The Dangers of Decoupling: Earth System Crisis and the "Fourth Industrial Revolution"

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Abstract

The question of whether global capitalism can resolve the earth system crisis rests on the (im)possibility of "absolute decoupling": whether or not economic growth can continue indefinitely as total environmental impacts shrink. Ecomodernists and other techno-optimists argue for the feasibility of absolute decoupling, whereas degrowth advocates show that it is likely to be neither feasible in principle nor in the timeframe needed to ward off ecological tipping points. While primarily supporting the degrowth perspective, I will suggest that the ecomodernists have a wildcard in their pocket that hasn't been systematically addressed by degrowth advocates. This is the "Fourth Industrial Revolution", which refers to convergent innovations in biotechnology, nanotechnology, artificial intelligence, 3d printing, and other developments. However, I will argue that while these innovations *may* enable some degree of absolute decoupling, they will also intensify emerging risks in the domains of biosecurity, cybersecurity, and state securitization. Overall, these technologies will not only place unprecedented destructive power in the hands of non-state actors but will also empower and incentivize states to create a global security regime with unprecedented surveillance and force-mobilization capacities. This reinforces the conclusion that mainstream environmental policies based on decoupling should be reconsidered and supplanted by alternative policy trajectories based on material-energetic degrowth, redistribution, and technological deceleration.

Introduction

The question of whether global capitalism can solve climate change (or the earth system crisis more broadly) rests on the potential of "decoupling". This refers to whether economic growth can continue indefinitely as resource use and environmental impacts grow more slowly (*relative* decoupling) and eventually shrink (*absolute* decoupling). On one side of the debate are "ecomodernists" and techno-optimists who believe that present trends towards relative decoupling, combined with the promise of technological innovation, will make absolute decoupling possible in the future (Asafu-Adjaye et al, 2015; Lynas, 2011; Brand, 2012; Rockstrom & Klum, 2015; Falk et al, 2018). Therefore, they argue that economic growth need not come at the expense of climate and earth system stabilization. On the other side are "degrowth" proponents who challenge the evidential basis on which claims for relative decoupling rest and argue that visions of absolute decoupling are unlikely to be realized in the future (Hickel, 2019; Wiedmann et al, 2015; Kallis, 2018; Hickel & Kallis, 2019; O'Neill et al, 2018; Kerschner et al, 2018). Thus they claim that a transition to a post-growth global economy will be necessary to prevent runaway climate change and stabilize the earth system.

To date, the bulk of contemporary evidence appears to favor the degrowth perspective. This is primarily due to the so far limited progress on relative decoupling, the lack of evidence for the possibility of absolute decoupling, and even less evidence that the latter could be achieved with the necessary speed to prevent transgressing ecological tipping points (Kallis & Hickel, 2019; Wiedmann et al, 2015; Schandl et al, 2016). However, the ecomodernists and techno-optimists have a wildcard in their pocket that has not been systematically addressed by degrowth proponents. This is the "Fourth Industrial Revolution" (FIR), sometimes referred to as the "NBIC convergence": the convergence of auto-catalytic innovations in biotechnology, nanotechnology, the internet-of-things, Artificial Intelligence (AI), 3d printing, robotics, and other emerging technologies (Schwab, 2017; NAS, 2014; Ramsden, 2016; Blum & Wittes, 2015). Many futurists believe that this emerging technological revolution will have political, economic, and social consequences that could match the scale of those felt during the 19th century (Schwab, 2017; Diamandis & Kotler, 2014). As its proponents emphasize, the *convergent* nature of these technologies is what harbors the most potential for catalyzing a 21st century industrial revolution: innovations in computing will amplify and catalyze innovation in biotech, nanotech, robotics, and 3d printing; which would facilitate further innovations in computing and AI; then enabling further nanotech and biotech innovations and applications; and so on in a positive feedback circuit (Schwab, 2017: 1-3; NAS, 2018: 87).[1]

It is not necessary to buy into all the hype surrounding these technologies, often promoted by entrepreneurs with financial investments in these industries, to accept that they are indeed enabling new vistas of technological creativity that may significantly alter the geopolitical, economic, and ecological landscape. Degrowthers would be right to critically scrutinize the claims of their advocates, which they have done to a limited extent (Kallis, 2018; Kerschner et al, 2018). However, when forecasting technological trends there is an irreducible element of uncertainty, and skeptical technology assessments will always be insufficient in the eyes of techno-optimists. Given the powerful belief held by many that technological innovation will enable humanity to resolve the earth system crisis by decoupling economic growth from environmental impacts (Brand, 2012; Falk et al, 2018; Lynas, 2011; Asafu-Adjaye et al, 2015; Schwab, 2017), it is therefore important to consider the following (even if only as a thought experiment): *what if the ecomodernists and techno-optimists are right?* What if these technologies *do* succeed in enabling a trajectory of compound economic growth that rapidly decouples from environmental impacts? What new problems might they create? And would it be worth the risks? Following this line of questioning, I will argue that the FIR *may* enable global capitalism to decouple economic growth from environmental impact with sufficient speed to substantially mitigate (if not fully "resolve") the earth

[1] Existing applications enabled by this convergence include 3d printing organic tissue and replacement organs, automated DNA synthesis using AI and big data, nano-3d printing, and (still in its very early phases) nano-robotics and nano-biotechnology (NAS, 2018: 87-91; Wintle et al, 2017; Ramsden, 2016).

system crisis; however, this would intensify emerging risks in the domains of biosecurity, cybersecurity, and state securitization while potentially giving rise to a global security apparatus with unprecedented surveillance and force mobilization capacities.

The key contribution of this article will be to bring together the decoupling debate with existing literature on catastrophic risks posed by FIR technologies, which will proceed through literature review and synthesis.[2] Importantly, the key claim is not simply that technologies needed to achieve decoupling will exacerbate risks in these domains *individually,* but that the feedbacks between them will create a *spiral of insecurity and securitization* that will make it difficult (if not impossible) to avoid the emergence of an authoritarian global security apparatus.[3] To develop this argument, I will first give an overview of the decoupling challenge. Next, I will introduce the FIR and show how it *might* catalyze unprecedented technological breakthroughs that enable the trajectory of absolute decoupling dreamed of by ecomodernists. I will then show how these breakthroughs would shift problems into the domains of biosecurity, cybersecurity, and state surveillance, while catalyzing a spiral of insecurity and securitization that will push global capitalism towards a qualitatively novel form of techno-authoritarianism. Finally, I will conclude by suggesting that while the FIR may enable global capitalism to resolve (or at least manage while muddling through) the earth system crisis in a context of continuous growth, a trajectory of material-energetic degrowth, redistribution, and technological deceleration and democratization would give humanity the best chance of warding off the twin dangers of ecological collapse and techno-authoritarianism.

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[2] See appendix for an explanation of my methodology for conducting a systematic literature review.
[3] For similar arguments see Deudney (2007), Bostrom (2018), and Blum & Wittes (2015), though these authors do not consider how efforts to resolve the earth system crisis through decoupling will intensify these risks.

Infinite Growth on a Finite Planet: The Decoupling Challenge

As both its critics and defenders agree on, global capitalism as a system relies on continuous compound growth (about 3% per year) for its stability and survival (Smith, 2016; Lynas, 2011). Without growth (and by extension the expectation of future profit), investment dwindles, interest on debt cannot be repaid, unemployment rises, and consumer spending falls, thereby catalyzing a reinforcing spiral of economic contraction. The problem for global capitalism in a context of earth system crisis, then, is how to make this compound growth compatible with climate stabilization and ecological regeneration. This has clearly been a challenge thus far. As Roger Pielke explains: "if there is an iron law of climate policy, it is that when policies focused on economic growth confront policies focused on emission reductions, it is economic growth that will win out every time"; therefore, any successful policy "must be designed so that economic growth and environmental progress go hand in hand" (quoted in Lynas, 2011: 68). The philosophy known as "ecomodernism", which can be considered the dominant approach to climate policy in the World Bank, OECD, and UNEP, believes these goals can be simultaneously attained by "decoupling" economic growth from resource use and environmental impact. In the words of the Ecomodernist Manifesto:

> Intensifying many human activities — particularly farming, energy extraction, forestry, and settlement — so that they use less land and interfere less with the natural world is the key to decoupling human development from environmental impacts…Together they allow people to mitigate climate change, to spare nature, and to alleviate global poverty (Asafu-Adjaye et al, 2015: 7).

The ecomodernists distinguish between relative and absolute decoupling: *relative* decoupling means that "human environmental impacts rise at a slower rate than overall economic growth", whereas *absolute* decoupling would occur when "total environmental impacts…peak and begin to decline, even as the economy continues to grow" (ibid: 11). Modern technology and urbanization are considered the keys to achieving decoupling, which they claim enable humanity to "[use] natural ecosystem flows and services more efficiently" (ibid: 17). In this way, the ecomodernists not only believe that it is possible to decouple economic growth from CO2 emissions, but that *all* environmental impacts – including deforestation, biodiversity, soil depletion, air and water pollution, etc. – can decline even as the global economy continues to grow.

There are a number of indicators that ecomodernists and other proponents of decoupling draw upon as evidence for their theoretical claims. First, the "domestic material consumption" indicator, which measures the total material and energy consumption in a given nation-state, shows that GDP has grown faster than total material consumption in rich countries like the United States, with some European countries going further towards absolute decoupling (Pearce, 2012). In particular, ecomodernists highlight trends in wealthier countries toward reforestation, reduced air pollution, plateauing meat consumption, and saturating demand for material-energy intensive goods (e.g. cars) (Asafu-Adjaye et al, 2015: 13-14) This shift is often attributed to the transition from manufacturing to service-based economies in these countries, which are thought to promote "dematerialization" by relying on less material and energy intensive services to create economic value (ibid). Ecomodernists also point to steady improvements in the carbon intensity of the global economy (roughly 1.4% per year, though the rate of improvement has slowed in the past 2 years), which has enabled global growth to relatively decouple from CO2 emissions (IEA, 2016). Ecomodernists therefore conclude: "taken together, these trends mean that the total human impact on the environment, including land-use change, overexploitation, and pollution, can peak and decline this century" (Asafu-Adjaye et al, 2015: 15).

Unfortunately for the ecomodernists, degrowth scholars and ecological economists have begun to poke holes in their optimistic assessments. Their response can be summarized according to three key counter-arguments: 1) the evidence that ecomodernists provide for *relative* decoupling is flawed and limited at best; 2) their evidence for the possibility of *absolute* decoupling is even weaker, and 3) even if absolute decoupling were possible in principle, there is *even weaker* evidence that this could occur with the necessary speed to stabilize the earth system before reaching irreversible tipping points.

First, claims that rich countries have seen relative or even absolute decoupling of economic growth from domestic material consumption have been shown to focus solely on correlations between national GDP and material throughput while ignoring the material-energetic costs embodied in imported consumer goods. For example, Thomas Wiedmann and colleagues show that while the EU, the US, and Japan have grown economically while stabilizing or even reducing domestic material consumption, a broader analysis of their material footprint embedded in their imports shows that it has kept pace with GDP growth. They conclude that "no decoupling has taken place over the past two decades for this group of developed countries" (Wiedmann et al, 2015: 6273). Focusing on the global economy as a whole, Krausmann et al show that its resource intensity improved over the course of the 20th century, though the early 21st century has seen a faster rate of growing resource consumption than global economic growth (cited in Kallis & Hickel, 2019). Thus as Giorgos Kallis and Jason Hickel explain: "global historical trends show relative decoupling but no evidence of absolute decoupling, and twenty-first century trends show not greater efficiency but rather worse efficiency, with *re-coupling* occurring" (ibid: 4; italics added).

Second, given the limited evidence for even relative decoupling, it is little surprise that the evidential basis on which claims for the possibility of *absolute* decoupling rest is even flimsier. In the most comprehensive summary of the modeling evidence to date, Giorgos Kallis and Jason Hickel (2019) show that even the most optimistic scenarios fail to prove the possibility of absolute decoupling. For example, a modeling study by Schandl et al shows that in a "high efficiency" scenario, one that combines a high and rising carbon price plus a doubling in the rate of material efficiency improvement, global resource use grows more slowly (about a quarter the rate of GDP growth) but steadily to reach 95 billion tons in 2050, while global energy use grows from 14,253 million tons of oil equivalent in 2010 to 26, 932 million in 2050 (Schandl et al, 2016: 8-9). The authors therefore conclude: "while some relative decoupling can be achieved in some scenarios, none would lead to an absolute reduction in ... materials footprint" (ibid: 8). A high efficiency scenario modeled by the UNEP comes to even less optimistic conclusions (with global resource use rising to 132 billion tons in 2050), since it incorporates the "rebound effect" in which efficiency improvements lead to increased consumption due to resulting price reductions (Kallis & Hickel, 2019: 6). In short, as Kallis and Hickel conclude, these "models suggest that absolute decoupling is not feasible on a global scale in the context of continued economic growth" (ibid).

Third, the critics show that even if absolute decoupling (from both emissions and total environmental impact) *were* possible in principle, this would need to occur fast enough to prevent transgression of ecological tipping points. Just focusing on the climate problem, the 2018 IPCC report claims that emissions must be reduced 7% annually to reach net zero by 2050 in order to achieve the 1.5 C target, whereas they must reduce 4% annually to reach net-zero 2075 for a shot at the 2 degree target (IPCC, 2018: 15). However, even under optimistic assumptions (e.g. a near-term implementation of a high and rising carbon price, alongside heroic carbon intensity improvements), studies suggest that annual declines of 3-4% might be the fastest rate possible assuming continued economic growth (Hickel, 2019: 55). Thus it would most likely be impossible to meet the 1.5 C target in a context of continuous compound growth. While the 2 degree target *might* be feasible in this context (assuming implementation of a globally coordinated program starting in 2020), many argue that the IPCC's estimates downplay the existence of positive feedbacks in the earth system (e.g. Steffen et al, 2018), and thus more rapid emissions cuts might be needed even for 2 degrees. On top of this, economic growth must also be decoupled from impacts on other "planetary boundaries" that may have already been overshot, especially land use change and biodiversity loss (Raworth, 2017: 44-45). A number of ecologists believe that to bring humanity back into a "safe operating space", total resource consumption should be reduced from roughly 70 to 50 gigatons per year (Hoekstra & Wiedmann, 2014), while a "Half earth strategy" should be implemented that protects 50% of the planet's surface from direct human interference (up from roughly 18% today) (Wilson, 2017), possibly by 2050 to prevent tipping points in biodiversity loss and land use change (Kallis & Hickel, 2019: 8). Even if these claims are exaggerated, the magnitude of the overall decoupling challenge remains clear. It would mean that total resource consumption and land use needs to shrink, remain stable, or only increase moderately (depending on our assumptions regarding the further stress (if any) that planetary boundaries can handle) even as the total output of the global economy *triples* by 2060. It is thus not hyperbole to say, as Boris Frankel puts it, that this goal of absolute decoupling is “overwhelmingly staggering in its ambition and historical novelty” (Frankel, 2018: 127).

Given the magnitude of the decoupling challenge and limited evidence for even relative decoupling so far, what arguments could believers in the possibility of absolute decoupling in the future possibly turn to? Some would claim that we simply need to ramp up government regulations and planning to accelerate efficiency improvements. However, the Schandl et al study cited above shows that even under highly optimistic scenarios in which such policies are globally implemented, absolute decoupling still fails to occur (Schandl et al, 2016). Others point to the potential of the “circular economy” in which wastes are converted into inputs for other industrial processes across the global economy (e.g. Rockstrom & Klum, 2015). However, only a fraction of total throughput (roughly 29%) can be converted to a circular economy, since agricultural and energy inputs (44% of the total) are irreversibly degraded, while buildings and infrastructure (27%) involve net additions that cannot be recycled until the end of their lifespan (Kallis & Hickel, 2019: 6). Even for the 29% of the economy that *is* convertible to the circular economy, the reality of entropy means that total recycling is likely to be physically impossible, while additional constraints on re-using other materials (particularly the rare earth minerals in electronic goods) may lower this potential even further (Frankel, 2018: 145-146).

The best hope for advocates of absolute decoupling, therefore, appears to be a technological revolution that would render projections of potential material-energy efficiency improvement rates obsolete. Indeed, the Schandl et al study makes "very conservative assumptions regarding the development of new technologies" (Schandl et al, 2016: 4), and thus significantly faster rates of efficiency improvement are possible (at least in principle) via technological breakthroughs. And as Kallis and Hickel acknowledge, "we cannot rule out substitutions or technological breakthroughs that will push such limits [to efficiency improvements] so far into the future as to render them irrelevant" (Kallis & Hickel, 2019: 13). The belief that future innovations *will* in fact enable such breakthroughs is likely responsible for the fact that ecomodernists and other advocates of decoupling remain undeterred by limited evidence to date. Is there any basis for their optimism?

The Fourth Industrial Revolution

While it remains to some extent speculative, there is a wildcard in the pocket of ecomodernists that lends at least a degree of plausibility to their confidence in future decoupling. This is the Fourth Industrial Revolution (FIR): the convergence of technological developments in the fields of nanotechnology, biotechnology, information technology, AI, and 3d printing among others. As noted earlier, it is the convergent and reinforcing nature of these technological trends that lead many to believe that they will deliver exponential breakthroughs in all fields of science and engineering, even catalyzing a transformation that will be "unlike anything humankind has experienced before" (Schwab, 2017: 1). Klaus Schwab, the founder and executive chairman of the

World Economic Forum, effectively captures the hope that many place in these converging technologies:

> We have yet to grasp fully the speed and breadth of this new revolution…think about the staggering confluence of emerging technology breakthroughs, covering wide-ranging fields such as artificial intelligence (AI), robotics, the Internet of Things (IoT), autonomous vehicles, 3-D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing. Many of these innovations are in their infancy, but they are already reaching an inflection point in their development as they build on and amplify each other in a fusion of technologies across the physical, digital, and biological worlds (ibid).

Given the immensity of the decoupling challenge, it seems likely that to sustain economic growth in the coming decades while stabilizing the earth system *would* require such a technological revolution. And indeed, this is what many ecomodernists anticipate. Stewart Brand, for example, affirms the need for environmentalists to embrace these "self-accelerating" technologies, which he claims can be "deployed against the self-accelerating problems of world industrialization and against the positive feedbacks in climate itself" (Brand, 2012: 19). In particular, both Brand and Mark Lynas envision an important role for biotechnology and synthetic biology, which they claim will enable the production of more resilient crops with higher yields, clean and renewable biofuels, and microbes engineered to cleanse polluted environments and sequester carbon (ibid; Lynas, 2011). Recent breakthroughs in gene-editing and DNA synthesis have enabled new techniques for restoring damaged ecosystems, conserving endangered species, improving biological fixation of carbon, developing bio-based materials, and boosting crop yields by enhancing the efficiency of photosynthesis (Wintle et al, 2017; Maxmen, 2015), thereby raising hopes among environmentalists and governments that the emerging "bioeconomy" can help solve sustainability challenges (Synthetic Biology Leadership Council, 2016).

Others focus on the promise of emerging developments in information technology, particularly AI, big data, and the "Internet of Things" (IOT) – the global network of online devices, sensors, and databases forming a "world-spanning information fabric" (Goodman, 2016: 284). For example, a recent report commissioned for the 2018 Global Climate Action Summit highlights the importance of these "exponential technologies" for accelerating the transition to a low-carbon economy. It places particular emphasis on the power of the IOT and machine learning to "enable next-generation mobility and electric vehicle breakthroughs, improvements in energy and space efficiency for buildings, and electricity generation and storage" while making cities orders of magnitude more efficient through traffic, energy, and infrastructural optimization (Falk et al, 2018: 80). It also highlights the potential of 3d printing to "democratize production" by enabling local communities to print their material and infrastructural needs, thereby making them "far less dependent on global supply chains" (ibid: 33). Overall, the authors believe these technologies can fuel a rapid decarbonization and dematerialization of the economy, with IOT and AI-driven efficiency gains alone enabling 15% emissions reductions by 2030, *without* sacrificing economic growth or rising material standards of living (ibid: 18).

While its technological flowering may not occur for at least another decade or two, nanotechnology may further revolutionize the above fields. For example, inventor and futurist Eric Drexler claims that nanotech

> will increase energy efficiency across a wide range of applications and sometimes by large factors…In ground and air transportation, the accessible improvements include ten-fold reductions in vehicle mass and a doubling of typical engine efficiencies…reductions in the costs of physical capital will lower the cost of new installations of all kinds, facilitating replacement of capital stock at rates that could surpass any in historical experience (Drexler, 2013: 229).

Combined with 3d printing, nanotechnologists claim that "personal nanofactories" will enable any product to be assembled locally, atom by atom, which would bypass energy-intensive supply chains; reduce energy consumption by an "order of magnitude" (Ramsden, 2016: 288); "essentially eliminate waste" and overcome scarcity by disassembling and reassembling any atomic assemblage into novel material compounds (ibid: 296); and may even enable the rapid creation of a carbon sequestration and storage infrastructure that would "return the Earth's atmosphere to its pre-industrial composition in a decade, and at an affordable cost" (Drexler, 2013: 234).

Whatever the actual potential of these technologies, it is clear that a powerful technological imaginary exists among policy-makers, technologists, and economists that contributes to an unshakeable faith in innovation and human ingenuity to solve the decoupling challenge. Degrowth proponents have so far mainly challenged this optimism by emphasizing the limited potential of renewable energy due to its intermittency and high land and raw material demands (e.g. Kallis, 2018: 80-81). However, this may downplay the (at least theoretical) potential for convergent breakthroughs in nanotechnology, synthetic biology, and AI to vastly improve renewable energy efficiency and storage systems while designing new materials to substitute for depleting minerals (Diamandis & Kotler, 2014: 172). More broadly, while degrowthers have to some extent considered *individual* FIR technologies (particularly AI and biotechnology) (e.g. Kallis, 2018: 80-81; Kerschner et al, 2018), they have yet to address their *convergent* and mutually amplifying character, which leaves them vulnerable to the arguments of techno-optimists.

Of course, the revolutionary promise of these technologies may fail to materialize, and, given the magnitude of the decoupling challenge, degrowth advocates are right to be skeptical. However, due to irreducible uncertainty combined with the "exponential" and "revolutionary" potential of the FIR (Schwab, 2017), even more rigorous critical assessments would always be insufficient in the eyes of the techno-optimists. Therefore, an alternative line of response should also be pursued: what if the FIR *does* succeed in decoupling economic growth from total environmental impact? What unintended consequences then might this give rise to?[4]

Dual-Use Technologies and the Democratization of Violence

First, we must consider that all these are "dual-use technologies", or technologies with potential both for economic productivity and violence. As Gabriella Blum and Benjamin Wittes explain, these technologies are driving a trend referred to as the "democratization of violence" in which the "destructive power once reserved to states is now the potential province of individuals" (Wittes & Blum, 2015: 2). Rather than simply a matter of creating new individual weapons, Blum and Wittes emphasize that convergent FIR technologies are generating "whole technological fields – a series of breakthroughs in basic science and engineering" that "facilitate generative creativity in their users to build and invent new things, new weapons, and new modes of attack" (Wittes & Blum, 2015: 39, 7-8). And to compound the problem, while FIR technologies empower individuals to kill and provoke systemic chaos unlike any other time in history, they also

[4] It is worth noting that I do not discuss nuclear energy in this paper, even though this is a crucial dimension of the technological solution-set proposed by ecomodernists for achieving decoupling. However, I do not discuss nuclear power primarily for reasons of space as well as the fact that its negative unintended consequences have already received significant attention from environmentalists and ecomodernists (e.g. Brand, 2012).

empower states to monitor the minute details of private and public life and potentially constrict individual and collective freedoms, while the unprecedented threats enabled by these same technologies will likely reinforce governmental efforts to intensify securitization as deeply as is technologically feasible. Blum and Wittes summarize the emerging predicament as follows:

> How should we think about the relationship between liberty and security when we both rely on governments to protect us from radically empowered fellow citizens around the globe and also fear the power those same technologies give to governments? (ibid: 13).

Blum and Wittes do not consider how the earth system crisis will intersect with these threats, either as a positive or negative feedback. But it should be clear that, in a world of FIR-driven sustainability solutions, they would inevitably intensify, and it is thus necessary to consider what new problems and governmental responses they would engender.[5]

Without claiming to exhaustively describe the security risks created by the FIR, I will focus on three emerging areas of concern: biosecurity, cybersecurity, and state securitization, and will then discuss how they may collectively generate a spiral of insecurity and securitization.

Biotechnology and the Emerging Terrain of Biosecurity

To begin with biosecurity, both the promise and peril of biotechnology – particularly the still nascent field of synthetic biology – is its immense creative potential. As a recent report from the National Academies of Sciences (NAS) describes:

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[5] Klaus Schwab also recognizes the potential for FIR technologies to democratize access to violence capacity (Schwab, 2017: 88). But he does not systematically consider how they may unleash a spiral of insecurity and securitization or how this could be constrained. Instead, he simply notes that "concerned stakeholders must cooperate to create legally binding frameworks as well as self-imposed peer-based norms", with the private sector taking the lead (ibid: 90).

> synthetic biology is expected to (1) expand the range of what could be produced, including making bacteria and viruses more harmful; (2) decrease the amount of time required to engineer such organisms; and (3) expand the range of actors who could undertake such efforts (NAS, 2018: 4).

For example, manipulating DNA structures in microorganisms can make certain agents more virulent, improve their resistance to antibiotics and vaccines, make them less detectable by already limited surveillance systems, transform harmless microorganisms into deadly ones, and make pathogens more resilient to diverse atmospheric conditions, thus increasing their lifespan (ibid; Charlet, 2018). At present these capabilities remain limited and dependent on highly advanced techniques and laboratory equipment, which is why most experts believe there have to date been no mass casualty bioterror attacks (NAS, 2018: 116). However, the NAS notes that improvements in synthesis technology "have followed a 'Moore's Law–like' curve for both reductions in costs and increases in the length of constructs that are attainable", and that "these trends are likely to continue" (ibid: 18-19). Moreover, automated DNA synthesis techniques remove much of the time-consuming and technically difficult aspects of manipulating DNA, further reducing barriers to access (Wintle et al, 2017). And in the future, experts warn that "convergent capabilities" between synthetic biology, information technology, nanotechnology, and 3d printing may enable "sudden" breakthroughs in bio-weaponization (e.g. by improving bio-agent stability and delivery, providing advances aerosolization capability, and accelerating the "Design-and-Build" cycle) (NAS, 2018: 87).

The possibilities of bio-weaponization will expand as these techniques diffuse, which are already enabling the formation of a "DIYbio" movement in which amateur scientists, inventors, and others are increasingly "capable of doing at home what just a few years ago was only possible in the most advanced university, government or industry laboratories" (Bennett et al, 2009: 1109). The new CRIPSR/Cas9 gene editing technique further expands the range of genomic tinkering available to individuals, which has been widely embraced by the DIYbio community as a powerful tool that "makes it easy, cheap, and fast to move genes around—any genes, in any living thing" (Maxmen, 2015). The capacities of DIY biohackers remain limited in important ways, though the trends described above suggests they will continue to increase as barriers to advanced bio-weaponization fall (NAS, 2018). And while the risks are evident, the democratization of these techniques may also facilitate the diffusion and customization of local solutions to environmental and health challenges while enhancing popular participation in the direction of biotechnological evolution away from transnational corporate dominance (Bennett et al, 2009).

We can therefore say that these emerging technologies pose a unique kind of "security dilemma": while their development and diffusion may strengthen local and global capacities to solve environmental challenges, they may also imperil global security by unleashing uniquely powerful and complex violence capabilities. Synthetic biology is only in its early stages, and governments from the UK to China aim to "accelerate [its] industrialization and commercialization" in order "to drive economic growth" and "develop solutions to key challenges across the bioeconomy, spanning health, chemicals, advanced materials, energy, food, security and environmental protection" (Synthetic Biology Leadership Council, 2016: 13, 4). If calls for emergency action to exponentially expand the green economy indeed accelerate these trends (Falk et al, 2018), then by 2030 (and more so by 2040) we will live in a world where genetically engineered biofuels dramatically increase, genetic tinkering with crop varieties is normalized to enhance agricultural resilience, and gene drives are deployed to control old and new disease vectors intensified by climate change (among other potential applications), which would exponentially expand the number of individuals with biotech expertise and access to the needed equipment. Therefore, while we have yet to experience a catastrophic bioterror attack, rapid advances in synthetic biology are nonetheless creating a "black swan waiting to happen" (Bennett et al, 2009: 1110), and the risk is that such black swans could become increasingly "normal" if this technology becomes a key engine of economic growth and green technological innovation.

Cybersecurity in an Age of "Smart Everything"

The second key problem with the FIR is that "exponential technologies" deployed to decouple growth from environmental impact will also intensify ongoing cybersecurity threats. Cybercrime has increased to the point of costing the global economy an estimated $500-600 billion per year, while new vulnerabilities in civilian infrastructures continue to be discovered and exploited more quickly than they can be secured (Goodman, 2016). We are thus dealing with an already significant problem, though it remains important to consider how it will deepen in a world reliant on FIR-dependent solutions to the earth system crisis, especially once we take into account the cyber-vulnerabilities posed by next generation information systems (ibid).

In particular, we should consider the risks associated with the incipient Internet-of-Things (IOT), which is a key component of the solution-set offered by techno-optimists for decoupling economic growth by dramatically improving efficiencies in energy, transportation, and agriculture (Falk et al, 2018; World Economic Forum, 2018).

One of the prerequisites of a future renewable energy system capable of providing at least 80% of growing electricity demand would be the creation of national or regional "smart grids" in which energy surpluses in areas with lots of wind and sun at a given time can be transmitted to areas with energy deficits. While this system would itself increase cyber-vulnerabilities relative to more modular systems, the efforts of Cisco and others to enhance the efficiency of smart grids via the IOT would intensify these vulnerabilities even more. In this vision, the smart grid would form "an intelligent network of power lines, switches, and sensors able to monitor and control energy down to the level of a single lightbulb", which would be enabled by IOT connected sensors that "monitor energy use and manage demand, time shifting noncritical applications like delaying the start of your dishwasher to the middle of the night, when energy is cheaper" (Diamandis & Kotler, 2014: 169-171). In this way, every connected device – from iphones and laptops to dishwashers and microwaves – would become a possible point of entry for hackers to the overall network (Goodman, 2016: 287). The IOT is also envisioned as a possible to solution to traffic congestion and fuel efficiency for the future fleet of self-driving electric vehicles that are set to (potentially) transform the market over the next decade. While advocates of "smart" cars and "smart" cities are enthusiastic regarding the possibilities for improved energetic and economic efficiency, it would also leave vehicles vulnerable to remote hijacking, as researchers Chris Valasek and Charlie Miller demonstrated in 2014 by taking control of a 2014 Jeep Cherokee (Markey, 2015). Adding further to the IOT-hype, a recent World Economic Forum report proposes deploying it to create "precision agriculture" systems, which could link farms with global positioning systems and weather data collection to monitor water and soil conditions while enabling farms to automatically optimize inputs (World Economic Forum, 2018).

If these IOT powered energy, urban, and agricultural systems come into being, this would constitute an *exponential expansion of attack vectors* for would-be-hackers, whether they come from states, criminal organizations, or non-state terrorist networks. Cybersecurity analyst Mark Goodman effectively captures the scale the problem:

> The IoT will be a global network of unintended consequences and black swan events…we cannot even adequately protect the standard desktops and laptops we presently have online, let alone the hundreds of millions of mobile phones and tablets we are adding annually. In what vision of the future, then, is it conceivable that we will have any clue how to protect the next fifty billion things to go online? (Goodman, 2016: 301-302).

In short, while the expansion of cyber vulnerabilities is already stressing if not overwhelming the defense capacities of governments, corporations, and public utilities, it is also practically assured that these vulnerabilities will expand significantly if the global economy relies on smart energy grids and the IOT to maximize energy efficiency and decouple growth from growing resource use.

State Securitization and Totalitarian Dangers

The third key risk domain involves the securitization powers of states. FIR technologies may not qualitatively transform state power individually, though their *convergent* character could offer immense power to states able to systematically harness these capabilities for the ends of surveillance and militarization. Unsurprisingly, such capacities are being intensively pursued by leading states. In particular, the US and China appear to be engaged in an AI arms race, with China aiming to create a $150 billion AI industry by 2030 and the Pentagon seeking to triple its AI warfare budget to match

China's ambition (Ashizuka, 2019). Military robotics is also a key field of competition, with worldwide spending tripling between 2000 and 2015 from $2.4 to $7.5 billion, and which some estimate will double again by 2025 (Allen & Chan, 2017: 14). The US has also spent $29 billion on nanotechnology research since 2001, with about 20% of its investments involving military applications (National Nanotechnology Initiative, 2019). A short list of potential military applications includes powerful and lightweight body armor, microscopic and networked nano-bots with capacities for "swarm intelligence", and more compact and powerful chemical and nuclear weapons (ibid; Drexler, 2013: 260).

The full extent of the capabilities these technologies may unleash cannot be known in advance, though it seems possible that they could become an "axial" capability of states. As Daniel Deudney describes, an axial capability is one that can dominate an entire system due to its unique character (Deudney, 2007: 44). While FIR technologies may not offer axial capabilities individually, their *convergent* character is such that they could collectively offer an axial advantage to states able to systematically harness their potential. This could take the form of a *globally networked and nano-IOT-AI powered system* harnessing vast capacities for force-mobilization and information gathering and processing. By integrating nanotechnology, the IOT, big data, and robotics while harnessing the processing power and flexibility of advanced AI, states may in this way be in the midst of unleashing technological capabilities that will enable them to informationalize and monitor humans populations while mobilizing destructive power with an unprecedented degree of precision and sophistication.

Of course, without speculating on the future, we can already see how states are taking advantage of the global information infrastructure to enhance control over the security environment. In particular, the metastasizing US security state is already in process of forging an incipient Techno-Leviathan – a "global-surveillance-state-in-the-making" – whose drive for informational omniscience is pushing it beyond territorial boundaries in an effort to control the global infosphere and erode all pretense of legality and democratic oversight (Engelhardt, 2014: 107). And we are seeing comparable developments in China, where advances in AI, the IOT, and big data are being used to construct a "citizen score" system that incentivizes "good" (i.e. regime-friendly) behavior and punishes citizens for critical thinking (Mitchell & Diamond, 2018). Thus while securitization trends in the US and China should already give us pause, they will only become more extensive and intensive by integrating increasingly advanced FIR technologies over time, which would likely be the case if the latter are relied upon to achieve decoupling.

The Spiral of Insecurity and Securitization

Overall, due the combination of democratized violence capacities and totalitarian state powers that it would create, the FIR would likely generate a reinforcing spiral of insecurity and securitization that produces a qualitatively new kind of techno-authoritarianism on a global scale. To understand how this may come about, it is first important to recognize that even if the FIR enables the global economy to grow while stabilizing climate at 1.5 or 2 degrees C (a highly optimistic assumption), this would still (according to one study) leave 16 to 29% of the world's population (mostly in the global south) vulnerable to lethal climate impacts (Byers et al, 2018). Technological advance could certainly improve adaptation capacities even amidst such environmental changes, but poverty and deprivation will remain difficult to reverse, and deep grievances felt towards the global north – due to its primary responsibility in creating the problem whose consequences are primarily suffered in the global south – will make militant and/or terrorist violence a likely response. Second, we can see that the increasing dependence of the global economy on FIR technologies would create an exponential expansion of possible bio and cyber attack vectors. In conjunction with steady advances in technologies of securitization and rising fear among policymakers and populations, it may only require a relatively "minimal" attack (e.g. something comparable to 9/11, rather than the kind of million or even billion casualty attack feared by some bioterror experts) to catalyze a further threshold of intensified global securitization.

What might this threshold entail? Abstractly, it could be understood as a shift from a predominant "liberal" security apparatus to an "authoritarian" mode that establishes a permanent "state of emergency" on a global scale (Opitz, 2011). While we can only speculate on what this might look like in practice, especially as technologies of securitization advance, it would likely involve a conjoined transformation in and integration of both technological-surveillance and institutional-legal assemblages, with the former being intensified and extended while the latter sheds all pretext of democratic oversight to become an increasingly absolutist form of sovereign authority on a global scale. Surveillance would reach from the planetary to the molecular scale through a networks of satellites, distributed environmental sensors, and AI-facilitated data collection and processing techniques; military force-mobilization capacities of nearly absolute speed and global reach could be created through a combination of space-based and networked AI-robotic weapons systems; and the right of the planetary sovereign to detain individuals, mobilize force without legal pretext, and constrict the mobility of people and goods to more tightly regulated territories, would be enshrined. While such an apparatus may seem far-fetched, philosopher and futurist Nick Bostrom envisions a similarly totalitarian global surveillance system as the necessary prerequisite of global security in an age of democratized weapons of mass destruction (Bostrom, 2018). And he notes that "thanks to the falling price of cameras, data transmission, storage, and computing, and the rapid advances in AI-enabled content analysis, [it] may soon become both technologically feasible and affordable" (ibid: 25).

In sum, while techno-authoritarian trends are already evident in the US and China, FIR technologies would further enhance their capabilities while "democratizing" WMD capacities among non-state actors (Blum & Wittes, 2015). This would incentivize states to extend and deepen surveillance as far as possible while making democratic populations more willing to accept intensified securitization, therefore making it difficult to avoid an authoritarian global security apparatus.

Conclusion

To return to the question that opened this essay: can global capitalism solve the earth system crisis? I have shown that the answer is an ambiguous *maybe*: the FIR *may* enable economic growth to decouple sufficiently rapidly from CO_2 emissions and broader environmental impacts to stabilize the earth system, though these technological solutions would then intensify risks in the domains of biosecurity, cybersecurity, and state surveillance, thereby unleashing a spiral of insecurity and securitization that will push global capitalism towards a new kind of techno-authoritarianism. It is thus worth showing, in a way that differs from yet complements the arguments of degrowth advocates, that even if global capitalism *can* succeed in stabilizing the earth system in a context of endless growth, then it would likely create security threats and totalitarian dangers that would undermine the desirability of such a system.

This conclusion reinforces the need for a set of global policies that break decisively from the growth-oriented status quo. On one hand, to dampen these technological trends and improve the prospects of earth system stabilization, the pursuit of GDP growth should be replaced by alternative goals based on new metrics (e.g. the Genuine Progress Indicator or Index of Sustainable Economic Welfare) that more accurately represent social welfare (Kallis, 2018: 92). The European Commission's *Beyond GDP* project shows that steps are being made in this direction, though they should go further by explicitly ending reliance on growth by placing hard caps on material-energy throughput while restructuring economies so that livelihoods are not dependent on increasing GDP (O'Neill et al, 2018; Hickel, 2019). On the other hand, many FIR technologies (especially open source synthetic biology) offer great promise for improving human welfare through advances in sustainable energy, agriculture, and medicine. Thus transitioning beyond growth should not necessarily entail abandoning these technologies, and strong global regimes for regulating and monitoring their use would therefore be necessary. However, rather than simply strengthening existing regimes like the Biological Weapons Convention (Charlet, 2018) or relying on private sector-led initiatives to regulate emerging risks "without impeding the capacity of research to deliver innovation and economic growth" (Schwab, 2017: 90), more far-reaching changes are needed to enhance democratic control over the pace and direction of technological innovation, thereby counter-balancing the influence of multinational firms and militaries. In particular, "citizens assemblies" should be empowered to debate the relative benefits and risks posed by FIR technologies (from synthetic biology to the internet of things, nanotechnology, and AI) and set mandates regarding investment levels and priorities, the direction of research, and the pace of deployment, while also having the right to "relinquish" certain technological trajectories if their risks are perceived to outweigh the benefits.[6]

Overall, a "post-growth" economy based on more democratized ownership of common wealth, reduced overall material-energetic throughput, decelerated and democratically controlled technological innovation, and prioritization of production for meeting essential human needs rather than profit (Kallis, 2018; Hickel, 2019; Raworth, 2017), has the potential to create a global political-economy that meets all human needs within planetary boundaries *without* shifting problems into the realms of biosecurity, cybersecurity, and state securitization. While the obstacles it confronts are of course formidable, the alternatives may be ecological collapse and civilizational breakdown (if the FIR fails to decouple economic growth from environmental impacts) or global techno-authoritarianism (if it succeeds).

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[6] See Stevenson and Dryzek (2014: 18-19. 183) for an analysis of citizen assemblies in the context of climate policy.

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