health and have a longer life expectancy than people in Western countries. There is a strong evidence that dietary algae is a major explanatory factor (Wells et al. 2017). Astaxanthin is a carotenoid pigment that occurs in microalgae and in salmon, and it is known to be a powerful antioxidant with many health benefits, including a healthier skin, improved endurance, a healthier heart and reduced joint pain. It is even used as a cancer treatment.[38,39]

Algae could indeed well become a major cornerstone for our daily life in the latter part of this century, helping it transform into a bioeconomy (Ibid.). We know that they can be economically viable and that they are non-polluting. They conserve rather than squander energy. They also conserve other natural resources as we can use algae to produce the food, chemicals and energy we need.

Since algae have this real potential to become substantial trigger for the bioeconomy, there is much ongoing research and development around algae in different parts of the world, and it is expected that algae could indeed revolutionize the food we eat, the medicine we take and the energy we rely on (Khan et al. 2018). There is immense potential for algae to be a source of solutions critical for the seventh wave. Researchers say that algae factories of the future could produce "liquid, solid and gaseous biofuels [that] may become commercially available in the years

[36] https://www.responseable.eu/wp-content/uploads/key-story-eutrophication-0518.pdf

[37] https://www.williamsbrosbrew.com/beer/kelpie

[38] https://www.healthline.com/health/health-claims-astaxanthin

[39] https://www.clinicaleducation.org/resources/reviews/astaxanthin-the-key-to-a-new-you/

2020–2025" (Raslavicius et al. 2018, p643). They also conclude that "future climate change mitigation will rely on a synergistic combination of CO_2 capture and utilization technologies, with microalgal carbon capture and biomass production playing a significant role" (Raslavicius et al. 2018, p652).

As Fabris and colleagues have convincingly pointed out, the scaling up of algae use would help to tackle the hardest equation to solve in the world today: the growing needs for food, energy and materials cannot be met simply by stepping up the intensity of agriculture and fossil fuel extraction (Fabris et al. 2020). Microalgae have higher photosynthetic efficiency than plants and therefore greater potential to produce biomass that can be cultivated on non-arable land. Moreover, algae function as next-generation, cell-sized industrial plants, with the capacity to produce highly diverse products ranging from chemicals to skin creams.

In the seventh wave, this tremendous capacity of algae could be put to full use by drawing on advances in synthetic biology and IoT automation to develop algal manufacturing technology. As we need to move decisively from petroleum-based manufacturing and energy production, this new dominant form of economy will establish itself and flourish once production is ramped up some time in the 2050s, if not earlier.

6 Conclusions

Humans have a long history with nature, and hopefully a long future, too. In this introductory chapter to Bio#Futures book compilation I have used various frameworks to show how our relationship with nature has developed over time. As we move forward in this century, we will see how this relationship will intensify and assume new forms via two very different routes: through our crash course that has already destroyed many natural habitats and changed weather patterns, but also through innovation and development, bringing in more technology and science in an attempt to understand how we can cater for human needs without crossing planetary boundaries.

The seventh wave will be a defining time for the human race, a last chance to rehabilitate its relationship with nature. This is why I call this phase a wave of living systems technology. During this phase, our technology will increasingly begin to intelligently mimic the way in which nature operates. Inspired by the capacities of nature, a whole new set of technologies will be developed that will allow us to build a much more efficient and productive economy, while creating a much more human-friendly but at the same time nature-oriented way of life. As we move on in 2020s, it will become ever more apparent with more violent and extreme weather events that we are indeed currently on the crash-course with nature.

The real challenge is this: how do we learn to collaborate with nature instead of just extracting and using its resources? We need to and hopefully we will make biology work for us as a primary source of economic wealth and human well-being. In the case of algae, which currently produce half of the world's oxygen, we have

50,000 documented species, which means that they represent a huge genetic diversity. If we can learn how to put to use even a fraction of the intelligence and potential inherent in different algae species, leave alone all other intelligence in nature, then we would be well on our way to sustainably access much of the food, energy and medicine we need. Then, and only then, can we call our economy a true bioeconomy.

References

Adeniyi, O.A., Azimov, U. & Burluka, A. (2018). Algae biofuel: Current status and future applications. Renewable and Sustainable Energy Reviews, volume 90, July 2018, Pages 316–335

Bardi, U. (2014). Extracted. How the Quest for Mineral Wealth Is Plundering the Planet. Chelsea Green Publishing, London.

Beck, U. (1992). Risk society: Towards a new modernity. London; Newbury Park, Calif.: Sage Publications.

Berman, M. (1981). All that is Solid Melts into Air: the Experience of Modernity. New York: Simon & Schuster

Brown, L. R (2012). Outgrowing the Earth. The food security challenge in an age of falling water tables and rising temperatures. London, Earthscan.

Cleveland, D. (2014). Balancing on a planet. The future of Food and Agriculture. University of California Press.

Fabris, M., Abbriano, R.M., Perinice, M., Sutherland, D., Commault, C., Hall, C.C., Leen, L., McCauley, J.I., Unnikrishnan, K., Ray, P., Kahlke, T., Ralph, P.J. Emerging Technologies in Algal Biotechnology: Toward the Establishment of a Sustainable, Algae-Based Bioeconomy. Frontiers in Plant Science. Front. Plant Sci., 17 March 2020

Gert-Jan Nabuurs, G-J., Delacote, P., Ellison, D., Hanewinkel, M., Hetemäki, L., Lindner, M. (2017). By 2050 the Mitigation Effects of EU Forests Could Nearly Double through Climate Smart Forestry. Forests 2017, 8, 484

Guillemette, Y. and D. Turner (2018), "The Long View: Scenarios for the World Economy to 2060", OECD Economic Policy Papers, No. 22, OECD Publishing, Paris, https://doi.org/10.1787/b4f4e03e-en

Haskel, J. & Westlake, S. (2018). Capitalism Without Capital. The Rise of the Intangible Economy. Princeton University Press.

Hetemaki, L., Hanewinkel, M., Muys, B., Ollikainen, M., Palahí, Marc., Trasobares, A. (2017). Leading a way to European cricular bioeconomy strategy. Euroepan Forest Institute, From Science to Policy 5.

Hurmekoski, E., Lovrić, M., Lovrić, N., Hetemäki, L., Winkel G. (2019). Frontiers of the forest-based bioeconomy – A European Delphi study. Forest Policy and Economics 102 (2019) 86–99

IPCC. 2018. Summary for Policymakers. In: Global Warming of 1.5 °C. Special Report of the Intergovernmental Panel on Climate Change.

IPCC. 2019. Climate Change and Land: An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial 31 ecosystems.

Jabobs, M. & Mazzucato, M. (2016). Rethinking Capitalism: An Introduction. In: Jabobs, M. & Mazzucato, M. (eds.). Rethinking Capitalism: Economics and Policy for Sustainable and Inclusive Growth. Hoboken, N.J.: Wiley / Political Quarterly

Khan, M.I., Shin, J.H., Kim, J.D. The promising future of microalgae: current status, challenges, and optimization of a sustainable and renewable industry for biofuels, feed, and other products. Microbial Cell Factories. 2018;17(1):1–21

Kondratieff, N. (1928/1984). ‘Long wave cycle’ and ‘Theses of N.D. Kondratieff’s paper: Long cycles in economic conditions’ in the long wave cycle. New York: Richardson & Snyder (trans: Daniels, Guy), 25–99 and 101–5, 137–8. In: F. Louçã & J. Reijnders (Eds.), The foundations of long wave theory. Models and methodology. Volume I. Cheltenham, UK: Edward Elgar
Lal, R. (2020). Managing soils for negative feedback to climate change and positive impact on food and nutritional security. Soil Science and Plant Nutrition, Volume 66, 2020 - Issue 1
Laloux, F. (2014). Reinventing Organisations. A guide to creating organisations. Brussels: Nelson Parker.
Malaska, P. (1999) A Conceptual Framework for the Autopoietic Transformation of Societies. FUTU-publication 5/99. Futures Research Centre. Turku School of Economics and Business Administration. Turku.
Piketty, T. Capital In the Twenty-First Century. Cambridge Massachusetts: The Belknap Press of Harvard University Press, 2014.
Pouru, L., Wilenius, M., Holstius, K., Heinonen, S. (2018). Pentti Malaska. A Visionary and Forerunner. Futures Series 9, The Finnish Society for Futures Studies.
Raslavicius, L., Striugas, N., Felneris, M., (2018) New insights into algae factories of the future. Renewable and Sustainable Energy Reviews. Vol. 81, 643–654.
Stager, C. (2011). Deep Future. The Next 100 000 Years of Life on Earth. Thomas Dunne Books, New York.
von Weizsacker E. U., Hargroves, C, Smith M.H., Desha, C., Stasionpoulos, P. (2009). Factor Five. Transforming the Global Economy through 80% improvements in Resource Productivity. London, Earthscan.
von Weizsacker E. U., Lovins, A.B., Lovins, L.H. (1998). Factor Four. Doubling wealth, halving resource use. London, Earthscan.
Wells, M.L., Potin, P., Craigie, J.S., Raven, J.A., Merchant, S.S., Helliwell, K.E., Smith, A.G., Camire, M.E., Brawley, S.H. Algae as nutritional and functional food sources: revisiting our understanding. Journal of Applied Phycology, 2017; 29(2): 949–982.
Wijkman, A. & Rockström J. (2011). Bankrupting Nature. Denying our planetary Boundaries. Earthscan, Routledge.
Wilenius, M. (2014). Society, Consciousness and Change. An Inquiry into Pentti Malaska’s futures thinking. Futures Volume 61, September 2014, Pages 58–67
Wilenius, M. (2017) Patterns of the Future: Understanding the Next Wave of Global Change. World Scientific, London
Zomer et al. (2017) Global Sequestration Potential of Increased Organic Carbon in Cropland Soils. Nature, Scientific Reports 7,