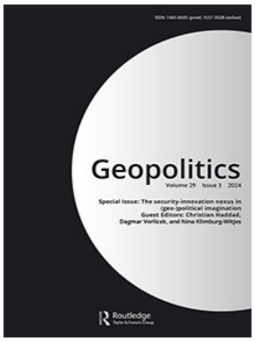


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# Rethinking Energy Geopolitics: Towards a Geopolitical Economy of Global Energy Transformation

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**ABSTRACT**
We are in the midst of a global energy system transformation (GEST) which is rewiring the world economy, opening new axes of political contestation, and revolutionising the energetic basis of human civilisation. Energy geopolitics has not yet reconciled itself to this challenge. The field has traditionally been preoccupied with the dependence of Western states on cross-border flows of fossil fuels. More recently, efforts have been made to prospectively map out what the geopolitics of a fully renewable world might look like. What both literatures miss, however, is the very fact of the GEST: that we are living through a changing and contested process of global transformation, across interacting high- and low-emissions systems, whose contours are open and actively constructed over time. In this paper, we start to develop a provisional framework to make sense of the GEST, that is able to capture the full scale of the transformation, and its dynamic, contingent, constructed nature. We attend to three areas of geopolitical economy: the wide-ranging material dimensions of the transformation, its geographical space-making, and its conflict-ridden political economy. We then apply this framework to two case studies, one looking at the fraught role of fossil gas as a 'transition fuel', the other at lithium-ion batteries.

## Introduction

For a century, international energy relations have been dominated by fossil fuels, whilst energy geopolitics has had a great deal of influence over how we frame these relations. More recently, however, a global energy system transformation (GEST) has commenced,[1] which forces us to reckon with what is too often downplayed: the contingent, conflictual, socially produced character

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of the global energy system. It is precisely because of this that so much is at stake. On the one hand, greenhouse gas (GHG) emissions reductions are a key characteristic of the GEST: countries responsible for over 88% of global emissions have committed to net zero GHG emissions (Zero Tracker 2024), and renewable energy has started to scale at pace, with some now projecting a peak in oil demand by 2030 (IEA 2023c). On the other hand, the world still derives over 80% of its energy from fossil fuels, and the threat of catastrophically over-shooting the Paris Agreement is palpable. Visions of the transition reflect this discrepancy, offering different accounts of the pace, scope, technologies, and socio-political forms of change (Bazilian et al. 2019; BP 2022; IEA 2021; Newell 2019; Shell 2021; Sovacool 2016). The GEST opens out into many, competing futures.

Attempts to reduce global emissions are now taking place in an era of multiple crises, amidst frequently competing priorities of energy security, affordability, and economic development, and as the physical effects of climate change continue to bite. The 2022 energy crises, resulting largely from Russia's war on Ukraine, highlight these tensions within the GEST. European governments have responded with a mix of newly-ambitious renewable targets and an expansion of fossil fuel exploration and import infrastructure, as they have negotiated between the short-term exigencies of energy security and the long-term imperative of decarbonisation. In Asia difficulties in accessing Liquid Natural Gas (LNG), in part due to the EU's scramble for gas to replace Russian imports, have caused energy affordability crises and a switch back to coal for electricity generation (Kuzemko et al. 2022). The current energy crisis highlights how geopolitics can create pressures to both decelerate and accelerate the transition (Blondeel et al. 2024).

In this paper we stage a thematic and theoretical re-orientation of energy geopolitics. We rethink each of the constituent elements of 'energy geopolitics', energy, geography, and politics, to make sense of the reality of the *transformation* of the global energy system – its drivers, contradictions, and contingencies. This necessitates breaking from purely 'realist' and 'geotechnic' understandings of energy geopolitics, and offering a constructivist alternative capable of understanding the active and changing social production of energy materialities, geographies and political economies over time. This also allows us to better encompass the complexity and interconnections between these three areas. Our aim is to reorient the direction of the field of energy geopolitics towards, rather than offer a final account of, the GEST. The provisional framework we offer here is conceived in this spirit; it is intended to be suggestive, not exhaustive, and to spur a wide process of rethinking.

The paper proceeds as follows. In section two we set out the starting coordinates of this re-orientation by articulating a critique of existing approaches to energy geopolitics. In section three we draw from disparate literatures, ranging from energy geography, to socio-technical transitions, to international political economy (IPE), to rethink each element of 'energy geo-politics'. In section four we work through all three dimensions of this approach in relation to two case studies, the role of fossil gas as a 'bridge' fuel, and electrochemical energy storage – both focal points of the GEST. In the conclusion we briefly explore some of the conceptual, empirical and policy implications of our attempt to reorientate energy geopolitics.

## A Critical Review of Energy Geopolitics

Is energy geopolitics equal to the challenge of understanding this tension-riddled global transformation? Despite the field's multifarious insights, we think not. In order to see why, it is necessary to say something about the field of 'geopolitics' as such, and the emergence of both 'neo-classical' approaches to energy geopolitics, and the fledgling field of renewable geopolitics. We use this brief history and critique as a foil for our own approach.

The original, or 'classic', tradition of geopolitics stretches from the fin de siècle to the end of the Second World War. Proponents held in common the modernist goal of creating a scientific macro-mapping of the world to guide their nations in an era of inter-imperial conflict, as well as certain ideas: like social Darwinism, geographical determinism, and moral relativism (Criekemans 2022; Kearns 2009). But the perceived association of geopolitics with Nazism tainted the enterprise, at least outside of South America. This was largely on account of the Bavarian geopolitical thinker Karl Haushofer's relationship to the Nazi party, influence on the writing of *Mein Kampf*, and apologia for German revanchism, which met with sensational and exaggerated coverage in America's wartime press (Specter 2022, 50-67, 118-119; Barnes and Abrahamsson, 2015). What followed? On the one hand, there is the afterglow of classical geopolitics. It was one of the cocktail of ingredients blended into the more palatable theory of 'realism', which came to dominate the post-war study of international relations in the United States (Specter 2022, 132–135, 203–205). The term 'geopolitics' was slowly re-popularised from the 1970s, most notably by Henry Kissinger, largely as shorthand for a realist-inspired vision of global power politics (Hepple 1986). This loosely-defined body of thought is sometimes called 'neo-classical geopolitics' (Mamadouh 1998), a convention we follow. On the other hand, a constructivist school of 'critical geopolitics' emerged in the academy in the 1990s, investigating and problematising all spatialised representations of international politics, across theories, statecraft and popular media (Ashley 1987; Tuathail 1996; Tuathail and Agnew 1992).[2]

Born of the 1973–74 OPEC oil crisis, energy geopolitics first emerged as a genre of neo-classical geopolitics (Bradshaw 2009; Conant and Gold 1978; Mitchell, Beck, and Grubb 1996; Odell 1974; Schlesinger 1979; Yergin 2012). Neo-classical authors tend to view the energy system from the vantage point of net energy importing Western states, and their interest in securing cross-border oil and gas supplies. While this focus on the fragility of internationally-traded oil and gas does have the salutary effect of emphasising the role of energy as the 'lifeblood' of modern economies, sustaining daily life and socio-economic development, it also occludes a great deal. Among other things, we hear little about the downstream energy services and domestic policy driving demand, about land use change, society and environment, or about other sources of energy. Its politics fixate on the significance that asymmetries of fossil fuel trade and dependency have for interstate rivalry. Its geographical vision foregrounds uneven resource endowments, critical waterways and transit routes. Often these geographical factors are taken as given, creating one-way causality where a reified geography conditions international politics, but not the other way round (a point emphasised by Blondeel et al. 2024). A focus on cross-border fossil fuel flows, a reified geography unilaterally conditioning international politics, and a fixation on state power politics: these are the limits of neo-classical energy geopolitics.

More recently, a literature on renewable energy geopolitics has emerged (IRENA 2019; O'Sullivan, Overland, and Sandalow 2017; Scholten 2018; Scholten et al. 2020; Vakulchuk, Overland, and Scholten 2020). Much of this work follows a common pattern.[3] It starts with the geotechnical features of a world powered by renewables, from which it then deduces constraints and opportunities binding on the future of international politics. By juxtaposing this picture with a fossil-powered world, it is able to bring into relief the nature and scale of these predicted changes, as well as its beneficiaries and losers. We can, for example, deduce from the global dispersion and abundance of renewable resources that it will give rise to a less oligopolistic global energy trade. Or, from the techno-economics consequent to the efficiency losses per distance travelled of high-voltage electricity cables, that the benefits of interconnection will find an upper-limit at the level of regions, leading to bounded 'grid communities'. Rich with insight, a major lesson to come out of this literature is that a fully renewable global energy system will likely be a less tension-ridden one.

But there are limits to renewable energy geopolitics, too. It, like neo-classical variants, tends to represent politics as a response to, or as an *outcome* of, fixed energy geographies and materialities, rather than as a *key social input* into how energy systems and geographies change. Its synchronic analysis of a fully renewable system, held in static juxtaposition to a fossil-powered world, elides the global energy system *transformation* – a diachronic, unfolding process. It can only proffer predictions as to a renewable world in the distant future by focusing on those *necessary* features of it that can be deduced from the fixed geotechnical characteristics of renewables. Taken together, this means it systematically downplays the role of contingency, uncertainty and politics, and the dynamic process of social change that will lead to some *specific* renewable future. More prosaically, over the coming decades, it is the global energy system transformation, and not a fully renewable-powered world, that we will have navigate. The latter depends on the former's success.

Our aim in this paper is to re-orientate energy geopolitics to the challenge of transformation, by offering a provisional framework for understanding the GEST as a socially produced, conflictual and diachronic process. This requires, first, starting from the reality of the unfolding transformation, where low-carbon and high-carbon sub-systems intersect and compete, and where neither can therefore be understood independent of the other. We need a 'whole systems' geopolitics reaching *across* high- and low-carbon subsystems, and *up and down* their entire supply chains. But, more substantively, it means taking seriously the *socially produced* character of the GEST. In saying this, we are not suggesting a voluntarism where human agency supersedes social structure, or an ontological idealism in which the physical world does not figure. The point is a constructivist or historicist one. The global energy system does not have a determinate structure, it is not reducible to pre-given characteristics of geography, power politics, or techno-economics. Rather, it is contingent and open-ended because it is mediated by the contested social practices of specific historical contexts. While we can speak of a certain distribution of fossil or renewable resources as conditioning geopolitics, for example, how these conditions emerge from and impact society, how actors understand and respond to them, and what their secondary effects are, reflect socio-political processes. The geopolitical economy of the energy system is not self-instantiating.

## Re-Orienting Energy Geopolitics

In this section, we build on the principal critiques of each aspect of energy geo politics, outlined in "a critical review of energy geopolitics", to rethink 'energy' and 'geo-politics'. In doing so, we delineate a provisional geopolitical economy framework for approaching energy system transformation. We take a constructivist, inter-disciplinary approach that integrates insights from energy geography, socio-technical transitions, and international political economy. This process of re-orienting energy geopolitics necessarily involves big picture thinking within each of these three elements. This leaves abundant room for future scholarship to add to and complicate our account, including by attending to the meso- and micro-levels.

### *Foregrounding the Materialities of Energy*

Neo-classical and renewable energy geopolitics both focus our attention on the importance of natural resources, where they are found and produced and how they are transported, to energy systems and politics, but leave other material and technological aspects of energy underdefined. Neo-classical energy geopolitics has tended to define the material aspects of energy in relation to fossil fuels, sometimes just oil, and their associated conversion and transport infrastructures (Jones 2016).[4] Unsurprisingly, given that the emphasis has been on understanding existing production and consumption patterns and cross-border flows of energy resources, both energy and geography in neo-classical energy geopolitics are treated as 'givens' – the former is reduced to oil and gas, and the latter to a 'static mosaic of inherited difference' (Bridge et al. 2013, 337).

Renewable energy geopolitics scholarship has typically focused on static comparisons of fossil-based and renewable-based systems, rather than attempting to get to grips with their simultaneous, interacting and dynamic roles in the GEST. But it is, nonetheless, rich with insight. It explicitly extends the definition of energy to include renewables, draws attention to the increasing importance of critical materials within renewable energy systems and highlights the growth of demand-side technologies and infrastructures such as storage (Criekemans 2018; Scholten 2018; Vakulchuk, Overland, and Scholten 2020). Our conceptualisation of GEST continues this direction of travel by defining energy materialities to include a wider range of resources, technologies, and global production networks and supply chains to reflect better how energy systems are changing.

Further, although forms of energy, infrastructures, and technologies are deeply embedded within society today, making them seem fixed, we explicitly see energy materialities as constructed and maintained to meet socio-economic demands, and therefore open to active recreation (Geels 2005; Shove and Walker 2010; Stripple and Bulkeley 2019). For one, energy systems are changing because the extensive role of fossil fuels in (re)producing (the materiality) of lives, and generating rents and profits, is no longer socially tenable.

### *Complexity and Diversity in the Material Attributes of Energy*

Centring the material attributes of energy systems, and emphasising their interdependencies and tensions, is a primary step towards revealing growing energy diversity and complexity. Inspired by Van de Graaf and Sovacool (2020, 16), we see the global energy system as comprised of a wide-ranging array of interconnected, material attributes that together deliver energy services to society. This includes: primary and secondary energy resources; non-fuel material inputs; systems of energy conversion, including prime movers; transport infrastructures; household, commercial and industrial users; technologies for storing and harnessing energy; and GHG emissions. By including GHG emissions, non-fuel material inputs, and technologies for storage, we seek to emphasise just how important these attributes of energy systems have become.

This capacious understanding of the material basis of the energy system allows us to recognise the full gamut of its transformation as the world decarbonises. For example, not only are primary sources becoming increasingly diverse, now including oil, gas, coal, biomass, geothermal, wind, solar, hydro, and wave, but differences in their GHG emission attributes increasingly matter to their (continued) role in energy systems. The growing role of hydrogen as a secondary source is also significant, not least as it creates increasing complexities in the conversion of primary to secondary energy. Non-fuel inputs, including manufacturing processes and material resources, are also diversifying, and becoming an increasingly significant aspect of energy systems.

Foregrounding the material attributes of energy helps us to see how primary resources do not equate to globally accessible energy services without the, now increasingly complex, material systems that sustain energy extraction, harnessing, processing, conversion, transport, and trade (Balmaceda et al. 2019; Scholten and Bosman 2016). In short, the material qualities of energy systems matter and not only because of their high- or low-emissions potential: changes in one set of material attributes – such as substitution among primary resources – implies shifts in many other attributes of the energy system, including its sources, infrastructures, key sites, and spatial connectivity. Attention to the material qualities of energy systems, then, is a first step to examining the implications of energy system transformation for geographies and political economies.

One illustrative and important example is the ongoing shift from fuels as primary resources, defined by energy content, released by combustion, and consumed by use, to materials that harness ambient energy sources. This is important, in political economy terms, as these mineral-based materials are not valued by decision-makers in R&D, industry and policy for their energy content but for their technological capacities, and because they are not consumed by use, they can potentially be recovered, recycled, and reused. During the global renewable electricity build-out phase there will be significant demand for minerals and metals, including many classified by governments as ‘critical’ given their importance in national economies and degree of import dependency. However, the life cycle and temporal profile of these materials are different to those of fossil fuels (and the fuel rods in nuclear energy) in important ways: minerals and metals can, if well designed, be reused multiple times so that they remain in circulation, as opposed to oil, coal and gas whose function as fuels is destroyed through use. One implication of this is the emergence of a whole new political economy of materials associated with low-emissions systems which is not present in high-emissions, fossil-fuel heavy systems (Bridge and Faigen 2022).

This includes an emerging 'circular economy' of materials reuse and recycling and associated geopolitical efforts to capture and 'territorialise' these circular flows, for example the EU's Circular Economy initiatives. These imply new international relations because of the fundamentally different character of e-tech materials versus fossil fuels and nuclear energy.

### *High- and Low-Emissions Energy*

An equally important step towards centring the material complexity of energy is to see the global energy system as being made up of two distinct, connected and transitioning sub-systems, which we refer to simply as *high-* and *low-emissions*. Each of these sub-systems, in turn, can be further disaggregated into more sub-systems – such as gas, electricity, or electro-chemical storage. This is a significant departure from neo-classical and renewable energy geopolitics as it means we are no longer analysing just one global energy system, i.e., an incumbent fossil fuel OR renewables-based system, but two major sub-systems competing and intersecting with one another.

There are important temporalities at work here, beyond questions of whether energy emissions can be reduced in time to meet global targets. The low-emissions energy system needs to be sufficiently developed, providing resilient, accessible, and affordable services, in time to replace high-emissions energy. At the same time, material changes in the energy system have, thus far,

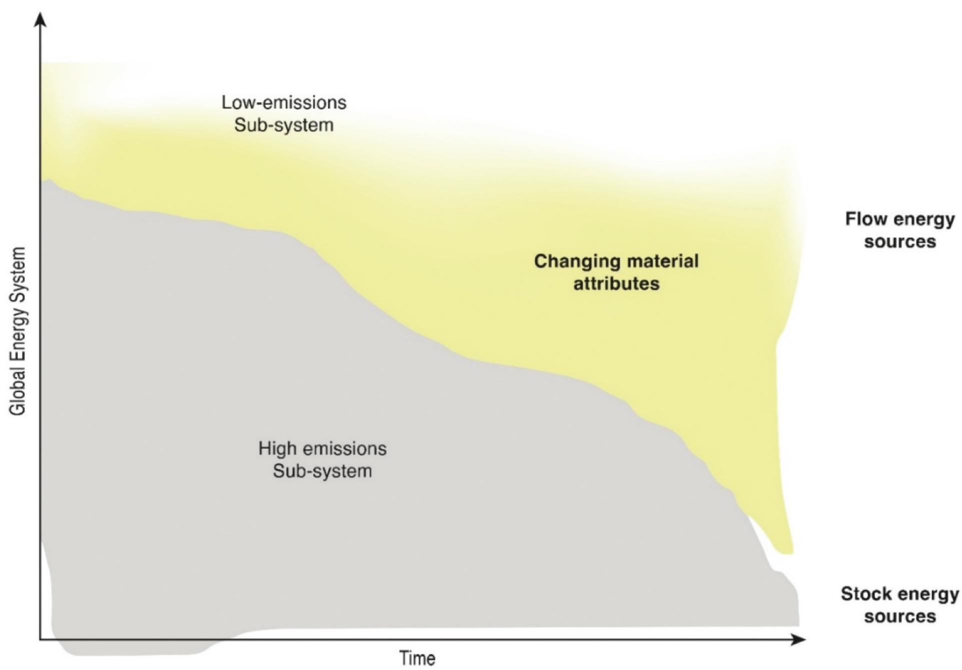


**Figure 1.** Changing material attributes of the global energy system.

been heavily concentrated in adding low-emissions technologies, but far less in decommissioning and disassembling the high-emissions system (Blondeel et al. 2021; Bridge 2018). As such, when considering the material attributes of energy, we see the high- and low-emissions systems co-existing for many decades to come – see Figure 1. Ultimately, given global GHG emissions reduction targets, the end point should be a low-emissions energy system.

This conceptualisation also reveals ambiguities and material crossovers between sub-systems. Take, for example, fossil gas. If carbon capture and storage (CCS) is successfully deployed, fossil gas could be a primary resource in the low-emissions system, albeit involving very different systems of conversion. This would have knock-on effects across the energy system. It implies a future that would be less renewables based, and more complex, than that which renewable energy geopolitics often envisages (IRENA 2019). By studying high- and low-emissions sub-systems together within the transformation, we can ask increasingly pressing questions about the persistence of fossil fuels and their interdependencies with low-carbon materialities, rather than just assuming low-emissions energy will 'disrupt' high-emissions energy by providing alternatives. This is important when considering questions of political economy about incumbency and stranding, and how the costs and benefits of the global energy system are distributed over the course of the GEST.

### *Geography, Space & Scale*

There are useful notions of space embedded within energy geopolitics, such as the strategic importance of location, geographical differences between fossil fuels and renewables, and the influence of physical geography on transportation routes (Scholten et al. 2020). For example, renewable energy geopolitics argues that the relative geographical ubiquity of renewable versus fossil fuel primary resources alters the basis for international energy relations (Overland 2019). The range of renewable resources, combined with their wide distribution, means that most countries in the world will be able to produce some form or another (Criekemans 2018, 54–56). Geographical constraints still apply to renewables – certain locations, of course, have a relatively greater abundance of solar, wind, land (for biomass) or wave energy. Renewable energy geopolitics, then, begins to acknowledge the consequent spatial changes of renewables.

Thus far, however, the geography of energy geopolitics is understood rather narrowly – still emphasising resources, territory, states and borders. Research in the field of energy geographies has, however, begun to think more systematically about the re-working of space consequent to energy system transformation and provides a useful vantage point for rethinking geography in relation to energy and politics. Energy geography largely adopts a socio-technical, constructed view of energy system transformation. To enrich the spatial repertoire of GEST further, we draw on this literature to outline four additional ideas – production of space, uneven development, scale/scaling, and power density. These help to reveal further geographical aspects of energy systems as they undergo transformation.

Neo-classical energy geopolitics acknowledges that energy geographies have implications for politics but offers few insights on how transformations in the way energy is captured, transformed, and consumed can also have far reaching geographical consequences. The emergence of new landscapes of, and possibilities for, energy generation associated with renewables vividly illustrates how energy transformation can re-work both place and space (Kuzemko 2019). The closure and abandonment of facilities associated with fossil fuel production, transport and consumption, and parallel calls for 'just transitions', highlight the other pole of this creative-destructive process, and its capacity to marginalise places and communities within regional and national economies (Bridge and Gailing 2020; Bridge et al. 2013; Calvert 2016; Castán Broto and Baker 2018; Jiusto 2009; Nadai and van der Horst 2010).

### *Production of Space*

Production of space, a first-order concept for much of human geography, expresses an important idea for understanding the geopolitical economy of the GEST. To describe space as 'produced' is to understand geography as a social product, an outworking of political-economic relations and, therefore, historically malleable and open-ended rather than fixed. This contrasts with neo-classical energy geopolitics' understanding of space, which regards geography as a set of fixed dimensions and attributes, primarily those of physical geography, in which space is akin to a stage or container upon/within which energy systems unfold. The production of space is a valuable conceptual tool, given our task in this paper, because it centres very directly on how energy system transformation is a 'space making process' (Bridge and Gailing 2020, 2; see also Newell 2019). The production of space offers a 'post-Cartesian' perspective, directing attention away from mapping 'geographical consequences' of energy (Bridge, Özkaynak, and Turhan 2018, 13).[5]

This production of space is consistent with energy geography's focus on understanding energy not only 'as an economic asset or ecological phenomenon … (but) as a social relation' (Calvert 2016, 110). Highlighting the produced character of space draws attention to the new geographies emerging from the GEST, such as the way low-emissions energy systems introduce new economic, cultural and political attachments to places that can radically transform their meaning and wider role. For example, the scaling up of battery electric vehicle production has substantially revised the meanings and global role of the Salar de Atacama (Chile) and Salar de Uyuni (Bolivia). It has produced the space of the 'Lithium Triangle', as a target of largely foreign investment in extraction and processing, and as an object of state strategy in both countries (Forget and Bos 2022). Such places have consequently become sites of existential struggle for traditional land users (often not recognised as landowners) who value them for subsistence farming and their ecology, biodiversity and water rather than their lithium (Bustos-Gallardo, Bridge, and Prieto 2021). Here new productions of space intersect directly with new social and political contestations of low-emissions energy.

### *Uneven Development*

The 'uneven' character of development builds on the production of space and alludes to the spatially variegated character of energy systems. This stubborn fact of geographical difference is characteristic of the 'messy' and contingent nature of the GEST. Rather than attribute this variegation to fixed or innate qualities, however, it focuses on how difference emerges and is reproduced over time. Work on uneven development thus highlights the tension and interplay between processes that tend to equalise conditions across space (such as the diffusion of technology or norms of consumption like thermal comfort), and those that actively differentiate it, including national territories differentiated by institutions, policies and norms (cf. Smith 2008).

Energy system transformation, then, may be a space-making process, but it is one also shaped by spatial and historical context (Bridge and Gailing 2020, 2). This is an important insight for GEST as it draws attention to how processes of transformation produce new regional winners and losers because of the way 'remnants of previous eras . . . are carried over and come into conflict with [the] new' (Brophy 2018), sometimes recreating existing power relations. In sum, the concept of uneven development allows us to see how geographic variation is inherent to the GEST and, moreover, how it arises through novel re-combinations of old and new shaped by geographical and historical context. The broader insight here is to move beyond accounts of emergent geographies of energy system transformation that stop at describing their spatial form and pattern, to explore how these new geographies reproduce or challenge existing distributions of political and economic power (Bridge and Gailing 2020).

### *Scale*

Scale describes the material size and areal extent of phenomena and focuses our attention on hierarchies of *potential* organisational forms that characterise the material attributes, and politics, of energy systems (Bridge et al. 2013; Goldthau 2014; Kuzemko 2019). Scale, therefore, is a very useful concept for examining the claims and objectives of a socially produced energy system transformation, which is frequently characterised by normative claims about the technical, organisational, and geographical forms through which both supply and demand should be managed. Such questions are particularly significant for renewable energy technologies as they can be deployed across a very wide range of material sizes. This is what Walker and Cass (2007) termed the 'hypersizeability' of renewable energy hardware, as exemplified by the enormous variation in the diameter of wind turbine blades, from 1 metre to over 150 metres. Scale, then, is important for an analysis of GEST as it highlights political questions such as who is affected, who has a capacity for action, and where boundaries of responsibility may lie. This question of scale features in several dominant narratives of energy system transformation, such as the need to 'scale-up' critical technologies (be it CCS or battery storage) or the potential for re-scaling traditionally large installations (such as small modular reactors for nuclear power generation). Scale here references both the installed capacity of such technologies and geographical reach of their deployment.

Energy geography and IPE scholars have drawn out the analytical value of spatial scale by exploring links between hierarchies of technical and geographical scales and the administrative scales at which these technical and geographical elements are governed. Work has shown, for example, how decentralised parts of the energy system – distributed supply, end use technology, and determinants of demand – can be marginalised in settings (like the UK) where energy policy makers operate predominantly at the national scale (Kuzemko et al. 2016; Newell and Johnstone 2018). A tendency to treat decentralised actors as remote and unpredictable leads to a preference for 'reliable', centralised, supply side solutions, while 'the centralisation of policy arguably . . . results in ineffective policy when the object of "delivery" is widely distributed' (Bridge et al. 2013, 338; Eyre et al. 2010). Other scholarship has explored how small and medium scale renewable energy generation affects the geographies of energy systems (e.g., Scholl and Westphal 2017), a decentralisation that compresses the distances between primary energy sources, such as wind, conversion, electricity generation, and prime movers. This also affects the range of actors involved in sustainable energy to the extent that distributed renewables broadens out who can generate and who, for example, can become involved in active local trade and demand responses (Kuzemko 2019).

### *Power Density*

Finally, the geographical concept of surface power density can help us to reflect on where some of the political tensions and points of control arise in the shift away from fossil fuels. Surface power density can tell us, for each primary energy source, the horizontal surface area needed to produce the same quantity of exploitable energy (Nøland et al. 2022; Smil 2015). Renewable energy landscapes, as currently conceptualised, have power densities that are several orders of magnitude lower than resource landscapes associated with fossil fuel extraction and thermal power generation. This is because the latter rely on 'vertical', subterranean energy regimes that are, effectively, dense concentrations of solar energy accumulated over time and space (Huber and McCarthy 2017; Sieferle 2001).

As work in renewable energy geopolitics has begun to recognise, the logistics of energy capture and distribution for renewables are different to those of fossil fuel extraction and thermal power generation. Fossil fuel generation is based on: the control of highly concentrated energy forms, the transformation of energy into usable forms at very high power densities and in a relatively small number of locations, and the centralised distribution of energy from those large facilities. By contrast, energy strategies that target flow resources, like wind or solar, for electricity production require the co-ordination of multiple dispersed locations to manage their relatively low power densities and intermittency. This implies a growth in the number of energy resource landscapes, their potential overlay upon other land (or marine) uses, and the development of extended and new networked energy resource landscapes in which non-contiguous elements are nonetheless managed.

To the extent that renewables and electricity make up a greater share of energy, then, the GEST will involve a sharp uptick in the energy system's land requirements (Nøland et al. 2022). A low-emissions sub-system implies a '(re) turn to the surface' and, with it, potential for the intensification of the political economy of land ownership and control (Huber and McCarthy 2017). This will involve fraught, conflict-ridden trade-offs between energy conversion, and a range of competing demands on land, including biodiversity and forestation, meat agriculture, crop agriculture, local populations, and urbanisation. It will also heighten the visual impact of power production, bringing all the familiar political dynamics of contested infrastructural development, including location choice, planning permissions, and environmental concerns. At the same time, however, the lower power densities of renewables make it harder to replicate the level of control and excludability associated with concentrated fossil sources, potentially, increasing security of supply (Huber and McCarthy 2017). Of course, not all renewable installations require land given that solar and wind can be placed on existing surfaces, such as rooftops, as part of infrastructural installations. Decisions to increase offshore wind replicate old energy norms of 'out of sight, out of mind' – but open up other environmental and spatial planning issues along with a need for extensive new transmission networks.

### *Politics as Political Economy*

Both neo-classical and renewable energy geopolitics underplay the role of politics, and policy, in the social (re-)construction of energy system materialities and geographies. Neo-classical energy geopolitics focuses on assessing the implications of energy geographies *for* international relations and/or state-level energy security (Bradshaw 2009; Hogselius 2019), whilst renewable energy geopolitics explores potential outcomes of renewables-based energy *for* patterns of cooperation and conflict between countries (Criekemans 2018; Overland 2019; Scholten 2018; Smith Stegen 2018; Vakulchuk, Overland, and Scholten 2020). We argue that politics, and policies, actively drive, constrain, and shape energy materialities and geographies.

We turn here to Paterson's (2021) tri-fold conceptualisation of politics, as power relations, as arena for decision-making, and as inherently conflictual (Paterson 2021, 19–22), as a helpful framing device through which we can start to rethink the political aspect of the GEST. This framing acknowledges the traditional interest within energy geopolitics in conflict and power relations between states – but places relatively greater emphasis both on the agency of policy, in particular climate change mitigation, and on economic interests and actors in shaping the nature of the GEST. We adapt Paterson's conceptualisation, originally conceived to understand climate politics, to energy by incorporating insights from the political economy of sustainable energy transitions, particularly critical and constructivist perspectives (Kuzemko et al. 2016; Newell 2021; Roberts et al. 2018).

### *Politics as Power Relations*

Power relations shape the overall direction of the GEST and how the benefits and costs of change are distributed (Paterson 2021, 20–21). In part, the GEST reflects struggles between coalitions of actors pursuing strategies *for* and *against* GHG emissions reduction (see Burke and Stephens 2018; Kuzemko et al. 2016). Those actively resisting tend to be those that need to change their practices, and therefore both stand to lose the most and can leverage their power as incumbents to resist and shape change. Incumbent national (NOCs) and international oil and gas corporations (IOCs) continue to shape debates about, and delay, emissions reductions (Franta 2021; Newell 2021). The value and uneven distribution of fossil fuels means corporate and national fossil fuel actors have considerable capacities to influence energy and climate policy, bending markets, politics and geography to their interests (Colgan 2014; Mamadouh 1998; Vakulchuk, Overland, and Scholten 2020).

We deepen these explanations of power relations and incumbency by applying insights from research that places (fossil) energy systems at the heart of capitalism (Di Muzio 2015; Malm 2016; Mitchell 2011). IPE also emphasises the continued dominance of a broad range of elite factions of capital within global (energy) politics. This, like human geography's concept of uneven development, takes the politics of the GEST beyond matters of high versus low-emissions energy, to questions of *economic* incumbency and related questions of energy equity and justice (Bridge, Özkaynak, and Turhan 2018; Newell 2021). Recognising inter-dependencies between fossil fuels, finance, transport, and economic development extends the range of powerful actors with vested high-emissions interests. Banks, investors, global transport incumbents, political groups funded by high-emissions interests, and others that enjoy, profit and/or generate a wage from high-emissions energy all potentially stand to lose out financially and/or socially from the GEST. Powerful financial actors continue to invest in high-emissions businesses and to shape who has access to finance for low-emission alternatives, with many developing countries facing prohibitive costs of capital (Newell 2021). This expands our understanding of actors involved in the GEST to incorporate the breadth and depth of high-emissions incumbency.

Too much emphasis here can, however, obscure significant changes within energy power dynamics, including recent growth in the political influence and economic power of coalitions seeking to reduce emissions. Climate change mitigation is a fast-growing policy arena, reflecting in part ever-more perilous warning signs of climate breakdown. Today 133 countries and 1,064 companies have adopted net zero emissions targets (Zero Tracker 2024). Related shifts in energy power relations can be seen in: the emergence of a global clean-tech 'race' (Lachapelle, MacNeil, and Paterson 2017); the growth in influence of low emissions transnational networks, such as IRENA; the rise of sustainable finance and fossil fuel divestment campaigns (Blondeel 2019); and the diffusion of distributed energy resources (DER) that enable new forms of decentralised ownership (Brisbois 2020; Burke and Stephens 2018; Johnstone et al. 2021; Kuzemko 2019). Indeed, the International Energy Agency (IEA) has become a leading global voice for low-emissions energy. The GEST is fashioned, then, by the overall direction of travel within struggles between elite factions fighting for against climate mitigation from diverse sectional interests.

This is not simply a matter of whether actors position themselves as pro or contra climate mitigation. What also matters is its sociological and organisational form, i.e., *how* emissions reduction happens. For example, in terms of struggles to shape low-emissions energy systems, some incumbent high-emissions actors have recently shifted from strategies based on resistance, towards efforts to actively shape and participate in emerging low-carbon energy systems by, for example, championing 'technofixes' and calling for an 'orderly and secure' transition (Buller 2022, 73–85; Newell 2021; Stokes 2020). The ability of incumbents to shape the GEST in their interests has significant implications for the speed and scale of transitions, and for who benefits and who bears its costs.

### Politics as Arena

Paterson conceptualises the arena of politics as formal and informal sites of collective and authoritative decision-making (Paterson 2021, 19). Energy policy decisions, designed to deliver an increasingly complex range of policy goals (Bridge, Özkaynak, and Turhan 2018), play a fundamental role in driving and conditioning the GEST. Policies and rules shape markets, (re-)construct energy materialities, spatialities, and geographies, (re-)distribute authority and resources, and arbitrate between competing interests (Paterson 2021, 20). T

Increasingly, energy politics, directly or indirectly, is influenced by the norms agreed at UNFCCC conferences of the parties (COPs). Hard-won global climate mitigation norms, in turn, reflect difficult compromises made to facilitate consensus and political agreement. One such compromise was the accommodation of developing economies through the principle of 'Common but Differentiated Responsibilities'. This recognises that states have different levels of responsibility for historic emissions and varying capacities to mitigate their emissions. It allows some high emitting countries like China, India and Indonesia to reach net zero later than advanced economies. This multi-speed timetable is an expression of uneven development in the arena of climate policy, and has been a long-standing axis of diplomatic wrangling.

Although built through successive compromises, global climate agreements have encouraged a series of energy emissions reduction policies at the national level (Death and Tobin 2017). In the other direction, domestic policies have international implications. National solar PV support policies in a range of countries, particularly China and Germany, have contributed towards the widespread diffusion of solar PV, associated demand for panel manufacturing, and rapidly lowered the economic costs of PV uptake for other political actors (IEA 2016, 2022). This points towards a multi-level, multi-directional political economy of energy transformation.

Importantly, however, climate mitigation policies have impacts well beyond emissions reduction, which are important to consider given the extended timespan of the GEST and difficulties experienced in many parts of the world in keeping climate mitigation on energy agendas. Here we turn to the notion of 'policy feedback' effects, which emphasises the often broad and long-lasting socio-economic political effects of policy decisions (Béland and Schlager 2019; Lockwood 2016; Pierson 1993). Energy decarbonisation policies can have non-emissions effects that are *positive* for other public policy goals, in which case they create socio-economic co-benefits. For example, energy efficiency policies are not just good for climate mitigation, but for reducing fuel poverty, driving job creation, and strengthening energy security. Positive feedback effects can help legitimise climate mitigation and build supportive social constituencies, and embed low-emissions technologies and business models in the economy and help build pro-climate corporate interests (Jordon and Matt 2014; Lockwood 2013, 2016).

It is important, however, that the benefits of the GEST have so far been unevenly distributed, both between and within countries. Lachapelle, MacNeil, and Paterson (2017) show that only a limited number of, mainly industrialised, countries have benefitted from the clean-tech race – influenced by access to patents and low-cost capital. Countries and companies with access to critical mineral reserves have the opportunity to benefit from rapid increases in global demand, but only if they can access the capital and expertise to develop these deposits. At the same time, the US Inflation Reduction Act and the EU's RePowerEU plan include policies to onshore aspects of low-emissions energy systems to reduce their global supply chain dependencies. It is not yet clear, then, what new power relations will emerge over access to unevenly distributed fixed resource inputs into low-emissions energy (Di Odoardo et al. 2022).

### *Politics as Conflictual*

Energy geopolitics scholarship has long emphasised inter-state conflict over resources. Here, following Paterson (2021, 20), conflict is taken as endemic to the GEST, but for an extended range of reasons. This is partly, building on the previous section, because climate mitigation has a wide range of socio-economic consequences, whose costs and benefits are unevenly distributed. Politics as an arena can sublimate and compromise between these differences, and how it does so is key to the politics of the GEST.

These are iterative processes, once decisions have been made and policies implemented, new conflicts arise. We highlight the dynamic and ongoing nature of GEST conflict through the notion of *negative* policy feed-back effects. Examples abound – from new land struggles as demand for non-fuel material inputs intensifies, to financial losses from stranded assets, to the potentially negative socio-economic implications of fossil fuel phase out. Many, amongst them the IPCC and IEA, argue that significant percentages of fossil fuel reserves must be kept in the ground to limit warming to 1.5°C – according to Welsby et al. (2021), 65% of all oil and gas reserves. This could lead to an existential loss of economic and political advantage for some fossil fuel incumbents. The capacity of different actors to adapt and diversify ranges widely (Ivleva and Tänzler 2019).

Negative and uneven socio-economic outcomes emphasise arguments about the need for the GEST to become more equitable in the eyes of those countries, companies, workers, and shareholders who stand to lose out from emissions reduction (Heffron and McCauley 2018; Le Billon and Kristoffersen 2020; Newell and Mulvaney 2013). There has, as a result, been an increased tendency to craft policies, at domestic and regional levels, that address negative feedback effects – examples being the EU's 'Just Transitions' and 'Social Climate' funds. Political approaches taken to coal mine closures in Spain, and to coal-fired power generation phase-outs in Germany, demonstrate that objections from corporations and citizens experiencing negative effects of phase-out policies can be assuaged by political action (Healy and Barry 2017; Sanz-Hernández et al. 2020). This supports the notion of policy shaping the politics of the GEST over time, and specifically its ability to *pre-empt* and reduce potential conflict.

Fossil fuel phase-out lies at the heart of attempts to ensure that emissions reduction remains a core characteristic of the GEST. Yet there is no firm global agreement on oil and gas phase-out, and no mechanism to decide which reserves should stay in the ground (Le Billon and Kristoffersen 2020; Pye et al. 2020), notwithstanding the expansion of movements like Beyond Oil and Gas Alliance, and the emergence of the Fossil Fuel Non-Proliferation Treaty. Meanwhile, some fossil fuel corporations have created scenarios that envisage 1.5°C compliant energy systems with significant levels of fossil fuels, especially gas, made possible through extensive use of unproven technologies (Blondeel et al. 2024). High gas scenarios have the potential to stoke conflict over the attenuation of low-emissions alternatives (Carton et al. 2023). Scenarios, technologies and policies that enable continued fossil fuel production can also perpetuate the geopolitical pathologies associated with the high-emissions energy system.

## Two Illustrative Case Studies

In this section we use two case studies to elucidate the reoriented perspective on energy geopolitics that we have tried to develop in this paper thus far. We bring together the three areas we have explored, and show how their criss-crossing influence helps to make sense of concrete sub-sectors of the GEST as socially produced, diachronic, contingent, and contested. It bears emphasising that we are not offering an explanatory theory, a set of nomothetic tendencies or propositional 'if-then' statements, which would be an exuberantly immodest task. Indeed, to do so would threaten a return to the modernist

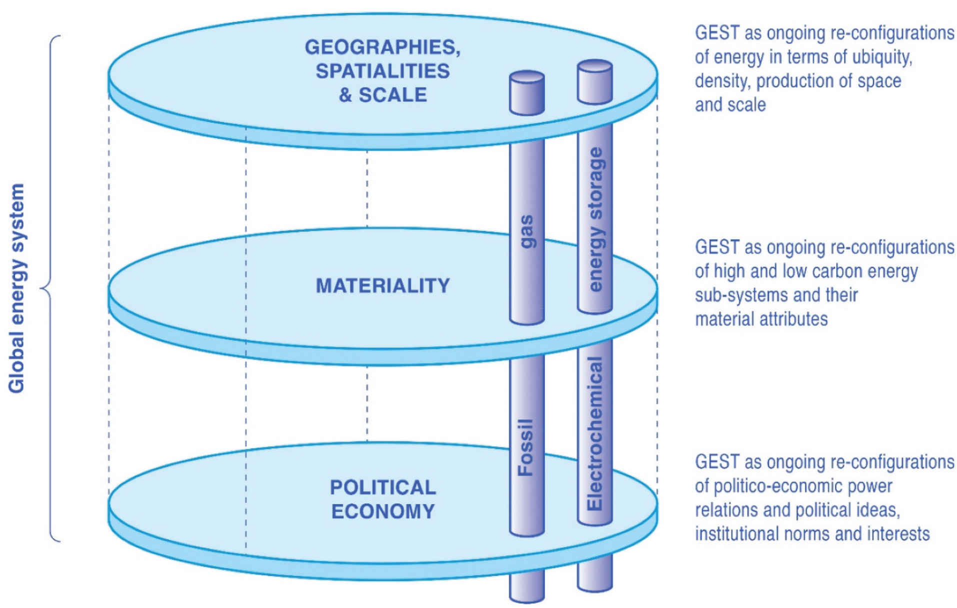


**Figure 2.** A geopolitical economy of global energy system transformation.

confabulations of early twentieth century classical geopolitics. We are attempting to re-orient the thematic and theoretical outlook of energy geopolitics by rethinking its constituent elements in answer to the reality of the GEST, and against the foil of neo-classical and renewable energy geopolitics. In part by inserting constructivism into the heart of energy geopolitics. It is a framework for making sense of the GEST *as* a process of social transformation (see Figure 2).

We look first at the role of fossil gas as a 'bridge' fuel during the transition, a narrative pioneered by the gas industry (Szabo 2022), but one that helps to foreground the conflicted and changing role of the fossil gas sector. Next, we look at how the lithium-ion battery sector is both creating new products, business models and value chains, but also augmenting oil, gas and fossil incumbents, traversing high- and low-carbon sub-systems. These are keystone sectors of the GEST, whose future will modulate its nature, scale and speed.

### *Fossil Gas*

In this case study we look at the contested and uncertain role of fossil gas as a 'bridge fuel'. It has long been spoken of as a playing a 'bridging' role in the transition on the basis of claims that it has a lower carbon-intensity than coal (though upstream methane emissions complicate this), and can provide energy system functions to support renewables as they are progressively built-out (McGlade et al. 2018; Szabo 2022). Gas-fired power plants can provide ballast to intermittent renewable electricity systems as a source of flexible generation, while residual fossil gas infrastructure can serve as a backstop of redundant import capacity. Hydrogen is also often assigned a large role in future low-carbon systems, as a form of long-duration storage, and as a source of high specific heat, crucial to the decarbonisation of 'hard-to-abate' sectors like shipping, heavy-goods vehicles and industrial heat processes (e.g., CCC 2023). Blue hydrogen, created with fossil gas using steam methane reformation and CCS to capture most of its emissions at the point of combustion, could represent a large share of hydrogen production during the transition when renewable output is too constrained to produce low-cost green hydrogen at scale. Yet CCS remains entirely unproven, and is shrouded in questions about its opportunity costs and social legitimacy (Storrs, Lyhne, and Drustrup 2023). Blue hydrogen would leave upstream emissions intact and CCS has a mean capture rate of roughly 80% (Rosenow and Lowes 2021). It would also expose many countries to continuing gas supply risks. The fear, across these possible use cases, is that the fossil gas industry is lobbying to push the fuel from a temporary bridge across the transition, justified from exigency, to a permanent and desirable part of its end-state (Szabo 2022).

The global fossil gas system is therefore undergoing an open-ended process of transformation around synergies between the low- and high-carbon transition, where the scale and forms of its future role are mediated by socio-politics. Its makes for an exemplary case study for our approach, then. We look at how the uncertain role of fossil gas as a 'bridge fuel' is being shaped by two developments: the coming of age of the global LNG market, and the nascent hydrogen industry.

LNG involves supercooling natural gas to −163°C to increase its volumetric energy density six-hundred-fold, overcoming the diseconomies of space that prohibits the commercial transport of fossil gas by freight (Bradshaw and Boersma 2020; Bridge and Bradshaw 2017). This necessitates new capital-intensive coastal infrastructures for liquefication, shipping and regasification and storage. By opening up seaborne trade, it unchains gas supplies from fixed pipeline routes, increases the scope of inter-regional arbitrage, and diversifies potential fossil gas suppliers. It rescales the fossil gas market from the regional to the global according to the uneven development of economic infrastructures and relations. The LNG trade has existed for almost 50 years, but over the past 15 years or so, the growth in LNG trade, in terms of geographic reach, volume and value, has been quite remarkable. In the period 2005–2021, total trade in LNG grew by 264% (BP 2022), and by 2021 LNG accounted for 50.5% of all gas traded. While LNG trade has traditionally been conducted via long-term purchase agreements indexed against the price of oil, creating fixed point-to-point shipping, the scale of growth in global capacity and the emergence of less vertically integrated commercial arrangements, has facilitated the emergence of a short-term and spot trade. In 2023, 28% of all trade LNG volumes were on a spot basis, and 35% on a spot or short-term basis (GIIGNL 2023, 9). LNG's reworking of spatial and organisational forms can helpfully be understood as a production network, a platform 'through which actors in different regional and national economies compete and cooperate for a greater share of value creation, transformation, and capture through geographically dispersed economic activity' (Coe and Yeung 2015, 30).

The development of an increasingly global seaborne trade in fossil gas, including a growing flexible market, has unsettled energy markets and tied importers and exporters into volatile market relations. Take the recent role of LNG in European energy geopolitics. In 2015 the Nord Stream 2 was announced, a subsea pipeline intended to connect Russia directly to Germany via the Baltic Sea. In 2016, the first LNG cargo left port in the US, the start of a rapid ramp-up in American export capacity. These two events set the coordinates for a triangular conflict over the terms of European gas imports. Declining European gas production, Germany's attempt to simultaneously phase out coal and nuclear power and its long-standing policy of *Ostpolitik*, and the technical and geopolitical risks of Ukraine as a transit route for Russian gas, initially motivated Nord Stream 2 (EPRS 2021; Jong 2023). Western European energy companies Engie, Shell, OMV, Wintershell and Uniper helped to finance the project, and together with Germany, Austria, Belgium, and the Netherlands, lobbied for its completion. Yet the European Commission repeatedly tried to halt construction on legal grounds and publicly favoured LNG as a more secure alternative (EC 2016), while Eastern European member states – Czechia, Estonia, Hungary, Latvia, Poland, Slovakia, Romania, Lithuania – concerned about Russian influence and lost transit revenues objected to the project's 'destabilising geopolitical consequences' (Sytas 2016). When Poland received its first shipment of US LNG in 2017, Prime Minister Beata Szydlo declared it a historic occasion, and that Poland could finally say that it was 'a safe and sovereign country' (Scislowska 2017). In 2019 the US Congress passed 'Protecting Europe's Energy Security Act', introducing sanctions against companies involved in the construction of Nord Stream 2, later expanded in 2021, at the same time as the Trump administration promoted US LNG exports to Europe as 'freedom gas' (Jong 2023). This was a consequential and multi-level conflict, involving infrastructure and energy companies, dissensus within the institutions and between the member states of the EU, and pitting the US and Russia into direct competition, developing around the new geographies of trade made possible by the materialities of LNG.

Russia's invasion of Ukraine, and the subsequent sabotage of the pipeline by unknown actors, terminated Nord Stream 2. Soon after Russia's invasion, the EU launched the REPowerEU plan, aiming to cut Russian gas imports by two-thirds by the end of 2022, and to phase them out completely by 2030 (EC 2022). The EU's diverging range of policy responses reflect the tensions and contingencies of the transition. REPowerEU turned to renewables as a redoubt against soaring gas prices, setting newly ambitious targets. But in the short-term US LNG filled the supply gap, with Germany and other member states constructing LNG import capacity, and signing long-term LNG supply contracts, endangering EU climate goals (GEM 2022). European demand for LNG saw the rechannelling of supplies away from emerging Asian economies dependent on spot LNG as a bridge away from coal, most notably Pakistan, Bangladesh and Vietnam, driving inequalities of crisis (Kuzemko et al. 2022).

What about hydrogen? Hydrogen is already produced and consumed at scale, with 95 MT combusted in 2022, almost all of it produced from gas ('grey hydrogen') or coal ('black hydrogen') (IEA 2023b, 20). But the viability of hydrogen as a technology of decarbonisation depends on the success of two principal alternatives, at a far greater scale. The renewable-powered electrolytic separation of hydrogen from water ('green hydrogen'), or the production of hydrogen with gas via steam methane reformation, using CCS to capture the majority of the emissions released ('blue hydrogen'). Yet, as of 2023, electrolytic hydrogen accounts for just 0.1% of global hydrogen production (IEA 2023b, 68), while there are just 47 operational CCS projects worldwide (IEA 2023a).

One of the defining features of the geopolitics of hydrogen, therefore, is uncertainty. Blue hydrogen's prospects are entwined with the economic, security and environmental credibility of fossil gas, and the viability of CCS with efficient capture rates (Rosenow and Lowes 2021). Green hydrogen on whether renewable deployment can ramp-up quickly enough in the medium-term to power electrolysis at scale given competing demands on electricity grids, and the scale of future international hydrogen trade (CCC 2023). It also depends on electrolyser manufacturing capacity, and one of its two dominant technologies – proton exchange membrane electrolysers – require platinum and iridium, 'critical' minerals with tight and securitised supplies over the transition (Clapp, Zalitis, and Ryan 2023; Rasmussen et al. 2019). Hydrogen's future role in industry, space heating, energy storage, road transport, aviation, and shipping are subject to wind-ranging forecasts (Quarton et al. 2020).

The supply, technological and demand uncertainty afflicting hydrogen means its expansion depends on the ability of the state to superintend the sector and facilitate investment, development and security. What we see, therefore, are wide differences of approach mediated by politics. The UK has adopted a 'technology neutral' approach that ultimately subjects the future balance of green and blue hydrogen deployment to price competition (DESNZ 2023), for example, while the EU has set a decisive target to produce 10 mt/y of green hydrogen in the EU, and to import a further 10 mt/y from abroad (EC 2022). In the US debate about tax subsidies for clean hydrogen under the Inflation Reduction Impact revolve around how to establish that the power used in the production of electrolytic hydrogen is attributable to renewable generation that is 'additional' to the existing grid (Hedreen 2024). In the EU it has centred on if and how to include nuclear-powered electrolytic hydrogen under renewable targets (EU 2023a), pitting a pro-nuclear France against an anti-nuclear Germany. Unlike Western states, South Korea has de-emphasised battery electric vehicles, and pursued a multi-decade industrial strategy to develop a world-leading hydrogen fuel cell vehicle industry (Yoo and Park 2023).

Hydrogen also risks augmenting existing fossil gas geographies. Hydrogen is similar enough to fossil gas that it could utilise existing or retrofitted gas infrastructure, although its lower volumetric density, and its embrittling, dissipative and explosive properties, mean this is still subject to trialling. Given this potential interoperability, it is often argued that fossil gas or blue hydrogen infrastructure can be built as a stopgap in the transition and later converted to green hydrogen (CCC 2023). Thus, the German government has justified its build-out of LNG import capacity since the Russian invasion of Ukraine as a far-sighted strategy to support green hydrogen (Reed and Schuetze 2022). In the EU, a coalition of national gas network operators – 'EntsoG' – has been tightly linked to the development of the EU list of 'projects of common interest' entitled to financial assistance from the bloc, and under which dozens of hydrogen infrastructure proposals have found support (Maggiore 2020). Similarly, transmission network operators in Europe have tried to piggyback on the European Hydrogen Backbone, even though 90% of all newly proposed pipelines are expected to, at least initially, transit gas or a blend of gas and hydrogen (GEM 2023, 15). This process of co-optation by the gas industry works to preserve otherwise defunct assets, repurposing old energy geographies for the transition, and leveraging the path-dependent hold of 'locked-in' infrastructures, regulations and markets (Unruh 2000).

### Electrochemical Energy Storage: Lithium-Ion Batteries

The second illustrative case is that of lithium-ion batteries, which are an important energy storage solution in the context of expanding the role of (intermittent) renewables in electricity generation and decarbonising transportation.[6] There are extensive renewable energy and electric vehicle (EV) support policies in place in many parts of the world – the EU's REPowerEU, for example, includes a raft of new policies to accelerate their deployment. These, and other emissions reduction policies aimed at the transportation sector, will result in significant demand destruction for oil. At the same time, intermittent renewables and EVs depend on the availability of electrical energy storage. The rapid uptake of lithium-ion batteries in the context of commitments to emission reductions (primarily in the power generation and transportation sectors) highlights three significant aspects of GEST, each demonstrating the interaction of the material, geographic, and political-economic dimensions.

First, we highlight one material aspect of the shift away from fossil fuels towards renewably generated electricity and electrical energy storage that, while acknowledged in some critical scholarship (e.g. Huber and McCarthy 2017; Malm 2016), is currently under-emphasised in energy geopolitics. Fossil 'fuels' are stock energy sources, that is, materials defined by their potential energy *content*, whilst renewables are flow sources that *harness ambient sources*, like sun, water, and wind (Blondeel et al. 2021).[7] The intermittent nature of flow sources requires adapting energy systems, and electrochemical energy storage can help offset the intermittency of ambient flows (at grid scale) while also (at household scale) adjusting the rhythms of electricity demand. Rechargeable lithium-ion batteries exemplify the evolution of the electricity system towards renewable assets that 'harness, convert, store and use' energy from flow sources, rather than the linear 'extract, refine, store and consume' sequence associated with stock sources – see Figure 3 below.[8]

What is more, the rapid uptake of lithium-ion batteries illustrates how the GEST is characterised by new products, business models and value chains that simultaneously disrupt markets while also reproducing existing relations of economic and political power. The automotive sector illustrates this very well:

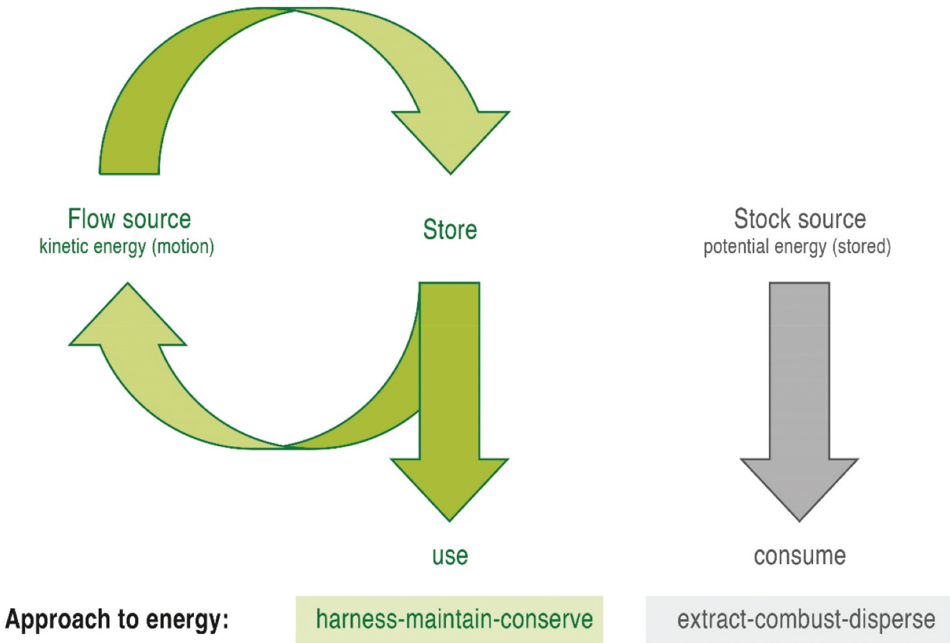


**Figure 3.** Flow & stock sources of energy.

lithium-ion battery production is currently tied closely to the performance needs of incumbent producers. As such, the geopolitical economy of energy storage is profoundly shaped by the geo-economic strategies of global automotive firms, states, and regions with significant automotive manufacturing capacity (Bridge and Faigen 2022). The role of IOCs in rolling out EV charging is another example of these complex interconnections between high- and low-emissions systems, characteristic of the 'messy' process of energy system transformation. Shell, for example, has a significant role in direct current (DC) high performance charging across South-east Asia. This exemplifies the ability of large, incumbent corporations, and their interests, to shape the GEST through their involvement in clean energy technology roll out, thereby maintaining positions of political and economic power.

Second, the material foundations of lithium-ion batteries, and other manufactured technologies for harnessing, converting and storing energy, are mineral-based and, therefore, mining intensive, especially during large-scale infrastructure construction programmes (Bazilian 2018; Krane and Idel 2021; Riofrancos 2023). The uneven distribution of the various minerals involved, and their central role in low-emissions energy, means the GEST replicates some of the competition over access and control seen in the high-emissions system. This is exemplified by the recent political promotion of international supply chain partnerships in the US and Europe aimed at 'delinking' from China, alongside domestic sourcing and 'friend-shoring' strategies for critical minerals (Bridge and Faigen 2023). And, like oil and gas, electrochemical energy storage has its own space-making character, expressed for example in the 'new geographies' of resource extraction associated with the 'Lithium Triangle' (Bustos-Gallardo, Bridge, and Prieto 2021; Forget and Bos 2022; Riofrancos 2023), cobalt in the Democratic Republic of the Congo, or the 'Nordic battery belt' for gigafactory deployments. Some of these new spaces replicate geographical dependencies and forms of control familiar from fossil fuel systems – a long-distance trade in raw materials that structures political-economy relations, and forms of green extractivism that reproduce historical inequalities of land access and raw material supply. In other cases, like in Canada's burgeoning EV battery industry linked to the country's lithium supply, or Saudi Arabia's push to maximise the extraction of its critical mineral deposits to support its Vision 2030, we see incumbent fossil fuel states attempting to soften declining rents by diversifying into the critical mineral value chain – giving rise to competing industrial bases. It needs emphasising that dependence on these raw materials is temporally different to dependence on fossil fuel sources of energy. Fossil fuels need to be constantly extracted to support energy usage, but dependence on critical mineral extraction will become less intensive once new, low emissions infrastructures have been built-out.

Importantly, unlike fuels, mineral-based materials for batteries are stock resources that are *not* consumed by use, although they do degrade, and so they can, in principle, be recycled and reused.[9] Reuse can take two forms. It can involve cascading end-of-life batteries into secondary uses that mimic patterns of first use, for example using former EV batteries for stationary forms of energy storage in industrial or municipal settings. Or it can involve recycling battery content into the manufacture of new batteries – see, for example, the EU's (2023b) Battery Regulation. Indeed, the recycling of end-of-life batteries has the potential to reduce global demand for lithium by 25%, and by 35% for cobalt and nickel, by 2040 (Dominish, Florin, and Wakefield-Rann 2021), with attendant implications for the need to compete internationally over access to these resources.

This is significant for GEST. It introduces new axes of political and economic policy, not found in fossil fuels, that derive from the potentially 'circular', and more sustainable, character of these mineral flows. Examples include economies of 'material surveillance' linked to the adoption of Environmental, Social and Governance (ESG) criteria and to firms creating partnerships for secondary resource uses along the value chain, such as in the case of Glencore. Some governing bodies work with extended producer responsibility (EPR), to ensure both secondary material uses and security of supply for critical minerals, by promoting investment in infrastructures to collect, recycle and reuse batteries – capturing and 'territorialising' circular flows (see also Albertsen et al. 2021). A primary goal of the EU's Circular

Economy initiatives, for example, is to re-scale waste flows and territorialise processes of resource recovery. Such initiatives demonstrate the multifaceted role of the state in energy system change as, variously, producer, buyer, facilitator and regulator (cf. Horner 2017).

Third, harnessing, converting, and storing *flow* resources requires a new range of non-fuel, manufactured key inputs such as wind turbines, photovoltaic panels, and lithium-ion batteries. This means that the geopolitical economy of energy is increasingly shaped by competition and strategy in relation to technology and manufacturing knowhow and the trade of goods, and less over time by resource extraction, refining and the trade of fuels. For example, the geopolitics of manufactured goods are subject to WTO trade regulation in value-added activities in a way that fossil fuels are typically not. This aspect of the GEST, then, supplements a geopolitical economy of energy founded on supply security concerns and resource rents (Hache 2018), with one founded on regulated trade, patenting/technology rents, and manufacturing capability. It also extends to new business and ownership models based on energy-as-a-service rather than as commodity (e.g., batteries-as-a-service).

Further, this aspect of the GEST is based on creating localised ecosystems of battery research, innovation, and production, that provide education and employment, and from facilitating the *decentralised* development of micro grids. These offer a degree of autonomy in governing the transformation and mix of emerging energy systems unimaginable from options provided by fossil fuel energy sources. The ubiquitous nature of ambient *flow* sources, and the scalability of technologies for harnessing and storing energy, provide for alternative topologies of electrification, characterised by 'decentralised interconnection' (Blondeel et al. 2021). The emergence of the 'prosumer' and 'distributor' in relation to EV energy storage, for example, suggests a web of multidirectional electricity flows with multiple, decentralised yet interconnected nodes for harnessing, storing, and releasing energy – rather than a unidirectional transfer from producer to consumer. This, in turn, suggests a far wider diversity of energy actors within energy systems alongside energy incumbents, with the potential to dilute some of their power dominance (Brisbois 2020; Kuzemko 2019).

These insights into the emergence of lithium-ion batteries as an increasingly important part of the energy system show how material changes within sub-systems can have competing tendencies: in this case, towards greater decentralisation, to the extent that batteries support the creation of micro-grids; and, simultaneously, the replication of large-scale oil, gas, and automotive incumbents. The case of batteries illustrates the value of understanding the GEST as a messy process of transformation in which political decisions shape the nature of change, with significant material and geographic outcomes remaining unsettled. It also highlights each dimension of the geopolitical economy of energy and their convergence: the different material attributes of low-emissions energy technologies add a new significance to minerals, manufacturing and trade, drive novel energy geographies, while also reproducing some existing political-economic dependencies.

## Conclusion

Our aim has been to re-orientate the study of energy geopolitics towards the global energy system transformation now taking place by rethinking each of its three constituent elements – energy, geography, and politics – along constructivist lines to capture the diachronic, conflictual and open-ended character of this process. That means, substantively, engaging with the whole energy system comprising interacting material attributes across high- and low-carbon sub-systems, with the uneven social production of energy spaces across scales and densities, and with conflict-ridden struggle pitting contending power structures against one another and playing out across decision-making fora. We have tried to illustrate where this re-orientation might lead in two case studies, showing that the role of two core sectors of the GEST – fossil gas and lithium-ion batteries – are far more messy, complex and contingent that existing approaches to energy geopolitics allow for. This is what 'transformation' looks like, and it overflows the conceptual structure of cross-border fossil fuel competition among great powers, or geo-technical necessity.

At the start of this paper, we suggested that a defining characteristic of the GEST is decarbonisation. But we have given emphasis throughout to the fact that complex materialities, social relations of geography, and political economies of power and conflict, will shape how, where and at what pace emissions will be reduced. Which fossil fuels will be kept in the ground, how fast their low-carbon substitutes will be built and deployed, who will benefit and who will lose: these basic questions remain open, and it is essential for any geopolitical economy of energy today to recognise the indeterminacy of the present conjuncture brought about by the GEST. Yet, recognising and foregrounding this contingency also has a salutary effect. It presents us with a view of geopolitical energy relations as having the potential to drive more sustainable, and more just change, rather than as a constraint, or as something unfolding along pre-given tracks set by fixed attributes of geography, politics or the energy system.

We end by re-emphasising that we intend this paper to be a first step towards a geopolitical economy of GEST. Certainly, we make no claim to completeness or finality. We hope others bring their own perspectives, imagination and specialisms to this task of rethinking energy geopolitics. In this spirit, we want to highlight two important limitations to this paper.

First, although we have disaggregated the GEST into two systems and recognised that beneath these there are many more sub-systems (like fossil gas and energy storage), each sub-system has discrete, changing materialities that we have not had the space to elaborate on here. Secondly, we have taken the constituent elements of 'energy geo-politics' as our starting point, and have anchored our rethinking in this tradition. But the GEST strains against these conceptual limits. Other dimensions deserve attention, too, not least the role of nature and the environment – in particular land, water, and ecosystems. Our approach has skirted some of these questions, like the relationship between new inputs into energy systems, the reproduction of uneven geographies, and land use change. But there is much more to be done.

## Notes

1. 'Transition' refers to the progressive phase-out of high-carbon systems and ramp-up of low-carbon systems. 'Transformation' here denotes the scope, degree, and depth of social, technical, economic, and political change attendant in that transition.
2. Critical geopolitics injected much needed self-reflexivity and theoretical sophistication into geopolitics. Our own approach is constructivist in the broad sense that we treat interstate relations, the energy system, and global geography, as socially produced in the last instance. But clearly the GEST cannot primarily be understood through the second-order analysis on language, but requires dealing with the concrete, first-order problems of energy, geography, and political economy. We are therefore sympathetic to critical geopolitics, but pursue different kinds of questions.
3. This is, of course, a general characterisation. Notably, there have also been limited efforts to use scenarios to explore how geopolitics might shape the GEST (Bazilian et al. 2019; Goldthau et al. 2019).
4. Originally 'oil' was the almost sole preoccupation of neo-classical energy geopolitics, but work on the geopolitics of fossil gas has emerged over recent decades (e.g., Stegen 2011; Vivoda 2014).
5. By 'post-Cartesian' we mean it diverges from a view of space as a plane described by absolute fixed points, as initially expressed in the coordinate system developed by René Descartes in the 17th century (Bridge 2018).
6. See Bridge and Faigen (2022) for a more comprehensive analysis of the global production network for lithium-ion batteries.
7. The first law of thermodynamics, also known as the law of conservation of energy, describes how energy cannot be created (i.e. generated) or destroyed, only transferred from one form to another. Therefore, we refer to the 'harnessing' of energy (see also Riofrancos, 2023), i.e. making use of ambient energy from flow sources by controlling it.
8. The return loop associated with the combination of flow energy sources and storage refers to the way (a) mineral-based materials of electrochemical storage can be reused, enabling a new cycle of recharging; and (b) the potential for stored energy to feed into another energy system (e.g. a micro-grid), and not only be directly consumed.
9. Battery cathode materials, for example, degrade due to impurities which cause the formation of dendrites and affect the lattice structure that receives lithium ions.

Battery minerals are used for a period of time, until recharging capacity dwindles, but then, if designed for recyclability, these mineral-based materials may be reused.

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