The Global Politics of the Renewable Energy Transition and the Non-Substitutability Hypothesis: Towards a 'Great Transformation'?

By Michael J. Albert
SOAS University of London

(PLEASE CITE PUBLISHED VERSION at *Review of International Political Economy*. DOI: 10.1080/09692290.2021.1980418)

Abstract: This essay will investigate the question of how the renewable energy (RE) transition may reshape world politics. To date, most IPE scholars of the RE transition assume that renewables will simply substitute for fossil fuels and thereby continue similar patterns of economic growth and military competition that have characterized world politics over the past two centuries. However, they do not systematically consider what I call the 'non-substitutability hypothesis,' or the view that renewables will be unable to substitute for many of the services that fossil fuels provide for economies and militaries. In contrast, I will argue that if the non-substitutability hypothesis is correct, then a fully decarbonized global political economy would require a 'Great Transformation,' or a structural transformation in the political-economic and military bases of world order. In particular, I suggest that this would require two conjoined transitions: 1) a transition towards a 'post-growth' global political economy, or an economy that does not depend on continuous annual increases in GDP; and 2) a shift towards 'demilitarization,' in the sense of 'leaner' low-energy force structures; weakening pressure for military arms racing; and a transformation in national security priorities to focus on climate mitigation, adaptation, and disaster response.

Keywords
Energy Transition, Renewable Energy, Climate Change, Post-Growth Economics

Introduction

The renewable energy (RE) transition is steadily gaining momentum as the COVID-19 pandemic provides an opportunity to accelerate the shift away from fossil fuels. The International Energy Agency (IEA) claims that the world's best solar power installations 'now offer some of the lowest cost electricity ever seen,' and surprisingly rapid cost reductions have led it to project a more rapid uptake of renewables than previously expected (IEA, 2020: 18). Meanwhile, more and more states are calling for a transition to 'net zero' emissions by mid-century. The EU has agreed to make its net zero by 2050 target legally binding through the European Climate Law. China surprised the world with its groundbreaking announcement in September 2020 that it would aim for carbon neutrality by 2060, and it has been followed by announcements from South Korea, Japan, and Canada that they will seek carbon neutrality by 2050, while putting pressure the US, Australia, India, and other states to do the same (Climate Action Tracker, 2020).

While the future trajectory of the RE transition remains uncertain, these potential accelerants have recently provoked greater reflection on how the transition will reconfigure world politics (The Economist, 2020), which builds on a steadily growing literature investigating the geopolitical and political-economic implications of the RE transition (Helm, 2017; IRENA, 2019; Newell, 2019; Hafner & Tagliapietra, 2020; Elliot, 2020; Yergin, 2020). While the sub-fields of energy geopolitics and IPE continue to focus overwhelmingly on oil and gas (e.g. Klare, 2015; Högselius, 2018), IR and IPE scholars of the RE transition have instead begun to systematically investigate how the transition may reshape the inter-state balance of power, global political-economic interdependencies, global governance institutions, and possibilities for peace and/or conflict. The majority of this literature tends to follow a realist mode of IPE that foregrounds the 'geopolitics' of the transition, understood in terms of inter-state competition over resources and geographic spheres of influence (Hafner & Tagliapietra, 2020), which focuses on issues like the geoeconomics of RE technologies and value chains (Helm, 2017; Yergin, 2020), the new trading relationships and geopolitical interdependencies that may emerge from the transition (IRENA, 2019; Elliot, 2020), and the political-economic implications of the transition for contemporary petro-states (Van De Graaf, 2018; IRENA, 2019; Helm, 2017). In contrast, Critical IPE scholars draw more attention to the role of social movement struggles and rivalry between capitalist fractions in shaping the RE transition, and they emphasize that a truly 'just transition' would require a transformation of political-economic power relations rather than merely a socio-technical transition (Scoones et al., 2015; Newell, 2019; Eckersley, 2020; Paterson, 2020).

This emerging literature provides a vital compass to make sense of the transformations that may emerge in the coming decades as a result of the RE transition, which has become more urgent than ever due to the growing momentum behind the net zero by mid-century movement. However, I will argue that renewable energy may require an even deeper transformation in world politics than these scholars typically recognize. On one hand, the realist IPE approaches typically assume that the RE transition, while changing the inter-state balance of power and forging new interdependencies, will simply substitute for fossil fuels and thereby continue similar patterns of economic growth and military competition experienced over the past two centuries, with some arguing that it will have more pacifying than conflictual tendencies overall (IRENA, 2019; Overland, 2019; Hafner & Tagliapietra, 2020). On the other hand, critical IPE approaches often recognize that the RE transition may require something akin to the 19th century 'Great Transformation' that brought forth the modern industrial world order (Buzan & Lawson, 2015), which would go well beyond shifts in the inter-state balance of power to encompass a deeper structural transformation in the political-economic foundations of world order (Eckersley, 2020; Newell, 2019; Paterson, 2020). However, these approaches do not clearly specify the nature of this 'Great Transformation.' At times they imply that it may simply involve a hegemonic transition towards a new regime of 'green growth' (e.g. Newell, 2019: 28; Eckersley, 2020: 17); in other cases they recognize the need for more radical transformations beyond the paradigm of endless economic growth (e.g. Paterson, 2020; Foster et al., 2011), though without specifying the global political-economic and geopolitical transformations this would likely require or how they may emerge. In both cases, this limits their analysis of how the RE transition may reshape world politics and the struggles needed to push it in more genuinely sustainable and just directions.

In particular, I will suggest that an important limitation of these approaches is that they do not systematically consider what I call the 'Non-Substitutability Hypothesis' (NSH), which is the view that renewable energy will be unable to substitute for many of the services that fossil fuels provide and would therefore require an energy-constrained world relative to the fossil fuel era. If, as many energy scholars and ecological economists argue (e.g. Friedrichs, 2013; Di Muzio, 2015; Heinberg & Fridley, 2016; de Castro & Capellán-Peréz, 2020; Hall, 2017; Dupont et al., 2020; de Blas et al., 2020), renewables will most likely be unable to support the same levels of economic growth, mobility, and military power relative to the fossil fuel era, then we need to consider both the challenges this poses to the RE transition as well as the opportunities it may create for a Great Transformation in world politics. To clarify, I do not argue that the NSH is necessarily correct: it remains an hypothesis, and one that could be proven wrong by technological advances in renewable energy and battery systems, nuclear energy, green hydrogen, biofuels, negative emissions technologies, etc. However, following the work of energy scholars and ecological economists, I will demonstrate why the NSH at the very least warrants serious consideration, particularly given the significant implications for the future of world politics (if it's correct), which have not yet been systematically explored by IR and IPE scholars. If correct, it implies significant constraints on the possible futures that may emerge from the RE transition, and thus considering its implications can help illuminate the possible contours of a 21st century Great Transformation in world politics.

Specifically, I will argue that if the NSH is correct, then a 100% global RE system would require two conjoined transitions. First, a transition towards a 'post-growth' global political economy, or an economy that does not depend on continuous annual increases in Gross Domestic Product (GDP) and material-energy throughput to secure systemic stability (Daly, 1996; Jackson, 2015; Fioramonti, 2017; Ferguson, 2018; Pettifor, 2019). Second, a transition towards 'demilitarization,' which does not necessarily entail an *abolition* of military-industrial complexes (a utopian if normatively desirable scenario) but rather a transition towards 'leaner' low-energy force structures; weakening pressure for military arms racing; and a transformation in national security priorities to focus on climate mitigation, adaptation, and disaster response (Belcher et al., 2020; Klare, 2019; Oels, 2012; Dalby, 2018). Though scholarship is flourishing in the heterodox sub-fields of ecological and post-growth economics, work on the IPE of post-growth transitions remains in its infancy. Some critical IPE scholars have begun to investigate the possible contours of a post-growth global political economy (e.g. Ferguson, 2018; Koch & Buch-Hansen, 2020; Paterson, 2020), though existing approaches focus overwhelmingly on *why* a post-growth transition is needed rather than *how* it could emerge at the global scale. I will suggest that the NSH not only provides a key reason why a post-growth transition is likely necessary, but can also help illuminate how it could potentially emerge: in short, if the NSH is correct then global capitalism will likely confront an eventual energy crisis that pressures it to evolve in post-growth directions, though this is by no means inevitable. Furthermore, scholars of the RE transition (as well as post-growth theorists) have for the most part ignored the military and security implications of the transition, even though the feasibility of the RE transition, and especially a post-growth RE transition, will depend on conjoined transformations in the nature of military power and global security practices (Ferguson, 2018; Belcher et al., 2020). Therefore, to understand the possible contours of an RE-powered Great Transformation requires an analysis of global political economy, security practices, and military power as co-evolving components of a global totality (Cox, 1987), rather than analyzing the political-economic and security implications of the RE transition in isolation from each other.

I will first elaborate the NSH by drawing on the arguments of energy scholars and ecological economists, which will emphasize the limited 'Energy Return on Investment' (EROI) of renewables relative to fossil fuels, the challenges facing substitute technologies, and the particularly difficult challenges facing efforts to decarbonize military power. Next, I will consider the possible implications of the NSH for the future of world politics by exploring three future scenarios and the conditions that may facilitate their emergence, including 1) climate catastrophe; 2) a post-growth, demilitarized RE transition that cements existing global inequalities; and 3) a post-growth, demilitarized RE transition that facilitates the emergence of a more egalitarian world order. Finally, I will suggest pathways for further research that deserve more attention from IPE scholars.

The Non-Substitutability Hypothesis

The dominant perspective on renewable energy, held by the majority of economists, policy makers, and IR and IPE scholars alike, is that it is a potentially limitless source of energy that is currently constrained primarily by political and economic factors (Capellán-Peréz et al., 2020: 15-16). From this view, transitioning to a 100% RE economy will merely require investing 1-2% GDP per year in RE systems and energy efficiency improvements, while future innovations can be expected to overcome any current constraints faced by RE technologies (IMF, 2020: 87-89; Turner, 2020). Thus while they agree that the RE transition will reshape world politics in important ways – e.g. by shifting the relative power between fossil fuel importers and exporters; diminishing the geopolitical significance of the Middle East and chokepoints like the Strait of Hormuz; deepening reliance on lithium, cobalt, and rare earth imports for most states, etc. – they do not believe that the transition away from fossil fuels will require any deeper transformation of the political-economic and security structure of world order (Hafner & Tagliapietra, 2020; IRENA, 2019).

Given the current pace of RE cost declines and the potential for unexpected technological breakthroughs, this view may ultimately turn out to be correct. However, there are two problems with this argument that should make us skeptical or at least cautious. First, the economic models used by mainstream economists and institutions like the IMF and IEA, on which these optimistic projections are largely based, have questionable value when modeling the energy transition, since they often simply assume perfect substitutability between different energy sources and focus on price while ignoring the material and energy demands of the transition (Capellán-Peréz et al., 2019; Hall, 2017). As Iñigo Capellán-Peréz and colleagues explain:

> the abundance of both fossil fuels and renewable energy sources is a default assumption in most of the prominent [Integrated Assessment Models] used for climate policy analysis; hence, future energy transitions are thus largely modeled as demand-driven transformations only constrained by available monetary investments (Capellán-Peréz et al., 2020: 2).

As a result, these models merely assume precisely what requires deeper investigation – whether renewables can effectively substitute for fossil fuels – and their results should therefore be approached with caution at best.

Second, these approaches focus on total energy rather than *net* energy or "Energy Return on Investment" (EROI) (sometimes called Energy Return on *Energy* Investment), which, as energy scholars and ecological economists emphasize, is one of the key metrics for evaluating the relative potential of different energy sources (Hall, 2017; Heinberg & Fridley, 2016; Ahmed, 2017; Capellán-Peréz et al., 2019; Dupont et al., 2020). EROI refers to the surplus energy that marks the difference between total energy consumption and the energy used to extract a given amount of energy (e.g. the energy used to manufacture and maintain a power plant or oil rig, or to deliver the energy to its point of use) (Hall, 2017: 15-18; Capellán-Peréz et al., 2019). In this sense, what matters most is not the *total* energy that can theoretically be produced by renewable sources (which is indeed immense), but rather the *surplus* energy that is available after subtracting the energy costs that went into producing that energy. The significance of EROI is that it shapes and constrains a society's capacities for expansion and functional differentiation: lower EROI means that more energy is needed simply to extract and utilize energy, and thus less energy is available for the rest of society; higher EROI, on the other hand, means greater levels of net or surplus energy that can be used to power a more expansionist and functionally differentiated political economy (Hall, 2017).

From this perspective, the 19th century 'Great Transformation' that gave rise to the industrial capitalist world order should be understood as a massive increase in EROI and the net energy available to European states via the mutually catalyzing dynamics of industrialization, fossil fuel exploitation, and colonialism (Buzan & Lawson, 2015; Mitchell, 2011). There were many intersecting processes that made this transformation possible, though the unprecedented EROI levels of the emerging energy system based on coal, steam power, iron smelting, and railroads was a key material catalyst that powered the 16-fold increase of annual economic output over the course of the 20th century (Mitchell, 2011: 16-17). While there are numerous methodological disagreements and difficulties in calculating EROI, Charles Hall estimates that new coal-based energy systems enabled an EROI of 30-40 joules extracted for every joule of input (30-40:1) between 1800 and 1920 (Hall, 2017: 92-93). The rise of oil in the early 20th century created an even higher level EROI system, which was estimated to reach about 60:1 during its peak in the 1960s – the 'Golden Age' of Keynesian capitalism (2017: 93). Oil has declined to an estimated average EROI around 17:1 today as a result of the global economy's increasing reliance on energetically costly-to-extract sources like shale, offshore, and arctic oil, which many ecological economists associate with the trend towards 'secular stagnation' in rich countries (Jackson, 2015; Ahmed, 2017: 27), though the average EROI of coal and natural gas is estimated to be higher (roughly 46:1 for coal, and 20-40:1 for natural gas) (Hall, 2017: 93; Hall et al., 2014). In short, EROI levels of 30-40:1 in the late 19th century, reaching 60:1 during its mid-20th century peak, were the energetic bases on which modern capitalism, empire, and industrial war machines were forged.

A key question, then, is whether RE sources can replicate the net energy affordances of fossil fuels. It is challenging to compare the EROI of fossil fuels and renewables in a methodologically consistent way, since common EROI measurements of fossil fuels often focus primarily on energy invested at the point of extraction (sometimes called "EROI standard") rather than the total energy invested in refining and delivering that energy to the point of use (or "EROI final"), which creates an unfair comparison with RE-based electricity (Raugei, 2019; Brockway et al., 2019). Using an EROI final approach, Brockway and colleagues estimate that global average EROI levels for fossil fuels are about 6:1 and declining – much lower than the EROI standard estimates described above (Brockway et al., 2019). But by using an approximately similar EROI final methodology, Carlos de Castro and Iñigo Capellán-Peréz demonstrate that RE sources on average (particularly solar, but also wind, which have by far the most potential for expansion) currently provide significantly lower net energy than fossil fuels: about 2.9:1 for onshore wind, 2.3:1 for offshore wind, 1.8:1 for solar PV, and 0.8:1 for concentrated solar power (de Castro & Capellán-Peréz, 2020: 14). Even more importantly, while technological innovation can help increase the EROI of solar and wind energy in the future, numerous scholars argue that their average EROI will most likely fall over time for four reasons: first, the need for large-scale battery storage and smart energy grids as the share of renewables increases (due to their intermittency), which will impose additional high energy costs; second, due to the steady exhaustion of the sunniest and windiest locations, requiring a shift to lower EROI sites; third, due to the increase in energy requirements for mining over time as the highest quality ores decline (or due to the shift to more abundant minerals characterized by lower technology performance, e.g.

from lithium to sodium-ion batteries); and fourth, due to the need to eventually shift to a system in which RE systems are *themselves manufactured and distributed by renewable energy*, rather than being 'subsidized' by coal-based manufacturing (particularly cheap coal in China) and oil-based distribution systems (Capellán-Peréz et al., 2020; Hall, 2017: 136-137; Heinberg & Fridley, 2016: 130; Elliot, 2020: 100-101; Dupont et al., 2020). Furthermore, Capellán-Peréz and colleagues, using a *dynamic* EROI model, show that the EROI of a 100% RE system will be even lower during the early to middle phases of the transition due to the need for high-upfront energy and mineral costs to build out an RE electricity infrastructure (Capellán-Peréz et al., 2019). Overall then, while EROI measurements should be taken with a grain of salt given their methodological uncertainties, the above suggests that renewables, once their system-wide energy costs involving storage, grid-balancing, and mineral extractivism are taken into account, and once they are primarily manufactured and distributed by renewables, will require a net energy-constrained world relative to the fossil fuel era (*especially but not solely* during the early to middle phases of the transition).

Additionally, there is also the issue of notoriously difficult to decarbonize sectors like long-haul transportation, aviation, and high-temperature heat-intensive manufacturing (de Blas et al., 2020). While there are many efforts to innovate our way through these limits, all of them face major challenges. Biofuels, for one, while often touted as a possible fuel substitute, are notoriously expensive in energy, water, and land-use demands, and efforts to bio-engineer 'next generation' biofuels continue to face high costs and skepticism from many scientists (Storrow, 2020). While efforts to electrify trucking and oceanic shipping are making some progress (Elliot, 2020: 94-95), it is questionable whether a low-EROI global RE system would enable shipping to be sustained at its present rate, since this would put significant extra burden on RE electricity grids that may be already over-taxed in their ability to meet future electricity demand (Heinberg & Fridley, 2016: 93). Many believe that hydrogen can play a big role in decarbonizing long-distance transportation, but again this assumes there will be an abundance of *net* renewable energy, since hydrogen (an energy *carrier* rather than source) must be produced through energy-inefficient processes (electrolysis in the case of "Green Hydrogen"), and thus EROI constraints would limit green hydrogen potential as well. Furthermore, the barriers in the way of producing hydrogen cheaply with RE remain formidable (Heinberg & Fridley, 2016: 90), and the recent "hydrogen hype" may be attributable more to the way it meshes with the infrastructures and business models of incumbent energy firms rather than promise of the technology itself (Szabo, 2020). Again, we should not discount the potential for breakthrough innovations in these areas but, given the challenges, neither should we automatically assume that they will enable a continuation of the same mobility patterns bequeathed by fossil fuels.

Another important question concerns the future of military power in a 100% RE world, which has rarely been addressed even by realist IPE approaches to the RE transition. As Neta Crawford shows, the US military is 'the world's largest institutional user of petroleum and, correspondingly, the single largest producer of greenhouse gases in the world,' with annual emissions higher than those Portugal, Sweden, and Denmark (Crawford, 2019: 1-2; see also Belcher et al., 2020). The jet-fueled Air Force is by far the largest consumer of oil within the US military, making up more than 70% of the total, followed by diesel fuel for ground combat vehicles, logistical operations, electricity generation at military bases, and emissions from US arms manufacturing (estimated to be about 15% of US industrial emissions) (Crawford, 2019: 7-15). The Pentagon has made efforts to decarbonize its activities by promoting energy efficiency, increasing its use of RE at military bases, converting its fleet of aircraft carriers to nuclear power, and pursuing research on biofuels in military vehicles and aircraft (Belcher et al., 2020; Dalby, 2018). However, these investments remain comparatively trivial relative to its overall spending and energy use; far from moving towards decarbonization, the US military has committed itself to 'war-fighting paradigms…weapon systems, bureaucratic structures' and industrial complexes that will 'sustain a heavy reliance upon carbon-based fuels into the interminable future' (Belcher et al., 2020: 67). Furthermore, the same difficulties faced by efforts to decarbonize long-distance transportation apply to military activities, even more so given their *particularly* gluttonous energy needs. To put this in perspective: commercial airliners typically average about 64 miles per gallon of jet fuel, whereas US military aircraft require between 2 and 5 *gallons per mile* (Crawford, 2019: 11). Therefore, given the likely limited EROI of RE and serious obstacles confronting efforts to scale up fuel substitutes like biofuels and hydrogen, it appears that significant levels of *demilitarization* would be necessary to enable the transition to a 100% global RE system (Belcher et al., 2020), and it is not at all clear what military power would look like in a fully decarbonized world.

Towards a Great Transformation? The Implications of the Non-Substitutability Hypothesis for the Future of World Politics

Taken together, these obstacles suggest that the NSH should be taken seriously. But they do not mean that it is necessarily correct. Powerful states from the US to China are currently directing much of their techno-scientific energy towards solving these challenges – China through its state-led industrial policies to become a global leader in RE technologies, Artificial Intelligence, biotechnology, quantum computing, and other industries of the future; the US through its DARPA initiatives and private technology sector (Helm, 2017: 62-88). A 'nuclear renaissance' might also compensate for the limits of RE, particularly if breakthroughs in new reactor technologies reduce manufacturing costs, but these are unlikely to be scalable until 2040 or 2050 at the earliest (Helm, 2017: 67-68), and in the meantime the combination of high costs, aging power plants, security concerns, the waste disposal dilemma, and uranium depletion makes a major expansion of nuclear energy unlikely (Elliot, 2020: 38-39; IRENA, 2019: 17; Heinberg & Fridley, 2016: 132-134). Therefore, while I do not claim that the RE transition will *inevitably* lead to an energy-constrained future, the NSH nonetheless warrants serious consideration.

This section considers what the implications might be for the future of world politics if it turns out to be correct. To do so I will explore a set of possible scenarios, which should not be understood as predictions but rather as plausible descriptions of how the future may unfold under a range of alternative conditions and assumptions (O'Neill et al., 2020: 1074). I suggest that there are two broad possible scenarios that may emerge if the NSH is correct: 1) climate catastrophe, and 2) a 'Great Transformation' towards a fully decarbonized post-growth, relatively demilitarized world order. In what follows, for normative reasons, I will focus primarily on the Great Transformation scenario, and in particular I will elaborate two possible variants a): a global transformation that solidifies existing global inequalities, which I call the 'Post-Growth Climate Apartheid' scenario; and b) a more normatively desirable scenario in which globally redistributive policies facilitate global decarbonization in a way that mitigates global inequality, conflict, and injustice, which I call the 'Climate Justice Transformation' scenario.

Starting with climate catastrophe, one way in which this scenario may unfold would simply be a continuation of business-as-usual fossil fuel production plans in which polarization, gridlock, and lobbying by the fossil fuel and high-emitting industries continuously thwarts efforts to accelerate decarbonization, and thus net zero by 2050 targets are never seriously pursued. However, one can also envision a scenario in which a "green capitalist" decarbonization bloc – composed of centrist/center-left politicians, environmentalists, "green" industrial sectors, investor groups like Climate Action 100+, and financial institutions concerned with the financial risks posed by climate change – succeeds in pushing states to adopt more ambitious climate policies that could put them on track for net zero emissions by mid-century (e.g. a global carbon price floor, an end to fossil fuel subsidies, mandatory disclosure of climate-financial risks, and more ambitious state investments in RE research and development) (Newell, 2019). In this case, declining EROI as the transition advances (particularly due to the high upfront energy and material costs of the transition) creates a negative feedback that stymies the transition (Capellán-Peréz et al., 2019). Contrary to the expectations of most contemporary analysts (e.g. Turner, 2020), RE costs then increase rather than decline as the share of RE increases, putting a brake on economic growth and catalyzing a backlash against climate policies in core states. Militaries around the world realize that continuing access to secure oil supplies and fossil-fueled arms manufacturing remain critical for their force projection capabilities. China, for example, discovers that it is simply not possible to reconcile its goals of net zero emissions by 2060, continuing economic growth, and strengthening military power, and the first of these is sacrificed; similarly, the US finds its economic growth and military force projection requirements at odds with the constraints of renewable energy. Fossil fuel production then continues to increase, taking up at least 50% of the total energy mix by 2050, thereby setting us up for a 3 to 3.5 °C (or more) increase by 2100 (UNEP et al., 2020; Lynas, 2020: 161). The result is climate chaos, unprecedented levels of food and water insecurity, and (most likely futile) efforts to restore climate stability through Negative Emissions Technologies (NETs) and solar geoengineering. The stability of even rich states and global capitalism as a whole is threatened, and positive feedbacks risk being triggered that would push the earth down a 'Hothouse' trajectory (Steffen et al., 2018). Therefore, in this scenario, at best we would witness 'muddling through' adaptation to a 3°C world that is particularly devastating for Sub-Saharan Africa, the Middle East, Southeast and Central Asia; at worst gradual human extinction; or, between these poles, some form of global political-economic collapse (Lynas, 2020: ix, 119-164; Paterson, 2020).

If the NSH is correct, then climate catastrophe is probably the most likely scenario, since it would mean that the green capitalist decarbonization bloc – currently the most powerful set of actors (at least in the near-term) capable of decisively overcoming the power of fossil capital – is based on an economically-energetically infeasible project, which would falter soon after it begins accelerating emissions reductions. Alternatively, however, it is possible that the limits of RE may instead facilitate a Great Transformation that breaks from the patterns of continuous economic growth and militarization that have been key features of world politics since the 19th century transformation (Buzan & Lawson, 2015), though this would require a sufficiently powerful counter-hegemonic coalition capable of driving a post-growth/demilitarization transition. I will first describe the broad outlines of this scenario and the possible conditions in which it might materialize, and will then outline its 'Climate Apartheid' and 'Climate Justice' variants.

To start, the first key element of this scenario involves a transition to a 'post-growth' global political economy, since evidence demonstrates that it is almost certainly impossible for global energy use to *decline* overall while global GDP continues to grow exponentially: models suggest that, even in a best case scenario with historically unprecedented efficiency improvement rates, particularly when accounting for rebound effects (which are largely ignored in most energy transition scenarios), the most we can hope for would be a *relative* decoupling where energy use grows more slowly than economic growth but continues to steadily increase (Kallis & Hickel, 2020; Parrique et al., 2019; Brockway et al., 2021). Therefore, a fully decarbonized, low-energy future would most likely require post-growth economies in which GDP is replaced by alternative metrics and principles (e.g. 'well-being'), global material-energy consumption declines and reaches a steady-state, capital controls and nationalized banking systems give states greater control over money-creation and investment, and new welfare policies like Universal Basic Income are designed to break the link between growth and economic security (Daly, 1996; Fioramonti, 2017; Pettifor, 2019; Ferguson, 2018). Energy constraints would raise transportation costs and make globalized markets less profitable, thereby leading to a slower, more regionalized global economy with reduced mobility and more localized production of goods and services (Fioramonti, 2017: 192-194; Di Muzio, 2015: 163-164). Financial systems would be transformed so that money-creation is no longer a privatized power that drives debt accumulation and pressures for further economic growth to pay off accumulated interest, but rather a public good that channels investment into renewable energy projects, carbon-sequestering regenerative agriculture, ecosystem restoration, and other climate stabilization and adaptation initiatives (Di Muzio, 2015: 163-164; Pettifor, 2019). Whether this would require the end of 'capitalism' is contested, which depends on how it is defined (Daly, 1996; Foster et al., 2011; Ferguson, 2018). Features of contemporary capitalism like markets, private enterprise, and wage-labor would most likely continue, though they would be constrained by new regulatory frameworks that socialize production to pursue state-determined ends that prioritize well-being and security rather than private profit.

In what conditions could a global post-growth transition materialize? It is certainly difficult to envision in current circumstances, where the 'growth consensus' remains powerful across the political spectrum in most countries. However, future crises may weaken this consensus. Rich countries already confront the malaise of what economists call 'secular stagnation,' and this may worsen with time as a result of the 'debt overhang' exacerbated by responses to COVID-19 (Gordon, 2016; Jackson, 2015). Furthermore, global economic stagnation may be reinforced not only by the relatively low EROI of renewable energy, but also by long-term EROI declines in fossil fuels themselves (particularly oil), which, as previously noted, numerous analysts associate with the long-term decline in global economic growth rates (Jackson, 2015; Ahmed, 2017; Hall, 2017). Therefore, even if states desire to revamp fossil fueled growth in response to the geophysical limits of renewables, this will likely become increasingly difficult as the global economy relies more heavily on lower EROI fossil fuel reserves and increasingly expensive extraction techniques. Combined with intensifying climate shocks in the coming decades across the intersecting realms of agriculture, energy, and finance (Ahmed, 2017), the global economy will be confronting numerous headwinds that may weaken the capacity of states to restore growth in response to crises. Therefore, if it is increasingly recognized by states, in response to public pressure, that endless economic growth is *itself* the source of these crises, and that left unimpeded it will endanger both national and global security, then it may be possible for bottom-up networks of labor and environmental organizations, scientists, and heterodox economists to push core states to enact post-growth policies (Ferguson, 2018: 82-83).

The second key element of this transformation would involve a conjoined shift to a more demilitarized world order, which would in turn make a post-growth political-economic transition more feasible by weakening systemic pressures to pursue growth as a national security imperative (Ferguson, 2018). In short, lower net energies means less energetic power available for 'non-essential' industries like arms manufacturing; diminished mobility and hence force projection capacities by land, sea, and especially air power; and less systemic pressure to drive the 'rapid escalation of destructive technological power' that has been a constant of world politics since the 19th century (Buzan & Lawson, 2015: 309). Counterinsurgency operations around the globe would need to be significantly retrenched, since they rely on numerous highly energy-intensive Forward Operating Bases (FOBs), logistical supply chains, and ground vehicles, though drone-based operations that don't rely on FOBs could hypothetically continue near current levels, since drones are more lightweight and easier to decarbonize (Belcher et al., 2020: 75). As Constantine Samaras and colleagues note, militaries may even prefer a transition to 'leaner' low-energy force structures, or at least some of their segments, since it would increase operational autonomy and reduce the need for risky extended fuel supply lines and truck convoys (Samaras et al., 2019: 7). Furthermore, the combination of energy constraints and intensifying climate impacts would make militaries and security agencies 'far less inclined to spend vast sums on sophisticated weapons systems or to engage in provocative adventures abroad' (Klare, 2019), leading them to rethink their foreign policy and national security priorities by refocusing on climate mitigation, adaptation, and disaster relief and response. In this way, we may witness the deepening of what Angela Oels calls the 'climatization of security,' where management of and response to intensifying climate disasters becomes the central preoccupation of leaner military force structures, while traditional security concerns like great power conflict are de-prioritized (Oels, 2012; see also Dalby, 2018).

Like the transition to a post-growth global political economy, a shift towards a more demilitarized global security landscape appears unlikely at present given the recent revival of great power competition. But multiple factors, in conjunction with EROI decline for both renewables and fossil fuels, may facilitate demilitarization in the future. First, the RE transition may diminish the relevance of military force projection in the Middle East and elsewhere, since the wider geographic availability of RE sources and minerals would likely weaken incentives for overseas military commitments (IRENA, 2019; Overland, 2019). Second, the end of the oil trade, in conjunction with the growing prominence of the Chinese renminbi in global trade, may weaken US financial power and force it to retrench its military spending, since the ‘petro-dollar’ nexus is a key source of demand for US dollars and foundational to its financial hegemony (Di Muzio, 2015: 123; Mitchell, 2011: 30). Overall, the combination of dwindling geo-strategic interests in oil-based interventionism, pressures on military budgets, and the potential for radical shifts in national security priorities in a context of intensifying climate-energy-economic crises, means that a trajectory of demilitarization may not be as far-fetched as it seems today.

This gives us a broad sketch of a post-growth, relatively demilitarized Great Transformation. However, while this scenario would be far more desirable than climate catastrophe, it would not, contrary to the expectations of some analysts of the RE transition (IRENA, 2019: 23), necessarily bring about a more egalitarian and/or peaceful world. Instead, a Post-Growth Climate Apartheid version of this scenario is arguably more likely (Besteman, 2020), which would be a scenario in which post-growth transitions in the core zones of the global economy (mainly the G7 plus China) catalyze a collapse of the global fossil fuel economy and facilitate sufficiently rapid decarbonization to meet the Paris agreement targets, though this occurs without sufficient redistribution or compensation mechanisms for fossil fuel producers and primary commodity exporters across the global south. The G7 plus China focus on decarbonizing and restructuring their own economies while managing the domestic tensions resulting from convergent economic-climate-energy crises, which makes them resistant to calls for global redistribution and compensation for stranded fossil fuel assets in the global south. Militaries and security agencies in these states, while shifting to leaner, low-energy and decarbonized force structures and prioritizing climate disaster response, focus primarily on protecting their own populations from perceived threats originating elsewhere. Thus global inequality remains high, many countries in the global south experience economic decline as a result of stranded fossil fuel assets and reduced demand for other primary commodity exports, state fragility and violent conflict intensifies in the Middle East and elsewhere, and militarized borders and xenophobic migration regimes are further entrenched.

Alternatively, it is possible to envision a more normatively desirable scenario in which globally redistributive policies enable a post-growth transition that reduces inequality between the global north and south and enhances overall peace and stability, which I call the Climate Justice Transformation scenario. In this scenario, G7 countries plus China realize that the interests of climate stabilization and global security are best served by facilitating decarbonization, biodiversity protection, and genuinely sustainable and inclusive development throughout the rest of the global economy. A key strategy here would be to negotiate agreements for petro-states and other developing countries to leave their fossil fuels in the ground and protect critical ecosystems in exchange for debt cancellation and technology transfers. By cancelling debts and facilitating RE technology transfers by reforming intellectual property law, as well as providing adequate finance for the Green Climate Fund along with other compensation mechanisms for states to forego profits from fossil fuels, logging, mining, and other forms of extractivism that harm critical ecosystems, developing states would in turn become less dependent on fossil fueled and export-led growth. In effect this would entail something like a 'Marshall Plan for the Earth' (Klein, 2014: 458), which would drive global-scale decarbonization, adequately fund climate adaptation throughout the global south, and facilitate the emergence of new ideologies and practices of 'development' beyond the GDP growth consensus (Fioramonti, 2017). In turn, a ‘Marshall Plan’-type effort could diminish conflict pressures by promoting inclusive rural development, improved public services, greater protection from climate shocks, and increased state legitimacy (Barnett, 2019). In this case, the hope among some analysts of the RE transition – that it may facilitate a more peaceful, sustainable, and regionally autonomous world order – may be realized (IRENA, 2019; Overland, 2019), though in a far more radical way than they imagine.

Conclusion

In sum, we can see that if the NSH is correct, then this would likely have quite radical implications for the future of world politics. While climate catastrophe would be the most likely outcome, a successful RE transition based on post-growth political economies and diminished military arms racing and force projection capacities is also possible, which could take more or less globally egalitarian forms. We can also envision multiple variations of these different scenarios. For example, it is possible that growth could continue in rich countries through a process of ‘green energy imperialism’ that drains other regions of their mineral and solar resources, leading to a climate apartheid scenario in which growth continues for a minority of the world’s population (perhaps G7 countries, or the G7 plus China) while fueling socio-ecological devastation for most of the rest. But if the NSH is correct, then it is difficult to see how this scenario would avoid descending into climate catastrophe, since sustaining continuous compound growth for these states would mean exponentially growing their GDP up to three-fold by 2060 and eight to ten-fold by 2100 relative to current figures (with correspondingly huge increases in material-energy demands, even with significant ‘relative decoupling’), which would almost certainly require levels of fossil fuel usage and land-use conversion that would be incompatible with the 2°C (let alone 1.5°C) target (Hickel, 2020: 133-144). This does not, however, preclude the possibility that privileged elites could sustain their energy-intensive lifestyles in a post-growth scenario by appropriating the majority of increasingly constrained net energy supplies, thereby creating a highly unequal Post-Growth Climate Apartheid both within and between states. We could also imagine a variant of the Post-Growth Climate Apartheid scenario where military powers maintain ample strategic reserves of petroleum to retain similar-to-today air and ground-based force projection capacities while NETs are used to ensure carbon neutrality, thus avoiding significant levels of demilitarization. This is certainly plausible, though it would be difficult for this scenario to avoid tipping into climate catastrophe, since it would be very challenging to scale-up NETs sufficiently rapidly to compensate for military emissions *in addition* to residual emissions from other sectors (but not impossible in principle).

Thus there is good reason to believe that avoiding climate catastrophe would require a post-growth transition and shrinkage of military-industrial complexes, at least insofar as the NSH is correct. But I do not claim to exhaustively describe all possible scenarios. More research that involves interdisciplinary collaboration between IPE scholars, energy researchers, and modelers could shed more light on different possible variants of these scenarios and their economic, ecological, technological, and geopolitical parameters, involving different 'what if' assumptions about the final energy technology mix, energy efficiency improvements and rebound effects, future levels of military activity and its emissions intensity/decarbonization potential, the role of NETs, and the speed of positive earth system feedbacks.

There are other areas for further research that also deserve more attention from IPE scholars. Numerous questions remain about the conditions in which states may agree to cooperatively restrain economic growth and military power; the sorts of crises that might make this possible; the role of social movements and transnational advocacy networks in bringing it about; the fractions of the capitalist class (if any) that may be plausibly moved to support it; the complex distributional conflicts it would entail; and the new regimes for regulating global finance, trade, and investment that may emerge in a fully decarbonized, post-growth future. Furthermore, deeper investigation of the linkages between the political-economic and global security dimensions of the RE transition is needed, including more fine-grained analysis of both the technical challenges of decarbonizing military force structures as well as the counter-hegemonic struggles both within and between states that would be needed to shrink military-industrial complexes. While a Great Transformation of this sort appears unlikely in the present context, the combination of net energy decline as the RE transition advances and worsening ecological crises makes it a plausible future that is worth exploring for those interested in envisioning and working towards a more just, peaceful, and genuinely sustainable global political economy.

Author Bio: Michael J. Albert is a lecturer in International Relations at SOAS University of London. His research is situated at the intersection of global environmental politics, political economy, and the transdisciplinary study of socio-ecological systems. His current book project investigates the convergence of political-economic and ecological crises in order to illuminate potentials for world system transformation in the coming decades.

Acknowledgements: I'd like to thank Nils Kupzok and the two anonymous reviewers for their incisive and constructive feedback on the manuscript, which helped to clarify and sharpen the argument.

References

Ahmed, N. (2017). *Failing States, Collapsing Systems: Biophysical Triggers of Violence*. Cham: Springer.

Barnett, J. (2019). Global environmental change I: Climate resilient peace? *Progress in Human Geography* 43(5): 927-936.

Belcher, O., Bigger, P., Neimark, B., & Kennelly, C. (2020). Hidden carbon costs of the 'everywhere war': Logistics, geopolitical ecology, and the carbon boot-print of the US military. *Transactions of the Institute of British Geography* 45(1): 65-80.

Besteman, C. (2020). *Militarized Global Apartheid*. Durham, US: Duke University Press.

Brockway, P. et al (2019). Estimation of global final-state energy-return-on-investment for fossil fuels with comparison to renewable energy sources. *Nature Energy* 4: 612-621.

Brockway, P. et al (2021). Energy efficiency and economy-wide rebound effects: A review of the evidence and its implications. *Renewable and Sustainable Energy Reviews* 141: 1-20.

Buzan, B., & Lawson, G. (2015). *The Global Transformation: History, Modernity, and the Making of International Relations*. Cambridge, UK: Cambridge University Press.

Capellán-Peréz, I., de Castro, C., & Gonzalez, L. (2019). Dynamic Energy Return on Energy Investment (EROI) and material requirements in scenarios of global transition to renewable energies. *Energy Strategy Reviews* 26: 1-26.

Capellán-Peréz, I., de Blas, I., Mediavilla, M. et al. (2020). MEDEAS: a new modeling framework integrating global biophysical and socioeconomic constraints. *The Royal Society of Chemistry*. DOI: 10.1039/c9ee02627d

Climate Action Tracker (2020). Global Update: Paris Agreement Turning Point. Retrieved from at https://climateactiontracker.org/publications/global-update-paris-agreement-turning-point/

Cox, R. (1987). *Production, Power, and World Order: Social Forces in the Making of History*. New York, US: Columbia University Press.

Crawford, N. (2019). Pentagon Fuel Use, Climate Change, and the Costs of War. Providence: Watson Institute.

Dalby, S. (2018). Firepower: Geopolitical Cultures in the Anthropocene. *Geopolitics* 23(3): 718-742.

de Blas, I.; Mediavilla, M.; Capellán-Peréz, I.; Duce, C. (2020). The limits of transport decarbonization under the growth paradigm. *Energy Strategy Reviews* 32: 1-23.

de Castro, C.; Capellán-Peréz, I. (2020). Standard, Point of Use, and Extended Energy Return on Energy Invested (EROI). *Energies* 13: 1-42.

Di Muzio, T. (2015). *Carbon Capitalism: Energy, Social Reproduction, and World Order*. London, UK: Rowman & Littlefield International.

Dupont, E.; Koppelaar, R.; Jeanmart, H. (2020). Global available solar energy under physical and energy return on investment constraints. *Applied Energy* 257: 1-17.

Eckersley, R. (2020). Greening states and societies: from transitions to great transformations. *Environmental Politics*. DOI: 10.1080/09644016.2020.1810890

Elliot, D. (2020). *Renewable Energy: Can it Deliver?* Cambridge, UK: Polity.

Ferguson, P. (2018). *Post-Growth Politics: A Critical Theoretical and Policy Framework for Decarbonisation*. Cham: Springer.

Fioramonti, L. (2017). *The World After GDP*. Cambridge, UK: Polity.

Friedrichs, J. (2013). *The Future is Not What it Used to Be*. Cambridge, US: MIT Press.

Hafner, M., Tagliapietra, S. (2020). The Global Energy Transition: A Review of the Existing Literature. In Hafner. M., & Tagliapietra, S. (eds) *The Geopolitics of the Global Energy Transition*. Cham: Springer, 1-24.

Hall, C. (2017). *Energy Return on Investment: A Unifying Principle for Biology, Economics, and Sustainability*. Cham: Springer.

Heinberg, R., Fridley, D. (2016). *Our Renewable future: Laying the path for one hundred percent clean energy*. Washington, D.C: Island Press.

Helm, D. (2017). *Burn Out: The Endgame for Fossil Fuels*. Yale University Press: New Haven & London.

Hickel, J. (2020). *Less is More: How Degrowth Will Save the World*. Windmill: London.

Högselius, P. (2018). *Energy and Geopolitics*. Abingdon, UK: Routledge.

International Energy Agency (IEA) (2020). *World Energy Outlook 2020*. Paris.

International Monetary Fund (IMF) (2020). *World Economic Outlook: A Long and Difficult Ascent*. Washington D.C.

International Renewable Energy Agency (IRENA) (2019). *A New World: The Geopolitics of the Energy Transformation*. Abu Dhabi.

Jackson, T. (2015). The post-growth challenge: Secular stagnation, inequality, and the limits to growth. *CUSP Working Paper No 12*. Guildford: University of Surrey.

Kallis, G., & Hickel, J. (2020). Is green growth possible? *New Political Economy* 25(4): 469-486.

Klare, M. (2015). From Scarcity to Abundance: The Changing Dynamics of Energy Conflict. *Penn State Journal of Law & International Affairs* 3(2).

Klare, M. (2019). Welcome to a World in Which All Hell is Breaking Loose. *Common Dreams*. Retrieved from https://www.commondreams.org/views/2019/11/14/welcome-world-which-all-hell-breaking-loose accessed 16 February 2021

Klein, N. (2014). *This Changes Everything: Capitalism Vs. the Climate*. New York, US: Simon & Schuster.

Koch, M., & Buch-Hansen (2020). The IPE of degrowth and sustainable welfare. In Vivares, E. (ed) *The Routledge Handbook of Global Political Economy: Conversations and Inquiries*. Abingdon, UK: Routledge, 375-390.

Lynas, M. (2020). *Our Final Warning: Six Degrees of Climate Emergency*. 4th Estate: London.

Mitchell, T. (2011). *Carbon Democracy: Political Power in the Age of Oil*. London, UK: Verso.

Newell, P. (2019). *Trasformismo* or transformation? The global political economy of energy transitions. *Review of International Political Economy* 26(1): 25-48.

O'Neill, B, Carter, T, Ebi, K. et al. (2020). Achievements and needs for the climate change scenario framework. *Nature Climate Change* 10: 1074-1084.

Oels, A. (2013). From 'Securitization of Climate Change to 'Climatization' of the Security Field: Comparing Three Theoretical Perspectives. In Scheffran, H., Brauch, H., & Schilling J (eds) *Climate Change, Human Security, and Violent Conflict,* pp. 185-206.

Overland, I. (2019). The geopolitics of renewable energy: Debunking four emerging myths. *Energy Research & Social Science* 49: 36-40.

Parrique, T., et al (2019). *Decoupling Debunked: Evidence and arguments against green growth as sole strategy for sustainability*. Brussels: European Environmental Bureau.

Paterson, M. (2020). Climate change and international political economy: between collapse and transformation. *Review of International Political Economy*. DOI: 10.1080/09692290.2020.1830829.

Pettifor, A. (2019). *The Case for a Green New Deal*. London: Verso.

Raugei, M (2019). Net energy analysis must not compare apples and oranges. *Nature Energy* 4: 86-88.

Samaras, C., Nuttall, W., & Bazilian, M. (2019). Energy and the military: Convergence of security, economic, and environmental decision-making. *Energy Strategy Reviews* 26: 1-11.

Scoones, I., Newell, P., & Leach, M. (2015). The Politics of Green Transformations. In Scoones, I., Newell, P., & Leach, M. (eds) *The Politics of Green Transformations*. Abingdon, UK: Routledge, 1-24.

Steffen, W. et al (2018). Trajectories of the Earth System in the Anthropocene. *Proceedings of the National Academy of Sciences* 115(33): 8252-8259

Storrow, B. (2020). Exxon's climate fix is algae. Experts say it won't work. *E&E News*. Retrieved from https://www.eenews.net/stories/1063717527?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20201103&utm_medium=email&utm_source=Revue%20Daily

Szabo, J. (2020). Fossil Capitalism's Lock-ins: The Natural Gas-Hydrogen Nexus. *Capitalism Nature Socialism*. DOI: 10.1080/10455752.2020.1843186.

The Economist (2020). The new energy order: Is it the end of the oil age? Retrieved from https://www.economist.com/leaders/2020/09/17/is-it-the-end-of-the-oil-age

Turner, A. (2020). The costs of tackling climate change keep on falling. *Financial Times*. Retrieved from https://www.ft.com/content/33bb3714-93cf-4af5-9897-e5bf3b013cb7?desktop=true&segmentId=d8d3e364-5197-20eb-17cf-2437841d178a#myft:notification:instant-email:content

United Nations Environmental Programme (UNEP) et al (2020). The Production Gap: the discrepancy between countries' planned fossil fuel production and the production levels consistent with limiting warming to 1.5 or 2 C. Retrieved from https://productiongap.org/wp-content/uploads/2020/12/PGR2020_FullRprt_web.pdf

Van de Graaf, T. (2018). Battling for a Shrinking Market: Oil Producers, the Renewables Revolution, and the Risk of Stranded Assets. In Scholten, D. (ed) *The Geopolitics of Renewables*. Cham: Springer, 97-121.

Yergin, D. (2020). *The New Map: Energy, Climate, and the Clash of Nations*. London, UK: Allen Lane.