Biodigital Technologies and the Bioeconomy: The Global New Green Deal?

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Keywords: biodigitalism, bioinformationalism, biopolitics, bioeconomy, postdigital, convergence, knowledge ecology, technoscience, New Green Deal

The New Green Deal

Presented in December 2019, the European Green Deal has established the legislative framework for achieving the European Union's climate neutrality by 2050. The Explanatory Memorandum (2020) puts the objective in unambiguous terms:

> The European Green Deal Communication launched a new growth strategy for the EU that aims to transform the EU into a fair and prosperous society, improving the quality of life of current and future generations, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. The European Green Deal reaffirms the Commission's ambition to make Europe the first climate-neutral continent by 2050. (European Commission, 2020)

The European Green Deal suggests that reaching the target requires coordinated investment in environmentally-friendly technologies, support for industrial innovation, cleaner public and private transport, energy-efficient buildings, decarbonising the energy sector and 'working with international partners to improve global environmental standards' (European Commission, 2020).

In the U.S. Joe Biden's election website supports 'the Biden plan to build a modern, sustainable infrastructure and an equitable clean energy future':

> At this moment of profound crisis, we have the opportunity to build a more resilient, sustainable economy – one that will put the United States on an irreversible path to achieve net-zero emissions, economy-wide, by no later than 2050. Joe Biden will seize that opportunity and, in the process, create millions of good-paying jobs that provide workers with the choice to join a union and bargain collectively with their employers. (Biden for President, 2020)

The website plays up the difference with Donald Trump's science denial and his withdrawal from the Paris Agreement. It also announces that Biden will 'make a $2 trillion accelerated investment, with a plan to deploy those resources over his first term, setting us on an irreversible course to meet the ambitious climate progress that science demands' (Biden for President, 2020) with investments in infrastructure, auto-industry, transit, power sector, buildings, housing, innovation, agriculture, conservation, and environmental justice. The figure of two trillion is about double the notional level of investment in Europe.

China's president Xi Jinping announced that the country aims to achieve carbon neutrality by 2060 in his much-publicized video speech at the United Nations General

Assembly[1]. He pledged 3.4 trillion yuan for China's New Green Infrastructure with commitments to reduce reliance on coal and clean energy revolution, making it central to the next Five-Year Development Plan (2021-2025). The vision of an 'ecological civilization' has also been an important part of domestic policy discourse. Xi's announcement is significant, because China is responsible for around 28% of global greenhouse gas emissions.

At the end of 2020, when Covid-19 is peaking in second wave infections and deaths, the co-incidence of Europe, US and China new green deal policies, together with the international cooperation of many nations, seems like a promising intersection of national and global intentions. These concordances not only promise some real progress about reaching climate targets but also create an international culture of collaboration based on *biodigital technologies* and their implications and contribution to the *bioeconomy*. In this paper we chart out the scienfic backdrop of biodigital technologies, review recent bioeconomy policy proposals, historicize these technological changes and policy initiatives, and point towards possible directions for future development of the bioeconomy.

The Scientific Backdrop: Biodigital Convergence

Biodigital convergence is a complex mash-up of new conceptual and practical reconfigurations between biology, physics (nanotechnology), and information science. These reconfigurations are dialectically intertwined with a strong technologization of today's sciences. In line with different foci of their work, scientific researchers often speak of the 'Nano-Bio-Info-Cogno *Paradigm*' (Peters 2020a) (emphasis added), while institutions such as the US National Science Foundation speak of the 'NBIC *technologies*' ('nano-bio-info-cogno') (Institute of Medicine and National Research Council 2006) (emphasis added). Implied in a new scientific 'unity at the nanoscale' (Bainbridge and Roco 2006: 49) are also radically changed relationships between science and technology. We now live in the age of techno-science, where technological development has taken the lead in scientific inquiry. Based on increased technological capabilities, existing and new scientific theories now have more practical applications than ever. In our forthcoming book, *Bioinformational Philosophy and Postdigital Knowledge Ecologies* (Peters, Jandrić, and Hayes, forthcoming, 2022), we explore philosophical and social implications of this great convergence at length. In the context of the bioeconomy, we need to turn to its new practical applications now that humanity has scope for environmental self-renewal and enhancement, which is key to sustainability.

Compiled from the Institute of Medicine and National Research Council (2006), Table 1 represents a classification scheme for biotechnologies covering the main areas of development. Many of these short lines, fit for neat table presentation, contain truly revolutionary changes in ways we understand and do science and technology. DNA synthesis, for instance, is the holy grail of border-crossing between life and matter. In the words of Craig Venter, "[w]e can digitize life, and we generate life from the digital world. Just as the ribosome can convert the analogue message in mRNA into a protein robot, it's becoming standard now in the world of science to convert digital code into protein viruses and cells." (Venter 2012). Referring to "the use of genetically modified plants to produce a wide range of pharmaceuticals and industrial products" (PlantForm, 2020), the notion of plants as production platforms, or biopharming, offers a revolutionary transition from *production of medicines* to *farming medicines*; this transition can easily scale to production of food and other products.

[1] See https://youtu.be/5Zm2dKMiWZM. Accessed 24 November 2020.

Acquisition of novel biological or molecular diversity	Directed design	Understanding and manipulation of biological systems	Production, delivery, and 'packaging'
DNA synthesis DNA shuffling Bioprospecting Combinatorial chemistry, and generating chemical diversity High-throughput screening	Rational drug design Synthetic biology Genetic engineering of viruses	RNA interference. High-affinity binding reagents (aptamers and tadpoles). Computational biology and bioinformatics Systems biology Genomic medicine Modulators of homeostatic systems	Plants as production platforms—'biopharming' Microfluidics and microfabrication Nanotechnology Aerosol technology. Microencapsulation technology Gene therapy technologies Complementarity and synergy of technologies

Table 1: Main areas of development of biotechnologies according to the Institute of Medicine and National Research Council (2006).

DNA synthesis and biopharming alone could transform the face of the earth – and in Table 1, they are just two amongst many technologies with similar transformative potentials. Therefore, some consider this convergence of bio-, nano-, and information technologies, along with the neuro- and cognitive sciences, a transformation that will prove as powerful as the Industrial Revolution (Salter et al. 2016). It is against the techno-scientific backdrop, that we now see the emergence of bioeconomy.

The Emergence of Bioeconomy

The notion of the bioeconomy was developed in the OECD book *The Bioeconomy to 2030: designing a policy agenda* (2009) which contains the principle policy conclusions:

1. Prepare the foundation for the long-term development of the bioeconomy.
2. Reverse the neglect of agriculture and industrial biotechnologies.
3. Prepare for a costly but beneficial revolution in healthcare.
4. Turn the potentially disruptive power of biotechnology to economic advantage.
5. Reduce barriers to biotechnology innovation.
6. Promote the integration of biotechnology research across commercial applications.
7. Create an ongoing dialogue among governments, citizens and firms. (OECD, 2009)

In a recent Special Issue, Trends in Bioeconomy, Aguilar, Twardowski, and Wohlgemuth (2020) show that while the concept of bioeconomy is still very new, over 50 countries from all over the world have now developed related strategies and initiatives. Among the common features are "the need of a strong and vibrant science and technology base, the development of infrastructure and capacity building, and developing a coherent policy framework". Scientists writing in this issue suggest that a new conceptual framework is now developing synergistically with other initiatives at a global and national level on sustainability. "Bioeconomy is evolving from the mostly policy and industrial drive towards a more active inclusion of societal issues such as: investing in education and research; favouring a healthy and innovative industrial environment and, promoting a genuine dialogue with all societal stakeholders related to bioeconomy." (Aguilar, Twardowski, and Wohlgemuth, 2020) Reaching far beyond an

economy's traditional areas of interest, bioeconomy requires a holistic approach which includes areas such as science and technology, education, political science, and many others.

One of the early leaders in the field is the Bioeconomy Council appointed in 2012 by the German Federal Government's Minister of Education and Research and the Minister of Food and Agriculture. The Bioeconomy Council brings together 17 members and their knowledge from different disciplines and links research, businesses, and civil-society organizations to develop practical and "knowledge-based bioeconomy" and strategies for a global sustainable economy. In 2020 the Council made a direct appeal to Government arguing for the need of political action in four related areas:

1. **Promoting sustainable consumption and investment decisions** by means of appropriate framework conditions and incentives so that companies can establish themselves with biobased innovations in Germany.
2. **Ensuring policy coherence** in order to advance the bioeconomy effectively and efficiently. The new strategy for the bioeconomy needs to be coordinated and implemented across departments. The coordination of the High-Tech Strategy could act as an example.
3. **The bioeconomy can make a significant contribution to global food security, to climate, biodiversity and environmental protection and to a better quality of life.** It is important to emphasize these contributions and to consider them in the national agendas on climate protection and sustainability.
4. **Assuming responsibility and encouraging science, business and society to work together to shape the transition to a sustainable bioeconomy**. In concrete terms, change requires a) an implementation plan for the new strategy, b) a platform that links the most important bioeconomy actors and initiatives in Germany, c) a new scientific advisory body consisting of independent experts and d) an umbrella concept for the societal dialogue and participation of the population.
   'The alarming news about global species extinction has once again shown: **We must now take action and worldwide bring our consumption and production behaviors in harmony with nature.** The Bioeconomy offers important approaches and solutions for this,' emphasizes Joachim von Braun, Chairman of the Council. (The Bioeconomy Council, 2019) (emphasis from the original)

The German Federal Cabinet adopted the new National Bioeconomy Strategy on 15th January 2020 which focuses on:

- Expanding biological knowledge and the use of biological processes and systems.
- Increasing availability of biogenic raw materials to the industry via cycle-oriented concepts.
- Integrating the bioeconomy strategy within the German economy.
- Scaling up current and future cross-border cooperation. (Bundesministerium für Bildung und Forschung, 2020)

The bundling of the federal government's bioeconomy policy and recommendations of the bioeconomy council into an overall strategy serves to link the previous goals and measures even more than before with the further development of the national research strategy.

At a European level, a similar strategy is put forward in the report "Leading the way to a European circular bioeconomy strategy". Given that "the current economic model has a systemic failure by assuming unlimited resources", a new economic paradigm is needed "that puts the basis for human prosperity within the planetary boundaries" (Hetemäki et al., 2017, p.

12). Citing first of all the world agreement "in 2015 on Agenda 2030 (the Sustainable Development Goals, SDGs) and the Paris Climate Agreement, it is also widely agreed that the business-as-usual model – the policies, production and consuming habits we have followed so far - will not help us to reach these goals" (Hetemäki et al., 2017, p. 5). In a update, some of these authors now respond to the European Green Deal and argue that bioeconomy is "the missing link to connect the dots" (Palahí, Hetemäki, and Potočnik, 2020). This requires looking at the essence of the economic model we have created and rethinking how we produce and consume. "What is needed is a system change, to dematerialise our economic model and upgrade resource efficiency logic to resource sufficiency, based on the decoupling of economic growth, or better wellbeing, from resource use and environmental impacts." (Palahí, Hetemäki, and Potočnik, 2020) This entails replacing our quantity-oriented, profit-driven economy with an economy that is focused on delivering people's needs in a sustainable way.

This replacement is a process that "challenges the current balance and distribution of power and interests" (Palahí, Hetemäki, and Potočnik, 2020). The combination of digital and biological transformation has significant implications for companies as it changes the design and handling of production processes and their products. Working with the physical world as digital, means that many companies now need to become technology businesses too, if they are to survive (Peters, Jandrić, and Hayes, 2020). Writing about complexism and biology in generative design, Cogdell (2018) points out the problem that "[u]ntil architects, designers, manufacturers, consumers, and politicians integrate life cycle analysis into their everyday decision-making, claims of 'sustainability' remain unsubstantiated" (Cogdell, 2018, p. 214). The necessity though to replace "the *linear fossil-based economic paradigm* on which we have relied since the Industrial Revolution" comes in the price of escalating resource use, global environmental degredation and unprecedented human-induced climate impact. The 'industrial era has provided global economic convergence, but at the risk of sacrificing the safe operating space of our planet' (Hetemäki et al., 2020, p. 10). Yet a long-term viability of the bioeconomy still depends on a more coherent and holistic approach towards the social, economic and environmental aspects not yet addressed.

To 'join the dots' in the Green Deal, Palahí, Hetemäki, and Potočnik (2020) point to three key features of the bioeconomy:

1. **Bioeconomy is fundamental for inclusive prosperity and fair social transition**, but it entails a more complex ownership of biological resources. While costs, transporting and processing biomass is more costly than fossil resources, it offers the possibility of a more inclusive distribution of income, jobs, infrastructures and prosperity especially in rural areas, in line with the Green Deal's inclusive growth ambitions.
2. **Moving towards a carbon neutral EU** does not only require moving towards fossil free *energy*. It also requires efforts to move to fossil free *materials*, and replace carbon intense products like plastics, concrete, steel and other materials like synthetic textiles. The transformation in the Green Deal is not possible without using a new range of renewable biobased materials that can replace and outperform carbon-intense materials.
3. **Bioeconomy addresses past failure of the economy to value nature and biodiversity** and place nature and life at the centre of the economy. Biological diversity determines the capacity of biological resources to adapt and evolve in a changing environment. Biodiversity is therefore a prerequisite for a long-term, sustainable and resilient bioeconomy. New biobased solutions to replace fossil products are crucial to mitigate climate change – biodiversity's main threat, in line with the aims of the Green Deal of *preserving and restoring ecosystems and biodiversity (page 13).* (Palahí, Hetemäki, and Potočnik, 2020) (emphasis from the original)

The bioeconomy powered by nature and emerging from nature has, if managed in a sustainable way, major potential to help deliver the ambitions set by the European Green Deal. It is an important missing piece of the complicated puzzle to overcome the past dichotomy between economy and ecology that very much defined the 20th century. We can build a new and synergistic relationship between technology and nature, between ecology and economy, that can define the 21st century: the century where we would finally start respecting the laws of physics and integrating biology (Hetemäki et al., 2007, p. 10).

Therefore, alongside new means of production that are consistent with bioeconomy (Philp and Winickoff, 2018) developed through biodigital technologies, our task is to engineer *environmental self-renewal* that becomes the basis of long-term sustainability (Peters, Jandrić, and Hayes, 2020). Key to this is both meeting and reviewing the Sustainable Development Goals (SDGs) and also the role of Education for Sustainable Development (ESD), whose goals cannot afford not to engage, with the implications of this biodigital context. "The tipping points will eventually change not only our lives and environments, but also our discourse on sustainability. Some 'old' problems will be resolved, but new challenges and risks will arise. ESD for the future cannot afford not to address the implications of the technological era." (UNESCO, 2020) As modern biotechnology continues to provide breakthroughs in terms of addressing diseases, reducing our environmental footprint, relieving poverty, feeding the hungry, using cleaner more efficient energy, providing clean drinking water, protecting biological diversity on land and in oceans and improving manufacturing processes, this brings us closer towards practically achieving many of the SDGs.

In the holistic bioeconomy, many areas of society need to change alongside the biotech sector. Globally there need to be policies and incentives that will enable researchers, investors, companies and governments to foster biotechnology innovation. Regulatory systems, higher education science programs to train the next generation of scientists, biotechnology laboratories and strong intellectual property systems are further considerations. Additionally, it is necessary "to implement sustainability governance for the bioeconomy which safeguards against negative impacts while fostering positive options" (Niestroy et al., 2020). In this sense sustainability becomes something of a balancing act, with debate on SDG trade-offs and on the substitutability of SDG targets:

> Without regulations, policies, and investments ensuring sustainability, or in case the substitutability of SDG targets is not allowed, the bioeconomy concepts have the potential to jeopardize the achievement of several SDGs. In contrast, the sustainable bioeconomy scenario assumes strong sustainability measures that reveal the extensive potential of the bioeconomy to support the achievement of the SDGs. (Heimann, 2020).

Saachi, Lotti, and Branduardi (2020) place education at the centre of a model for a bio-based economy. They underline the necessity of developing a more flexible educational framework that might facilitate interdisciplinary combinations "[t]o cross the boundaries of a single sector and integrate tools, language and knowledge drawn from different disciplines and sub-disciplines" (Saachi, Lotti, and Branduardi, 2020). Arguing for the design of high-level education programmes that cut across subjects such as science, innovation, economics and education, they suggest this approach is more likely "to promote and guide society towards bio-based innovation". Specifically they point out that:

- Bio-based economy requires crossing the boundaries of single sector competences.
- A novel and flexible educational framework can help with creating a shared language.
- The transition to a bio-based economy entails the support of the social sciences.

- Personal consciousness can guide and leverage desirable technological transitions. (Saachi, Lotti, and Branduardi, 2020)

Looking more generally, Jandrić and Ford show that development of education fit for our biodigital moment "is a global cognitive and affective project, which stretches beyond environment and indeed education". Therefore, they conclude that "[w]e need critique and criticism as well as courage, creativity, imagination, hope, and organization. We need new goals, and new practical measures towards reaching these goals. We need new utopias, new pedagogical and political programs, designs, and experiments that fit our pandemic age of the (post-)Anthropocene" (Jandrić and Ford, 2020).

Based on the 'rethinking' that sits at the centre of a new bioeconomy, models, strategies and policies reviewed in this article represent early steps in our opinion towards anticipating the future and reinventing our theories and practices in and for the biodigital context. We predict that many new postdigital knowledge/education ecologies will emerge at the intersections of disciplines and sectors as they cluster around common sustainable scenarios and goals (Peters, Jandrić, and Hayes, 2020; Peters, Jandrić, and Hayes, forthcoming, 2022).

Conclusion

Biodigital convergence and its various implications from biotechnology to bioeconomy seem to promise a Copernican shift in our current way of life. However, it was not that long ago, that predictions of a similar magnitude were expected from other technologies – and our experience in handling past expectations can offer a lot to this latest challenge. A few years ago, while we prepared the book, *Education and Technological Unemployment* (Peters, Jandrić, and Means, 2019), the technologies of the day were digitalization and automation. Bombastic titles such as 'The future of employment: How susceptible are jobs to computerisation?' (Frey and Osborne, 2013), and 'Technology at work v2.0: The future is not what it used to be' (Frey, Osborne, and Holmes, 2016), have been widely read and discussed from academic journals through daily newspapers to office watercoolers. With the advent of the Covid-19 pandemic, now everyone seems to speak of viruses and biotechnology (Neary, 2020). Yet in huge areas of human activity, such as work, education, and private communications, the main answers to global lockdowns are firmly situated in the digitalization / automation paradigm. Whatever could be done online, is now done online; whatever could be automated, is now automated (Bonilla-Molina, 2020; Jandrić, 2020).

In these processes, our insights into automation and the changing nature of work (Peters, Jandrić, and Means, 2019), and many earlier insights in diverse fields including philosophy of technology (such as rejection of instrumentalisms and determinisms) and digital education (such as the posthumanist nature of learning online), have now transformed into lived experiences. As we write this article at the end of 2020, for instance, anyone working from home while home-schooling children and / or taking care of the elderly intimately feels the relationships between digital technology, work, and education (see Jandrić et al., 2020). After doing a lot of research on these pandemic-induced transformations[2], we are quite proud (although not necessarily happy) that our pre-pandemic theoretical insights have largely stood up to this global test of practice.

[2] See, for instance, *Postdigital Science and Education*, Volume 2, Issue 3, which contains 56 articles about early responses to the pandemic: https://link.springer.com/journal/42438/volumes-and-issues/2-3. Accessed 24 November 2020.

Focused to pandemic responses from within the digitalization / automation paradigm, the world is still not in the age of bioeconomy. However, the first signs of the new age of bioeconomy are all around us. A few years ago we read OECD reports on the future of work in the age of digitalization and automation: we now read OECD reports on the biodigital future of work. A few years ago we analysed "data capitalism (Fuchs 2019), algorithmic capitalism (Peters and Jandrić 2018: 32), communicative capitalism (Dean 2009; Ford 2018), surveillance capitalism (Zuboff 2019), technoscientific capitalism (Birch and Muniesa 2020), high tech and low pay capitalism (Marcy 2009)" (Jandrić and Ford, 2020); we now speak of bioinformational capitalism (Peters, 2012). These concepts and ideas do not arrive in a neat temporal progression and are far from isolated. For instance, Zuboff's (2019) concept of surveillance capitalism contains a good measure of biodigital thinking relevant for the pandemic moment.

Biodigital convergence is not a completely new paradigm; it is merely the latest (and by now the widest) techno-social convergence, based on earlier convergences (such as digital-analog), which are built into its very core. Looking at theory, biodigital convergence is an intrinsic building block of earlier concepts such as the postdigital condition described as 'hard to define; messy; unpredictable; digital and analog; technological and non-technological; biological and informational' (Jandrić et al., 2018, p. 895). In many fields, we have already been well aware of the biodigital challenge for a while now – with the Covid-19 pandemic, however, the biodigital challenge has risen in importance and prominence in the blink of an eye. Thankfully, our earlier works and their lineages provide us with sound conceptual tools for dealing with the new biodigital challenge in and beyond our pandemic moment (Peters, Jandrić, and Hayes, 2020). When we researched digitalization and automation of work and education (Peters, Jandrić, and Means, 2019), no-one could predict the Covid-19 pandemic – yet when the pandemic arrived, and when lockdowns started, these insights have been hugely important in developing adequate responses.

Today, we again need to anticipate the future and reinvent our theories and practices in and for the biodigital context. Under pandemic conditions, our work has been transformed by an increasing sense of global oneness and solidarity (Mañero, 2020; Suoranta, 2020), some environmental benefits such as a decrease in carbon emissions (Lewis, 2020), and also many losses from most obviously human lives, to the sorrows of living in a time of 'no touch' (Sapon-Shevin and SooHoo, 2020). Political responses to the pandemic vary from balanced approaches based on solidarity (Kerres, 2020) to the downright craziness of the Trump administration (McLaren, 2020), and we now see emerging initiatives such as the Global New Green Deal that may well herald a new green age that at last takes sustainability seriously. Yet in our age of bioinformational capitalism (Peters, 2012), all these changes and initiatives will be worthless without a solid material base. It is with this conclusion, that we urgently need to develop new understandings of bioeconomy fit for our biodigital moment in history.

References

Aguilar, A.,Twardowski, T, Wohlgemuth, R. (Eds.)(2020). Trends in Bioeconomy. *New Biotechnology*. https://www.sciencedirect.com/journal/new-biotechnology/special-issue/10JHZ84SNZ2. Accessed 28 November 2020.

Bainbridge, W. S., & Roco, M. C. (2006). *Managing Nano-Bio-Info-Cogno Innovations: Converging Technologies in Society*. Dordrecht: Springer.

Biden for President (2020). The Biden plan to build a modern, sustainable infrastructure and an equitable clean energy future. https://joebiden.com/clean-energy/#. Accessed 24 November 2020.

Bonilla-Molina, L. (2020). Covid-19 on Route of the Fourth Industrial Revolution. *Postdigital Science and Education, 2*(3), 562-568. https://doi.org/10.1007/s42438-020-00179-4.

Bundesministerium für Bildung und Forschung (2020). Nationale Bioökonomiestrategie. Kabinettversion, 15.01.2020. Berlin and Bonn: Bundesministerium für Bildung und Forschung. https://www.bmbf.de/files/bio%c3%b6konomiestrategie%20kabinett.pdf. Accessed 24 November 2020.

Cogdell, C. (2018). Towards a living architecture? Complexism and Biology in generative design. 214 . London: University of Minnesota Press.

Dean, J. (2009). Democracy and other neoliberal fantasies: Communicative capitalism and left politics. Durham and London: Duke University Press.

European Commission (2020). Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law). Brussels: European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020PC0080&from=EN. Accessed 24 November 2020.

Ford, D. R. (2018). Queer communist study: The sinthomostudier against the capital-debt-learning regime. Journal of Curriculum and Pedagogy, 15(1), 8-23. https://doi.org/10.1080/15505170.2018.1437575.

Frey, C. B., & Osborne, M. A. (2013). The future of employment: How susceptible are jobs to computerisation? 17 September. https://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pdf. Accessed 7 October 2020.

Frey, C. B., Osborne, M. A., & Holmes, C. (2016). Technology at work v2.0: The future is not what it used to be. *Citi GP: Global Perspectives & Solutions, January*. https://www.oxfordmartin.ox.ac.uk/downloads/reports/Citi_GPS_Technology_Work_2.pdf. Accessed 7 October 2020.

Fuchs, C. (2019). Karl Marx in the age of big data capitalism. In D. Chandler & C. Fuchs (Eds.), Digital Objects, Digital Subjects: Interdisciplinary Perspectives on Capitalism, Labour and Politics in the Age of Big Data (pp. 53–71). London: University of Westminster Press. https://doi.org/10.16997/book29.d.

Hetemäki, L., Hanewinkel, M., Muys, B., Ollikainen, M., Palahí, M. and Trasobares, A. (2017). Leading the way to a European circular bioeconomy strategy. From Science to Policy 5. European Forest Institute. https://efi.int/sites/default/files/files/publication-bank/2018/efi_fstp_5_2017.pdf. Accessed 25 November 2020.

Institute of Medicine and National Research Council. (2006). *Globalization, Biosecurity, and the Future of the Life Sciences*. Washington, DC: The National Academies Press. https://doi.org/10.17226/11567.

Heimann, T. (2020). Earth's future: bioeconomy and SDGs: does the bioeconomy support the achievement of the SDGs? *AGU*. https://doi.org/10.1029/2018EF001014 https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018EF001014. Accessed 28 Novemebr 2020.

Jandrić, P. (2020). Postdigital Research in the Time of Covid-19. *Postdigital Science and Education, 2*(2), 233-238. https://doi.org/10.1007/s42438-020-00113-8.

Jandrić, P., & Ford, D. (2020). Postdigital Ecopedagogies: Genealogies, Contradictions, and Possible Futures. *Postdigital Science and Education.*

Jandrić, P., Hayes, D., Truelove, I., Levinson, P., Mayo, P., Ryberg, T., Monzó, L.D., Allen, Q., Stewart, P.A., Carr, P.R., Jackson, L., Bridges, S., Escaño, C., Grauslund, D., Mañero, J., Lukoko, H.O., Bryant, P., Fuentes Martinez, A., Gibbons, A., Sturm, S.,

Rose, J., Chuma, M.M., Biličić, E., Pfohl, S., Gustafsson, U., Arantes, J.A., Ford, D.R., Kihwele, J.E., Mozelius, P., Suoranta, J., Jurjević, L., Jurčević, M., Steketee, A., Irwin, J., White, E.J., Davidsen, J., Jaldemark, J., Abegglen, S., Burns, T., Sinfield, S., Kirylo, J.D., Batarelo Kokić, I., Stewart, G.T., Rikowski, G., Lisberg Christensen, L., Arndt, S., Pyyhtinen, O., Reitz, C., Lodahl, M., Humble, N., Buchanan, R., Forster, D.J., Kishore, P., Ozoliņš, J., Sharma, N., Urvashi, S., Nejad, H.G., Hood, N., Tesar, M., Wang, Y., Wright, J., Brown, J.B., Prinsloo, P., Kaur, K., Mukherjee, M., Novak, R., Shukla, R., Hollings, S., Konnerup, U., Mallya, M., Olorundare, A., Achieng-Evensen, C., Philip, A.P., Hazzan, M.K., Stockbridge, K., Komolafe, B.F., Bolanle, O.F., Hogan, M., Redder, B., Sattarzadeh, S.D., Jopling, M., SooHoo, S., Devine, N., & Hayes, S. (2020). Teaching in The Age of Covid-19. *Postdigital Science and Education, 2*(3), 1069-1230. https://doi.org/10.1007/s42438-020-00169-6.

Jandrić, P., Knox, J., Besley, T., Ryberg, T., Suoranta, J., & Hayes, S. (2018). Postdigital Science and Education. *Educational Philosophy and Theory, 50*(10), 893-899. https://doi.org/10.1080/00131857.2018.1454000.

Kerres, M. (2020). Against All Odds: Education in Germany Coping with Covid-19. *Postdigital Science and Education, 2*(3), 690-694. https://doi.org/10.1007/s42438-020-00130-7.

Lewis, T. E. (2020). Cities Gone Wild. *Postdigital Science and Education, 2*(3), 597–600. https://doi.org/10.1007/s42438-020-00120-9.

Mañero, J. (2020). Postdigital Brave New World and Its Educational Implications. *Postdigital Science and Education, 2*(3), 670-674. https://doi.org/10.1007/s42438-020-00129-0.

McLaren, P. (2020). Religious Nationalism and the Coronavirus Pandemic: Soul-Sucking Evangelicals and Branch Covidians Make America Sick Again. *Postdigital Science and Education, 2*(3), 700–721. https://doi.org/10.1007/s42438-020-00122-7.

Neary, M. (2020). Odyssean Education Plays the Coronavirus: Ideation and the Immune Institution. *Postdigital Science and Education, 2*(3), 665–669. https://doi.org/10.1007/s42438-020-00136-1.

Niestroy, I., Hege, E., Dirth, E., & Zondervan, R. (2020). Europe's approach to implementing the Sustainable Development Goals. In F. Dodds et al. (Eds.), *Governance for Sustainable Development Volume 4: Challenges and Opportunities for Implementing the 2030 Agenda for Sustainable Development*. London: Friends of Governance for Sustainable Development.

OECD (2009). *The Bioeconomy to 2030: Designing a Policy Agenda*. Paris: Organisation for Economic Co-operation and Development.

Palahí, M., Hetemäki, L., & Potočnik, J. (2020). Bioeconomy: the missing link to connect the dots in the EU Green Deal. European Forest Institute, 20 March 2020. https://pr.euractiv.com/pr/bioeconomy-missing-link-connect-dots-eu-green-deal-202385. Accessed 25 November 2020.

Peters, M. A. (2012). Bio-informational capitalism. *Thesis Eleven, 110*(1), 98–111. https://doi.org/10.1177%2F0725513612444562.

Peters, M. A. (2020). Critical Philosophy of Technological Convergence: Education and the Nano-Bio-Info-Cogno Paradigm. In M. Stocchetti (Ed.), *The Digital Age and Its Discontents* (pp. 235-252). Helsinki: Helsinki University Press. https://doi.org/10.33134/HUP-4-12.

Peters, M. A., Jandrić, P., & Hayes, S. (2020). Biodigital Philosophy, Technological Convergence, and New Knowledge Ecologies. *Postdigital Science and Education.*

Peters, M. A., Jandrić, P., & Hayes, S. (forthcoming 2022*). Bioinformational Philosophy and Postdigital Knowledge Ecologies*. Singapore: Springer.

Peters, M. A., Jandrić, P., & Means, A. J. (Eds.). (2019). *Education and Technological*

Unemployment. Singapore: Springer.
PlantForm (2020). What is biopharming? https://www.plantformcorp.com/biopharming.aspx. Accessed 24 November 2020.
Philp, J., & Winickoff, D. E. (2018). Realising the circular bioeconomy. OECD Science, Technology and Industry Policy Papers, No. 60. Paris: OECD. https://doi.org/10.1787/31bb2345-en.
Salter, B., Zhou, Y., Datta, S., & Salter, C. (2016). Bioinformatics and the Politics of Innovation in the Life Sciences: Science and the State in the United Kingdom, China, and India. *Science, Technology, & Human Values*, *41*(5), 793-826. https://doi.org/10.1177%2F0162243916631022.
Sapon-Shevin, M., SooHoo, S. (2020). Embodied Social Justice Pedagogy in a Time of 'No Touch'. *Postdigital Science and Education*, *2*(3), 675–680. https://doi.org/10.1007/s42438-020-00177-6.
Saachi, S, Lotti, M., & Branduardi, P (2020). Education for a biobased economy: Integrating life and social sciences in flexible short courses accessible from different backgrounds. *New Biotechnology*, *60*, 72-75. https://doi.org/10.1016/j.nbt.2020.10.002.
Suoranta, J. (2020). The Covid-19 World: Learning or Downfall. *Postdigital Science and Education*, *2*(3), 538-545. https://doi.org/10.1007/s42438-020-00189-2.
The Bioeconomy Council (2019). Actively shaping a sustainable future: German Bioeconomy Council issues final call for action to politicians. 26 June. https://biooekonomierat.de/en/press/press-releases/press-release-boer-190626/index.html. Accessed 24 November 2020.
United Nations Educational, Scientific and Cultural Organization (UNESCO). (2020). Education for Sustainable Development: a roadmap. https://unesdoc.unesco.org/ark:/48223/pf0000374802. Accessed 24 November 2020.
Venter, J. C. (2012). What Is Life? A 21st Century Perspective. On the 70th Anniversary of Schroedinger's Lecture at Trinity College. The Edge. https://www.edge.org/conversation/j_craig_venter-what-is-life-a-21st-century-perspective. Accessed 24 November 2020.
Zuboff, S. (2019). *The age of surveillance capitalism: The fight for a human future at the new frontier of power*. New York: PublicAffairs.