Archimedes 65 New Studies in the History and Philosophy of Science and Technology

Sophia Kalantzakos *Editor*

Critical Minerals, the Climate Crisis and the Tech Imperium

Springer

Archimedes

New Studies in the History and Philosophy of Science and Technology

Volume 65

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ISSN 1385-0180 ISSN 2215-0064 (electronic)
Archimedes
ISBN 978-3-031-25576-2 ISBN 978-3-031-25577-9 (eBook)
https://doi.org/10.1007/978-3-031-25577-9

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

This book covers an enormously important set of topics that provide foundational insights for the successful decarbonization and digitalization of the global economy. For governments, critical minerals have steadily risen on the political and policy priority list as demand has soared from cornerstone technologies such as electric car batteries. Additionally, as a result of some deep supply/demand imbalances and other market issues, prices have risen sharply for many minerals, and ongoing volatility looks likely. Opinions diverge as to whether the critical materials supply growth implied by various net zero scenarios can be met in the short and medium term. Thus emerges an important question: Will the lack of supply or the high prices of critical minerals slow down transitions to low-carbon technologies?

The field can be bewildering to outsiders. To begin with, there is no clear definition for critical minerals and materials. Various lists exist in several geographies, but they tend to change over time. The 30–100 unique minerals are part of myriad supply chains. The way "criticality" is measured typically relies only on supply side metrics and import dependency. The markets are largely small and opaque and offer neither good governance nor price discovery. Security of supply is important, but so too are the societal and environmental impacts as well as trade and market effects.

Adequate natural mineral resources exist. However, mining companies are often hesitant to invest in light of volatile markets, poor price signals, and highly uncertain policies. It is feared that current high prices may result in a flurry of new mine developments and a subsequent price collapse. This has happened before: a period of high rare earth prices 17 years ago resulted in 400 mine developments, but only one project made it to realization when prices collapsed again. Demand projections for 2030 and 2050 vary widely, thereby adding to the hesitancy.

The growth in demand for minerals and materials needed for the energy transition has already put a strain on supply. Mining and processing are the two key bottlenecks—and both deeply reliant on permitting and planning reforms. However, new capacity is not the only problem: the geographical concentration of where the mining and the processing is being conducted represent a key risk. China's dominance in processing, for instance, means economic or geopolitical shocks can disrupt markets. Discussions, however, tend to be fragmented and often focus on the minerals themselves. Rather, a holistic supply chain perspective is needed that includes advanced manufacturing and recycling.

Innovation is an important way to ease, or even radically change, demand for key materials. This includes battery chemistries, product design, processing technologies, recycling and circular economy concepts, new ways to incorporate sustainability in mining, as well as novel engagement with communities.

The markets for many of these minerals are thin and not transparent. As an example, volumes of lithium and REE are kt scale, compared to Mt-size copper, aluminum, or steel markets. The number of mines and processing is limited. Because of the small volumes, market growth to 2030 can be multiple times today's market volume. Thus, a few new mines can make a big difference, but the opacity, price discovery, and governance of such small markets will always present some difficulties.

Environmental and social concerns have to be addressed, as well. New mining operations are often controversial, and the development of a mine may take several years. The cancellation of the Rio Tinto Jadar project in Serbia in 2022 offers a salient example. The opposition of local communities continues to play a key role as it always has. A debate, moreover, is brewing around deep-sea mining and its environmental cost and benefits, notably for nickel, compared to mining in the biodiverse rainforests of Indonesia and the Philippines. There are also ongoing and significant governance issues in many of the critical minerals and products.

All critical materials are different, and there will be no "one size fits all" policy solutions. New forms of multinational cooperation are needed as well as partnerships with industry.

Finally, critical materials are a relatively new aspect for modeling and scenario development. This analytical work can help better understand the varied critical minerals supply chains and markets and inform investment and policy decisions. There is also a need for more comprehensive industrial ecology, materials flow analysis, life cycle analysis, trade flow analysis, and market analysis for critical materials.

The authors that contributed to the realization of this volume shed much needed interdisciplinary light on the range of challenges and opportunities as well as the complexities of the global green and digital transitions, accelerated by the urgency of the climate crisis and taking place in an era of hyper-competitive geopolitics. Importantly, their analyses help foster a conversation between the often siloed worlds of the academy, industry and finance, global institutions, and civil society.

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Introduction

In July 2021, a cohort of scholars, experts from industry, finance, and global international institutions participated in a Summer Institute at Caltech and the Huntington called "Rich Rocks, the Climate Crisis and the Tech-imperium." It provided insights into the latest manifestation of resource competition. China's spectacular rise, the launch of its signature Belt and Road Initiative, the PRC's Made in China 2025 project (heavily focused on technological leadership and innovation), its growing assertiveness both economically and militarily, and its desire to make new norms and institutions have become areas of concern for the USA and other industrial nations, driving a wedge between them and accelerating power rivalries. As a result, the decarbonization and digitalization of the global economy, while no longer in question, is taking place in a climate of extremely fraught geopolitics that continue to deteriorate. Critical minerals are protagonists in this unprecedented economic and industrial transformation currently underway. Decarbonization, in fact, has become the main narrative driving COVID recovery. As of 2019, major economies have announced their goals to reach climate neutrality by mid-century. Political will combined with the rapidly declining production costs for clean technologies such as renewables and the electrification of transport are pushing the transition forward.

The assembled cohort examined different aspects of material criticality that have transformed these simple inputs for modern applications into materials of strategic and economic importance worthy of front-page news. Sessions were dedicated to the view from industry with a special focus on the nexus of government, industry, and finance. This is particularly significant given the growing push to reconstitute supply chains in ways that range from decoupling from China as much as possible to building resilience without rejecting interdependence. It also dived into an examination of the development and deployment of new technologies in light of the climate crisis and the next wave of digitalization. A session was devoted to the socioeconomic and environmental impacts of mining and processing of these important minerals which are mostly concentrated in the developing world. Moreover, participants discussed how the long-awaited green transition and the digitalization of the global economy could be more sustainable, inclusive, and equitable.

The Summer Institute led to the production of this volume which reflects an ongoing and fruitful collaboration among members of a diverse and rich cohort. It focuses on the nuts and bolts, the norms, values, economics, policy implications, environmental impacts, and geopolitics of the global green transition and digitalization drive. The volume is broken down into three distinct sections. The first tackles the geopolitics of decarbonization and digitalization especially in light of growing and acrimonious Sino-American competition. The second section brings together scholars and industry representatives in a discussion about critical minerals themselves and their supply chains. The material intensity of the transition and the possible bottlenecks are examined. Authors explore ongoing government responses and new pathways to secure uninterrupted access to the minerals and build resilient supply chains without severing ties of interdependence. In the third and final section, the mining of the materials themselves takes center stage. Authors discuss the environmental impacts, the role of ESG and smart mining strategies, and the pros and cons of deep-sea mining to diversify and augment the supply of minerals essential to decarbonization and digitalization.

In the opening chapter, Kalantzakos emphasizes that the decarbonization and digitalization of the global economy is taking place in an atmosphere of geopolitical upheaval. China's rise, its growing global impact, increased assertiveness, and more frequent heavy-handed autocratic policies launched under Xi Jinping's leadership have triggered an aggressive response by the USA, giving rise to a new cycle of bipolar competition. Alarmingly, in a spillover effect, the geopolitics of contention have polarized the transition to a decarbonized global economy and have made digitalization a battleground over who will control the tech imperium. Kalantzakos argues that this constitutes a dangerous development that undermines the formulation of an international coordinated response to the climate crisis which she views as the existential challenge for the global commons. Moreover, she argues, uninterrupted access to critical minerals (CRMs) that include rare earths (but also lithium and cobalt) are indispensable for both the decarbonization and digitalization of the global economy, but as a result of contentious and hypercompetitive geopolitics, a new race to control both the resources themselves and their extensive globalized supply chains is underway. Kalantzakos warns that the overuse of economic statecraft to settle a wide range of disputes is further fueling renationalizing narratives that seek to break ties of interdependence. In such a globally interconnected world economy, however, Kalantzakos argues that decoupling does not constitute a realistic option. Nor does it make the best strategic sense for either power. Her chapter recommends the lowering of the rhetoric of hyper-competition to allow the world the space for new possibilist thinking that recognizes interdependence and with a new geopolitics that includes the aspirations of both the developing and the developed world. In the end, she maintains that the response to the climate crisis must not become a starting pistol for a new scramble: for inputs, "geopolitically engineered" supply chains, the building up of tech and knowledge barriers, and new exclusions and inequities that engender securitized solutions to global challenges.

Pu's chapter focuses on how strategic competitions and political tensions are now shaping economic and technological ties between the USA and China. His chapter outlines the security concerns of both powers. Pu argues that China is deeply concerned that the USA is attempting to disrupt its domestic order and increasingly constrain its global reach. Moreover, according to Pu, the USA is principally worried about what it perceives as China's challenge to a US-led international order. Calls for commercial and technological decoupling from China have grown in Washington in the name of resilience and national security. China too is increasingly supporting a dual circulation strategy to build up its autonomy and offset US encirclement, emphasizing self-reliance and indigenous innovation. Pu's chapter provides argumentation for why a New Cold War narrative that is gaining momentum is both ill-advised and unrealistic. It would break the transnational production chain which would be too costly and unwelcome by other nations. Moreover, Pu posits that within a framework of competitive co-existence, both sides should build a recoupling scenario that he describes as partial recoupling. The author outlines the differences between partial recoupling from the notion of limited decoupling because the latter moves in the direction of reducing interaction and lessening interdependence. In Pu's view, this scenario would help preserve most normal economic ties between the two countries while carefully managing dependencies and risks. Given the growing rivalry and the short time frame for decarbonizing and digitalizing the global economy, Pu's analysis offers particularly helpful insights for policymakers who are concerned about securing uninterrupted global supply chains needed for the massive industrial transformation currently underway.

In her chapter, Vekasi argues that the high geographic concentration of critical minerals for the decarbonization and digitalization of the global economy has produced different policies and approaches to ensure uninterrupted access and build resiliency. Her chapter focuses on how best to secure supply chain resiliency for critical rare earth minerals. Critical minerals, including rare earths, face a rapidly increasing demand for the production of technology products and for the energy transition. China's rare earth industry has become more sophisticated and difficult to compete with in both mining and post-processing. Even though the demand for rare earths is projected to greatly rise, it unfortunately seems that the world is repeating the same debates and perhaps mistakes about supply risks. Her chapter outlines countries' efforts to reduce their dependence on Chinese rare earths, focusing particularly on the challenges and opportunities in diversifying supply and assessing possible paths forward. Vekasi describes the political economy of the rare earth market, focusing on the role of industrial and trade policy. She traces the policies that have resulted in the rare earth market becoming concentrated in China. She also examines the policies used in Japan and the USA to help suggest paths to greater independence, including diversification in production and capacity building, as well as talent retention in post-production processes. The chapter also provides an analysis of the political risks and challenges in geographic diversification along the supply chain. She finds that international cooperation in this sector is absolutely vital to meet future demand, a task that becomes more difficult given the strong anti-China rhetoric surrounding the PRC's role in the market. In her conclusion, Vekasi underscores that in the drive for increased resilience and supply, states must ready themselves to commit to investment in the full infrastructure of the industry, including education and training as well as sustainable new mining sites and processing projects.

In his chapter, Eggert raises the question about what kinds of public policies the USA and other market economies should have toward critical minerals. He rejects the false dilemma of the two “caricature like,” mutually exclusive approaches to policy formulation on this issue. On the one hand, some are proponents of letting the market decide. They defend a sector-agnostic approach and argue for limiting government activities to establishing legal and regulatory frameworks for efficient and effective decision-making about private initiatives and activities. On the other hand, there are those who favor governments picking winning commercial sectors, companies, technologies, and products. Both these approaches ignore the most common and desirable middle ground. Eggert examines what constitutes this messy middle ground. He, moreover, provides a framework for and proposes seven principles to guide the development of public policy toward critical materials. Eggert underscores that market and industrial-policy solutions to supply-chain risks—rather than being mutually exclusive—are complementary. As an economist, he acknowledges his preference in anchoring public policy toward critical materials around market solutions but insists that they should also very selectively incorporate aspects of industrial policy.

In the next chapter, Karayannopoulos along with Tsianos provide readers a detailed and nuanced view from an industry perspective. Karayannopoulos, a veteran in the rare earth sector for several decades, witnessed how the global rare earth markets have ridden a dizzying roller coaster that has, at times, shaken the faith of industrial consumers in the reliability of supply chains for these critical materials. The chapter argues that currently rare earth production and associated supply chains are stronger and more diversified than at any other time in the last two decades. Still, the amount of materials will skyrocket, to meet rising demand driven by advanced technologies and global decarbonization. The authors argue that fundamental demand-driven industrial economics, coupled with a lack of coherent industrial policies in the West, led to the current supply chain map. It is the high growth of downstream industry participants and Original Equipment Manufacturing (“OEM”) customers, either inside or in the proximity of the PRC, that have driven the rare earth industry’s growth in China, not China’s desire to dominate global rare earth markets as an end in itself. The chapter offers a different thesis to a dominant narrative that attributes the rare earth industry’s current geographic concentration in Asia to an intersection of geopolitical forces and environmental policies. It claims, in fact, that supply chains are eminently rational and form efficiencies over time. In the case of rare earths that has meant that rare earth supply chains tend to develop in geographic proximity to their downstream customers and value-added manufacturing facilities, not necessarily near rare earth mining and processing facilities. Moreover, they conclude by examining industrial and policy strategies, that are being implemented with some success, to encourage the continued growth and resiliency of this important industry and detail ways to successfully establish resilient, diversified, and vertically integrated rare earth supply chains.

Berry's chapter makes an important point about the material intensity that the electrification of transport now requires. Both broad decarbonization and wider electric vehicle (EV) penetration will require more, not fewer, battery raw materials possibly raising the carbon intensity of industry, just as governments are coordinating a response to minimize carbon emissions. To hit even modest EV penetration rates (10% of new light-duty vehicle sales by 2025, for example) will require an even greater amount of raw material. Berry argues that innovation along the entire supply chain is a sine qua non in order to successfully decarbonize, and he calls for public-private sector collaboration to ensure that the resources necessary for further R&D are allocated. The chapter, moreover, looks at the challenges and opportunities facing the electric vehicle (EV) ecosystem as the industry embarks on a rapid growth phase. Berry emphasizes that there has been tremendous volatility in the pricing of battery metals since 2017, and this has contributed to much uncertainty for stakeholders along the lithium-ion battery supply chain. Lithium and cobalt in particular will be in even higher demand. As a result, technologies focused on sustainable battery production that include direct lithium extraction (DLE) or battery repurposing and recycling may offer viable solutions. Transparent pricing is key, but so is the identification of ways by which the governments can help the mining sector increase capacity sustainably and achieve decarbonization goals. Berry acknowledges that the unprecedented levels of extraction required for this transition raise questions about how to achieve the mining and refining of the materials while lessening the industry's carbon footprint.

In their chapter, Gauß, Gellermann, and Maurer warn that the ambitious government announced targets for reaching carbon neutrality by mid-century underestimate the extent and nature of the challenges involved in the access to vital materials for this massive transition. The "green deals" that will help achieve climate neutrality are dependent on quickly growing raw material demands, especially of primary metals, minerals, and advanced materials as well as biomass. All these resources will have to be extracted and produced, and come with significant environmental footprints. The authors argue that in the case of Europe, for instance, there is a growing danger of limiting policy formulation to a mere selection of technological choices in downstream manufacturing industry and energy sectors without considering the consequences in terms of costs, environmental footprints, and societal aspects along the entire life cycle of technologies and related value chains. More specifically, there is a real concern that Europe will become even more dependent on the import of advanced materials, overlooking the fact that it will also turn into an exporter of waste and CO_2 emissions to others. The chapter draws on Europe and Germany to illustrate the changing demand scenarios of supply chains needed to scale-up sustainable mobility and a bio- and hydrogen-based economy. Gauß, Gellermann, and Maurer argue that the European Commission has promoted sector-specific industrial alliances to foster public-private partnerships in accelerating innovation and sustainable industrial growth. Examples are, the formation of the

European Battery Alliance launched in 2017, the European Raw Materials Alliance launched in 2020, and the Chips Act of 2022.

In her chapter, Klinger addresses the environmental impacts of rare earth mining and processing. She raises the question of whether an upfront investment in mitigating social and environmental hazards that may result from rare earth mining and processing is more or less expensive than cleaning up after the fact. While seemingly straightforward, the question itself raises a host of other issues, particularly around how costs and responsibilities for them are defined and delimited. Klinger uses qualitative, historical, environmental, and epidemiological research from a range of sectors to outline the basis of comparison between *ex ante* and *ex post* pollution controls in the rare earth sector. Following an introduction to the problem, the chapter reviews the contemporary social and environmental impacts of rare earth mining, mainly in China, and considers the political economic frameworks that limit effective mitigation of social and environmental harm as well as supply chain diversification. Klinger then assesses and provides a preliminary scope for evaluating the social and environmental costs of mining within and beyond the site of extraction, and on this basis compares the possible cost parameters for *ex post* vs. *ex ante* mitigation of social and environmental harms. In conclusion, her chapter discusses the need for further research efforts and open publication of data and results, in order to accurately assess the costs of rare earth mining and processing, to calculate the difference between *ex ante* and *ex post* pollution controls, and to guide effective policy formulation and implementation.

In his chapter, Ali argues that even though extractive industries have had immense social and environmental impacts, they remain the foundation of modern society. However, as the climate crisis worsens necessitating global economic decarbonization and digitalization, a number of minerals have become absolutely vital for the production of green technologies. Ali argues, however, that the opportunity to extract minerals on land is diminishing due to community opposition to new mines. He offers examples of several countries such as El Salvador and the Philippines that have moratoria on new mining projects. Even in the USA, opposition to mining remains high, and while the Trump presidency was receptive to extractive industries, a large metal mine in Alaska was rejected due to concerns about pollution impacts. In this context, the author posits that oceanic mineral resources are now being looked at as an important option since there are no direct social impacts in the deep sea. The oceans remain a vast but vulnerable frontier for scientific and industrial inquiry. The Anthropocene, moreover, continues to bring new challenges and opportunities for ocean conservation. Ali acknowledges that ecological impacts are largely unknown and remain a point of concern for conservationists. This has been a momentous time for the International Seabed Authority (ISA), which was formed over two decades ago as part of the United Nations Law of the Sea Convention, because it is scheduled to release a set of environmental standards and guidelines related to the implementation of its mining code in 2023. In this chapter, therefore, Ali provides a review of some of the key issues that can help highlight points of contention for more informed decision-making. Moreover, he considers the ways in which international environmental governance of the extractive industries is developing to address conflicts and how more effective decisions can be made in consideration of social and environmental tradeoffs.

In his chapter, Pell points to how the accelerated efforts to decarbonize the economy because of the climate emergency have spotlighted lithium's importance as an input in the global economic transformation. As a result, there is growing scrutiny, not only over the way that lithium is being mined and the massive amounts of material that will be needed moving forward, but also across the entire supply chain, from mine to market. Pell's chapter focuses on Latin America's "Lithium Triangle" which accounts for over 60% of global lithium reserves where extraction is concentrated in brine deposits and uses water-intensive processes that affect both environmentally fragile salt flats and adjoining biodiverse wetlands—areas that are also linked, both economically and culturally, to Indigenous populations. Pell argues that the management of lithium mining challenges will be changing due to the recent Escazu Agreement (2018) and emerging ESG disclosure and diligence requirements, particularly from the European Union (EU), whose standards are the most developed. His chapter examines ways by which the Escazu Agreement and EU ESG standards provide a paradigm for how companies can be encouraged to pay greater attention to long-term environmental and social issues, and the role that partnerships among industry, government focal points, and civil society organizations (CSOs) could play in maximizing ESG value strategies.

We would like to express our deepest gratitude to Jed Buchwald and Dan Lewis for their support of our cohort of the Summer Institute at Caltech and The Huntington and the production of this volume. Warm thanks to Steve Hindle and Jean-Laurent Rosenthal and to the wonderful Caltech staff that facilitated our meetings.

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About the Editor

Sophia Kalantzakos is a Global Distinguished Professor in Environmental Studies and Public Policy at New York University Abu Dhabi. Her research centers on the geopolitics of critical minerals, the transition to a net zero future, and the fourth industrial revolution. Her work, in particular, examines how resource competition in an era of fraught geopolitics has tilted the balance toward more securitized assessments of global interdependence. Moreover, she examines China's global aspirations manifested in the Belt and Road Initiative, Europe's reckoning with a seismic push against both its normative and economic power, and the US's re-evaluation of its leadership role in the global order. Kalantzakos' work examines how current epistemic systems will need to give way to new modes of thinking. As nation-states are turning inward in response to demands for de-globalization even while future challenges remain intensely global, her work advances the construction of dynamic, inclusive, and action-oriented responses. Her publications include *China and the Geopolitics of Rare Earths* (Oxford University Press, 2018; rev.2021) and The EU, US, and China Tackling Climate Change: Policies and Alliances for the Anthropocene (Routledge, 2017). She was a Rachel Carson (RCC) Fellow at LMU Munich in 2015 and 2018 and has served as a member of its Academic Advisory Board. She is currently the president of the RCC Society of Fellows. Recently, she has been a Fung Global Fellow at the Princeton Institute for International and Regional Studies (PIIRS) and Senior Fellow in the Research Institute for the History of Science and Technology at Caltech and The Huntington.

Part I
Geopolitics of Decarbonization and Digitalization

Chapter 1
Between Rocks and Hard Places: Geopolitics of Net Zero Futures and the Tech Imperium

Sophia Kalantzakos

Abstract The geopolitics of contention centering around growing US-China hyper-competition has polarized the transition to a decarbonized global economy and has made digitalization a battleground over control of the tech imperium. This dangerous development undermines the realization of a coordinated international response to the climate crisis. It has also led to the securitization of access to critical minerals and their extensive globalized supply chains, jeopardizing the manufacturing of technological end products at a time when an already narrow window for constructing new infrastructure and deploying green technology is rapidly closing. The overuse of economic statecraft to settle a wide range of disputes (exacerbated by the Russian invasion of Ukraine) has, moreover, further fueled renationalizing narratives that seek to break ties of interdependence. This chapter provides insight into the latest manifestation of resource competition. It recommends the lowering of the rhetoric of hyper-competition so that the response to the climate crisis does not become a starting pistol for a new scramble: for inputs, "geopolitically engineered" supply chains and the building up of tech and knowledge barriers that produce new exclusions and inequities engendering securitized solutions to global challenges.

Keywords Interdependence · Reshoring · Rare earths · European Battery Alliance · Net zero · Critical minerals · EVs

Two seismic economic and technological shifts are taking place in a climate of extremely fraught geopolitics. The global economy is set to urgently decarbonize because of the climate crisis, but also simultaneously digitalize thus ushering in the fourth industrial revolution. The transition constitutes a pivotal moment for global economic transformation. Unfortunately, though importantly, both these monumental shifts are happening in an atmosphere of geopolitical upheaval. First, China's growing global impact, increased assertiveness, and more frequent heavy-handed

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S. Kalantzakos (ed.), *Critical Minerals, the Climate Crisis and the Tech Imperium*, Archimedes 65, https://doi.org/10.1007/978-3-031-25577-9_1

autocratic policies launched under Xi Jinping's leadership have triggered an aggressive response by the United States, giving rise to a new cycle of bipolar competition which is negatively impacting the workings of the world order. Second, the Russian invasion of Ukraine in early 2022 resulted in the use of unprecedented levels of economic statecraft and triggered extraordinary energy and commodity shocks. Prices of coal, oil, and gas soared to levels that surpassed previous energy crises. By the end of 2021, even before the invasion of Ukraine began in earnest, prices of gas were ten times those of 2020 in Europe and Asia, while they tripled in the US. The continued supply chain disruptions because of COVID outbreaks and growing transportation costs, moreover, also slowed the growth of renewable energy projects worldwide, as this particular industry was designed to be global from the outset.

While one hundred and thirty five countries have adopted some form of a net zero target, governments all over the globe scrambled to keep the lights on, formulating policies to help diversify fossil fuel imports, especially if they were overly reliant on Putin's Russia as the EU has been. Fossil fuel production domestically was also ramped up wherever possible, and energy was subsidized to shield consumers who were particularly hard hit by these developments. China, for instance, announced an increase of coal production, the US experienced a boom of fracking and drilling projects, while the EU explored and introduced caps on the prices of fossil fuel imports and other policies to alleviate the economic strain to citizens and industry (REN21 2022). Making matters even worse, the summer of 2022 saw unprecedented forest fires, floods, droughts, and extreme weather conditions. It fueled confusion and urgency on how to proceed with the green energy transition as the addiction to fossil fuels had clearly resulted in states' prolonged energy vulnerability. Finally, the Russian invasion, China's reluctance to condemn Putin's actions, and Washington's more assertive support of Taiwan, drove an even bigger wedge between the US and the PRC to the point where the two powers halted, albeit temporarily, collaboration on climate leadership in August 2022 (Xu 2022).

Nonetheless, even under these chaotic conditions both the US and the EU pushed through new bills (Repower EU and the Inflation Reduction Act) meant to support the green transition, to build energy autonomy, reduce emissions, create jobs, and tackle inflationary pressures on the economy (European Commission 2022a; The White House 2022a). Political will combined with the rapidly declining production costs for clean technologies such as renewables and the electrification of transport continue to push the transition forward. At the same time, calls to diversify, reshore, and renationalize supply chains which had already started when the US threw down the gauntlet to China, continued to grow. Interdependence once lauded as an asset became a liability, a vulnerability that could be weaponized by rivals.

An explosive geopolitical landscape that centers around Sino-American hypercompetition thus formed and continues to worsen. Importantly, the transition to a net zero future has turned into a nationalist competition for normative, economic, technological, and military pre-eminence. Moreover, it appears that the response to the climate crisis has become a starting pistol for a new scramble: for inputs, "geopolitically engineered" supply chains, the building up of tech and knowledge barriers, that produce new exclusions and inequities engendering securitized solutions to global challenges (Kalantzakos 2020a).

Alarmingly, the geopolitics of contention has not only polarized the transition to a green global economy, but has also made digitalization a battleground over who will control the tech-imperium (Piore 2022). As a result, these transitions are no longer confined to the normal parameters of trade competition. They constitute an open and heated rivalry over influence, economic power, supply chains, information, norms, values, and governance. This represents a dangerous development because the rhetoric of division (framed as a dilemma between autocracy vs democracy) (Biden 2021a) is eclipsing the existential challenge for the global commons which is to produce an international coordinated response and blueprint to offset the worst impacts of the climate crisis and the disruption of the earth's systems.

Critical minerals are necessary protagonists in this unprecedented economic and industrial transition if the global community truly aims to keep temperatures from rising beyond 1.5 °C by cutting greenhouse emissions by 50% by 2030. This deadline is both fixed and pressing. There is, therefore, an existential crisis to solve, a terribly tense geopolitical atmosphere now entangled in normative dilemmas of autocracy vs democracy, and a short window of time left to realize this industrial transformation while also maintaining growth, jobs, and profits.

Moreover, digitalization accelerated significantly because of the pandemic, and forced many sectors to go virtual requiring the deployment of artificial intelligence (AI) and 5G networks. This ushered in the fourth industrial revolution earlier than initially anticipated. The deployment of 5G, for instance, will expand mobile networks to support a diversity of both services and devices. They will redefine a range of industries retail, education, transportation, and entertainment. AI, moreover, is being rapidly developed promising to accelerate innovation, efficiency, and sustainability in businesses and organizations. These complex systems that underpin the next industrial revolution are voracious consumers of critical minerals (Greenfield and Graedel 2013).

China's competitors and rivals have awoken to the realization that the PRC has again been better prepared. It has strategically invested in resources and globalized supply chains for key inputs and applications that are vital for the global economic transformation. Its signature Belt and Road Initiative, moreover, that re-imagines the ancient silk road, also builds maritime connections to directly bridge and streamline geographically, economically, territorially, and perhaps even politically, Eurasia and Africa while also looping in South America (Kalantzakos 2020b). The BRI thus forms a novel network of land, maritime, and digital connectivity. Importantly, industrial innovation and production are no longer the exclusive purview of the OECD economies, especially the US, European Union member states, and Japan. Compounding this new reality is the fact that the long era of stable resource competition is rapidly ending. Historically, empires locked in their economic supply chains and managed competition. And in the long post-1945 cycle of decolonization, the United States, as the global economic hegemon, was the power that defended and ensured that the rules and norms of world trade were enforced (Kalantzakos 2020a). China's growing consolidation of its commercial and military interests as well as its