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Global energy scenarios: A geopolitical reality check

Mathieu Blondeel [a,c], James Price [b,*], Michael Bradshaw [c], Steve Pye [b], Paul Dodds [b], Caroline Kuzemko [d], Gavin Bridge [e]

[a] Institute for Environmental Studies, VU Amsterdam, The Netherlands
[b] UCL Energy Institute, Bartlett School of Environment, Energy and Resources, United Kingdom
[c] Warwick Business School, United Kingdom
[d] University of Warwick, United Kingdom
[e] Durham University, United Kingdom

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ABSTRACT

The ongoing Global Energy System Transformation (GEST) has attracted the attention of multiple academic disciplines and practitioners, approaching the process with different analytical and conceptual tools. We explore the 'integration gap' that exists between, on the one hand, Energy System Modelling and the stylised scenarios they use, and on the other, energy geopolitics. We consider how these approaches can complement each other to further our understanding of the global energy system's future. Using a novel qualitative analytical framework, we review the extent to which a range of state-of-the-art global energy scenarios capture and reflect key issues in energy geopolitics in their narratives and model implementation. We find that few scenarios consider geopolitics in any depth. Those that do often treat it as a barrier to decarbonisation efforts that are aligned with the climate objectives of the Paris Agreement. Normative, Paris-aligned scenarios describe smooth processes of change where cooperation and coordination between countries are assumed and where geopolitics is often completely absent. Our findings emphasise the need for a more intricate understanding of the difference between 'paper transitions' and the real-world messiness and complexities of GEST, where geopolitics has a dual quality of simultaneously accelerating and hindering the transformation process.

1. Introduction

The ongoing Global Energy System Transformation (GEST) presents disruptive challenges to fossil fuels' longstanding dominance in the global energy system. GEST refers to structural changes in the organisation of the global energy system necessitated by decarbonisation to mitigate climate change. This is a process of profound change in the way that energy services are delivered - moving away from a system based on fossil fuel supply to one with lower energy consumption, higher electrification powered by renewables, with demand-side response and storage at its heart, and with biomass and hydrogen also having a role (IEA, 2021; Blondeel et al., 2021).

GEST has attracted the attention of multiple academic disciplines. All approach the process with different analytical and conceptual tools to understand the future of the energy system. In this paper we examine contributions from energy system modelling (ESM), an interdisciplinary approach on the boundaries of economics and engineering, and energy geopolitics. Grounded in social science, the latter takes account of the interplay between geographic and political factors. We explore what each has to contribute to our understanding of GEST and how they can complement one another to generate new insights.

1.1. Literature review

ESM mathematically represents the complex set of interactions that unfold across energy sectors within an economy, from supply, processing and distribution to end-use demand. Models often make use of stylised scenarios to create narratives of what the future may look like. They are generally driven by economic principles, with a single global investor making all decisions with the aim of minimising the global cost and without considering the impacts on any single country, and assuming no taxes or subsidies. The outputs of ESM are not predictions of what will happen but internally consistent scenarios of how the future *could* develop. ESM is typically employed to provide least-cost long-term strategic targets. It is very influential in the energy sector and among policymakers (Rivadeneira and Carton, 2022; Skea et al., 2017; Süsser

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* Corresponding author.
E-mail addresses: m.c.blondeel@vu.nl (M. Blondeel), james.price@ucl.ac.uk (J. Price).

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et al., 2022). Constraints can be added to represent geopolitical realities but the extent to which that happens in practice is not clear.

A burgeoning literature has started to compare and critically assess such energy and climate future exercises (Ansari et al., 2019; Hausfather and Peters, 2018; Lacroix et al., 2021; Peng et al., 2021; Pielke and Ritchie, 2021; Rosen, 2021; Skea et al., 2021). Modellers are criticised for failing to acknowledge the impact of the learning curves of clean energy technologies and their rapidly falling costs (Bond, 2021; Ives et al., 2021). For instance, the International Energy Agency's (IEA) scenarios, often unquestioned by policymakers, have long been scrutinised for their conservative projections regarding cost reductions and deployment rates of renewables (Carrington and Stephenson, 2018; Teske, 2020). The IEA admits that, by design, its scenarios generally describe smooth and orderly processes of change, although, in reality, transitions are fiercely contested, volatile and disorderly affairs (IEA, 2021, p. 247; 2022a).

Models are also often considered overly technocratic and driven by heroic cost-minimising decision-making that denies the complexity and uncertainty of human behaviour (Süsser et al., 2022). Peng et al., (2021, p. 174), for example, note that energy models currently fail to capture political dynamism and "do not characterise the difficult trade-offs that politicians face when they respond to constituencies." Coal can serve as an example. Depending on the temperature objective, 80 to 90 percent of coal reserves will have to be kept in the ground (McGlade and Ekins, 2015; Welsby et al., 2021), while the IPCC (2018a) sees a steep reduction of global coal consumption to near zero in 2050 in 1.5 °C compatible scenarios. Yet, the 2021 'Glasgow Climate Pact' was only the first ever official UNFCCC-negotiated outcome document that mentions coal, and then only in the context of "accelerating efforts towards the phasedown [author's emphasis] of unabated coal power." This phrasing more clearly reflects the current political realities associated with phasing coal out in practice. Moreover, soaring natural gas prices following the war in Ukraine have temporarily propped up coal consumption, reaching an all-time high in 2022 (IEA, 2022b). Even some of the most dedicated climate actors, like Germany and Austria, upped coal-fired electricity generation in the winter of 2022/23 in order to deliver on the geopolitical goal of reducing fossil fuel (gas) imports from Russia by two-thirds by the end of 2022 (Kuzemko et al., 2022).

The second approach, energy geopolitics, is grounded in social science and considers the influence of geographical factors, such as the distribution of centres of supply and demand, and political factors in ensuring affordable, reliable, [and sustainable] supply of energy (Bradshaw, 2009). Or, as Kelly (2016, p. 2) describes it, "geopolitics rests upon the relative spatial positions of countries, regions, and resources as these may affect foreign policies and actions."

Such classic interpretations of energy geopolitics suffer from a number of important shortcomings. Scholten (2018, p. 8), for example, only considers "interstate [renewable] energy relations", while Overland (2015, p. 3517) examines "*great power* (authors' emphasis) competition over access to strategic locations and natural resources." Both espouse a conventional realist understanding of geopolitics, mostly rooted in International Relations theory that centres around the'state' as the key actor in the international system. The primacy of national governments may well be the case, but it neglects the role of other relevant actors within the global energy system, such as sub-national governments, transnational social movements, or multinational corporations. Other authors, in turn, seem to conflate energy geopolitics—defined as, "who supplies and reliably secures energy at affordable prices"—with the notion of 'energy security' (Pascual and Zambetakis, 2008).

Moreover, there is a certain 'determinism' implied in these definitions that sees states' conduct as driven entirely by geography. Whereas, in our understanding, geopolitics considers the reciprocal relationship between geography, politics and the energy system at the global level. Geography (e.g. availability of scarce natural resources) does not simply determine international relations (e.g. competition between states). To the contrary, changing political configurations, real and perceived interests, threats and vulnerabilities of all stakeholders involved can also shape geographic arrangements (e.g. global trade patterns or the location of resource extraction). As such, geopolitics offers a conceptual toolkit to analyse the contested and messy nature of GEST by, for example, exploring the multiplicity of outcomes it may generate. Take, for example, EU regulations on the circular economy, particularly as it pertains to critical minerals. These are partly informed by geopolitical concerns regarding growing trade dependencies (on China). In turn, these new regulations may also impact geographies of trade as the EU becomes less dependent on another and less minerals need to be mined. Hence, the reciprocity in geopolitics.

Building on Bradshaw's (2009) definition, energy geopolitics then becomes the *interaction* of geographical factors, such as the distribution of centres of supply and demand, with state and non-state actors' attempts to ensure an affordable, reliable and sustainable supply of energy. A definition that is much closer to (critical) geopolitics scholarship that emphasises the 'interactivity' between political actors and the physical environments in which they operate (see, for example, O'Lear, 2018 or Criekemans, 2022; forthcoming). To conclude, then, energy geopolitics helps to include factors in its analysis that are often not considered in ESM when seeking to understand the GEST.

As the global energy system transforms, so does its geopolitics. Accordingly, a literature on the geopolitics of renewables and energy transitions has developed in the last decade or so (Vakulchuk et al., 2020). Yet, on top of some of the limitations discussed in the previous paragraph, much of this scholarship is concentrated on what energy geopolitics might look like in the final stage of a protracted process of transformation, i.e., the moment when renewables have become the dominant energy source and fossil fuels have largely been phased out (Hache, 2018; Månberger and Johansson, 2019; O'Sullivan et al., 2017; Overland, 2019; Scholten, 2018; Vakulchuk et al., 2020). This pays insufficient attention to the *process* of GEST, when two competing energy sub-systems (a high and low-carbon one) continue to co-exist, compete and overlap with one another throughout the coming decades. A shortcoming that only recently has come to be scrutinised and addressed (Bazilian et al., 2019; Blondeel et al., 2021; Goldthau et al., 2019; Irena, 2019; Palle, 2019; Scholten, 2023).

Although both disciplines discussed here study energy systems (and how they change) at a global level, so far there has been limited interaction between the two. Thus, what is needed is a structured and substantive conversation between the two to further the understanding of the complexities and messiness of GEST.

1.2. Bringing together energy system modelling and geopolitics

Bridging the 'integration gap' between ESM and energy geopolitics is a potentially rewarding but complex endeavour. A disconnect remains between (geo)political, social, and economic research and the modelling efforts of academics, international organisations, energy companies and consultancies (Trutnevyte et al., 2019; Vinichenko et al., 2021). This is problematic because some of the most prominent modelling (such as the IEA and IPCC's) has been attributed "world-making power" (Beck and Mahoney, 2018a, p. 1), precisely because of the influence it has in informing and shaping energy and climate policy (Beck and Mahoney, 2018a, 2018b; Berten and Kranke, 2022; Rivadeneira and Carton, 2022). Moreover, existing inadequacies in these models can constrain the imaginations of energy futures that are brought to the attention of energy policymakers and other relevant stakeholders (Beck and Oomen, 2021; Cointe, 2022; Mahony, 2022).

Some, however, have complemented ESM with insights from the social sciences. Pye et al. (2020) presented an equity-based modelling exercise that re-distributes remaining fossil fuel production towards developing countries. Mercure et al. (2021) model different futures that could materialise, as well as the associated shift in incentives and impacts this generates on the relationship between fossil fuel consumers and producers. Nevertheless, it is not at all clear in their methodology how they have engaged with geopolitical analysis. Energy geopolitics could give greater analytical and empirical depth to ESM-generated energy pathways. This would address the abovementioned criticisms about the failure to engage adequately with the real-world challenges associated with turning ambition into rapid emissions reduction whilst delivering security of supply and energy access.

Likewise, ESM can make a valuable contribution to energy geopolitics and other social science approaches to the GEST. There is, for example, a sizeable literature on 'unburnable fossil fuels' that is not supported by rigorous quantitative analysis (Muttitt and Kartha, 2020; Newell and Simms, 2020). Such calls to 'keep fossil fuels in the ground' could benefit from a more substantive engagement with ESM as to the impact on the interactions across energy sectors this may have. In yet another example, Goldthau et al. (2019) offer four scenarios of how a GEST could play out (see also, Bazilian et al., 2019). Although they account for the messiness of the process in all scenarios, their analysis is not supported by rigorous modelling that could increase its robustness and internal consistency.

In the remainder of this paper, we explore the benefits of considering geopolitics when developing ESM scenarios. First, we qualitatively review the extent to which a number of GEST scenarios engage with key issues in geopolitics of GEST, using the analytical framework developed from Blondeel et al. (2021). It was the first to conceptualise GEST as a complex two-fold process comprised of both high- and low-carbon transitions. Second, we quantitatively review key metrics of the GEST scenarios and consider the extent to which they have been influenced by the consideration of geopolitics. Finally, we reflect on the use of geopolitics as an input to ESM and vice versa.

The next section introduces the analytical framework for the qualitative scenario review and discusses case/scenario selection. Section 3 presents our qualitative review and our main findings. Section 4 contains the quantitative analysis and explores the impacts of geopolitical considerations on scenario outcomes. Based on our analysis, section five makes the case for considering geopolitics in energy system scenarios. In the conclusion, we reflect on our results.

2. Research design

2.1. Qualitative analytical framework

The qualitative analytical framework is based on Blondeel et al. (2021), which conceptualises GEST as a two-fold process that entails two simultaneous transitions: a high-carbon transition (HCT) and a low-carbon transition (LCT). The HCT refers to the gradual decline of unabated fossil fuels, while the LCT refers to the increase in renewables and low-carbon technologies that will form the backbone of the future global energy system. Both take place at the same time, with the dominance of a high-carbon energy system shifting to the low-carbon system over time. Both the HCT and LCT have their own core technical, political, economic and social topics (which we call 'sub-topics' in our framework). Each of these sub-topics, in turn, also has a number of distinct geopolitical features. It is precisely those geopolitical features that this framework, building on the Bradshaw (2009) definition, uncovers.

At face value, a topic may be considered highly technical. Yet, at the same time, there are important geopolitical drivers, barriers and implications at play that can be taken into account when developing related energy scenarios. The reference to the circular economy for critical minerals in the introduction may serve as a good example. The framework is deduced from Blondeel et al. (2021) and further expanded through an inductive process of extensive conversations within our interdisciplinary team of authors. Importantly, we do not claim that our framework constitutes an exhaustive list of sub-topics of both transitions, nor of the geopolitical features each sub-topic may have.

We divide the analytical framework into two parts that examine the HCT and the LCT separately. The framework is presented in Table 1. We conduct a qualitative content analysis of each scenario (see Section 2.2.) to examine how and to what extent they engage with geopolitical aspects. The objective is to explore the 'integration gap' between scenarios informed by energy models on the one hand and geopolitics on the other. The third column sets out the codes that we assign to each geopolitical sub-topic to review the extent to which the reports engage with them.

2.2. Scenarios

We apply the qualitative framework to examine GEST scenarios from five sources: BP's, 2022 Energy Outlook; Equinor's Energy Perspectives 2021; Shell's Energy Transformation Scenarios 2021; the IEA's World Energy Outlook 2021, and the IPCC's *Shared Socio-Economic Pathways* (SSPs). Case selection was based on multiple criteria. First, we have considered the public availability of quantitative scenario data that contains a number of broadly comparable variables to 2050. The second criterion concerns institutional variety. As scenario providers that we examine, we have selected fossil fuel companies (BP, Shell, Equinor), international organisations (IEA, IPCC), and academia (IPCC). We have thus conducted 'exemplary case studies' (Mills et al., 2010), with the selected cases being typical examples of a class of scenario providers. The third criterion refers to the relative public and policy attention received by scenario providers upon release of their reports. This is used as a proxy for the so-called 'world-making power' these scenario exercises have, which is considerably more significant than that of other scenario providers. A final, more practical consideration relates to the quantitative analysis, simply adding more scenarios to the plots, without any substantive added-value, would only confuse these figures, and make it harder to interpret them. Our cases, and the energy pathways they contain, are summarised in Table 2, where their scenario approach is categorised as follows (Skea et al., 2021):

- A *normative* approach designs a scenario that is goal driven, here toward a 'Paris-aligned' climate target (e.g. either limiting warming to 1.5 or 'well below' 2 °C); a model will normally meet the target at any price. Hence, we use 'normative' and 'Paris-aligned' interchangeably.
- An *outlook* is taken to be a 'projection' based on today's norms and active/announced policies.
- An *exploratory* scenario is formed of a potential qualitative future storyline and its resulting quantitative depiction.

Each organisation explores several energy pathways, yet the dominant focus is on normative scenarios that depict GEST driven by substantial decarbonisation, rather than those that see a more muted transformation in business-as-usual type cases.

We examine the consideration of geopolitics in all of these scenarios using the analytical framework from section 2.1. In our analysis of energy system metrics (Section 4), we consider normative, Paris-aligned scenarios as well as those that we identify as having more pronounced engagement with energy geopolitics based on the analysis in section 3. The aim is to highlight how qualitative differences in engagement with geopolitics also translate into quantitative scenario differences. In that respect, we hypothesise that those scenarios that engage more with geopolitics are less likely to entail a Paris-aligned transformation that is also reflected in quantitative metrics.

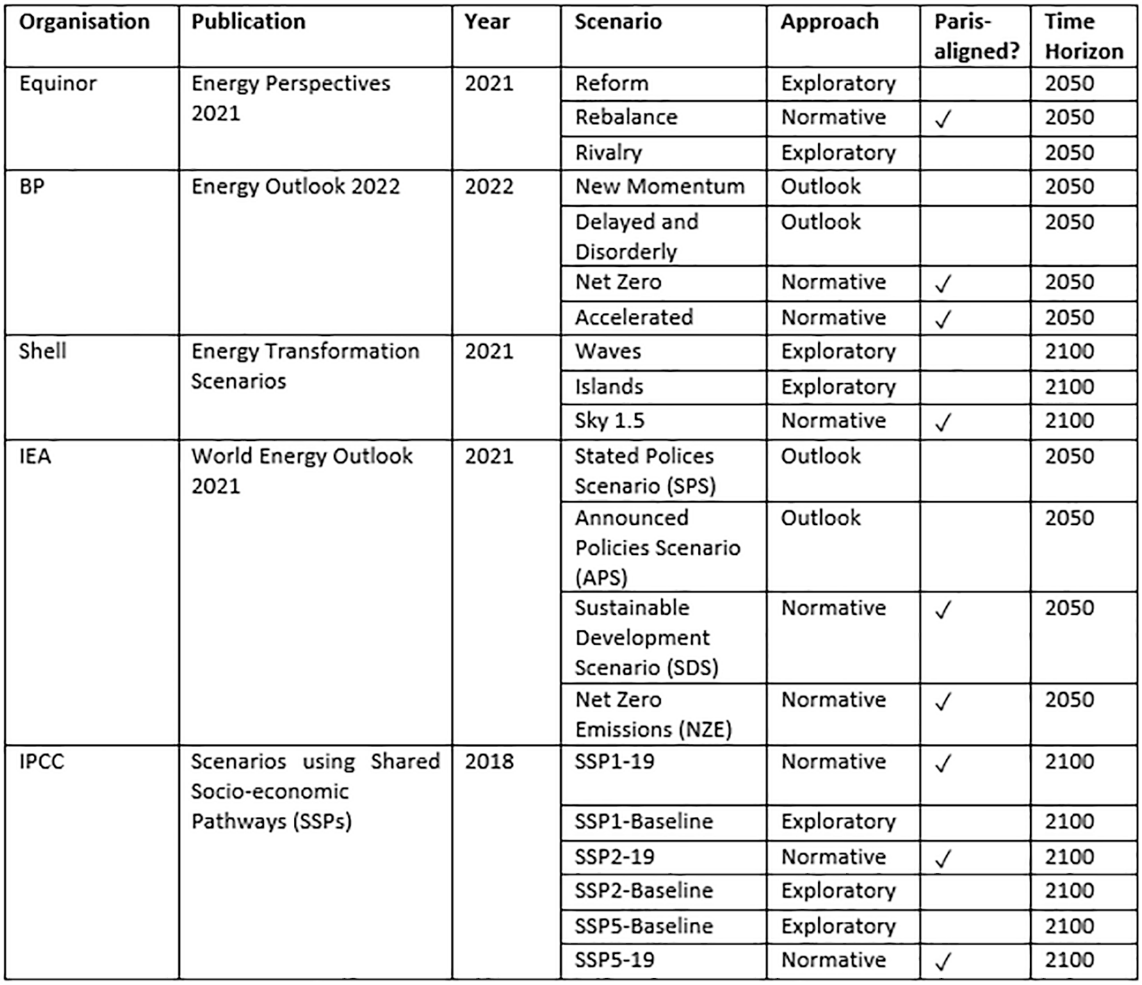
To conclude, most of the scenarios that we study here were prepared before Russia's full-scale invasion of Ukraine in February 2022. This event has had major geopolitical impacts on global energy markets (Kuzemko et al., 2022). As a result, some scenario providers have already released new scenarios that take geopolitics more explicitly into account. It underscores the fact that that current events make it difficult to ignore the importance of geopolitics and makes our insights all the more significant, although preliminary analysis shows no fundamental changes to their scenarios. Moreover, we are more interested in the role that geopolitics plays in the *process* of scenario-building as opposed to

Table 1
Qualitative analytical framework for high and low-carbon transitions.

HIGH-CARBON TRANSITION		
Sub-topic	**Key geopolitical features**	**Geopolitical codes**
Fossil fuel supply abundance due to new technologies & increasing demand-side pressure	• Demand-side pressure from low-carbon tech cost reductions • Water- and land-use conflicts of new fossil fuel extraction technologies • Production shift to low-cost, low-carbon intensity producers • Changes in relative importance of gas versus oil: implications for regional supply-demand dynamics	Fossil fuel producers; Demand destruction; Shale; Fracking; scarcity; abundance; Peak oil (demand/supply)
Resource curse	• Losses in fossil fuel rents • Producer competition and Green Paradox • Increase in relative concentration of power over fossil fuel production • Leap-frogging by developing countries • Strategic responses: ○ Economic diversification, green industrial policy, sovereign wealth fund (SWF) ○ Fossil fuel subsidies reform	Fossil fuel revenues; Green paradox; rents/rentier states; fossil fuel subsidies; diversification; green industrial policy; carbon curse; energy weapon; price volatility; leap-frogging; Sovereign Wealth Fund (SWF)
Fossil fuel carbon capture and storage	• Persistence of dynamics of high-carbon system due to continued role of fossil fuels	Blue hydrogen; CCUS
Unburnable carbon, stranded assets and divestment	• Stranded assets with risks for industry, producer economies, and markets • Carbon bubble and the risks of collapse in asset value • Divestment activities, investors acting on transition risks	Stranded assets; Carbon bubble; Divestment; unburnable carbon; carbon budget; Minsky moment; transition risk; financial risk
Supply-side constraints	• Carbon lock-in effects • Providing energy access through fossil fuels	(Carbon) lock-in; energy poverty; energy access
Activism and just transition	• Supply-side activism and 'keep it in the ground' campaigns • Issues of 'just transitions' – pace of transitions and capacity to transition ○ Just distribution of social and financial costs and rent losses	Supply-side policy; Keep it in the ground; Unburnable; Unextractable; Just transition
LOW-CARBON TRANSITION		
Harnessing renewable energy	• Low energy density • Land- and water-use trade-offs	Density; conflict; choke points; social acceptance; land-use; water-use
Electrification: interconnection and decentralisation	• Interconnection: ○ Trade (a)symmetries ○ Cooperation; large investments; cut-off risks • Decentralisation and self-sufficiency challenging central governments • Physical vulnerability of large, interconnected grids	Interconnection; Decentralisation; Electrification; Energy poverty; Energy access; Electricity trade; intermittency; market coupling; electricity weapon;
Critical minerals	• Demand increase for critical materials/minerals • Geographic concentration: supply chain control (through FDI), capacity constraints, and price volatility • Recycling and innovation resulting in re-use and replacement of minerals • 'Social licence to mine' • Conflicts over land- and water-use	Critical (raw) materials OR Critical metals OR critical minerals; Rare earth elements; new resource curse; supply chain; circular economy OR recycling; price volatility; land-use; water-use; social licence
Trade in low-carbon technologies and fuels	• Production capacity concentration • Biomass trade, and exposure to disruption • Large-scale green H_2 production & trade: ○ Trade dependency ○ Transition strategy away from fossil fuels; • Regional competition	Renewable technology OR Low-carbon technology; production OR manufacture; Biomass OR bioenergy OR biofuels trade; Green hydrogen; supply chains
Carbon Dioxide Removal (CDR)	• Negative emission technologies like BECCS, creating water- and land-use trade-offs (food vs fuel; displacement), and conflicts over justice (who provides what to whom; decision procedures)	BECCS; CDR; DAC; nature-based solutions; land-use; water-use
Digitalisation and cybersecurity	• Threats of digitalisation to cybersecurity (cyber warfare)	Digitalisation; Cyber-attack OR warfare; privacy; ICT

Source: authors' creation, based on Blondeel et al. (2021).

Table 2
Global energy scenarios under review*.



Organisation	Publication	Year	Scenario	Approach	Paris-aligned?	Time Horizon
Equinor	Energy Perspectives 2021	2021	Reform	Exploratory		2050
			Rebalance	Normative	✓	2050
			Rivalry	Exploratory		2050
BP	Energy Outlook 2022	2022	New Momentum	Outlook		2050
			Delayed and Disorderly	Outlook		2050
			Net Zero	Normative	✓	2050
			Accelerated	Normative	✓	2050
Shell	Energy Transformation Scenarios	2021	Waves	Exploratory		2100
			Islands	Exploratory		2100
			Sky 1.5	Normative	✓	2100
IEA	World Energy Outlook 2021	2021	Stated Polices Scenario (SPS)	Outlook		2050
			Announced Policies Scenario (APS)	Outlook		2050
			Sustainable Development Scenario (SDS)	Normative	✓	2050
			Net Zero Emissions (NZE)	Normative	✓	2050
IPCC	Scenarios using Shared Socio-economic Pathways (SSPs)	2018	SSP1-19	Normative	✓	2100
			SSP1-Baseline	Exploratory		2100
			SSP2-19	Normative	✓	2100
			SSP2-Baseline	Exploratory		2100
			SSP5-Baseline	Exploratory		2100
			SSP5-19	Normative	✓	2100

simply considering geopolitical outcomes of scenarios, allowing us to focus on reports from 2021 and early-2022. Take the IEA, although in its 2022 WEO, it explicitly raises the question whether “a messy transition [is] unavoidable”, it simultaneously writes that it only “explores approaches that can lessen the scope for volatility and turbulence ahead” (IEA, 2022c). This implies that it opts not to consider how geopolitical volatility and Paris-aligned climate action might be aligned in its 2022 WEO.

3. Qualitative analysis: Geopolitics in GEST scenarios

In this section, we analyse our scenarios while applying the framework that we have introduced above. For each organisation, we first discuss treatment of the geopolitics of HCT, followed by that of LCT. The narratives presented below are based on a separate content analyses of the entire report or article in which scenarios are presented.

3.1. BP Energy Outlook 2022

First, for the HCT, the 2022 BP Energy Outlook (henceforth, the Outlook) most concretely engages with geopolitics when covering competition between fossil fuel producers as demand declines over time. They argue that this “increases the bargaining power of consumers, with economic rents shifting away from traditional upstream producers towards energy consumers” (BP, 2022, p. 33). It reflects concern over how fossil fuel rents will decline for some producers and comes back in a discussion of market share competition between OPEC and non-OPEC producers.[1] In the discussion of the *Accelerated* and *Net Zero* scenarios, OPEC’s initial decline in production share, followed by an increase of market concentration in its favour, is discussed. This is particularly due to the lower carbon intensity of its oil supplies. However, the report stops short of reflecting on the geopolitical implications of such concentration of supply. Blue hydrogen is discussed as partially offsetting the decline in natural gas production, while liquified natural gas (LNG) drives changing geographies of natural gas consumption and production in both scenarios. As the transition progresses, the US loses its role as a major LNG exporter because of its physical distance—compared to competitors in Middle East and East Africa—from the remaining import hubs in Asia. That is, in these scenarios we see a persistence of the geopolitical dynamics of the high-carbon system due to continued role of fossil fuels, despite shifts in trade geographies.

Second, geopolitical analysis of LCT dimensions is particularly thin. At no point does the Outlook engage explicitly with key geopolitical features as identified in our framework. The Outlook recognises that accelerated installation of wind and solar capacity depends on a range of enabling (geopolitical) factors, such as the “availability of key materials”

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[1] The Organization of the Petroleum Exporting Countries (OPEC) has 13 members and includes some the world’s top oil-producing states. In 2016, it formally established ties with other non-OPEC oil producers, including Russia, to coordinate oil production. This extended group is called ‘OPEC+’.

(p. 69), but it is unclear if and how this is factored into the modelling and the scenario design. For biomass and low-carbon hydrogen, the expectation is that most trade will occur on a regional scale, although some inter-regional trade for hydrogen will develop. There is no need to increase from the current levels of land devoted exclusively to bioenergy, which is an implicit acknowledgement of the land conflicts associated with bioenergy production (p. 71).

In sum, the Outlook includes critical reflections on a number of issues related to the HCT and LCT but fails to explicitly analyse them through a geopolitical lens. It does not once mention the word 'geopolitics' (or any related term). This is emblematic of an identified lack of consideration in terms of how a changing geopolitical environment may impact BP's respective scenarios or what the geopolitical implications of these scenarios are. The difference with its peer, Shell, is quite striking. BP notes that the scenarios in its 2023 Energy Outlook are largely based on the analysis and scenarios from its 2022 Energy Outlook (BP, 2023, p. 13). One notably departure from last year is the inclusion and discussion of the Inflation Reduction Act (IRA) in the US as well as Russia's war in Ukraine as influencing GEST, albeit to a limited extent.

3.2. Equinor Energy Perspectives 2021

First, on the HCT, there is discussion of a number of topics associated with geopolitics. Again, the report discusses changes in share of oil production, focussing on OPEC+'s increasingly dominant position. According to Equinor, "this presents both threats and opportunities" because some countries' ambitions (UAE is mentioned) may create tensions within OPEC. As such, "competing strategies and bids to capture market share could rupture internal unity" (Equinor, 2021, p. 40). Further, the relationship between current rentier states and fossil fuel importers is discussed in terms of potential 'winners' and 'losers'.

In the report, the Norwegian sovereign wealth fund is presented as an example as to how future generations can benefit from current resource extraction and cope with the eventual loss of fossil fuel rents for producers (pp. 50–52). Carbon Capture, Usage and Storage (CCUS) is further considered as a measure to "extend the fossil fuel era" (p. 35), although a focus on producing reserves with low carbon intensity will lead to some currently undeveloped resources remaining in the ground. Lastly, there is attention to (geo)political dimensions of 'just transitions'. The remaining carbon budget, for example, needs to be shared equitably among states. If not properly managed, this can lead to a risk of populist leaders capitalising on discontent with an explicit reference to the *Gilets Jaunes* movement in France (p. 52).

For the LCT, the geopolitics discussion is much less extensive. The introduction notes that bottlenecks such as land space for renewables will have to be resolved. Electrification is a unifying theme across all three scenarios in the report. It recognises that variability and intermittency of renewables may impact grid stability in the future, so not all countries will be able to "trade their way out of imbalances" (p. 43).

The report also discusses risks associated with rare earth elements and other critical minerals for the energy transition, particularly in terms of concentration of control over mineral supply chains. As the report notes "oligopolistic supply may be a problem not only for geopolitical reasons" (p. 48). There is a special section dedicated to hydrogen but this does not include any geopolitical reflection. Bioenergy with Carbon Capture and Storage (BECCS) is mentioned as potentially crowding out food supply, harming biodiversity and requiring significant amounts of land. As the report notes, "there is available area that could be used for growing forests but there may be biodiversity, social and other concerns complicating execution" (p. 47).

All three scenarios include geopolitical reflections. In fact, Equinor explicitly notes that several factors, including geopolitics, drive and determine transition outcomes. *Rebalance* and *Reform* are framed as occurring in a context of geopolitical cooperation or "friendly competition". Whereas *Rivalry* shows a world of geopolitical tension and conflict. The GEST will have disruptive effects on the global order, simultaneously exacerbating as well as redressing tensions and instabilities (p. 50). Nevertheless, the report is mostly techno-economic in nature. At times, it does engage with some of the geopolitical implications for the *Rebalance* scenario. All in all, this report is one of the few with in-depth reflections on specific topics that includes geopolitical dimensions. This does not significantly change in its 2022 Energy Perspectives. The war in Ukraine is mentioned as significant geopolitical event but the principles of the *two* central scenarios are broadly in line with those from the 2021 version.

3.3. Shell Energy Transformation Scenarios 2021

For the HCT, Shell notes that in all three scenarios "regional and country oil and natural gas balances will continue to shape geopolitical alignments and rivalries for several decades to come" (Shell, 2021, p. 72). In *Sky 1.5*, global demand for oil and coal start to decline in the coming years, with gas demand peaking in the 2030s. Importantly, fossil fuel demand remains in hard-to-abate sectors. This observation leads to a reflection on the responses to falling oil demand by major producers OPEC, for example, is expected to manage supply to maximise revenues rather than to increase production volumesto maximise market share. Stranded assets are mentioned in the *Waves* scenario but not *Sky 1.5*. The latter scenario does refer to the role capital markets play as they "avoid fossil fuel options perceived to hold long-term risks" (p. 40). There is also explicit reference to the need for 'justice' throughout the HCT (pp. 75–76).

Shell's scenarios also discuss the geopolitics of the LCT. For example, it explicitly recognises that harvesting diffuse energy sources will require significant land use. Yet, given the importance and scarcity of land, tensions will likely emerge. Nonetheless, *Sky 1.5* relies heavily on negative emissions or nature-based solutions. It requires major reforestation of up to 700 million hectares of land—an area approaching the size of Brazil—without any critical reflection on what social, political or economic consequences this would generate. The scenario is also optimistic when it comes to cooperation between superpowers. China and the US are expected to work together to address pressing global issues that challenge their domestic interests, including protocols for cybersecurity.

Unlike Equinor, and especially BP, Shell explicitly, and relatively extensively, incorporates geopolitical analysis in its scenarios. Of the three corporate scenario providers discussed here, Shell has the mostly explicitly geopolitically-oriented analysis. It labels the *Islands* scenario as 'geopolitical', with a new geopolitical order taking shape, resulting in "increasing attention on national security and trade barriers" (p. 30). Geopolitics is seen as a key driving force behind the lack of transition progress. In other scenarios, particularly *Sky 1.5*, this engagement with geopolitics is less pronounced. This trend of Shell being the most geopolitically-oriented corporate scenario provider continues in their 2023 Energy Security Scenarios (2023).

3.4. IEA World Energy Outlook 2021

First, for the HCT, the IEA notes that lower demand for oil and gas "ultimately reduces some traditional security hazards but they do not disappear" (IEA, 2021, p. 270). This is particularly the case for Asia which continues to remain exposed to geopolitical hazards of the high-carbon system due to its dependence on fossil fuels from the Middle East. Moreover, the sharp drop in fossil fuel investments could destabilise regions and communities dependent on these incomes if not carefully managed.

The WEO discusses the increasing share of OPEC of total global oil production and the associated risks of physical disruptions and trade disputes. There will be a large number of producers that will seek to claim a share of the shrinking market. This will only complicate a managed decline in production and increases the possibility of a volatile and 'messy' transition, especially if fossil fuel rents/revenues decline significantly over time. The possibility of stranded assets is discussed, with LNG assets that are stranded in NZE worth up to USD 75 billion. The fossil fuel phase-out needs to be accompanied by sustained government commitments to manage impacts on communities, assets, land, and the local environment in a bid to secure 'just transitions'.

Second, for the LCT, there is extensive discussion of the issues of intermittency and variability when it comes to renewables-based power generation, especially in context of peak demand. It recognises that electrification come with decentralisation and zooms in on the positive (technical) elements of interconnection. There is a complete section in chapter 6 devoted to geopolitics and security of critical minerals. High and volatile prices for critical minerals are a key issue of concern with a combination of small market size and high levels of geographical concentration requiring vigilance. Shifts to new technologies could lower demand for specific minerals. It highlights that mineral demand will also create new trade flows and some countries will seek to nurture domestic supply chains. Geopolitical hazards for wind and solar are lower than for fossil fuels – particularly associated with trade in equipment and raw materials (green hydrogen). Cyber security (attacks and data privacy) is mentioned.

Geopolitics forms a crucial element of the discussions around energy security in the context of the NZE scenario (Chapter 6 of the WEO). The WEO report differs significantly in its geopolitical analysis from the corporate scenario providers. This is primarily explained by the nature of the organisation and the WEO. In the first place, the IEA is an intergovernmental organisation, established in 1974 by high-income consumer economies in response to the 1973–1974 oil crisis, with 'energy security' as the foundation of its mandate (IEA, 2015).

3.5. Shared Socio-Economic Pathways (SSPs)

The detailed narratives of all five SSPs[2] are translated into a set of quantitative techno-economic assumptions such as economic growth, population change and urbanisation scenarios. In turn, these are used by Integrated Assessment Models to develop SSP baseline and, combined with the Representative Concentration Pathways (RCP) which dictate climate objectives, mitigation scenarios. Despite their intricate and comprehensive nature, which are discussed in detail in O'Neill et al. (2017), these narratives engage with geopolitics in a broad manner which lacks detail. For instance, geopolitics is mentioned in the context of the "pessimistic" SSP3 scenario (*Regional rivalry*) where rivalry, competition and conflict between (blocs of) countries lead to a rocky transition with less global cooperation and trade. However, the geopolitical implications of this are generally not considered in the scenario's quantitative analysis beyond some high-level impacts on international energy trade (Fujimori et al., 2017).

For the HCT, there is only limited engagement with geopolitics across the papers that introduce the SSPs. High carbon lock-in is mentioned in SSP1 (*Sustainable development*) with the authors noting the transition "needs time as a result of existing infrastructure and the related competitive position of fossil fuels" (van Vuuren et al., 2017, 242). Yet, there is no discussion of what the geopolitical impact may be. SSP1 is seen to have risks "non-performance of technology, rebound effect of efficiency, free-rider behaviour, and a potential push-back from actors whose interests are not ensured [in the SSP1 scenario]", but this is not given any meaningful consideration (van Vuuren et al., 2017, 249). Similarly, it is noted that in SSP4 (*Inequality*) "energy companies hedge against price fluctuations partly through diversifying their energy sources" while being taken no further (Calvin et al., 2017, 285).

For the LCT, geopolitical analysis is arguably even more scant. For example, the impact of trade barriers in SSP3 on low carbon technology and fuel trade, which would be expected to originate from its more fragmented world, is not discussed. While the SSPs consider a range of social acceptance levels for non-biomass renewables, the details of how this might shape energy geopolitics in future are ignored. Popp et al. (2017) explore the land-use futures in the SSPs but fail to explicitly reflect on land-use trade-offs. They note that "as a result of land needed for large scale bioenergy production and afforestation programs in the mitigation scenarios, the use of land for food and feed production and pasture is reduced" (Popp et al., 2017, 338). Instead of discussing risks, this trade-off—which in essence is not even considered one—is addressed through a techno-fix such as agricultural intensification (in SSP5) or behavioural, dietary changes (in SSP2).

In summary, while including some broad geopolitical aspects, the SSPs, and particularly their quantitative implementation, contain very little detailed geopolitical analysis, instead preferring to take a more technoeconomic, global frame.

Next, we examine both the range of potential futures consistent with meeting the Paris Agreement goals and the impact of considering geopolitics on these futures, using insights from this section.

4. Quantitative analysis: Impact of geopolitics on HCT scenario outcomes

This section explores and shows how (differentiation in) the qualitative treatment of geopolitics of the high-carbon transition (HCT) translates into (differentiation in) a number of quantitative measures that describe the future of the global energy system. We situate our analysis of quantitative metrics primarily in a context of the HCT (decrease in demand for fossil fuels). This is explained by the predominant focus of scenario providers on this specific dimension of GEST (rather than the LCT, see Section 3). In addition to reviewing the key quantitative metrics in nine Paris-aligned scenarios, we also examine scenarios that we have identified as having more explicit engagement with geopolitics in the previous section, i.e., Shell *Waves* and *Islands* and *Rivalry* from Equinor.

We focus our comparison on the key energy system metrics of primary energy demand (particularly fossil fuels) and CO_2 emissions at the global level, given the diverse regional disaggregation available in each scenario, and expect that geopolitical scenarios will show slower and less 'radical' GEST across the selected metrics.

Fig. 1 shows that six scenarios see a reduction in total primary energy demand from 2019, with BP-Net Zero and SSP1-19 showing the most ambitious falls, while SSP2-19 shows a modest increase. This drop is largely driven by two factors: (i) substantial growth in the demand for energy from non-biomass renewables (NBR) from a deeper electrification of the energy system; and, (ii) a large drop in fossil fuel consumption.

The remaining two Paris-aligned scenarios, SSP5-19 and Shell-Sky 1.5, have a see substantial growth in primary energy demand First, SSP5-19 has a similar reliance on fossil fuels and NBR as the scenarios mentioned above but sees a large increase in biomass consumption. This is mainly to provide negative emissions to offset CO_2 emissions earlier in the century driven by high fossil fuel use, as is part of this scenario's narrative. However, as explained in the section 3, Popp et al. (2017) explore the land-use futures in the SSPs but fail to explicitly reflect on land-use trade-offs.. Given reasonable food security and environmental limits, it is questionable how feasible this scenario's level of biomass consumption in 2050 is (Creutzig et al., 2021; Kalt et al., 2020).

Second, Shell-Sky 1.5 sees a much smaller fall in fossil fuel consumption; it has the highest coal and oil demand in 2050 of the Paris-aligned scenarios. This continued dependence on fossil fuels in a 1.5 °C scenario is enabled by two factors: heavy reliance on major reforestation (estimated at 700 Mha) and by the scenario using a substantially larger carbon budget (29 %) than the IPCC suggests is compatible with a 50 % probability of limiting warming to 1.5 °C in 2100 (747 $GtCO_2$ from 2018 compared to 580 $GtCO_2$; IPCC, 2018a). With a larger carbon budget, geopolitical challenges of the current high-

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[2] They are: *Sustainable development* (SSP1), *Middle-of-the-road* (SSP2), *Regional rivalry* (SSP3), *Inequality* (SSP4), and *Fossil fuelled development* (SSP5).

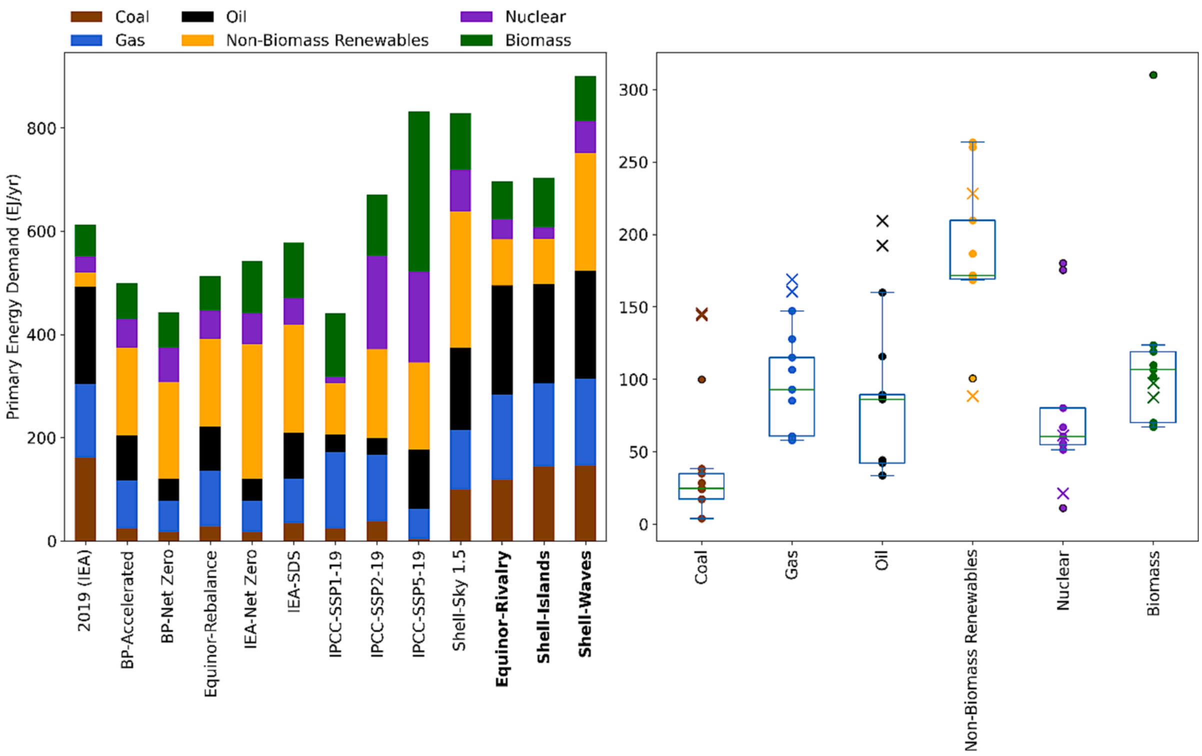

Fig. 1. The left panel shows global primary energy demand by scenario in 2050.[1] The three scenarios in bold in the left panel are non-normative scenarios that fail to meet Paris-aligned climate targets in large part because of geopolitical tensions. The right panel shows the spread in the consumption of each fuel across the scenarios with the three more geopolitical scenarios marked as crosses and the Paris-aligned cases as solid circles. The over plotted box plots are computed from the nine Paris-aligned scenarios. The green bar in each box shows the median fuel demand across these scenarios and the boxes span from the first to third quartile of the data. [1]The primary energy accounting of non-combustible energy sources has been harmonised to the physical energy content approach used by the IEA. This means that primary energy is defined at the point where multiple uses of an energy source are possible. For nuclear, this is the heat in the reactor while for non-biomass renewables (NBR) this is the electricity they produce. Combined, this convention means that a shift to an electrified and renewably powered energy system leads to lower primary energy consumption.

carbon system would be more persistent, while the major reforestation efforts will result in major land-use trade-offs and associated geopolitical tensions. Yet, the Shell report does not really explore these issues.

The three more geopolitically engaged scenarios, those in bold in Fig. 1, show almost no HCT, with fossil fuel energy consumption in 2050 essentially at today's levels, coupled with some NBR growth. This underscores how in worlds in which 'geopolitics' is considered, the global energy system does not succeed in meaningfully transforming.

Fig. 2 shows fossil fuel primary energy demand between today and 2050. Coal demand declines rapidly across all Paris-aligned scenarios except for Shell-Sky 1.5. Many countries have existing coal generation plants that can generate electricity at low marginal cost, and this has underpinned the reticence in international negotiations to commit to reducing coal use, as discussed in Section 1.1, and leave these assets stranded. The more geopolitical scenarios depict worlds where coal demand barely declines by 2050, in part because of the global tensions they envisage and the need to rely on domestic energy sources (with coal much less traded internationally than gas and oil). As noted earlier, this is supported by the response to the war in Ukraine that has seen a return of coal.

For natural gas, some of the SSP scenarios show growth to 2050, which would be coupled with CCS and probably reflects assumptions in 2017 that NBRs will be much more expensive than is now assumed—confirming longstanding critiques of the consistent underestimation of NBR cost declines in scenarios. IEA-Net Zero and BP-Net Zero have a steady decline. All three geopolitical scenarios show a growth in gas over this period. Lastly, oil demand falls in the Paris-aligned futures. The outliers here are SSP5-19, which shows a rapid growth in oil demand to 2030 before falling equally rapidly to 2050, and Shell-Sky 1.5 which has global oil consumption almost unchanged to 2050. No qualitative geopolitical discussion accompanied these striking findings in their respective scenario narratives. The geopolitical scenarios show either constant oil demand or limited growth, a markedly different future from the Paris-aligned scenarios, and one in which the geopolitics of the high-carbon system remain in place.

Fig. 3 shows a spread in potential pathways to 2050 for global CO_2 emissions from fossil fuel consumption and industrial processes (FF&I) from the Paris-aligned scenarios. In line with other figures, there is a major discrepancy between on the one hand the Paris-aligned scenarios and, on the other, the geopolitical cases. Perhaps the starkest observation is that the three scenarios with inherent geopolitical tensions show no decline whatsoever in emissions from today.

It is clear that the Paris-aligned scenarios see a range of potential routes along which GEST may unfold, leading to different real-world implications, both in climate and geopolitics terms. For climate, these differences drive a large range in cumulative CO_2 emissions to 2050 (e.g. IEA-Net Zero has 540 $GtCO_2$; BP-Net Zero has 655 $GtCO_2$; Shell-Sky 1.5 has 1035 $GtCO_2$).[3] Greater cumulative emissions prior to 2050 imply an increasing dependence on CDR post-2050 to meet the carbon budget in 2100, and beyond, for a given chance of 1.5 °C. Therefore, for scenarios providers such as BP who do not provide emissions data beyond mid-century, it is challenging to assess whether their scenarios are genuinely compatible with a certain probability of limiting long term warming. For geopolitics, Shell's optimistic assumptions, around large-scale reforestation, for example, will inevitably create significant

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[3] For BP and Shell this figure is based on integration of the emissions pathways they provide as they do not state cumulative FF&I CO_2.

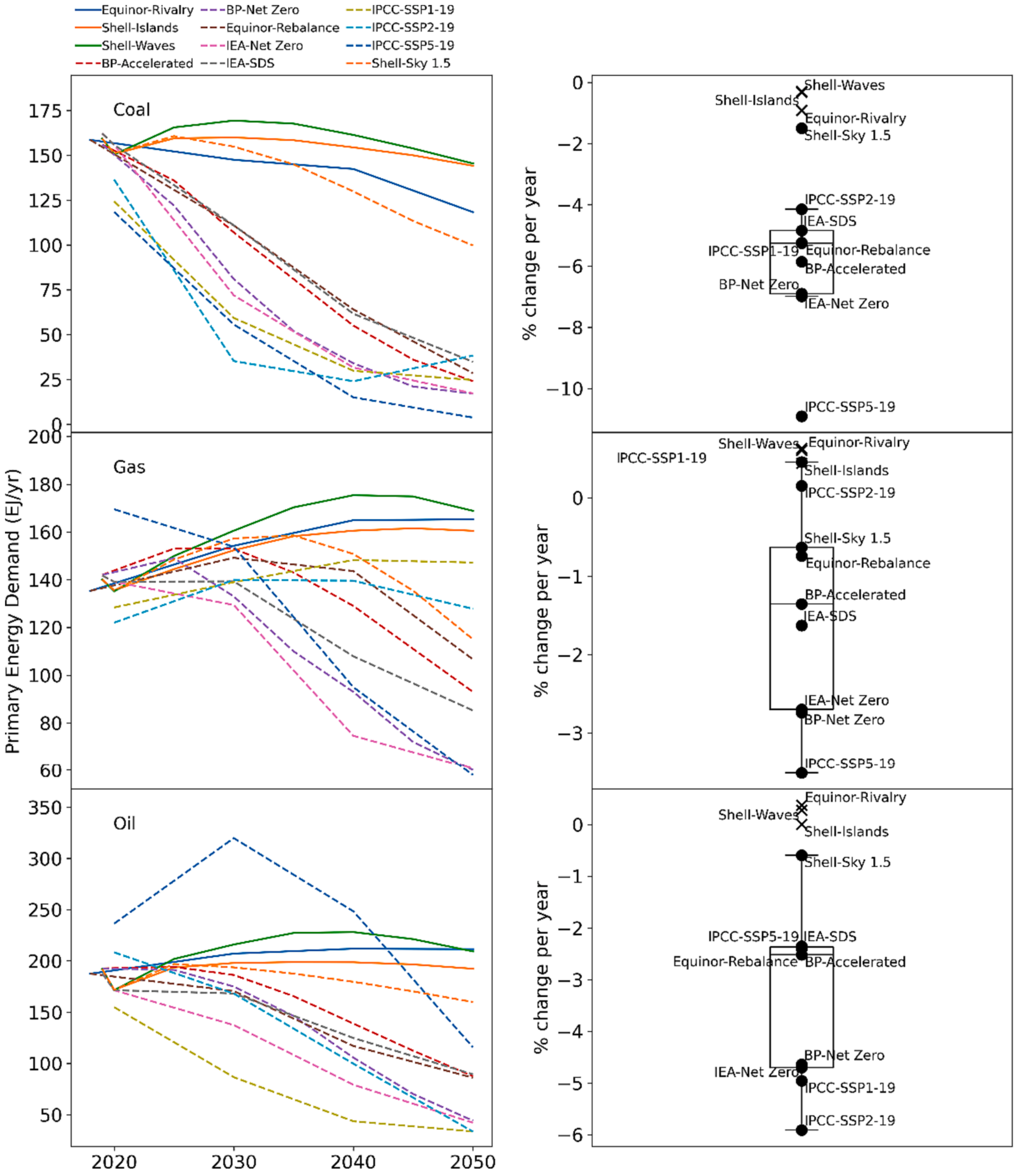

Fig. 2. The left panels show global primary energy demand for fossil fuels from today to 2050 in the nine Paris-aligned (dashed lines) and the three more geopolitically engaged (solid lines) scenarios we review. The right panels show the compound annual growth rate over this period for each scenario and fuel with Paris-aligned scenarios again denoted by solid circles, and used to compute the box plots, and the geopolitically engaged scenarios as crosses.

societal trade-offs outside the energy system.

The main takeaway of this quantitative analysis is that it confirms the findings of Section 3. Global energy scenarios which describe futures with some level of geopolitical tension, in one way or another, result in a limited or non-existent HCT, sustained high levels of emissions and, as a result, a failure to achieve the Paris climate objectives.

The following discussion section explores our findings more in depth and reflects on their implications.

5. The case for considering geopolitics in energy system scenarios

Generally, geopolitics is given little attention by these scenario providers. And when it is, the predominant focus is on the HCT, with particular attention to supply-side issues, as the recurrent discussion on the (changing) role of OPEC shows. In the LCT the geopolitics of industrialisation (e.g. gigafactories) and wastes (e.g. circular economy for critical minerals) are introduced in a way that is quite different to the HCT (Bridge and Faigen, 2022).

While many geopolitical sub-topics in our analytical framework are touched on or mentioned in passing, it remains unclear to what extent geopolitics genuinely informs modelling efforts. With a few exceptions, most of the ‘geopolitics’ in the reports is, in fact, mainly about ‘geo-economics’, shifts in the geography of demand and supply modified by technological innovation. In essence, it portrays a neo-classical economic world view of market rationality, rather than a political economy perspective that foregrounds (unequal) distributions of property, power, and control. Politics, then, is considered an ‘intrusion’ or ‘disruption’ into this rationality rather than a precondition for it; an observation that echoes the growing number of critiques of the techno-economic nature of energy scenarios and ESM cited in section 1.1.

Although our analysis shows that there is a range of pathways to meet the Paris Agreement objectives, it is only those scenarios in which a geopolitical context of relative peace and cooperation is sketched out,

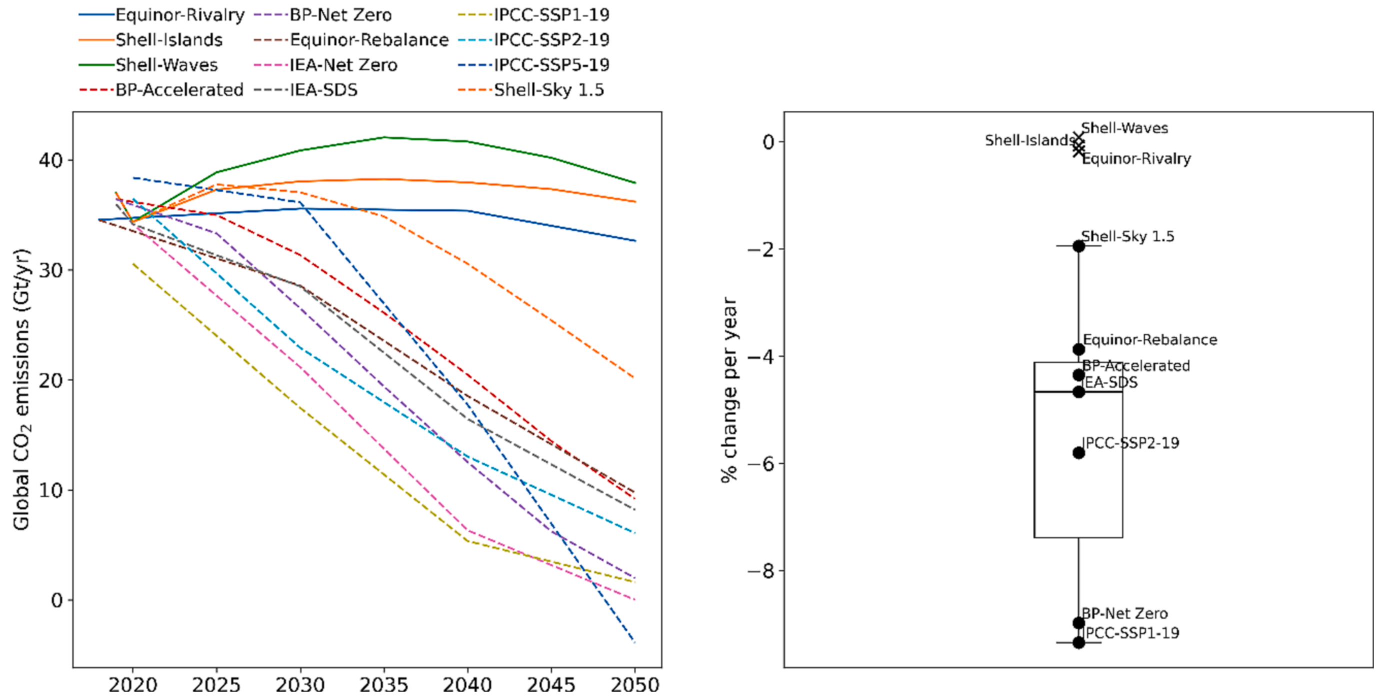

Fig. 3. The left panel shows global CO2 emissions (Gt/year) from today to 2050. The right panel shows the compound annual reduction rate over this period for each scenario. The markers are the same as in previous figures. Equinor provide energy-only CO_2 emissions for their scenarios and so we add on the process emissions from BP-Accelerated, a comparable 2 °C scenario that also provides process emissions separately, to estimate total FF&I emissions for their Rebalance case. No percent change in emissions per year to 2050 can be calculated for the IEA-Net Zero scenario and SSP5-19 as they reach net zero or net negative global emissions by 2050.

that ultimately achieve them. Geopolitics is an ‘obstacle’ (e.g. Fig. 3). A fundamental assumption of the Equinor scenarios, for example, is that the “scale and scope of the energy transition will be larger in a setting of peace and cooperation”, while Shell asserts that rapid and deep transitions “can only happen at the scale and pace the world needs with highly effective coordination” (Shell, 2021, p. 78). The NZE scenario “requires substantial international co-operation, with all countries contributing to the net zero goal.” (IEA, 2021, p. 110).

However, it is important to understand the extent to which the Paris-aligned pathways are deliverable in practice by seeing geopolitics as the real-world context in which policy is made. After all, as Equinor (2021, p. 11) has asserted, “*Rebalance* is an idealistic world and quite unlike anything seen historically.” Yes, national interests might preclude some pathways, equally, however, national interests could accelerate the development of some low-carbon technologies beyond what might be expected from socio-technical innovation studies. Equinor’s, 2022 key scenarios are *Walls* and *Bridges*, reflecting this tension (Equinor, 2022).

For example, NBR costs have declined much more rapidly than was assumed in models over the decade (Jaxa-Rozen and Trutnevyte, 2021), and several countries are now developing green industrial policy that is often considered as response to economic competitors and geopolitical changes; the IRA in the US is a case in point. In a similar vein, the EU’s REPowerEU plan in response to the Russia’s war on Ukraine is expected to accelerate both improvements in energy efficiency and the deployment of low carbon energy production. In other words, geopolitics can provide opportunities as well as barriers.

So, is ‘cooperation’ a *conditio sine qua non* to meet the Paris objectives? What form could successful cooperation take to persuade countries to transition away from fossil fuels? Equally, where is the evidence of a negative causal link between geopolitics and a lack of progress on climate change action? These questions require a real appreciation of geopolitics in ESM. After all, real-world geopolitical developments of recent years (e.g. COVID-19 pandemic; war in Ukraine; increased tensions between the US and China) seem to suggest that competition and conflict—in the form of political challenge, or geo-economic rivalry of the sort created by the ‘dumping’ of low-cost solar panels on world markets by China—is necessary to ‘face down’ the power of large hydrocarbon producers. It is therefore imperative not to ask whether cooperation or competition is better for GEST, but rather given the *current* state of geopolitics and international relations, what does it take to realise GEST? Or, can a competitive and fragmented world achieve rapid decarbonisation?

In the most recent scenario updates, some incremental changes regarding the abovementioned issues can be observed. BP’s, 2023 *New Momentum* scenario sees a relative decline in oil and gas demand through to 2050, compared to the 2022 version of the scenario, specifically as a result of the response measures to the war in Ukraine and the IRA in the US. At the same time, however, BP writes that its 2023 scenarios are “largely based on the analysis and scenarios in the Energy Outlook 2022” (BP, 2023, p. 13). Interestingly, Shell, in its 2023 *Energy Security Scenarios,* writes that “the security-first mindset results in aggressive, competitive rather than co-operative, decarbonisation” (Shell, 2023, p. 9); but decarbonisation nonetheless. In the end, however, the scenario where geopolitical competition is central (*Archipelagos*) still leads to 2.2 °C warming, although the Paris-aligned *Sky 2050* is not necessarily a scenario of benign cooperation either. Indeed, this scenario drives cost reductions and efficiency.

Accounting for geopolitics in models does remain challenging. Examining how scenarios account for geopolitical drivers—particularly how fossil fuel economics varies between supply and demand countries—could improve our understanding of national drivers for negotiations, and hence what types of cooperation might lead to successful emission reductions. Yet, most global models do not currently have the spatial resolution to represent individual countries. Even then, countries are not homogenous bodies and each government balances a different range of special interests. Perhaps a move away from optimisation models and towards simulation agent-based models will become appropriate to understand geopolitics in detail.

Lastly, the importance and influence of scenarios raises the question of *who* shapes the environment in which these scenarios actually can materialise. In other words, which actors possess geopolitical agency? The companies and organisations whose scenario exercises we have reviewed here are also active participants in energy geopolitics and have an interest in shaping the GEST in a beneficial way (Bricout et al., 2022). Yet, they seem to be blissfully unaware of their own role, not in the least when it comes to the impact of their reports and scenarios. Especially as Shell, BP and Equinor are among the very few that can afford and have access to sufficient information to devise visions of the future, this effectively grants them, in the words of Beck and Mahoney (2018a, 1), "world-making power."

6. Conclusions

Our primary objective has been to explore the disconnect between energy modelling and scenario-building on the one hand, and the geopolitical realities of GEST on the other. We find that geopolitics has received relatively little attention in the global scenarios we examined, although this varied between organisations. Geopolitics tended to be considered in non-normative scenarios, not aligned with the Paris Agreement. Analysis of the Paris-aligned scenarios shows that a range of pathways are depicted, but that some of these are arguably hard-to-achieve from a geopolitical perspective. It also highlighted that scenarios which actively engage with geopolitical tensions envisage radically different future energy pathways than Paris-aligned cases, which see a benign world of cooperation and collaboration. Although incremental steps have been taken to address these concerns in more recent scenarios (e.g. *BP Energy Outlook 2023* or *Shell Energy Security Scenarios*) after Russia's full scale invasion of Ukraine, the underlying assumptions remain broadly the same.

ESM tends to project GEST as an 'orderly' process, assuming that policies will always be conducive to sustainability and not the other way around. Geopolitics tends to suggest, however, that GEST is a 'messy' process, with some policies potentially slowing down change, or events preventing it from happening altogether, while other may accelerate change. The current geopolitical state-of-play only seems to underscore this. As such, the ESM community would benefit from more substantive engagement with geopolitics as an 'input' into their models in order to explore the complexities, dynamics and messiness of GEST. Such research could underpin more successful climate negotiations by enabling stakeholders to understand the underlying national interests of each party and the extent to which their economies will benefit or suffer from GEST. Put differently, given that the world we find ourselves in is far from orderly, can be we envisage a messy transition scenario that delivers sufficient climate action?

This paper is the result of an open dialogue between social scientists researching the geopolitics of GEST and energy modellers interested in incorporating such insights into the model and scenario-building processes. We end with an invitation to scholars from these fields to engage and bridge the remaining 'integration gap'.

CRediT authorship contribution statement

Mathieu Blondeel: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **James Price:** Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Michael Bradshaw:** Conceptualization, Project administration, Supervision, Writing – original draft, Writing – review & editing. **Steve Pye:** Conceptualization, Formal analysis, Writing – original draft, Data curation. **Paul Dodds:** Conceptualization, Writing – original draft. **Caroline Kuzemko:** Conceptualization. **Gavin Bridge:** Conceptualization, Writing – original draft.

Declaration of competing interest

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Data availability

Data will be made available on request.

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References

Ansari, D., Holz, F., Al-Kuhlani, H. (2019) Energy outlooks compared: Global and regional insights. DIW, German Institute for Economic Research, Berlin. Online available at: https://d-nb.info/1204430349/34.

Bazilian, M., Bradshaw, M., Gabriel, J., Goldthau, A., Westphal, K., 2019. Four scenarios of the energy transition: Drivers, consequences, and implications for geopolitics. WIREs Clim. Change 11 (2), e625.

Beck, S., Mahoney, M., 2018a. The politics of anticipation: the IPCC and the negative emissions technologies experience. Global Sustainability 1, 1–8. https://doi.org/10.1017/sus.2018.7.

Beck, S., Mahoney, M., 2018b. The IPCC and the new map of science and politics. WIREs Clim. Change 9 (6), e547.

Beck, S., Oomen, J., 2021. Imagining the corridor of climate mitigation – What is at stake in IPCC's politics of anticipation? Environ Sci Policy 123, 169–178. https://doi.org/10.1016/j.envsci.2021.05.011.

Berten, J., Kranke, M., 2022. Anticipatory Governance: International Organisations and the Politics of the Future. Glob. Soc. 36 (2), 155–169. https://doi.org/10.1080/13600826.2021.2021150.

Blondeel, M., Bradshaw, M., Bridge, G., Kuzemko, C., 2021. The Geopolitics of Energy System Transformation: A Review. Geogr. Compass 15 (7), e12580.

Bond, K. (2021) The Renewable Spring: The Interplay between finance and policy in the energy transition. Irena, Abu Dhabi. Online available at: https://irena.org/-/media/Files/IRENA/Agency/Technical-Papers/IRENA_Renewable_Spring_2021.pdf.

BP (2022) Energy Outlook 2022. BP, London. Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2022.pdf.

BP (2023) Energy Outlook 2023. BP, London: Available at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2023.pdf.

Bradshaw, M., 2009. The Geopolitics of Global Energy Security. Geogr. Compass 3 (5), 1920–1937. https://doi.org/10.1111/j.1749-8198.2009.00280.x.

Bridge, G., Faigen, E., 2022. Towards the lithium-ion battery production network: Thinking beyond mineral supply chains. Energy Res. Soc. Sci. 89, 102659 https://doi.org/10.1016/j.erss.2022.102659.

Calvin, K., Bond-Lamberty, B., Clarke, L., et al., 2017. The SSP4: A world of deepening inequality. Glob. Environ. Chang. 42, 284–296. https://doi.org/10.1016/j.gloenvcha.2016.06.010.

Carrington, G., Stephenson, J., 2018. The politics of energy scenarios: Are International Energy Agency and other conservative projections hampering the renewable energy transition? Energy Res. Soc. Sci. 46, 108–113. https://doi.org/10.1016/j.erss.2018.07.011.

Cointe, B., 2022. Scenarios. In: De Pryck, K., Hulme, M. (Eds.), A Critical Assessment of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 137–147.

Creutzig, F., Erb, K.-H., Haberl, H., et al., 2021. Considering sustainability thresholds for BECCS in IPCC and biodiversity assessments. GCB-Bioenergy 13 (4), 510–515. https://doi.org/10.1111/gcbb.12798.

Criekemans, D. (ed.) (2022a). *Geopolitics and International Relations. Grounding World Politics Anew.* Leiden & Boston: Brill Nijhoff.

Criekemans, D. (forthcoming) Geopolitics, Geo-Economics and Energy Security in an Age of Transition towards Renewables. In: Scholten, D. (ed.) *Handbook on the Geopolitics of the Energy Transition.* Cheltenham, Edward Elgar Publishing.

Equinor (2021) Energy Perspectives 2021. Equinor, Stavanger. Online available at: https://www.equinor.com/content/dam/statoil/documents/energy-perspectives/energy-perspectives-report-2021.pdf.

Equinor (2022) Energy Perspectives 2022. Equinor, Stavanger. Online available at: https://cdn.equinor.com/files/h61q9gi9/global/530bfee8bfbae0762ed3e99317126cc16a272f7d.pdf?energy-perspectives-2022-final-2.pdf.

Fujimori, S., Hasegawa, T., Masui, T., et al., 2017. SSP3: AIM implementation of Shared Socioeconomic Pathway. Glob. Environ. Chang. 42, 268–283. https://doi.org/10.1016/j.gloenvcha.2016.06.009.

Goldthau, A., Westphal, K., Bazilian, M., Bradshaw, M., 2019. How the energy transition will reshape geopolitics. Nature 569, 29–31. https://doi.org/10.1038/d41586-019-01312-5.

Hache, E., 2018. Do renewable energies improve energy security in the long run? International Economics 156, 127–135. https://doi.org/10.1016/j.inteco.2018.01.005.

Hausfather, Z., Peters, G.P., 2018. Emissions – the 'business as usual' story is misleading. Nature 577, 618–620. https://doi.org/10.1038/d41586-020-00177-3.

IEA, 2021. World Energy Outlook 2021. International Energy Agency, Paris.

IEA, 2022a. Security of Clean Energy Transitions. International Energy Agency, Paris.

IEA, 2022b. World Energy Outlook 2022. International Energy Agency, Paris.

IEA (2015). Summary of the Chair, he Hon. Ernest J. Moniz, U.S. Secretary of Energy, 2015 IEA Ministerial Meeting, 17-18 November 2015. International Energy Agency, Paris. Online available at: https://iea.blob.core.windows.net/assets/ad463be5-3484-4480-8797-5a1e6d247528/IEAMinisterialChairsSummary.pdf.

IEA (2022b) Coal 2022. Analysis and forecast to 2025. International Energy Agency, Paris.

IPCC, 2018. Global Warming of 1.5°C. Intergovernmental Panel on Climate Change, Geneva.

Irena, 2019. A New World: The Geopolitics of Energy Transformation. International Renewable Energy Agency, Abu Dhabi.

Ives, M., Righetti, L., Schiele, J. et al. (2021) A new perspective on decarbonising the global energy system. Smith School of Enterprise and the Environment, Oxford University, Oxford. Online available at: https://www.smithschool.ox.ac.uk/sites/default/files/2022-03/A-new-perspective-on-decarbonising-the-global-energy-system-summary.pdf.

Jaxa-Rozen, M., Trutnevyte, E., 2021. Sources of uncertainty in long-term global scenarios of solar photovoltaic technology. Nat. Clim. Chang. 11, 266–273. https://doi.org/10.1038/s41558-021-00998-8.

Kalt, G., Lauk, C., Mayer, A., et al., 2020. Greenhouse gas implications of mobilizing agricultural biomass for energy: a reassessment of global potentials in 2050 under different food-system pathways. Environ. Res. Lett. 15, 034066 https://doi.org/10.1088/1748-9326/ab6c2e.

Kelly, P., 2016. Classical Geopolitics. A New Analytical Model. Stanford, Stanford University Press.

Kuzemko, C., Blondeel, M., Dupont, C., Brisbois, M.-C., 2022. Russia's war on Ukraine, European energy policy responses & implications for sustainable transformations. Energy Research & Social Science 93, 102842. https://doi.org/10.1016/j.erss.2022.102842.

Lacroix, D., Laurent, L., de Mentière, N., et al., 2021. Multiple visions of the future and major environmental scenarios. Technol. Forecast. Soc. Chang. 144, 93–102. https://doi.org/10.1016/j.techfore.2019.03.017.

Mahony, M., 2022. Policy Relevance and Neutrality. In: De Pryck, K., Hulme, M. (Eds.), A Critical Assessment of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 197–206.

Månberger, A., Johansson, B., 2019. The geopolitics of metals and metalloids used for the renewable energy transition. Energ. Strat. Rev. 26, 100394 https://doi.org/10.1016/j.esr.2019.100394.

McGlade, C., Ekins, P., 2015. The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. Nature 517, 187–190. https://doi.org/10.1038/nature14016.

Mercure, J.F., Salas, P., Vercoulen, P., et al., 2021. Reframing incentives for climate policy action. Nat. Energy. https://doi.org/10.1038/s41560-021-00934-2.

Mills, A.J., Durepos, G., Wiebe, E. (2010) Encyclopedia of Case Study Research. Thousand Oaks, SAGE Publications. 10.4135/9781412957397.

Muttitt, G., Kartha, S., 2020. Equity, climate justice and fossil fuel extraction: principles for a managed phase out. Clim. Pol. 20 (8), 1024–1042. https://doi.org/10.1080/14693062.2020.1763900.

Newell, P., Simms, A., 2020. Towards a fossil fuel non-proliferation treaty. Clim. Pol. 20 (8), 1043–1054. https://doi.org/10.1080/14693062.2019.1636759.

O'Lear, S., 2018. Environmental Geopolitics. Rowman & Littlefield, Lanham.

O'Neill, B., Kriegler, E., Ebi, K.L., et al., 2017. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Glob. Environ. Chang. 42, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004.

O'Sullivan, M., Overland, I., Sandalow, D., 2017. The Geopolitics of Renewable Energy. Center on Global Energy Policy, New York.

Overland, I., 2015. Future petroleum geopolitics: Consequences of climate policy and unconventional oil and gas. Handbook of Clean Energy Systems 1–29. https://doi.org/10.1002/9781118991978.hces203.

Overland, I., 2019. The geopolitics of renewable energy: Debunking four emerging myths. Energy Res. Soc. Sci. 49, 36–40. https://doi.org/10.1016/j.erss.2018.10.018.

Palle, A., 2019. Bringing geopolitics to energy transition research. Energy Res. Soc. Sci. 81, 102233 https://doi.org/10.1016/j.erss.2021.102233.

Pascual, C., Zambetakis, E., 2008. The Geopolitics of Energy: From Security to Survival. The Brookings Institution, Washington DC.

Peng, W., Iyer, G., Bosetti, V., et al., 2021. Climate policy models need to get real about people – here's how. Nature 594, 174–176. https://doi.org/10.1038/d41586-021-01500-2.

Pielke, R., Ritchie, J., 2021. Distorting the view of our climate future: The misuse and abuse of climate pathways and scenarios. Energy Res. Soc. Sci. 72, 101890 https://doi.org/10.1016/j.erss.2020.101890.

Popp, A., Calvin, K., Fujimori, S., et al., 2017. Land-use futures in the shared socio-economic pathways. Glob. Environ. Chang. 42, 331–345. https://doi.org/10.1016/j.gloenvcha.2016.10.002.

Pye, S., Bradley, S., Hughes, N., et al., 2020. An equitable redistribution of unburnable carbon. Nat. Commun. 11, 3968. https://doi.org/10.1038/s41467-020-17679-3.

Rivadeneira, N.R., Carton, W., 2022. (In)justice in modelled climate futures: A review of integrated assessment modelling critiques through a justice lens. Energy Res. Soc. Sci. 92, 102781 https://doi.org/10.1016/j.erss.2022.102781.

Rosen, R.A., 2021. Why the shared socioeconomic pathway framework has not been useful for improving climate change mitigation policy analysis. Technol. Forecast. Soc. Chang. 166, 120611 https://doi.org/10.1016/j.techfore.2021.120611.

Scholten, D. (Ed.), 2018. The Geopolitics of Renewables. Springer, Cham.

Shell (2021) The Energy Transformation Scenarios. Shell, The Hague and London. Online available at: https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/the-energy-transformation-scenarios.html#iframe=L3dlYmFwcHMvU2NlbmFyaW9zX2xvbmdfaG9yaXpvbnMv.

Shell (2023) The Energy Security Scenarios. Shell, London. Online available at: https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/the-energy-security-scenarios/_jcr_content/root/main/section_926760145/simple/promo/links/item0.stream/1679344984968/5bc8327925d66e1402040d0e79fed7291bf9b7e9/energy-security-scenarios-full-report.pdf.

Scholten, D. (Ed.), 2023. The Handbook on the Geopolitics of the Energy Transition. Edward Elgar Publishing, Cheltenham.

Skea, J., van Diemen, R., Portugal-Pereira, J., Al Khourdajie, A., 2021. Outlooks, explorations and normative scenarios: Approaches to global energy futures compared. Technol. Forecast. Soc. Chang. 168, 120736 https://doi.org/10.1016/j.techfore.2021.120736.

Süsser, D., Martin, N., Stavrakas, V., et al., 2022. Why energy models should integrate social and environmental factors: Assessing user needs, omission impacts, and real-word accuracy in the European Union. Energy Res. Soc. Sci. 92, 102775 https://doi.org/10.1016/j.erss.2022.102775.

Teske, S. (2020) The IEA World Energy Outlook. A Critical Review 2000-2020. Institute for Sustainable Future, University of technology Sydney, Sydney. Online available at: https://www.uts.edu.au/sites/default/files/article/downloads/teske-2020-IEA-world-energy-outlook-a-critical-review-final.pdf.

Trutnevyte, E., Hirt, L.F., Bauer, N., Cherp, A., Hawkes, A., Edelenbosch, O.Y., Pedde, S., van Vuuren, D.P., 2019. Societal Transformations in Models for Energy and Climate Policy: The Ambitious Next Step. One Earth 1 (4), 423–433. https://doi.org/10.1016/j.oneear.2019.12.002.

Vakulchuk, R., Overland, I., Scholten, D., 2020. Renewable energy and geopolitics: A review. Renew. Sustain. Energy Rev. 122, 109547 https://doi.org/10.1016/j.rser.2019.109547.

Van Vuuren, D.P., Stehfest, E., Gernaat, D.E.H.J., et al., 2017. Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. Glob. Environ. Chang. 42, 237–250. https://doi.org/10.1016/j.gloenvcha.2016.05.008.

Vinichenko, V., Cherp, A., Jewell, J., 2021. Historical precedents and feasibility of rapid coal and gas decline required for the 1.5°C target. One. Earth 4 (10), 1477–1490. https://doi.org/10.1016/j.oneear.2021.09.012.

Welsby, D., Price, J., Pye, S., Ekins, P., 2021. Unextractable fossil fuels in a 1.5 °C world. Nature 597, 230–234. https://doi.org/10.1038/s41586-021-03821-8.

Further reading

Barrett, J., Pye, S., Betts-Davies, S., Broad, O., Eyre, N., Anable, J., Brand, C., Bennett, C., Carr-Whitworth, R., Garvey, A., Giesekam, Y., Marsden, G., Norman, J., Oreszczyn, T., Ruyssevelt, P., Scott, K., 2022. Energy demand reduction options for meeting national zero-emission targets in the United Kingdom. Nat. Energy 7, 726–735. https://doi.org/10.1038/s41560-022-01057-y.

Brecha, R.J., Ganti, G., Lamboll, R.D., et al., 2022. Institutional decarbonization scenarios evaluated against the Paris Agreement 1.5 °C goal. Nature. Communications 13, 4304. https://doi.org/10.1038/s41467-022-31734-1.

Kuzemko, C., Blondeel, M., Bradshaw, M., Bridge, G., Faigen, E. (forthcoming) Towards a Geopolitical Economy of Global Sustainable Energy Transformation.

Rogelj, J., Popp, A., Calvin, K.V., et al., 2018. Scenarios towards limiting global mean temperature increase below 1.5 °C. Nat. Clim. Chang. 8, 325–332. https://doi.org/10.1038/s41558-018-0091-3.

Victoria, M., Haegel, N., Peters, I.M., et al., 2021. Solar photovoltaics is ready to power a sustainable future. Joule 5 (5), 1041–1056. https://doi.org/10.1016/j.joule.2021.03.005.