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The geopolitics of energy system transformation: A review

Mathieu Blondeel[1] | **Michael J. Bradshaw**[1] | **Gavin Bridge**[2] | **Caroline Kuzemko**[3]

[1]Warwick Business School, University of Warwick, Coventry, UK

[2]Department of Geography, University of Durham, Durham, UK

[3]Department of Politics and International Studies, University of Warwick, Coventry, UK

Correspondence
Mathieu Blondeel, Warwick Business School, University of Warwick, Coventry, CV4 7AL, UK.
Email: Mathieu.Blondeel@wbs.ac.uk

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Abstract

In 2009, *Geography Compass* published a paper on 'The Geopolitics of Global Energy Security' that reviewed research on the key geographical factors influencing the secure and affordable supply of energy resources. Now, just over a decade later, the energy landscape is undergoing a dramatic transformation, and the focus is no longer on fossil fuel scarcity. Rather, this is an age of fossil fuel abundance and the emphasis is on the need to decarbonise the global energy system, constrain the production of fossil fuels and accelerate the deployment of low-carbon energy technologies. We conceive energy system transformation as a twofold process: a set of 'high-carbon' energy transitions related to phasing out fossil fuel consumption, 'low-carbon' energy transitions related to the emergence of new renewable energy and other low-carbon technologies. This paper reviews the past decade's research that examines the nature and pace of energy system transformation, as well as that which identifies a range of geopolitical challenges associated with these two transitions. The paper concludes by advocating for a 'whole systems' approach to energy geopolitics that captures the critical interactions between the two transitions in a global framework.

KEYWORDS
energy system transformation (EST), fossil fuels, geopolitics, transitions, renewable energy

1 | INTRODUCTION

This review revisits a *Geography Compass* paper on 'The Geopolitics of Global Energy Security,' published over a decade ago (Bradshaw, 2009). At the time, the emphasis was on the geopolitical tensions created by fossil fuel scarcity and the possibility of peak oil supply (Hirsch et al., 2005; Klare, 2012). Since then, the global energy landscape and energy geopolitics, as a field of study, have changed dramatically. Today, we live in a world of relative fossil fuel abundance, and the primary challenge is to reduce their consumption and accelerate deployment of low-carbon energy technologies, alongside energy demand reduction and improvement in energy efficiency. These changes are also reflected by the expanding literature on energy geopolitics which has started to direct its attention to the geopolitics of *renewables*.

This review considers the geopolitical dimensions of the required energy system transformation (EST) through a novel 'whole systems' lens. We characterise this transformation as a twofold process centred on transitions in fuel supply: 'low-carbon energy transitions' that see an increasing share of energy demand being met by low-carbon non-fossil energy sources; and 'high-carbon transitions' that see a fall in demand for fossil fuels. The whole systems approach allows a more comprehensive understanding of the intricate relations between these constitutive elements of EST, instead of focussing on only a specific aspect, such as oil in the past (Bradshaw, 2009), or the growing importance of renewables today (Vakulchuk et al., 2020).

The next section explores *energy* geopolitics as a field of study. The third section considers the nature of energy transitions. The paper then divides into two further substantive sections: one on 'high-carbon energy transitions'; and one on 'low-carbon energy transitions'. We conclude by considering how our whole systems approach to the geopolitics of energy adds to existing scholarship and outlines new research needs.

2 | ENERGY AND GEOPOLITICS

The study of 'geopolitics' was first established to capture the relationship between geography and the (international) politics of Western imperial states (Ivleva & Tänzler, 2019; Overland, 2019). As the Cold War and decolonisation came to dominate world politics, geopolitics described the contest between the United States and the Soviet Union for influence and control over states and strategic resources (Ó Tuathail, 1998). Today, conventional geopolitics remains particularly concerned with 'exploring and explaining the role of geographical factors (such as territorial location and/or access to resources) in shaping national and international politics' (Dodds, 2005, p. 1; see also Högselius, 2019, p. 7).

The field of *energy* geopolitics has been strongly influenced by conventional geopolitical thinking (Lehmann, 2017, p. 15). Bradshaw (2009, p. 1920), for example, defined energy geopolitics as 'the influence of geographical factors, such as the distribution of centres of supply and demand, on state and non-state actions to ensure adequate, affordable and reliable supply of energy.' Competition over access to fossil fuels, oil in particular, has been a key component of much geopolitical analysis since the oil shocks of the 1970s. The geopolitics lens has been trained on disputes and tensions over oil-rich parts of the world such as the Persian Gulf, the Caspian and the Arctic, or chokepoints such as the Strait of Hormuz. Later, it also came to include tensions over natural gas between the EU and Russia (Overland, 2015, 2019). Contrary to the global nature of oil and natural gas markets, coal markets remain largely domestic, so coal has received less academic attention.

Now, a research agenda on the geopolitics of *renewables* is emerging. It requires us to recognise energy as more diverse, and shows how geo-*technical* characteristics of different energy sources can have political consequences (Criekemans, 2011, 2018; Scholten & Bosman, 2016). Nevertheless, much of this scholarship remains firmly rooted in conventional state-centric, realist approaches to (energy) geopolitics. Scholten (2018, p. 8), for example, only considers '*interstate* [renewable] energy relations', while Overland (2015, p. 3517) examines '*great power* competition over access to strategic locations and natural resources' (see also Vakulchuk et al., 2020).

In opposition to conventional geopolitical thinking, the field of *critical geopolitics* has emerged, according to which geopolitics is best understood as a social construction that is iterated through varying and competing discourses of state and non-state actors (Agnew & Crobridge, 1995; Dalby, 2008; Dodds, 2005, 2019; Mamadouh, 1998; Ó Tuathail & Agnew, 1992; Ó Tuathail & Dalby, 1998). As such, 'geopolitics engages the geographical representations and practices that produce spaces of world politics' (Ó Tuathail & Dalby, 1998, p. 2).

This scholarship does not accept geopolitics as a 'realist and objective fact of world relations', rather it tries to show how certain tropes are (re)produced to legitimate power relations (Huber, 2015, p. 330). Geopolitical competition over scarce energy resources is thus often imaginary or constructed and a critical lens is required. Bridge (2010, 2011), for example, has applied this thinking convincingly to narratives of 'peak oil'. Moreover, it also moves away from a realist interpretation that assumes the primacy of state actors as it pays attention to the agency of relevant sub-national, non-state actors and even individuals. Feminist critiques of geopolitics, for example, highlight how geopolitical realities are reproduced through purportedly non-political, everyday actions as well as the lived experiences of marginalised communities. Or as Sharpe (2020a, p. 2) has described them, 'those normally hidden from geopolitical analysis' (see also Billo, 2020; Dowler & Sharp, 2001; Sharp, 2020b). Yet, although its contribution to the study of geopolitics should not be underestimated, our review suggests that the potential of critical geopolitics of energy has yet to be fully realised.

Whole systems geopolitics synthesises the critical and conventional strands. It contends that geographic arrangements change over time depending on political, economic, social technological change and that it does not only happen the other way around (Amineh, 2003, p. 20). This allows for a more comprehensive understanding of the intricate relationship between changing energy systems, geography and (international) politics. In our approach, politics and policy-making are driving forces of energy system change and associated geopolitical discourses. We share this position with students of Anthropocene geopolitics. We live in an era in which humanity is now changing 'natural' systems on such a scale that we have in effect become a geological force ourselves. This scholarship concurs that geopolitics is now shaping future climates, not the other way around (Dalby, 2007, 2014, 2018, 2020).

3 | ENERGY SYSTEM TRANSFORMATION

EST is a broad term signalling structural change in the organisation of the energy system and the social and power relations constituted through it. This paper considers transformation driven by a need to reduce the energy system's carbon intensity.

Academic debate focuses on both the *pace* and *nature* of energy transitions (Grubler, 2012; Grubler et al., 2016; Sovacool, 2016, 2017; Sovacool & Geels, 2016). Pace matters, because, as the International Energy Agency (IEA) notes, the decade 2020–2030 is a 'critical period', as total CO_2 emissions need to fall by around 45% from 2010 levels by 2030 to achieve net-zero emissions in 2050 (IEA, 2020c; IPCC, 2018) (Please add new reference 'IPCC, 2018' here as well).

There are two sides in this debate. One side considers energy transitions as long, protracted processes that take decades, or even centuries, to occur (Fouquet, 2010, 2016; Grubler, 2012; Grubler et al., 2016; Myhrvold & Caldeira, 2012; Smil, 2010a, 2016). In this view, rapid transitions, if they occur at all, are anomalies, limited to unique contextual circumstances and difficult to replicate. This is because the size of energy systems makes them subject to path dependencies. Furthermore, the complexity of the built infrastructure and institutional legacies protect the status quo and 'lock in' a fossil-fuel-dependent energy system (Sovacool, 2017; Unruh, 2000).

The other side argues that 'rapid transitions' can occur at varying scales, involving fuels, services and end-use devices. In that case, transitions are consciously governed; thanks to globalisation, changes unfolding in some parts of the world have important knock-on effects in other parts of the world; and there is a broad-based political consensus, driven by environmental imperatives, on the need for change (Kern & Rogge, 2016; Newell & Simms, 2020a; Sovacool, 2016; Sovacool & Geels, 2016). Technological advances also allow for developing economies to 'leap-frog', avoiding carbon-intensive economic development (Szabó et al., 2013). Added to which, the COVID-19 pandemic and 'green recovery' plans could act as trigger to accelerate the pace of transition (Kuzemko et al., 2020).

A second body of work considers the *nature* of transitions. In short, an 'energy transition' involves switching from one or more dominant primary energy resources and their associated technologies and prime movers to others (Fouquet & Pearson, 2012; Hirsch & Jones, 2014; Miller et al., 2015; Smil, 2010a, 2010b; Sovacool, 2016, p. 203), although it is important to note that low-carbon energy sources have not (yet) started to displace fossil fuels in the global energy mix (York & Bell, 2019). A narrow focus on energy sources alone, however, 'mask[s] the social and political dimensions of energy systems behind a false veneer of limited technological choices' (Hirsch & Jones, 2014, p. 110; Laird, 2013). Moreover, such an apolitical approach does not fully account for the spatial or geographical dynamics of transitions (Bridge et al., 2013; Bridge & Gailing, 2020; Huber & McCarthy, 2017; Newell, 2020; Newell & Simms, 2020a; Roberts et al., 2018; Sovacool, 2017). The literature on socio-technical transitions (STT), for example, also recognises these shortcomings. Nonetheless, despite recent interest in power, politics and incumbency, STT research remains primarily concerned with innovation (Geels, 2010, 2014; Johnstone & Newell, 2018; Sovacool, Hess, et al., 2020; Turnheim & Geels, 2012, 2013).

There is also a need to understand accompanying (geo)political, economic, social and cultural shifts that occur in the context of a deep and structural transition that, in turn, influence its pace and reach. How these various elements interact is best captured by the term 'transformation;' akin to the deep societal changes that occurred with the consolidation of market economies in the 18th and 19th centuries—what Polanyi (1944) referred to as the 'Great Transformation' (IRENA, 2019a; Jiusto, 2009; Newell, 2019; Paterson, 2020; Pearse, 2020). From this perspective, EST also captures institutional arrangements, geopolitical dimensions and uneven power distributions that simultaneously structure and are structured by the historical and future trajectories of energy systems. Consequently, the 'low-' and 'high-' carbon transitions must be taken together; and have far-reaching impacts on a variety of aspects of society at a variety of scales, from the global to the local.

In sum, EST heralds a 'new energy order' that is remaking the traditional geopolitical dimensions of energy supply and demand (Bocca, 2020; The Economist, 2020; van de Graaf & Bradshaw, 2018). By introducing 'sustainability' to these energy transitions, new and conflicting narratives emerge. While some argue that the transition towards a renewables-based energy system will see new types of conflict emerging, others expect a decline in such tensions (Bordoff, 2020; Vakulchuk et al., 2020). This creates space for a more critical geopolitics of EST.

4 | THE CHALLENGES OF 'HIGH-CARBON' ENERGY TRANSITIONS

This section reviews and explores the extent to which existing geopolitical assumptions and power structures, embedded in a reality of fossil fuel dominance, are challenged by high-carbon transitions. The discussion moves beyond past concerns with security of supply, though they remain, and serves as a necessary antidote to the current dominance of work on the geopolitics of *renewables*.

4.1 | From scarcity to abundance: an emergent new energy order

Two changes in technologies, markets and politics lie at the heart of the high-carbon transition for oil and gas (van de Graaf & Bradshaw, 2018). First, the 'shale revolution' and 'hydraulic fracturing' have substantially increased oil and gas availability, flattening cost curves and decreasing the elasticity of oil and gas supply (Blackwill & O'Sullivan, 2014; Bradshaw & Boersma, 2020; Grigas, 2017; O'Sullivan, 2017). Second, technological innovation and cost reduction in low-carbon energy generation and storage, as well as increasingly stringent climate policy (which includes calls for improved energy efficiency and demand reduction), are weakening the case for long-term growth in fossil fuel demand (Scholten, 2018). In this new energy order, fossil fuels are no longer scarce resources, and prices exhibit greater short-term volatility against a long-term declining trend.

Consequently, the oil and gas industry will do whatever it can to avoid the demand destruction the coal industry is already experiencing (IEA, 2020c). For now, the outlook for oil and gas remains more robust, with predicted post-COVID-19 recovery and growth in multiple scenarios for the coming decades (ExxonMobil, 2019; OPEC, 2020). However, fossil fuel reserves are unevenly distributed and hold significant differences in production costs (McGlade & Ekins, 2015). Accordingly, strategies to cope with this transition will differ among producer economies[1] and fossil fuel companies (Brower, 2020; Goldthau et al., 2019; Goldthau & Westphal, 2019; van de Graaf & Verbruggen, 2015).

Our understanding of the geopolitics of energy is being upended by this emerging new order. In a structurally declining market, the relative balance of power will shift to favour low-cost producers, fundamentally changing what it means to be an 'energy superpower' (Bradshaw et al., 2019; Rutland, 2008, 2020). Even if some producer states succeed in growing their market share, it will be increasingly difficult for them to dictate terms in a decarbonising global energy system (van de Graaf, 2017).

4.2 | The resource curse revisited

Historically, producer economies have exercised considerable geopolitical power. Furthermore, so-called 'Rentier states' have used revenues from the export of natural resources to maintain a 'social contract' with their citizens, strengthen military capacities or invest in foreign assets (Beblawi, 1987; Schwarz, 2008). Simultaneously many have been plagued with low levels of democracy, increased exposure to (civil) war, as well as poor economic diversification (Auty, 1993; Klare, 2002; Ross, 2001; Sachs & Warner, 1995). A significant body of research addresses this so-called 'resource curse', especially as it relates to oil (Colgan, 2013; Ross, 2012; van der Ploeg, 2011). However, only limited academic effort has been dedicated to contemplating the implications of high-carbon transitions for these economies' resource endowments (Bradley et al., 2018; Friedrichs & Inderwildi, 2013; Sim, 2020; Sinn, 2012). For example, an authoritative review article on the 'resource curse' did not mention its relation to EST (Ross, 2015).

As demonstrated by the 2020 oil price collapse and the COVID-19 pandemic, the loss of resource rents will cause future crises for producer economies (OECD, 2020). They will want to avoid becoming victims of both a rapid reduction in market share *and* revenue (Bazilian et al., 2019; Goldthau & Westphal, 2019; Goldthau et al. 2019). Saudi Arabia's 2014–2015 oil policy, and the short-lived oil price war in March 2020, can be understood in this context (Fattouh & Sen, 2015; Yermakov & Henderson, 2020). For low-cost producers, such as Saudi Arabia, a fight for market share might entail the short-term pain of falling revenues, but it may lead to a gain in revenues in the longer-term, as production in high-cost areas (US tight oil, Canadian tar sands or Venezuelan crude) falters in response to these lower prices (Fattouh, 2021). Importantly, however, producer economies have different relative production costs and not all are able to ramp up production. This strategy will inevitably create geopolitical winners and losers (Cust et al., 2017; van der Ploeg, 2016).

In this context, the idea of a 'green paradox' refers to producers increasing supply in anticipation of future demand reduction as a consequence of a high-carbon transition (Sinn, 2012). Producing as much as you can as fast as you can, causes an acceleration in emissions *and* delays EST. Research suggests that low-cost Gulf producers, such as Saudi Arabia, are increasing output to capture a larger part of remaining market share, thus potentially contributing to the green paradox (Fattouh, 2021). Moreover, producer economies themselves are typically high CO_2 emitters because fossil fuel consumption is embedded in their national energy systems. This 'carbon curse' makes it more difficult for them to transition to a low-carbon economy (Chiroleu-Assouline et al., 2020; Friedrichs & Inderwildi, 2013). Eventually, however, their international influence will wane unless they can reinvent their economies as the world transitions to the new energy order (IRENA, 2019a, pp. 31–35; World Bank, 2020).

Producer economies can still allocate their diminishing rents to manage this transition. First, revenues can be used to diversify economic activity and investments beyond a diminishing resource endowment (Bradley et al., 2018, p. 46; Lahn & Stevens, 2017; Stevens et al., 2015). Well-managed fossil fuel resource revenues can, in turn, be used to stimulate domestic 'green' industrial policy to avoid the carbon curse and diversify the economy. Even though not all producer economies have used windfalls to build up buffers and invest in a diversified economy (Ross, 2015; van der Ploeg, 2016).

Second, rent allocation for economic diversification can be complemented by fiscal reforms both within and outside the energy sector, broadening the overall tax-base and phasing out fossil fuel consumption subsidies that often capture these rents. In 2018, the Gulf Cooperation Council agreed on a collaborative VAT system, with some members increasing their domestic VAT further during the COVID-19 pandemic. Moreover, once rents begin to decline, fossil fuel subsidies will be difficult to maintain (Benes et al., 2015). Low oil prices offer an opportunity for pricing reform, even if they are notoriously hard to organise (Bradley et al., 2018, p. 48; Inchauste & Victor, 2017; Skovgaard & van Asselt, 2018). In the past, dozens of governments have been forced to backtrack on reforms as public protests erupted (Rentschler & Bazilian, 2016), a phenomenon not limited to developing countries. The French yellow vest protests erupted in 2018 directly following the government's fuel price reforms, while in the United Kingdom, the tax escalator on fuel prices was halted a few years ago.

Third, producer economies' sovereign wealth funds (SWF) can help insulate them from short-term price volatility—as was the case for Russia and Saudi Arabia during the oil price dip between 2014 and 2018—and generate long-term financial income from diversified sources (Overland, 2019, p. 37). Today, SWF investments in fossil fuel and other high-carbon assets have a 'double exposure' to carbon risk (Bradley et al. 2018, p. 49). Improvements in their design and management can help reduce that exposure. The Norwegian SWF, for example, has been divesting selectively from the fossil fuel industry for years (Bang & Lahn, 2020; van der Ploeg, 2016).

4.3 | Unburnable carbon, stranded assets and divestment

If the world is serious about the Paris Agreement, this will require leaving significant amounts of fossil fuel reserves in the ground (McGlade & Ekins, 2015): reserves, in other words, that hold 'unburnable carbon'. Furthermore, research suggests that existing *and* committed fossil fuel infrastructure will have to be phased out before the end of its expected economic lifetime or even abandoned before construction is finalised (Edenhofer et al., 2018; Pfeiffer et al., 2018; Smith et al., 2019; Tong et al., 2019). Put another way, the world has a finite 'carbon budget', the amount of carbon that can safely be emitted to maintain a given chance of remaining within Paris thresholds. According to the IEA (2020c), the world's existing energy infrastructure and that under construction would lock in a temperature rise of 1.65°C. The Agency further notes that from 2021 onwards no new oil and gas fields, and no new coal mines (or extensions of existing ones) can be approved for development to if we are to reach global net-zero emissions by 2050 (IEA, 2021a).

The Carbon Tracker Initiative (CTI, 2011) was among the first to publicly warn of the risks that hold for financial markets. Their notion of 'stranded assets' refers to the capital investment in fossil fuel infrastructure that could end up failing to be recovered over the operating lifetime of the asset because of reduced demand or reduced prices. There is an expanding research agenda on how fossil fuel assets may become stranded and the effects that this can have on markets, the industry (Ansar et al., 2013; Bridge et al., 2020; CTI, 2020; IRENA, 2017; OECD, 2015; World Bank, 2020) and producer economies (Ansari & Holz, 2020; Bos & Gupta, 2018; Cust et al., 2017; Jaffe, 2016; Lahn & Bradley, 2016; Overland et al., 2019; van de Graaf, 2018; van de Graaf & Bradshaw, 2018; van de Graaf & Verbruggen, 2015).

Failure to act to stay within this carbon budget could lead to a 'carbon bubble' (CTI, 2011). In time, this might even lead to a climate 'Minsky Moment' (Carney, 2015), when asset prices suddenly collapse once the scale of potentially stranded assets dawns on investors and other financial stakeholders. This would likely cause spill-over effects into the wider global economy; similar to the global financial crisis that started with a housing bubble in the United States. As much as US$ 1–4 trillion worth of fossil-fuel-related assets in the world economy could evaporate (Livsey, 2020;

Mercure et al., 2018), with some US$30 trillion in fixed assets at risk of devaluation (CTI, 2020). Central banks and financial regulators are starting to factor in climate change because of the risk it poses to systemic financial stability (Campiglio et al., 2018; Grippa et al., 2019).

Spurred in part by a global 'fossil fuel divestment' campaign, private investors are also increasingly acting on these 'transition risks', as some sectors of the economy face big shifts in asset values or higher costs of doing business (Ansar et al., 2013; Ayling & Gunningham, 2017; Healy & Barry, 2017; Langley et al., 2021). From mid-2019 to mid-2020, publicly listed oil and gas companies saw almost 40% of their market capitalisation evaporate (IEA, 2020c, p. 260). Banks, insurers and institutional investors—especially in OECD economies—have started to divest; among them some of the largest fossil fuel financiers (Ieefa, 2020). But the industry was well aware of the risks even before the pandemic. Shell (2018, p. 13) warned its shareholders back in 2018 that pressure from divestment campaigns 'could have a material adverse effect on the price of our securities and our ability to access equity capital markets'.

4.4 | Activism, supply-side constraints and a just transition

Entrenched fossil fuel interests, technologies and infrastructure, as well as existing institutions, norms or even geopolitical considerations—as is the case with China's Belt and Road Initiative—can constrain the pace of the high-carbon transition (Huang, 2016; Saha, 2020; Seto et al., 2016; Sovacool, 2017; Unruh, 2000). Empirical research on this 'carbon lock-in' effect has focussed on a variety of sectors, including transportation (Mattioli et al., 2020; Meckling & Nahm, 2019), petrochemicals (Janipour et al. 2020) and power generation (Brauers et al., 2020; Rentier et al., 2019; Trencher et al., 2020). It has also spanned different geographies in the Global North (Carley, 2011; Kraushaar-Friesen & Bush, 2020; Rentier et al., 2019) and the Global South (Strambo et al., 2020). But 'developing countries' do not always face incumbent technologies and companies and through 'leapfrogging' can avoid carbon lock in (Seto et al., 2016, p. 443; Szabó et al., 2013; Unruh & Carrillo-Hermosilla, 2006).

Accordingly, some activists now explicitly target fossil fuel infrastructure and supply through 'keep it in the ground' campaigns, demands for moratoria or permanent bans for new projects (Benedikter et al., 2016; Blondeel & Van de Graaf, 2018; Carter & McKenzie, 2020; Temper et al., 2020). This supply-side activism is best exemplified by the global campaign for a 'fossil fuel non-proliferation treaty', designed after the nuclear non-proliferation treaty (fossilfueltreaty.org, 2021; Newell & Simms, 2020b). There is also a growing number of climate law suits around the world that are directed both at companies and governments that fail to act on climate change (Eskander et al., 2020; Setzer & Vanhala, 2019).

Inevitably, however, the prospect of leaving reserves in the ground leads to the questions of whose fossil fuels will remain unburnt and whether foregone rents should be compensated for (Gaulin & Le Billon, 2020; Rayner, 2020). McGlade and Ekins (2015) adopt a cost-optimal approach to leaving fossil fuels in the ground, although they have been criticised for ignoring political economic and justice considerations (Pye et al., 2020). But the fact remains that their scenario remains the most likely to play out in the future due to a lack of adequate global governance to manage the high-carbon transition (Rayner, 2020).

Taking into consideration equity and justice criteria would allow developing countries to extract more for a longer period of time than advanced economy producers (Caney, 2016; Kartha et al., 2016, 2018; Le Billon & Kristoffersen, 2020). Otherwise, some of the greatest losses are likely to occur in the poorest and least prepared fossil fuel exporting countries, while OECD producers such as the United States, Canada and Norway have the financial means to absorb the consequences (Armstrong, 2020; Healy & Barry, 2017; Muttitt & Kartha, 2020; World Bank, 2020). Developing countries have therefore (unsuccessfully) called on transnational justice and solidarity when it comes to leaving fossil fuels in the ground. The Yasuní–ITT initiative in Ecuador is a palpable example of such failure (Sovacool & Scarpaci, 2016).

The notion of a 'just transition', or how to ensure a high-carbon transition that is both equitable and legitimate in the eyes of affected countries—and the workers, shareholders and citizens who may suffer its socio-economic impacts—is thus a key source of contention (Heffron & McCauley, 2018; Newell & Mulvaney, 2013). As demonstrated by the recent closure of coal mines in Spain and the phase-out of coal-fired power generation in Germany, moves towards a just transition will involve financial and technology transfers to fossil-fuel-dependent countries or regions, and strengthening key institutions to oversee industrial restructuring in a way that generates 'sustainable' jobs (Healy & Barry, 2017; Sanz-Hernández et al., 2020).

This discussion makes clear that the 'high-carbon transition' is no straightforward matter and comes with many political, economic and social costs and risks. The OPEC + coordination failure of March 2020 shows what destructive effects a lack of cooperation can generate, while the subsequent deal between the United States, Russia and Saudi Arabia highlights how collaboration and agreement—between these major producers—will continue to be required to ease future market distress, particularly in the context of high-carbon transitions (Yermakov, 2021; Yermakov & Henderson, 2020). Advocates of an accelerated production decline must realise that, if not adequately managed, it will fast become a source of geopolitical conflict between the potential winners and losers that could derail the progress of EST.

5 | THE CHALLENGES OF LOW-CARBON ENERGY TRANSITIONS

The geographic and technical features of a low-carbon energy system differ dramatically from one based on fossil fuels. Our main focus here is on renewables and energy supply. Nuclear energy is a low-carbon technology as well, but its large-scale growth potential is limited by unresolved issues of cost, radioactive waste, the potential for accidents, and its association with nuclear weapons (IEA, 2020c, p. 199; Ramana, 2016). Moreover, there is an inherent 'supply side' bias to the literature under review here due to the emphasis on security of supply in 'classic' energy geopolitics from which it derives much of its assumptions and analytical tools.

As the share of renewables rises in global power generation and the role of electrification increases, it is reshaping the geopolitics of the new energy order (IRENA, 2019a; Scholten, 2018; Scholten & Bosman, 2016). First, renewable power sources—solar and wind—are ubiquitous, unlike fossil fuels which have a patchier geographical distribution. This could minimise the risks of trade chokepoints, such as the Strait of Hormuz—through which the equivalent of about one-fifth of global petroleum liquids consumption passes daily (EIA, 2019; Emmerson & Stevens, 2012). Second, renewables have lower energy density, they are spatially extensive in nature but appear in the form of non-exhaustible flows; while fossil fuels are associated with a 'subterranean energy regime', reliant on underground, depleting stocks, creating less demand for land-based and spatially extensive energy sources (Huber & McCarthy, 2017). This means that not only fossil fuel projects but renewables projects as well are sometimes met with local and social resistance (Temper et al., 2020). The difficulty for most renewables, such as wind and solar, moreover, is that they are intermittent in nature and need storage capacity to bridge periods when the wind does not blow, and the sun does not shine. Third, renewable energy is mostly distributed through electricity, so in a world powered by renewables, electricity will become the dominant energy carrier (IRENA, 2019b; Scholten & Bosman, 2016).

5.1 | Electrification: interconnection and decentralisation

Electricity is expected to account for a quarter of energy demand by 2030 (IEA, 2020c, pp. 216–217). Electrification is also an essential component of the UN's objective to eradicate global energy poverty by 2030 under its Sustainable Development Goals (Pereira et al., 2010; Szabó et al., 2013; UN, 2015; Yadoo & Cruickshank, 2012). As renewables can be deployed at various scales, this has led to the co-evolution of two different 'topologies' of electrification: interconnection and decentralisation. Each with their own geopolitical implications.

First, the nature of a renewable electricity grid implies a physically integrated infrastructure that connects producers and consumers through interconnected grids between neighbouring countries, at a regional scale and possibly even inter-continentally (Scholten & Bosman, 2016). So far, attention has focused on the technical, economic and regulatory aspects of grid interconnection (Fischhendler et al., 2016; IEA, 2016a; Konstantelos et al., 2017; Pierri et al., 2017), while its geopolitical implications have only recently attracted interest (Arcia-Garibaldi et al., 2018; IEA, 2016b; IRENA, 2019a; Lilliestam & Ellenbeck, 2011, 2012; O'Sullivan et al., 2017; Overland, 2019).

The benefits of interconnection are clear. Electricity trading will likely be more symmetrical than trade in oil and gas. Oil and gas generally flow in one direction[2], from an exporter to an importer, while trade in electricity between countries can flow both ways (IRENA, 2019a; Overland, 2019). Moreover, such market coupling can address intermittency and is more cost-effective than self-sufficiency (Brouwer et al., 2013; Scholten & Bosman, 2016; Tröndle et al., 2020). It also reduces the risk of exporters using electricity as an 'energy weapon' as it allows for a less exclusive relationship with one supplier and leaves alternatives open in times of conflict (IRENA, 2019a; Lilliestam & Ellenbeck, 2012). Cross-border electricity trade can also intensify regional cooperation, creating 'grid communities'. These have existed for decades, for example, among Scandinavian countries, but they are now being developed elsewhere (IEA, 2016a, 2016b). Several renewable 'supergrids' have been proposed, including the 'Asia Super Grid', China's 'Global Energy Interconnection' (GEI), the 'Desertec' project and the 'North Sea Offshore Grid' (IRENA, 2019a; Lilliestam & Ellenbeck, 2011, 2012).

Interconnection, however, also presents risks, as electricity cut-offs could become a foreign policy tool (Johansson, 2013; Moore, 2017; Smith Stegen, 2018). Furthermore, actions in one part of the grid—such as power outages—could immediately affect others (Scholten & Bosman, 2016; Smith Stegen et al., 2012). Large-scale infrastructure projects also raise questions about indebtedness, transparency, sustainability and—in the case of the GEI—China's strategic objectives (IRENA, 2019a). Consequently, a lack of trust forms a major impediment to creating cooperative grid connections, as was the case for Israel and its Arab neighbours (Fischhendler et al., 2016). In the end, similar problems with fixed infrastructure and (inter)dependencies in relation to the physical security of supply arise, when swapping molecules and pipelines for electrons and cabling.

Some of the risks discussed above can be offset by decentralisation. Distributed generation allows for energy production and consumption to take place close to one another and for communities and households to exercise greater control over their energy supply through energy cooperatives, community energy, etc. As such, the energy system can undergo a process of 'democratisation' (Morris & Jungjohann, 2016; Szulecki, 2018). Such developments also reduce interaction with other states and could reduce geopolitical competition. Importantly, it is also an effective way of alleviating energy poverty in remote, rural areas (Pereira et al., 2010; Szabó et al., 2013).

Yet, decentralisation will not always reduce tensions, as O'Sullivan et al. (2017) write. First, self-sufficiency can reduce the incentive to avoid conflict. In the dispute between Russia and the West over Ukraine, the EU has ensured that natural gas remained exempt from sanctions. If the EU were better supplied with renewable energy, it could have imposed sanctions on natural gas, potentially aggravating the conflict with Russia. Second, decentralisation can weaken the control of central governments. The tax system and government revenues come under pressure if consumers go 'off the grid'. Third, if communities can meet their own needs, independently from central governments, this might empower them to demand far-reaching political reform. Fourth, geopolitical concerns will shift from energy inputs (fuel) to material and technological inputs (equipment).

5.2 | New trade patterns: low-carbon supply chains

5.2.1 | Critical materials

Minerals—including rare earth elements (REEs) and metals required for renewable technologies—form a key element of emerging low-carbon supply chains (Bazilian, 2018; Habib et al., 2016; IRENA, 2019a; Månberger & Johansson, 2019; OECD, 2019; O'Sullivan, 2017; Overland, 2019; Smith Stegen, 2015; IEA, 2021b) (Here, new reference 'IEA, 2021b' should be added). The main cause for concern is that the low-carbon transition will lead to soaring demand for critical materials, such as lithium and cobalt, in turn creating geopolitical competition (Bazilian, 2018; de Ridder, 2013; Rabe et al., 2017; Resnick Institute, 2011). One often invoked precedent is China's 2008 decision to restrict the sale of REEs to foreign buyers, which led to widespread panic and price hikes (Raman, 2013). In order to help manage the potential risks, research has also formulated policy recommendations to secure low-carbon supply chains (Goldthau & Hughes, 2020; Sovacool, Ali, et al., 2020).

Just as with oil and gas reserves, the geographic concentration of critical materials production and reserves can lead to a 'scramble for resources' as countries (and companies) seek to control strategic aspects of the supply chain. Today, China produces 63% of the world's REEs and currently holds 36% of reserves (USGS, 2020, p. 133). It provides 98% of the EU and 80% of the United States's REE supply. And China's expanding dominance goes beyond REEs. Gulley et al. (2019) warn that China's efforts to mitigate its own mineral supply risk—through overseas foreign direct investments—such as cobalt mines in DR Congo—could limit mineral availability for other countries, resulting in rivalry over access to different types of minerals (Gulley et al., 2017; Conway & Ackerman, 2020). There is also growing concern over China's potential control over lithium supply chains which, along with cobalt, is currently a critical raw material for electric vehicle (EV) batteries (BNEF, 2020a; Olivetti et al., 2017). Consequently, the United States and the EU are stepping up efforts to minimise their dependence by creating alternative supply chains and technologies (European Commission, 2020; The White House, 2020, 2021).

A 'new resource curse'—associated with the low-carbon supply chain, its possession and access to critical materials—could potentially emerge (O'Sullivan et al., 2017). The production and sale of these materials can carry significant rents, which in turn, could hinder development of domestic institutions, similar to that experienced by some fossil fuel producer economies (Månberger & Johansson, 2019)[3]. Others, however, warn against comparing it to the scramble for oil. First, REEs are not actually that scarce and are found in many countries (IRENA, 2019a; Lovins, 2017; Overland, 2019). Second, technological innovation to replace certain materials and recycling can help diminish unilateral dependencies (ICMM, 2012; Månberger & Stenqvist, 2018; Pavel, Lacal-Arántegui, et al., 2017a; Pavel, Thiel, et al., 2017b). Tesla, for example, recently announced that it will start developing cobalt-free EV batteries.

5.2.2 | Low-carbon products and energy carriers

New trade patterns are emerging around energy carriers (such as hydrogen), bioenergy and low-carbon technologies: from solar PV panels and wind turbines to smart meters and EVs (IRENA, 2019a, 48). As with critical materials, their global supply chains and production networks can cause new sources of geo-economic competition and conflict.

Today, China produces some 70% of the world's solar PV modules (IEA, 2020a, p. 21). In the early 2000s, the rise of China's solar PV industry could be attributed to international demand, mainly in Europe and the United States. As demand started to decrease in the aftermath of the global financial crisis, the EU and the United States initiated trade protection measures against Chinese solar producers, accusing them of receiving unfair state subsidies (Hughes & Meckling, 2017; Voituriez & Wang, 2015). To protect its industry, China had no choice but to expand demand in its domestic market (Liu & Xu, 2018, p. 863). Today, China has the highest installed capacity in the world and remains the largest solar investor (IEA, 2020b; REN21, 2020). Some authors observe a similar pattern of emerging geo-economic competition in the auto industry around EVs (Dimsdale, 2019; Paraskova, 2020).

Modern bioenergy provides around 5% of total global final energy demand, accounting for around half of all renewable energy in final energy consumption in 2018 (REN21, 2020). It fulfils an important role in the low-carbon transition strategy of many countries. Biofuels, such as bioethanol and biodiesel used in transport, have become important globally traded commodities (IRENA, 2019a, p. 53). Some countries, like Brazil, have benefitted from this biofuel 'push', turning them into 'renewable energy powers' (Bastos Lima, 2012; Bastos Lima & Gupta, 2013). In turn, biomass, in the form of wood pellets, is mainly used to decarbonise (coal-dominated) power generation and heating. Globally, pellet use for electricity generation alone increased 2.5-fold between 2014 and 2018 (REN21, 2020, p. 87). China and the EU are the world's largest producers and consumers, although China is far less involved in international trade.

Concerns have been raised about the environmental impact of bioenergy, the potential conflict with food production and the fact that bioenergy trade is vulnerable to the same supply risks as imported fossil fuels: exporters that control production and delivery could cut or reduce supply (Smith Stegen, 2018). But many countries are addressing the sustainability issue, including through stricter and more comprehensive regulation or the development of next-generation biofuels. Moreover, the 'energy weapon' argument seems unlikely. Only a small proportion of biofuels is traded internationally, while in the EU, the world's largest importer of biomass, total contribution of imported biomass is not expected to exceed 10% of supply (PwC, 2017, p. 15).

Low-carbon energy carriers, such as green hydrogen, also have the potential to create new trade patterns and associated risks. The question has been raised whether hydrogen will become the 'new oil' during the low-carbon transition (van de Graaf et al., 2020). Today, 99% of hydrogen today still is 'grey', or produced from (mostly unabated) fossil fuels (IEA, 2019). But green hydrogen, using renewable power, can help decarbonise hard-to-abate sectors such as the steel industry, it offers long-term storage solutions, and long-distance transportation options for renewable power (Patonia & Poudineh, 2020; van de Graaf et al., 2020). Coupled with rapid and massive renewable electricity cost declines and expected cost reductions for electrolysers, green hydrogen—produced from low-carbon power—is gaining political and economic momentum.

Hydrogen could meet up to 24% of the world's energy needs by 2050, with annual sales of around US$ 700 billion (BNEF, 2020b). Research focuses on the geopolitical implications of an emerging global hydrogen market (Nagashima, 2018; Pflugmann & De Blasio, 2020; The Royal Society, 2020; van de Graaf et al., 2020). van de Graaf et al. (2020) outline three geopolitical implications: first, the creation of new dependencies between states if a large-scale import path is taken (with the risk of hydrogen becoming an energy weapon); second, a change in constellation of energy transition 'winners and losers' as hydrogen can throw a lifeline to natural gas exporting countries; and third, technological and geo-economic rivalry between states.

5.3 | Digitalisation and cybersecurity

Developments in ICT—most notably smart grids—are radically transforming the interconnectivity, reliability and efficiency of the energy system. Digitalisation is important to ensure grid stability as the variability, scale and distribution of energy sources increase, and the distinction between consumer and producer begins to fade (IEA, 2017; IRENA, 2019a).

Digitalisation, however, creates new threats around cyber security and privacy, so it has attracted attention in policy-making and academic circles (Barichella, 2018; Hawk & Kaushiva, 2014; Johnson, 2017; Liu et al., 2012, McLarthy & Ridge, 2014; Overland, 2019; Pearson, 2011; Sivaram & Saha, 2018). Grid hacks have been described as 'the modern-day equivalent of a nuclear strike' (Hielscher & Sovacool, 2018, p. 987). The main argument is that dependence on complex control systems associated with electrification, interconnection and digitalisation can lead to strategic vulnerability, which could be averted by switching to small-scale distributed generation (Liu et al., 2012; Månsson, 2015; Vakulchuk et al. 2020).

In recent years, some European authorities have prevented China's State Grid from purchasing shares in certain electricity networks and utility companies because of national and security risks (IRENA, 2019a, p. 58). Another often-mentioned example is the December 2015 cyber-attack against Western Ukraine's power grid, leaving almost a quarter of a million people without electricity for hours in the middle of winter. This was the first ever confirmed hack to take down a power grid (Overland, 2019). But the Ukrainian hack did not involve a high-tech grid based on renewables; quite the contrary. Hence, these cyber risks are not limited to renewables-based electricity grids. Further, it can affect all types of critical (energy) infrastructure reliant on digitalisation, such as the control of oil and gas platforms and pipelines, LNG tanker navigation or even nuclear power stations, as the May 2021 cyber-attack on the Colonial pipeline in the United States shows (Overland, 2019; Vakulchuk et al., 2020), and it involves other sectors as well, such as banking, IT, industry and mobile telephony[4]. However, as the world becomes increasing reliant on electricity and smart grids, so the risks increase.

6 | CONCLUSIONS: TOWARDS A WHOLE SYSTEMS GEOPOLITICS

The global energy landscape has undergone a dramatic transformation since the 2009 review. Then, policy-talk was of fossil fuel scarcity and an impending peak in global oil production, while the key source of geopolitical tension was between fossil fuel exporting and importing states with armed conflict often being described as being "all about oil" (Bradshaw, 2009, p. 1927). Fast forward to 2021 and the emerging new energy order is foreseeing a world after oil, though still decades away, as EST gathers pace to address the existential threat of extreme climate change.

The current geopolitical landscape reflects a continuation of many of the familiar tensions associated with fossil fuels, with the added dimension of conflict over the world's remaining carbon budget as producers seek to ensure that their assets are not stranded, and rents foregone. In this world, geopolitics will intervene to ensure that the remaining fossil fuel demand is not simply allocated to the lowest cost producers. High-carbon transitions are going to be messy affairs with winners and losers that are likely to cause tension and conflict, particularly as many of the world's producer economies are already politically fragile and in regions that are unstable. As we have described, one potential route to avoiding conflict is to recognise the potential losses and the need to manage 'just transitions'. It should, for example, come as no surprise that one of the most hotly debated topics of the EU Green Deal concerns the distribution of funds within its 'Just Transition Mechanism'.

Coincidental to high-carbon transitions are the much-heralded low-carbon transitions that are the focus of a wealth of new research. We have demonstrated that a low-carbon energy system based on renewables and electrification would not be free of the geopolitical tensions associated with fossil fuels. Many elements are cases of 'new problems in old clothes' including, for example, geo-economic competition to control supply chains for critical materials associated with renewable energy generation, electrification and energy storage; the interdependencies created by transnational power infrastructure; and the emergence of new patterns in international trade in biofuels, biomass and potentially hydrogen all echo the types of problems associated with fossil fuel production, trade and consumption. While it is true that the relative magnitude of international trade in energy commodities will fall, it will be replaced by global production networks that deliver low-carbon technologies to consumers. Already we see international rivalry between states and corporations over these perceived threats as they are determined to be the winners in the emerging zero-carbon global economy. In other words, there is unfulfilled potential to deploy a more 'critical' approach to energy geopolitics that considers the social construction of the various narrative around energy transitions.

There is considerable disagreement over the pace of the EST, though there is consensus that it is currently too slow to constrain global warming to less than 2°C this century. It remains unclear whether 2020 and the COVID-19 pandemic will mark a turning point for global climate change efforts. What is clear, however, is that the 2020s will be the decade when the beginning of the end of the fossil-fuel-based energy system becomes clear and the geopolitical contours of a low-carbon system start to emerge. The two processes are not mutually exclusive and how they interact has not been subject to much research. Geopolitics scholarship must also transcend its current bias towards energy supply—replicated in this review—and start engaging with the growing impact of demand-side measures such as improvements in energy efficiency and demand reduction. These could reduce the cost of the transformation, for example, by reducing demand peaks and the total amount of power needed to provide the necessary energy services.

Thus, our final conclusion is to recommend a 'whole systems approach' that maps both sides of the transformation and the interplays between them to make possible a managed and just transition that reduces the tensions and conflict that could slow the progress of decarbonisation. A better understanding of the intricate relationship between politics and (changing) energy systems is required because the shape and pace of EST are largely dependent on the real and perceived interests, threats and vulnerabilities of all stakeholders involved.

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ORCID

Mathieu Blondeel https://orcid.org/0000-0002-3232-5817

ENDNOTES

[1] We define 'producer economies' as large oil and gas exporters who are 'pillars of global supply' and rely on hydrocarbon revenues to finance a significant proportion of their national budgets (IEA, 2018).

[2] Although this is not always the case. Bi-directional gas pipelines, or *interconnectors* (e.g., between the United Kingdom and mainland Europe) enable flow of natural gas in two directions.

[3] Alternatively, some research has focussed on how countries producing and exporting large amounts of renewable energy are also vulnerable to the resource curse, although this does not seem very likely (Eisgruber, 2013; Hancock & Sovacool, 2018; Månsson, 2015; Sovacool & Walter, 2019).

[4] Recent public discussions about the roll-out of Chinese G5 technology in the EU and United States show how this affects sectors other than energy.

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AUTHOR BIOGRAPHIES

Mathieu Blondeel is a postdoctoral Research Fellow at the Warwick Business School.

Michael Bradshaw is a professor of Global Energy at the Warwick Business School. He works at the interface between economic and political geography, business and management, and international relations. He is a Fellow of the Royal Geographical Society (and past Vice President) and a Fellow of the Academy of Social Sciences.

Gavin Bridge is a professor in the Department of Geography of the University of Durham.

Caroline Kuzemko is an associate professor in International Political Economy in the Department of Politics and International Studies of the University of Warwick.

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