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Equitable Transitions Away From Fossil Fuels: a Systemic and Narrative Literature Review.

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Abstract

What multi-faceted problems are there in countries transitioning away from fossil fuels, and how can the multilateral regime play a catalytic role? This working paper aims to identify novel insights in literatures relevant to equitable fossil fuel transitions. In reviewing literature on transitions away from coal, oil and gas, we focus on equity, science, and short- and long-term perspectives, as important elements in the outcome of the first global stocktake. The timing of phase-outs will differ for different contexts – without detracting from the urgency of phasing out as soon as possible, where possible. Several studies suggest a sequence, first halt new activities on fossil fuel, and then phase out existing facilities. Another novel suggestion is to spend the few remaining fossil fuels consistent with 1.5°C where they contribute most to human welfare. There is a significant body of literature which suggests that workers and communities should determine their own future, if fossil fuel transitions are to be called just. Some authors suggest building on just transition frameworks, which often address fossil fuels. Studies also emphasise procedural equity, and suggest inclusive processes, providing examples of commissions in different contexts. Based on the literature review, we argue that at any pace of change, all sustainable development goals should be met. When transitions become so rapid that they are disruptive, active policy measures are needed to ensure equity in fossil fuel transitions. Workers and communities bear less cost if social welfare systems are strong. Policies that are suggested frequently in the literature include compensation and skills redevelopment. Good governance and institutions are crucial for equitable fossil fuel transitions. Whether new or existing, institutions should do three things: a) set strategy, b) build consensus/mediate conflict, and c) coordinate implementation.

Studies suggest is may be helpful to bringing in actors not usually associated with just transitions. One study suggests that oil and gas lawyers are well placed to assist with equitable fossil fuel transitions. Setting norms against fossil fuels is proposed in various studies. The question arises whether it will be better to negotiate a new treaty, as some purpose, or to strengthen the norm-setting function of the Paris Agreement? The literature also suggests that it would be helpful to develop criteria and indicators to measure phase out and phase down. Given the importance of context, this would be a menu, not a single set. Such a menu would include Indicators that track the distributional implications, measures to ensure fairness, and the processes that deliver them, are needed. These are some of the novel and relevant findings in the paper, though an abstract cannot capture the full richness of 130 papers. We identified those through a systematic literature review, outlined in the next section. We then unpack the insights, of which this abstract has given a taste.

Keywords: Just transition, fossil fuels, sustainable development, global stocktake

JEL Codes: Q54, Q38, Q32, Q01, J48

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1. Introduction

The global economy has historically relied heavily on fossil fuels, yet their rapid reduction in production and use is essential to curb global warming. In the face of the climate emergency, and for the first time in its history, the United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP) in 2021 officially discussed a phaseout of fossil (Lujala et al., 2022). Energy related global carbon emission reached to 36.3 gigatonnes (Gt) CO2 in 2021 which is a high record[1] in history and the recovery from the COVID-19 pandemic was not sustainable although investment in clean energy increase to $470 billion USD from 2021 to 2023 (International Energy Agency, 2022). Consequently, climate change going to be a critical concern for our globe. Thus, we need to figure out the multifaceted problems and transition away from fossil fuels following the Paris agreement particularly focusing on transitioning away from fossil fuels, considering orderly, equity, science, short term and long-term perspective on near-term action.

To assess the multifaceted challenges of transitioning away from fossil fuels and how the multilateral regime can play a catalytic role, we apply a systematic and narrative literature review, acknowledging that there are three broad types of literature review, including meta-analysis. Meta-analyses strongly lean toward quantitative analyses and are not suitable where insights and quality are critical, making them inappropriate for our complex topic. Given these complexities, we approached the literature review by drawing on both systematic and narrative methods (Sovacool et al., 2018). The systematic literature review is a highly effective approach for extracting specific knowledge, identifying differences in the subject matter, segregating information across thematic areas, and, more importantly, providing a lens for future research (Bhattarai et al., 2022). The narrative component of our review was crucial for incorporating diverse perspectives, conducting exploratory reviews, and understanding complex issues where insufficient data exist to conduct a meta-analysis or systematic literature review across different disciplines (Sovacool et al., 2018). Thus, a combination of narrative and systematic literature reviews is best suited to developing deeper insights and understanding the nuances of transitioning away from fossil fuels based on emergent literature.

We screened out 130 journal publications pooled from Web of Science[2] using systematic literature review. The key criteria are relevance to the research question and novelty of the paper by concatenating a score given to relevance and novelty to provide a wider stronger perspective on transition away from fossil fuel: coal transition, oil and gas and to address the just, equitable and orderly transition. We apply a systematic review methodology using appropriate keywords to search for research publications on multifaceted problems on energy transition, screen them based on their relevancy to our overall objective, and finally synthesize information by critical review. The main objective of this study is to provide a comprehensive review of literature on the contemporary stock of knowledge on energy transition: Transitioning

[1] In 2021, coal emissions hit a record 15.3 Gt, driving over 40% of global CO_2 growth, while natural gas rose to 7.5 Gt and oil emissions reached 10.7 Gt (IEA, 2022).

[2] Following initial tests of Web of Science, Scopus and Google Scholar, we found significant overlap and Web of Science to provide most relevant results. We consulted a University of Cape Town (UCT) librarian with expertise in systematic literature review, who advised to use one database rather than multiple. Google Scholar includes a wider set of non-peer-reviewed papers, but we prioritised scientific rigour and thus choose Web of Science.

away from fossil fuels: equity, science, short- long-term on the global research arena based on empirical evidence.

In this context, we identified a key research question to guide our research and literature review, which is:

> ***Box 1: Key research question***
>
> ***What multi-faceted problems are there in countries to transitioning away from fossil fuels, and how can the multilateral regime play a catalytic role?***

To explore the key research question, furthermore specific questions can assist. These include: What are the opportunities and challenges for energy transitions in different contexts? How do transitions away from coal, oil and gas differ, and in what respects are they similar? What are the dynamics of transitions in energy systems, and how orderly management minimise disruptions to economies and societies? How can the principles of equity and common but differentiated responsibilities be operationalised when implementing transitions away from fossil fuels? How can energy transitions be designed and implemented to ensure livelihoods of workers and communities dependent on fossil fuels? OR What mechanisms and financing frameworks are needed to support just transitions for communities and workers affected by transitions away of fossil fuels? What is necessary so that just energy transitions increase employment, reduce energy poverty and ensure affordable and reliable energy access for all?

How to finance just energy transitions? How can enhanced international cooperation, including finance and reform of international financial architecture, support just transitions away from fossil fuels? How to mitigation targets in NDCs, and domestic mitigation measures to achieve them, drive ambitious and equitable transitions away from fossil fuels, considering different country contexts and resource endowments? What are the most effective policies and measures that countries can implement in the short term to accelerate the transition away from fossil fuels? How can international cooperation and coordination be strengthened to facilitate urgent action on transitioning away from fossil fuels in the critical decade? What role can non-state actors (e.g., cities, businesses, civil society) play in driving near-term action on transitioning away from fossil fuels? How can countries shift their development pathways to provide a good life for their people and achieve net zero emissions globally by 2050? And how can long-terms investments lead to net zero emissions, in context of sustainable development and poverty eradication?

The long list of specific questions illustrates the complexity of transitions away from fossil fuels. Analysing these transitions in relation to equity, science, in the short- and long-term, and recognising differences between coal, oil and gas, raises several specific questions. However, when identifying papers to include in our systematic literature review, the key research question, as shown in Box 1, guided our assessment.

Our findings emphasize the need for context-specific solutions, supported by global enablers and effective national implementation. A successful transition away from fossil fuels requires not only institutional arrangements and technological interventions but also strong political will

to ensure a just, equitable, and orderly shift. The transition should integrate short-term strategies, such as leveraging existing infrastructure and pricing mechanisms, with long-term goals like phasing out grey hydrogen and promoting green hydrogen adoption. While market mechanisms like optimal energy pricing and carbon taxation are essential, they are insufficient without societal norm changes and energy-saving technology promotion.

The literature highlights the necessity of aligning the technological capabilities of developed nations with the resource endowments of developing nations to ensure fairness. Achieving this requires innovative demand and supply-side policies, changes in firm dynamics, and fostering collaborative governance structures—such as stakeholder commissions and trust-building initiatives—to address conflicts. National policies should focus on phasing out fossil fuel subsidies, supporting renewable energy investments, and addressing the political economy of fossil fuel transitions. These measures are crucial for overcoming the multifaceted challenges of the transition, ensuring a sustainable, inclusive, and globally coordinated shift away from fossil fuels.

A contribution of this working paper is its systematically reviewed literature on equitable fossil fuel transitions, focusing on equity, science, and both short- and long-term perspectives. By searching systematically, as detailed in Section 2, the paper helps to address a critical gap in existing research – while earlier reviewed of energy transitions, only some fosuced on equity, and very few have appeared since the outcome fo the first global stocktake. The systematic review narrowed large serach results to 130 studies, from which this working paper identifies relevant and novel insights. Such insights include matters of distirbuitonal equity, such as sequencing of fossil fuel phase-outs, the role of social welfare systems in mitigating transition costs, and the importance of inclusive governance structures. We also highlight the need for procedural equity, consensus-building institutions, and innovative policy mechanisms. Additionally, the paper explores the role of norm-setting in fossil fuel transitions and the potential for new international agreements or strengthening existing frameworks. The study contributes to policy discourse by raising several questions and pointing to future research directions.

The next section of the paper is organized in the following format. Section 2 outlines the systematic literature review. Section 3 discusses the novel and relevant findings. Finally, Section 4 concludes.

2. Systematic literature review

The methodology section of this paper outlines the systematic literature review conducted to explore the multifaceted challenges associated with transitioning away from fossil fuels. This approach is critical for understanding the complexities involved in energy transitions, particularly in the context of equity and justice. By employing rigorous search strategy and clear inclusion criteria, this review aims to synthesize contemporary knowledge and identify novel policy options that can inform future research and practical applications.

2.1. Literature search

The literature review process is designed to capture a comprehensive and up-to-date understanding of the challenges and opportunities in transitioning away from fossil fuels. To achieve this, we employ a systematic approach involving several key steps. First, we develop a carefully crafted search string to identify relevant publications in the Web of Science database. We then apply specific exclusion criteria to focus on peer-reviewed journal articles, ensuring high scientific rigour. The process continues with a thorough screening of titles and abstracts to assess relevance to our research question, also addressing any potential bias.

2.1.1. Search string

This study employed a systematic keyword-based literature review utilizing a search string, (((Title) "Energy Transition" OR “phasing-out” OR “phasing down” OR transition* AND (equit* OR just* OR fair* OR science OR "short-term" OR "long-term") AND ("fossil fuel*" OR "coal*" OR "oil*" OR "gas*") AND ("multilateral regime" OR "international cooperation" OR "global enabler*" OR "global enabling condition*")) at the title, abstract, and topic levels from the Web of Science in September 2024, covering the years 2010 to 2024 in the English language. To ensure high scientific rigor, only peer-reviewed journal articles were included, while working papers, books, book chapters, book series, conference proceedings, patents, reports, and editorials were excluded. This focus on peer-reviewed journal articles aimed to enhance the reliability and quality of the evidence, as such articles typically undergo rigorous evaluation. The search process is illustrated in Figure 1.

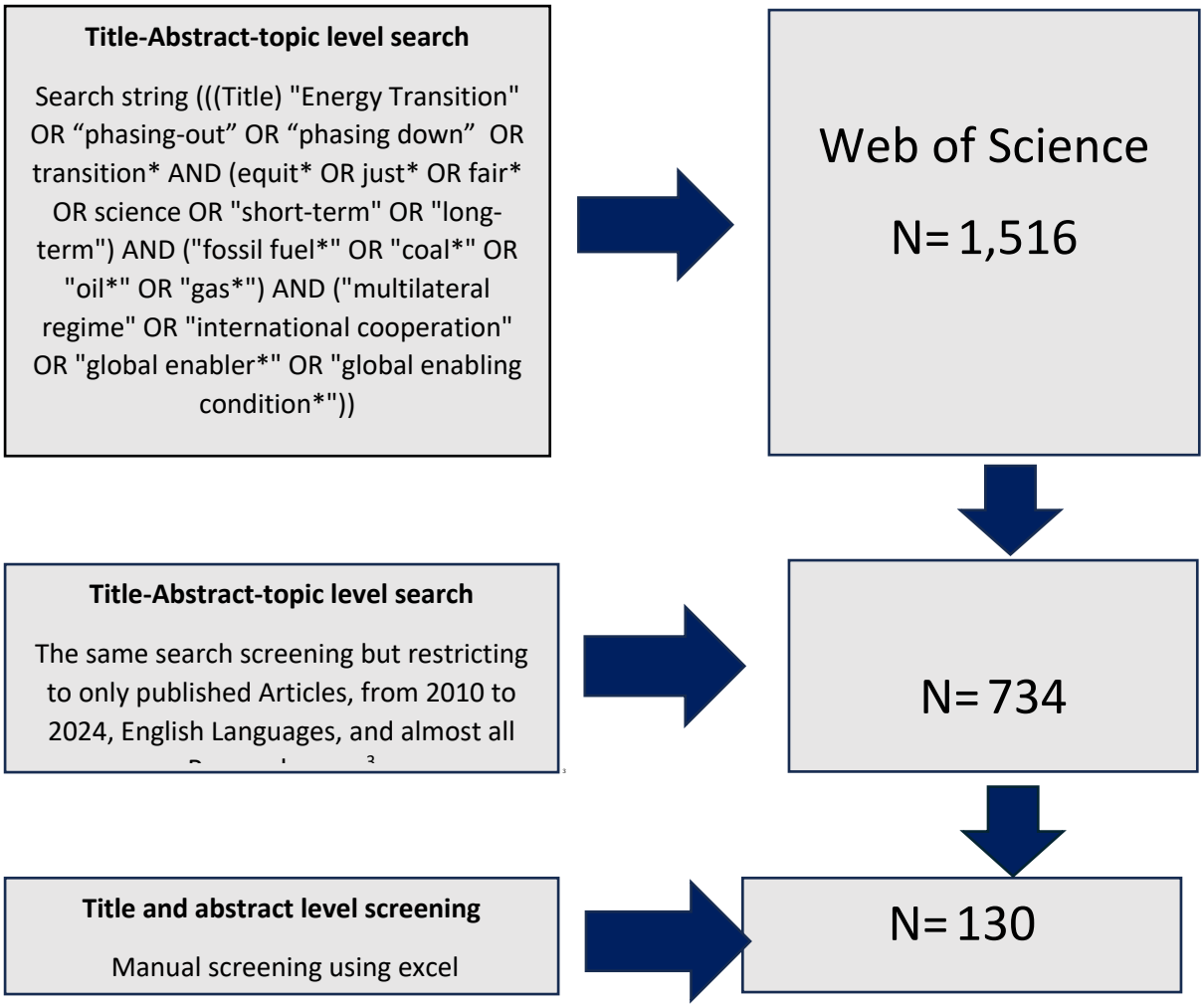

Figure 1: Literature search process

Source: Authors' own analysis

[3] *Environmental Sciences Ecology (N=400), Energy Fuels (161), Science Technology Other Topics (138), Engineering (119), Business Economics (74), Meteorology Atmospheric Sciences (38), Thermodynamics (38), Government Law (33), Chemistry (31), Public Environmental Occupational Health (30), Public Administration (24), International Relations (18), Water Resources (11), Mechanics (10), Materials Science (9), Nuclear Science Technology (9), Toxicology (9), Agriculture (8), Development Studies (8), Geography (8), Social Sciences Other Topics (7), Substance Abuse (7), Urban Studies (7), Electrochemistry (6), Sociology (6), Transportation (6), Biodiversity Conservation (5), Computer Science (5), Geology (5), Physics (5), Area Studies (4), Construction Building Technology (4), History (4), Physical Geography (4), Psychology (4), Telecommunications (4), Communication (3), Education Educational Research (3), Food Science Technology (3), Health Care Sciences Services (3), Information Science Library Science (3), Marine Freshwater Biology (3), Social Issues (3), Tropical Medicine (3), Behavioral Sciences (2), Biotechnology Applied Microbiology (2), Ethnic Studies (2), Forestry (2), Infectious Diseases (2), Instruments Instrumentation (2), Linguistics (2), Oceanography (2), Veterinary Sciences (2), Arts Humanities Other Topics (1), Automation Control Systems (1), Biochemistry Molecular Biology (1), Biomedical Social Sciences (1), Biophysics (1), Crystallography (1), Cultural Studies (1), Evolutionary Biology (1), History Philosophy Of Science (1), Imaging Science Photographic Technology (1), Life Sciences Biomedicine Other Topics (1), Literature (1), Mathematics (1), Medical Ethics (1), Nutrition Dietetics (1), Obstetrics Gynecology (1), Optics (1), Pediatrics (1), Psychiatry (1), Remote Sensing (1), Social Work (1), Spectroscopy (1), Transplantation (1), Women's Studies (1), and Zoology (1).*

2.1.2. Criteria for inclusion and exclusion

Our initial search yielded 1,516 results using the original search string outlined in Figure 1. We then refined the search to focus on papers relevant to our research question. Over half of the 734 results were from the Environmental Sciences and Ecology category, followed by Energy Fuels (21%), Science and Technology (18%), Engineering (16%), Business Economics (10%), and other categories covered small percentage. As previously mentioned, we applied a screening process based on titles and abstracts, which resulted in 734 relevant entries from the Web of Science database. These entries were exported to Excel, carefully reviewing titles and abstracts[4] to assess their relevance to our research question. We then further considered whether papers provided novel insights. In undertaking this analysis, we necessarily applied our judgement in reading, what is relevant and particularly what is novel.

After identifying the relevant papers, we implemented a systematic methodology to extract and synthesize information aligned with our research question. This process unfolded through several key steps. First, we evaluated and filtered research articles based on their relevance to our research question, assigning each a score on a scale from 0 (least relevant) to 5 (most relevant). Second, we assessed the novelty of each paper, similarly scoring them from 0 to 5. We then concatenated the relevance and novelty scores. For example, a paper with a combined score of 55 represents the highest possible rating for both relevance and novelty, while a score of 00 indicates a paper that is neither relevant nor novel. Papers with a combined score of at least 33 were selected for further consideration.

2.1.3. Papers identified as relevant and novel

Through the process outlined above and shown in Figure1, ultimately narrowing the selection to 130 articles, all of which were included in our analysis. Here our main criterion to the search is relevance and novelty. By relevance, we mean papers that are relevant to the research questions. Novelty refers to new insights and proposals. Additionally, we incorporated other studies, already known to the authors, that were particularly novel and highly relevant to the objectives of our study.

Systematic literature reviews offer a comprehensive, highly structured, and comparatively unbiased summary of the existing body of knowledge in each field, particularly within the energy sector (Sovacool et al., 2018). They are characterized by a well-defined, replicable methodology and are known for their rigor, incorporating both quantitative and qualitative studies. However, despite employing an explicit and transparent methodological approach, systematic reviews are not entirely free from bias, as search strings and coding are highly sensitive to search results (Sovacool et al., 2018; Bhattarai et al., 2022). We acknowledge that different researchers may evaluate the same body of literature differently, and it is unlikely that bias can be eliminated.

To mitigation potential bias, we firstly outline the criteria for inclusion and exclusion. Secondly, we make available the online Supplementary Information as an Excel file, in which readers can see the assessments we have made in each case (Y. K. Mogess & Winkler, 2025). This makes our selections fully transparent, without making a claim that our selection of papers would be yield the same result, if applied by others. Third, we incorporated a narrative review alongside the systematic review to enable a more exploratory and flexible approach. This

[4] We identified 200 articles from the 734 based on their titles. After screening the abstracts, this number was reduced to 163. Finally, after evaluating for relevance and novelty, we narrowed the selection down to 130 articles.

allows us to uncover nuances in papers that may not have been included in the systematic review. By combining both systematic and narrative literature review approaches, we aim to balance methodological rigor with the flexibility required for deeper qualitative insights.

2.2. Conclusion of systematic literature review

This systematic literature review provides a robust foundation for exploring the multifaceted challenges associated with transitioning away from fossil fuels. To address the potential weakness in synthesizing findings, Section 3 will directly link the selected articles to the research question, examining how they contribute to understanding the problems countries face in transitioning away from fossil fuels and the potential catalytic role of the multilateral regime. Additionally, the analysis in section 3 incorporates other relevant papers already known to the authors, enriching the review with established knowledge in the field. It's important to note that while Section 2 outlines the systematic approach to literature selection, Section 3 will present a narrative literature review. This narrative approach allows for a more nuanced and interpretative discussion of the findings, moving beyond the systematic methodology to provide a comprehensive and critical analysis of the current state of knowledge on equitable transitions away from fossil fuels.

3. Novel and relevant findings

The previous section concluded on the systematic literature review. We now turn to presenting a narrative description of findings in the literature, highlighting those that strike us as novel and relevant. Assessing novelty involves assessment and judgement, our consideration is what helps explore our research question (see Box I in the Introduction, above). We also include relevant findings, in other words ideas and recommendations that may not be new, but remain salient to understanding equitable fossil fuel transitions.

This section is organized in three sub-sections. The first two highlight findings related to coal, and then oil and gas, given that the literature suggests that transitions differ by fossil fuel. We then turn to policy implications, highlighting what we find novel and relevant to equitable fossil fuel transitions.

3.1. Coal Transitions

The literature reveals several critical aspects of coal transitions globally, with a central theme being the balance between phase-out strategies and the demand for equity. Equity considerations are paramount, as they ensure that transitions to low-carbon energy systems do not disproportionately burden communities least responsible for global warming. Gürtler et al. (2021) emphasize that equity is an ethical cornerstone of the transition, advocating for compensation mechanisms for the most affected communities. To achieve this, the authors recommend a national discourse to develop comprehensive strategies addressing the ethical and controversial complexities of coal phase-out. This approach should involve diverse stakeholders, from individuals to businesses, communities to government organizations, and local wards to entire regions.

Luo et al. (2024) build on this equity framework by underscoring the need for an orderly transition, as highlighted in paragraph 28 of decision 1/CMA.5, the outcome of first global staketake under the Paris Agreement. Their study introduces the concept of transitioning from

coal to nuclear (C2N) as a viable solution, suggesting that accelerated coal plant retirements can lead to stranded assets. C2N technologies, they argue, can address energy and equity concerns by substituting coal-fired plants with nuclear reactors. However, Luo et al. caution that while orderly Transitions like C2N are important, they must also incorporate anti-fossil fuel norms (AFFNs) to achieve distributional justice. Sugiyono et al. (2024) analyse a transition from coal to solar, and suggest that orderly action might apply to the timing of retirement of coal-fired power plants (Zhang & Chen, 2022; Zhao et al., 2021).

Nazareth et al. (2024) expand on this by emphasizing the need for norms targeting coal phase-out, ending public financing for fossil fuels, reforming subsidies, and phasing out oil and gas, all while considering marginalized communities. For instance, for Germany, phasing out coal and cancelling allowances improves welfare if citizens value CO_2 emission reductions at €65 per ton or more (Böhringer & Rosendahl, 2022). Furthermore, the phase out will impact Central Europe's electricity markets by driving decarbonization and altering trade (Kittel et al., 2020).

Zhang et al. (2024) explore optimal strategies for reducing coal-fired electricity generation while maximizing socio-economic benefits. Using a dynamic Computable General Equilibrium (CGE) model, the study outlines gradual pathways for phasing out coal, accounting for peak usage levels and phase-out timelines. The authors argue against the immediate shutdown of coal-fired plants, warning of adverse effects on goods and services production. Instead, they advocate for a phased reduction to enable a controlled decline in coal-sector employment—from 82% to 22% in China—providing workers time to adapt and ensuring a fair transition to sustainability.

The socio-economic implications of coal transitions are further emphasized by Brown & Spiegel (2019). They draw parallels with Britain's coal pit closures in the 1980s, highlighting the need to prevent mass unemployment and social upheaval. The authors critique how vested interests have historically exploited tensions between workers and environmentalists. They call for proactive measures, such as compensation and skill redevelopment (see also de Beer et al. (2014) to address job losses and foster collaboration between social and environmental movements. Additionally, Brown and Spiegel explore coal transitions through a climate justice lens, linking struggles to phase out coal with broader debates on colonialism, capitalism, and inequality. They stress the importance of transnational alliances and social movements in resisting coal-related development, particularly given the absence of major coal consumers from key international phase-out agreements. Muttitt et al. (2023) supports the findings that when socio-political factors are considered, such as different timing of phase out of coal fired power in the global North would be need to reduce CO2 emissions faster than in Integrated Assessment Models that does nto include socio-political factors in modleing in limiting warming to 1.5°C.

Equity also intersects with environmental and health considerations. Mayfield (2022) examines how equity and air pollution impact coal power plant retirement decisions, focusing on vulnerable populations disproportionately affected by coal pollution. In 2018, operating coal plants caused approximately 11,600 deaths and $100 billion in damages, primarily among low-income, non-white, and rural populations. The study optimizes phase-out strategies by considering climate goals and air pollution impacts, estimating that achieving net-zero emissions could prevent 134,000 deaths and save $1.2 trillion by 2050. Mayfield underscores that defining equity objectives—whether targeting vulnerable subpopulations or geographically defined communities—profoundly shapes policy design.

Radtke & Löw Beer (2024) further explore the controversies surrounding coal phase-out, particularly in coal-dependent countries. They highlight carbon lock-in as a significant barrier and integrate the concept of energy justice into democratic legitimacy. Their analysis of the Coal Commission argues that while legitimacy traditionally focuses on justifying actions by specific entities, energy justice emphasizes fairness and equity. These principles are essential to democratic legitimacy, underscoring the need for equity and justice as foundational pillars of a just energy transition. Furthermore, phasing out coal power to achieve net-zero emissions requires not only declining costs for alternatives and growing climate concerns but also strong democratic governance and economic capacity (Lægreid et al., 2023). Tan et al. (2021) also recommends using the local governments as an actor for power station closure in China.

Thus, the literature collectively underscores that achieving a fair and sustainable coal phase-out requires a multidimensional approach. This involves balancing equity, environmental justice, economic stability, and democratic legitimacy while addressing the unique challenges of different regions and communities.

One study explores how institutional carbon lock-in affects coal phase-out in countries with extensive coal use. It compares Coordinated Market Economies (Germany, Spain, Poland) with Liberal Market Economies (UK), showing that the UK's market-driven approach enabled a faster transition away from coal, while the CMEs faced slower, reluctant shifts (Rentier et al., 2019). Another study shows how Japan's fossil fuel regime is employing recurring narratives to promote continuation of the current coal-based energy system and to mobilise further investments in high-efficiency coal power technologies (Trencher et al., 2019 ; Hassen et al., 2023).On top of these, achieving the 2°C target requires global adoption of the most ambitious coal phase-out plans, despite challenges to energy security and fairness (Vinichenko et al., 2023).

Several studies examine strategies and challenges in phasing out coal in different contexts, including coal dependent economy and developing and developed countries:

- Economic incentives play a crucial role in facilitating fossil fuel phase-outs. Zhao et al. (2022) investigate electricity pricing mechanisms in China, finding that a premium pricing system was effective for wind power until 2018, after which a fully competitive mechanism became feasible. The study highlights how electricity market reforms have reduced wind power curtailment and increased social welfare, offering insights for broader transitions. Boute (2022) also suggests electricity market regulations in phasing out of coal in China.
- The Guangdong–Hong Kong–Macao Greater Bay Area (GBA) offers a regional perspective on energy transitions. Wang et al. (2023) identify an optimal path for the GBA's power transition under its "one country, two systems" framework, concluding that a mix of low-carbon technologies is the most effective strategy for achieving deep decarbonization.
- However, China's coal phase-out faces unique challenges. Kou et al. (2022)argue that China's "coal retreat" indicators lag behind Germany's, making a full phase-out unfeasible. The authors propose improving coal-use efficiency, adopting carbon capture and storage technologies, and gradually reducing coal's share in the energy mix to ensure stable economic and social development. This approach highlights the necessity of balancing environmental objectives with the socioeconomic realities of coal-dependent nations. Moreover, the phaseout can be achieved by framing coal

phase-out as regional development and transforming incandescent lighting into an LED market (David & Schulte-Römer, 2021).

- South Africa presents another distinct case. Afrane et al. (2024) employ the Global Change Assessment Model to evaluate strategies such as negative emission technologies (NETs) like direct air capture with carbon storage (DACCS), bioenergy with carbon capture and storage, and DACCS alongside fossil CCS. Their findings highlight the need for extensive renewable energy expansion, electrification, and careful management of land, water, and energy trade-offs to achieve a just and sustainable transition to net-zero. Oshiro et al. (2023) developed an alternative net-zero emissions pathway utilizing carbon capture and utilization (CCU), the CCU-based net-zero pathway stabilizes energy demand but faces high costs and challenges with scaling renewables and direct air capture.
- Fermeglia et al. (2020) examine Italy's struggle to decarbonize its energy sector, highlighting the critical technical uncertainties and regulatory challenges impeding progress. Their analysis emphasizes the importance of reassessing coal's role within Italy’s energy mix and enhancing legal and regulatory frameworks to achieve an effective coal phase-out.
- Germany's experience offers valuable lessons on managing coal's decline. Vögele et al. (2018) utilize an extended multi-level perspective (MLP) framework to explore potential pathways for phasing out coal-fired power plants, which historically enjoyed government and industrial support. The study identifies key economic, social, political, and technical factors contributing to coal's marginalization and stresses the importance of careful management to ensure a smooth transition. Similarly, Johnstone & Hielscher (2017)address the social dimension of coal phase-out, focusing on its potential negative impacts on local communities and the workforce in the United Kingdom.
- Political risks further complicate coal transitions. Egli et al. (2022) analyse the electoral consequences of coal job losses in the United States, revealing a significant increase in Republican vote share in coal-dependent counties. The findings underscore the socio-political challenges of phasing out coal, emphasizing the need for policies that mitigate voter backlash while pursuing climate goals.
- The health benefits of reducing coal use are equally compelling. Öztaner et al. (2024) estimate that Ontario's coal phase-out generated $1 billion CAD in annual health benefits in 2003, rising to $1.8 billion CAD by 2014. Their retrospective analysis also highlights the substantial transboundary health benefits Canada received from reduced emissions in U.S. coal plants, emphasizing the broader advantages of transitioning away from coal-fired power plants.
- Cultural and institutional factors can also obstruct the energy transition. Biddau et al. (2024) explore how media discourse in Europe has delegitimized coal phase-out and renewable energy adoption, identifying three distinct phases: coal legitimacy, regime destabilization, and reconfiguration. Meanwhile, Trencher et al. (2019, 2024) reveal Japan’s "coal lock-in," driven by recurring narratives and firm-level dynamics that sustain investments in high-efficiency coal technologies. Despite utilities targeting net-zero emissions by 2050, the focus remains on emission reductions rather than a full coal phase-out. Building non-proliferation fossil fuel treaties are also equally important (Newell et al., 2022).

There are many aspects in the case studies of strategies and challenges in phasing out coal in different contexts. Across these cases, some threads that seem important across multiple contexts are the role of economic incentives, regional stragies, balancing environmental and socio-economic objectives, and political challenges. That said, one should as a general matter be careful to generalize from specific cases. Further research should investigate which lesssons are applicable to other contexts, and which are context-specific. An important finding is that context matters, yet countries should learn from each other.

There are also numerous studies that investigate the coal phase-out process in many countries and regions. For instance, Böhringer & Rosendahl (2022) examined the economic and environmental consequences of coal phase-outs in Europe, focusing on CO2 emissions, the electricity sector, and broader economic impacts. Their study highlighted that welfare impacts depend on factors such as whether other countries adopt similar phase-out policies, the cancellation of emissions allowances, and the terms-of-trade effects within the Emissions Trading System (ETS) market. Using numerical simulations with a computable general equilibrium model of the European economy, they concluded that unilateral allowance cancellations could enhance welfare specifically for Germany, provided CO2 reductions are sufficiently valued.

The influence of the Paris Agreement on coal phase-out policies has also been studied, revealing differences in approach between Germany and the United Kingdom (UK). Bang et al. (2022) found that Germany prioritized just transition concerns, particularly when aligned with the interests of influential stakeholders. In contrast, the UK paid less attention to just transition issues due to the collapse of coal's market position, coupled with limited representation from coal interests. However, the study suggests that just transition concerns may gain prominence in the UK as the country faces a more challenging transition away from fossil fuel in the coming decades.

Similarly, Do & Burke (2024) explored the challenges of coal phase-out in Indonesia and Vietnam, despite their commitments to the 2021 Global Coal to Clean Power Transition Statement. Interviews with experts identified key barriers, including concerns over rising electricity prices in Indonesia and power shortages in Vietnam. Indonesia’s challenges are exacerbated by its heavy reliance on coal. The study recommends prioritizing renewable energy growth and halting the construction of new coal plants as practical steps forward, rather than prematurely focusing on coal plant closures. This analysis provides crucial insights for shaping both countries' plans under their Just Energy Transition Partnerships. Chang et al. (2023) further emphasized the impact of coal power on CO2 emissions, using a bottom-up energy model to show that higher coal usage significantly increases emissions. They advocate for energy-saving technologies and higher scrap ratios to mitigate these effects(see also Koretsky, 2021).

Global trends in coal phase-out are also addressed by Montrone et al. (2023), who estimate that 170 GW to 270 GW of new coal plants could still be built. Based on expert interviews across 10 countries, the study identifies key factors influencing this development, including the lingering effects of the COVID-19 pandemic. These findings serve as a baseline for future negotiations aimed at accelerating coal phase-out through Just Energy Transition

Partnerships. It was evidenced that COVID-19 accelerates phasing out of fossil fuels (Rempel & Gupta, 2021).

Adekoya et al. (2023) extended the analysis to the world's top coal-consuming countries, investigating the trade-offs between reducing coal consumption, environmental sustainability, economic growth, and health outcomes. Their findings suggest that a total coal phase-out could lead to significant economic and health costs. Instead, they recommend maintaining lower coal use in the energy mix to balance carbon emissions reduction with economic and health performance. A gradual reduction in coal intensity, combined with suitable substitutes, is proposed as the optimal strategy to achieve these objectives (see also Li et al. (2024)).

Finally, Debiagi et al. (2022) propose a solution that leverages existing coal power plant infrastructure to create energy carriers like iron reserves, thereby enhancing energy security. Their approach supports the development and implementation of specific technological interventions for renewable energy, hydrogen, and green steel production. This targeted technological intervention offers a pathway to transition from coal dependency while addressing broader energy and sustainability goals.

In the short term, coal remains an essential component of energy security in many countries due to its scale and reliability. For example, Turkey continues to rely heavily on coal, with 20 domestic and 9 imported coal plants supplying 34.5% of the country's energy needs (Uyanik & Dogerlioglu Isiksungur, 2024). Despite efforts to promote renewable energy (RE) and decarbonization, coal's role in ensuring energy security persists, making immediate phase-out plans challenging. Furthermore, energy storage technologies are not yet viable alternatives due to their limited scale and inability to replace the stability coal provides in power generation. The analysis suggests that while economically and technically unviable coal plants may be retired gradually without official timelines, coal will continue to dominate Turkey's energy mix in the short term, reflecting the complexities of transitioning to low-carbon systems.

Similarly, in regions like China, the immediate phasing out of coal is constrained by the significant role it plays in the national energy mix and economic stability. As the world's largest coal power producer, China's reliance on coal power for urban heating and industrial energy remains a key short-term challenge (Shan et al., 2024; Sun et al., 2022). Targeted policies to retire small, inefficient coal units, especially those without heating functions, are critical first steps toward achieving emission reduction goals without compromising energy security. However, such efforts need to address the socio-economic impacts, such as job losses and reduced heating capacity, particularly in northern provinces reliant on district heating.

By the medium term, coal is expected to transition from a primary energy source to a baseload provider in countries like Turkey, where decreasing capacity usage is anticipated by 2035 (Uyanik & Dogerlioglu Isiksungur, 2024). Nevertheless, maintaining economic stability and addressing social concerns, such as unemployment and regional dependence on coal, remain critical hurdles. In China, medium-term goals align with its carbon peaking by 2030, requiring substantial decommissioning of coal-fired units. The effect of decarbonization on unemployment is also evidenced in Poland (Baran et al., 2020). Shan et al. (2024) propose a robust stacking evaluation model to prioritize units for decommissioning based on generation efficiency and social responsibility. The model identifies 23.1% of coal units as candidates for retirement, enhancing sustainability while mitigating the adverse impacts of transitioning to cleaner energy sources.

In the medium term, coal-dependent economies like Indonesia and Vietnam must overcome barriers related to electricity price concerns and power shortages. Prioritizing renewable energy growth and halting the construction of new coal plants are seen as pragmatic solutions to balance economic and environmental priorities (Do & Burke, 2024). Additionally, Hauenstein et al. (2023) highlights the importance of collaborative governance to facilitate trust and compromise among stakeholders. Germany's stakeholder commission process, which set a 2038 coal phase-out target (later revised to 2030), underscores how inclusive decision-making can overcome deadlocks and accelerate transitions, even in contested environments. Furthermore, Rajakal et al. (2023) identifies the optimal renewable energy additions for Sarawak from 2020–2040 to meet carbon reduction targets. The co-firing scenario leads to a 14.09% decrease in new renewable additions, a 5.78% reduction in total costs, and a 66% drop in coal consumption by 2050 compared to 2020.

In the long term, natural phase-outs of coal are expected as renewable energy technologies mature and policy frameworks strengthen. For instance, Turkey anticipates a 30% reduction in emissions, contributing to its climate commitments by transitioning away from coal by mid-century (Uyanik & Dogerlioglu Isiksungur, 2024). Similarly, China's roadmap to carbon neutrality by 2060 involves the gradual retirement of coal units, despite the challenges of balancing energy security and urban heating needs (Shan et al., 2024).

Global case studies also highlight contrasting outcomes of long-term coal phase-outs. For example, Feng et al. (2023) evaluated Chile's transition scenarios, finding that while coal phase-out by 2030 or 2050 would generate a net economic gain and increase employment, it could also heavily impact coal-dependent communities (see also Agrawal et al. (2024) in case of India). Such findings emphasize the importance of a just transition framework that addresses local challenges while fostering national benefits. Adekoya et al. (2023) advocate for a gradual reduction in coal intensity rather than a complete phase-out to balance environmental, economic, and health goals.

In Germany, Heinrichs et al. (2017) argue that early coal phase-out strategies may fail to meet long-term climate goals, as technical analyses reveal that these approaches are insufficient to achieve the 2050 CO2 reduction targets. Instead, economic outcomes depend heavily on CO2 certificate prices and broader decarbonization efforts. Similarly, Walk & Stognief (2022) note the UK's plan to phase out coal by 2024, driven by strong policy support and political consensus. However, the authors argue that achieving net-zero emissions by 2050 requires a more ambitious timeline to align with climate justice principles.

Debnath & Mourshed (2024) examine Bangladesh's long-term reliance on fossil fuels and nuclear energy, influenced by Japan's official master plans. Although modeling indicates that transitioning away from coal is viable in the long term, domestic political and economic factors continue to hinder progress. Thus, considering geopolitical politics of coal should also be considered (Vold Hansen, 2024).

In summary, the literature reveals that short, medium, and long-term coal phase-outs require context-specific strategies. In the short term, energy security concerns and economic constraints necessitate a cautious approach to coal retirement, emphasizing renewable energy growth and targeted decommissioning of inefficient units. The medium term offers opportunities for collaborative governance and gradual capacity reductions to balance socio-economic impacts. In the long term, natural phase-outs supported by strategic policies, technological advancements, and just transition frameworks are essential for achieving global climate goals while addressing local economic and social challenges. Insights from diverse

case studies provide valuable lessons for policymakers to design effective, equitable, and sustainable coal phase-out strategies.

3.2. Oil and Gas Transitions

The transition from oil and gas to cleaner energy sources is a crucial aspect of addressing climate change. As the world faces the challenges of meeting the 1.5°C warming target, the transition away from fossil fuels is complex and must be managed in a way that ensures both fairness and effectiveness. A critical gap exists in defining the criteria and indicators required to design a globally coordinated phase-out strategy, one that aligns with a just transition. Market forces alone are insufficient to ensure an equitable global phase-out of oil extraction aligned with the 1.5°C warming target (see also Gupta & Arts (2018)). The order in which countries transition away from oil varies depending on the criteria used, and reliance on single-criterion approaches risks producing inequitable and poorly considered outcomes. Without considering a comprehensive set of indicators, the fairness and equity of the transition could be jeopardized, undermining development needs and procedural justice (Sanchez & Linde, 2023).

In the ongoing discourse on oil and gas equity, various scholars have underscored the importance of integrating fairness and justice in energy transitions. Weaver & Camp (2023) emphasize that oil and gas lawyers are uniquely positioned to address regulatory, legal, and equity challenges in the transition to low and zero-carbon energy infrastructures. By applying their expertise, these legal professionals can ensure sustainable growth and equitable access to energy, highlighting the importance of fair legal frameworks in facilitating this transformation. They identify seven specific challenges to this transition, including capital flows, geopolitical risks, title concerns, creeping expropriation, land use and local opposition, evolving standards, and maritime regulation, each of which complicates the achievement of equitable energy solutions.

The issue of equity in energy transitions is further complicated by global financial practices. Zhao et al. (2019) argue that removing producer subsidies for fossil fuel extraction, particularly in oil and gas, can play a crucial role in addressing the inequities entrenched in energy systems. These subsidies, often supporting the continued extraction of fossil fuels, disproportionately benefit large producers and contribute to the perpetuation of energy inequity. A reorientation of financial flows is thus necessary to promote more equitable energy systems that support sustainable development. However, Babatunde et al. (2021) argued that natural gas subsidy is not enough.

Journalism, too, plays a pivotal role in advancing equity in oil and gas sectors. Arsenault & Le Billon (2022) highlight how poor resource governance and questionable oil deals frequently undermine equitable development, often benefiting investors and elites while marginalizing local communities. Investigative journalism serves as a powerful tool in promoting transparency, exposing exploitation, and advocating for reforms that ensure fairer distribution of benefits and accountability in resource management. This highlights the critical role of the media in fostering a more just energy landscape (see also Bergmann & Ossewaarde (2020)).

The injustices resulting from oil extraction are starkly illustrated in the Ecuadorian Amazon Region (EAR), as documented by Codato et al. (2024). Despite the extraction of over 6.4 billion barrels of oil between 1972 and 2020, local communities in the EAR have seen little benefit from these resources. The region has faced severe socio-environmental impacts,

including widespread oil spills, pits, and gas flaring, leading to the marginalization of local communities. The findings underscore the urgent need for climate justice, advocating for the rights of these communities to a safe, clean, and sustainable environment in the face of environmental degradation.

The equity-efficiency trade-off in energy pricing has also been a focal point of research. Hahn & Metcalfe (2021) conducted an in-depth analysis of California's Alternate Rates for Energy (CARE) program, evaluating its welfare impacts and the inherent trade-offs between equity and efficiency. Their study found that aligning prices with the marginal social cost (MSC) and introducing cap-and-trade or taxation schemes could improve economic welfare. However, their analysis also revealed that the equity benefits of such programs must account for environmental costs. Specifically, they concluded that the benefits to low-income participants in the CARE program would need to increase by approximately 6% to fully offset the costs when environmental impacts are considered, thereby emphasizing the complex relationship between equity and efficiency in energy policy design.

Nazareth et al. (2024) address the equity challenges associated with the global phase-out of oil and gas. They argue that for many developing countries, oil and gas are central to energy access, national security, and financing social and economic development. These countries, which often rely heavily on revenues from fossil fuel extraction, face significant challenges in transitioning away from these resources. The authors criticize current discussions on just transition financing for focusing mainly on fossil fuel workers, while neglecting the broader needs of fossil fuel-dependent economies, particularly in the Global South. They advocate for a more comprehensive approach, ensuring that phase-out strategies are accompanied by adequate financial support for low- and middle-income countries to enable a fair and equitable transition. Given financial support, countries needs to identify prioritization and policy sequencing in phase out process (see the detail in (Do & Burke, 2023; Nacke et al., 2022).

Sanchez & Linde (2023) further explore the equity dimensions of phasing out oil extraction in line with the 1.5°C global warming target. They argue that market forces alone are insufficient to ensure an equitable distribution of remaining oil extraction. They highlight the varying sequencing of phase-outs across countries, which, if not managed with a comprehensive set of criteria, can lead to unjust outcomes. Their research stresses the importance of developing clear, inclusive criteria that consider the diverse circumstances of individual countries and ensure that the global phase-out does not undermine development needs or procedural justice.

Finally, Bugaje et al. (2022) stress the importance of equity in decarbonization efforts, especially in regions like Sub-Saharan Africa. They critique uniform approaches that fail to consider the socio-economic realities of different regions, such as blanket reductions in energy demand or blocking public financing for natural gas projects. The authors call for a more nuanced approach that allows countries to define their low-carbon pathways based on local contexts, ensuring that climate actions are both equitable and sustainable.

Together, these studies underscore the critical need for equity in the oil and gas sector, particularly as the world transitions to more sustainable energy systems. Addressing the legal, financial, social, and environmental dimensions of energy equity is essential for ensuring that the benefits of energy transitions are distributed fairly and that vulnerable communities are not left behind.

Reducing CO_2 emissions to combat global climate change is crucial. Addressing the impacts of sulfur-containing automobile exhaust on densely populated urban areas and alleviating the global fuel oil supply-demand imbalance are also significant near-term priorities. Replacing sulfur hexafluoride (SF6) in switchgear with alternatives technologies can significantly reduce greenhouse gas emissions(Billen et al., 2020). Yang et al. (2022) analyse China's policy to phase out backward coal production capacity, noting that deep coal mining[5] has become more intensive as the transition progresses. Theoretical models suggest that various policy instruments can promote the transition to fossil-fuel-free vehicles. However, a steady-state comparison of four policy scenarios indicates that climate policies tend to dampen economic growth compared to the business-as-usual (BAU) scenario in China.

Contrary to some earlier studies, Shindell & Smith (2019) demonstrate that phasing out fossil-fuel combustion while reducing toxic aerosol emissions does not cause a significant near-term increase in global warming. The warming effects of reduced aerosols are largely offset by gradual reductions in carbon dioxide and methane emissions. This dual benefit supports climate change mitigation and improved air quality over decadal to centennial timescales. It is also beneficial to use multi ultra-low emission control systems to reduce emissions (Tsai et al., 2021). For instance, seven years after phasing out leaded gasoline in Saudi Arabia, atmospheric lead concentrations in Jeddah have significantly decreased (Aburas et al., 2011).

Denmark is phasing out fossil fuel production by 2050 while repurposing offshore oil and gas platforms for integration with offshore wind farms (OWF). Alirahmi et al. (2023) propose a novel zero-carbon emission energy system using surplus electricity from OWFs to produce hydrogen via electrolysis. This hydrogen can be utilized for power generation in the Allam cycle or methanation to produce methane. Preliminary energy and exergy analysis shows a round-trip efficiency of 32%, enabling the system to convert wind farm electricity into controllable power and methane.

Hernandez Carballo & Sisco (2024) emphasize the importance of public acceptability for effective climate policy. They argue that reducing gasoline prices could foster public support for environmental policies. Their findings suggest that the effect of gasoline prices on climate policy acceptance is not primarily driven by environmental concerns but rather by public interest in economic growth. Brand et al. (2020) evaluate the impacts of more ambitious policies to phase out fossil fuel vehicles in the UK. They find that existing policies may fail to meet carbon reduction targets. The study suggests that deeper, earlier phase-outs, combined with reduced mobility demand, could significantly contribute to meeting Paris climate goals and improving urban air quality. However, these measures may disrupt technology providers, businesses, and governments.

Chedid et al. (2020) propose a hybrid energy system for micro-grids reliant on diesel generators, replacing them with photovoltaics and battery storage. By integrating heuristic genetic algorithms for system sizing with dynamic programming for optimal power flow, the system minimizes reliance on diesel, reduces operational costs, and enhances grid energy management. A case study on a university campus demonstrates its effectiveness. Codato et al. (2023) propose a framework for identifying "unburnable carbon areas" to phase out fossil

[5] The early shutdown of coal mines will heavily impact major coal-producing areas, with most mines closing by 2030. This will lead to stranded assets worth $120-150 billion by 2050, and an extra $100 billion if new projects go ahead. If demand drops as per 1.5°C climate goals, new mines will be unnecessary. These closures will particularly affect workers and local communities, making it crucial to ensure a fair transition and address the surplus coal supply to fight global warming (Hauenstein, 2023).

fuels. Using spatial analysis to model interactions between oil development and sensitive territories, the study offers policy insights for effective climate mitigation. Rinscheid et al. (2020) explore factors influencing Americans' preferences for policies phasing out fossil fuel vehicles, finding that a majority support such policies being implemented by 2030.

Zhou et al. (2024) propose an integrated framework to evaluate hydrogen fuel cell vehicle (HFCV) production pathways in China, with a focus on life cycle emissions and supply-demand optimization. The study assesses six hydrogen production methods, revealing that Natural Gas Steam Methane Reforming (NG_SMR) emits 0.215 g CO_2-eq/kJ H_2, while Clean Energy Water Electrolysis (CE_WE) emits only 0.02 g CO_2-eq/kJ H_2, demonstrating a tenfold reduction in emissions. Key hydrogen suppliers such as Shaanxi, Shanxi, and Shandong contribute over 50% of China's hydrogen production, with distribution concentrated from north to south. China have also coal-based production of methanol, ammonia, and PVCs contributed to 0.27 Gt of CO2 emissions, approximately 3% of China's total emissions (Jiang et al., 2024).

Raab et al. (2024) analyze the techno-economic impacts of replacing fossil-based kerosene with alternative fuels in aviation, comparing liquid hydrogen, liquid methane, and renewable kerosene across ten flight routes. Their findings show that fuel supply costs significantly outweigh aircraft acquisition costs. Among the alternatives, liquid hydrogen emerges as the most cost-effective option, with costs of 3.08 PAX€2020 per 100 km for a 180-passenger aircraft, compared to 4.57 for liquid methane and 5.11 for renewable kerosene. The study also highlights the challenges of storing cryogenic fuels and suggests that adapting aircraft sizes could help mitigate rising fuel costs. The authors advocate for adopting alternative fuels such as liquid hydrogen and methane to reduce costs and emissions in aviation. Furthermore, shifting from individual travel to public transport, and replacing buses and trains with electric or hydrogen options, would lead to a greater reduction in emissions (Logan et al., 2022).

Despite the global phase-out of leaded gasoline, São Paulo, Brazil continues to experience elevated levels of atmospheric lead (Pb) due to vehicular emissions, traffic dust, and industrial activities like cement production. Isotope analysis of aerosol samples collected in 2005 identifies vehicular emissions as the primary source. The maximum lead concentration in fine particles during the summer reached 0.055 mg/m³, which could exceed air quality standards during other seasons, posing significant health risks ((Gioia et al., 2017). Bugaje et al. (2022) argue that natural gas (NG) should remain part of the energy mix, especially for countries with unique socio-economic and political contexts. They critique the one-size-fits-all approach to decarbonization, advocating instead for energy transitions tailored to the specific circumstances of each country.

Taiwan's attempt to phase out fossil fuel vehicles—banning gasoline-powered scooters by 2035 and passenger cars by 2040—was suspended due to several challenges. Using the Multi-Level Perspective (MLP) framework, Liu & Chao (2022) analyses the barriers to this mobility transition. They identify the scooter industry's significant influence on policymaking, challenges in scaling up electric scooters, and a lack of effective policy coordination. The fragmented governance structure allowed the incumbent regime to reinstate subsidies for gasoline scooters, undermining the policy. Additionally, the scooter supply chain framed the policy as unfair, employing social justice rhetoric to rally opposition. Following a local election defeat in 2018, the government reversed its decision, illustrating the complexities of transitioning to sustainable mobility in regions where two-wheel vehicles dominate.

Röös et al. (2023) emphasizes the importance of phasing out fossil fuels to improve the sustainability of food systems. The study highlights the interconnectedness of energy transitions and food production, calling for integrated strategies to reduce emissions and enhance sustainability. Coulomb et al. (2019) model the transition from coal to gas and renewable energy under a carbon emissions cap. Their study focuses on optimal investment strategies, concluding that investments in renewable energy should precede the phasing out of fossil fuels. While gas-fired plants can serve as a temporary bridge to reduce reliance on coal, they will ultimately need to be decommissioned to achieve carbon-free power. Simulations using the European Commission's Energy Roadmap quantify these findings, demonstrating the importance of early investment in renewables for a cost-effective transition.

Efforts to reduce environmental lead contamination in Uruguay provide a compelling example of effective policy interventions. In response to elevated blood lead levels (BLL) in children from low-income neighbourhoods in Montevideo in 2001, policymakers implemented multidisciplinary actions across social, environmental, and healthcare sectors. Cousillas et al. (2012) evaluate these interventions, which included phasing out lead-related pollutants, such as those from fossil fuel combustion. The study reports a nearly 50% reduction in BLL for children and non-exposed adults, underscoring the health benefits of addressing lead contamination through comprehensive policy measures.

The short-term transition from oil and gas requires a careful balancing of current energy needs with the shift towards more sustainable energy sources. A key element in this transition is the use of gas-fired plants, which can act as a bridge while renewable energy infrastructure is developed. Although these plants may reduce the immediate need for costly renewable investments, they must eventually be decommissioned to make space for a carbon-free power system (Coulomb et al., 2019). In the case of Denmark, while phasing out fossil fuel production by 2050, the country is exploring the repurposing of offshore oil and gas platforms by integrating them with offshore wind farms, showcasing a method of leveraging existing infrastructure in the short term (Alirahmi et al., 2023).

However, challenges arise in securing long-term off-takers for renewable hydrogen, which is seen as a promising alternative to fossil fuels. Efforts to transition from Steam Methane Reformers (SMR) to water electrolysis for ammonia production face operational difficulties, although the transition could be enhanced with a carbon price of approximately 550 EUR/ton CO_2 (Martinez Alonso et al., 2024). However, the carbon pricing effect shows significant spatial disparity in China (Mo et al., 2021). In the short term, balancing the continued use of fossil fuels with the introduction of renewable energy options requires strategic investments and policies. For instance, Germany's response to the natural gas crisis, exacerbated by the war in Ukraine, involved increasing import capacity through Floating Storage and Regasification Units (FSRUs) and reducing demand across various sectors. These measures helped mitigate the immediate impact of the crisis while energy security remained a priority (Halser & Paraschiv, 2022).

In the Netherlands, where households consume twice as much gas as the EU average, the aim is to phase out gas use by 2030. A detailed understanding of the socioeconomic groups reliant on gas is essential for designing targeted policies that can ensure a smooth transition. These groups include those with high gas use and dependency, such as low-income households, senior citizens, and high-income groups (Mashhoodi, 2021). The country is focusing on implementing energy taxes, poverty safety nets, and demand response measures to manage these challenges effectively.

The short-term transition period, therefore, demands strategies that manage energy security, reduce dependence on fossil fuels, and ensure fairness across different segments of society. Temporary solutions such as gas-fired plants and the repurposing of oil and gas infrastructure can play an important role in facilitating the transition, but these must be phased out in favour of more sustainable solutions as the long-term goals are pursued.

The long-term transition from oil and gas involves a systematic approach to decarbonization, with a focus on the gradual phasing out of fossil fuels and a pivot towards renewable energy solutions. Denmark's decision to end oil and gas extraction by 2050 offers critical lessons for countries undertaking similar transitions, particularly in setting a clear and agreed-upon end date for fossil fuel extraction (Madsen et al., 2023). By establishing such goals, stakeholders can ensure a just transition that minimizes the negative impact on workers and communities dependent on fossil fuel industries. Zhang & Zhang (2024) give a direction that needs for proactive policies like participation and retraining to avoid hidden injustices.

A key component of this long-term shift is the role of renewable hydrogen, which is considered vital for achieving net-zero emissions. However, current deployment faces hurdles, such as securing long-term contracts and addressing operational challenges that arise when integrating renewable hydrogen into existing systems (Martinez Alonso et al., 2024). To support this transition, the development of an optimal dispatch model for green hydrogen and ammonia production is crucial to managing these complexities. Phasing out grey hydrogen and accelerating the transition to green hydrogen by 2040 is a recommended strategy to meet long-term decarbonization goals (Zhou et al., 2024).

The energy transition also requires significant changes in the energy mix. While gas-fired plants may provide a short-term solution, the long-term decarbonization strategy necessitates a shift to renewable energy sources. The need to phase out coal and nuclear power to achieve net-zero emissions by 2060 requires careful planning and investment in renewable technologies, as well as mechanisms to ensure energy security throughout the transition (Halser & Paraschiv, 2022). One aspect of the long-term transition that should not be overlooked is the socio-economic impact. For example, in the Netherlands, where the goal is to phase out gas use by 2030, addressing the needs of vulnerable populations will be key to ensuring social acceptability. These groups, which include low-income households and senior citizens, will require targeted support through energy subsidies, retraining programs, and other social safety nets to mitigate the effects of the transition (Mashhoodi, 2021). But, Breisinger et al. (2019) argued that removing energy subsidies is painful short term but beneficial long term.

In addition, the transition to renewable energy must be complemented by strategic policies that promote energy security. This includes managing the closure of traditional power plants, balancing the supply of renewable energy with demand, and ensuring that energy infrastructure can accommodate increasing shares of intermittent renewable sources. This is particularly relevant in Europe, where the continued reliance on natural gas is expected to persist until 2030, but stricter renewable targets will drive a reduction in domestic gas consumption. This shift will increase the dependence on foreign energy supplies, complicating the broader European energy transition (Scharf & Möst, 2024).

The long-term transition also involves an emphasis on environmental and public health benefits. Studies suggest that while the reduction of toxic aerosols during the phase-out of fossil fuel combustion may initially impact air quality, this will be offset by the gradual reduction in carbon dioxide and methane emissions, ultimately contributing to both climate change

mitigation and improved air quality (Shindell & Smith, 2019). The transition to hydrogen for heavy freight transport presents another promising avenue in the long-term decarbonization effort. While hydrogen has not yet achieved widespread adoption in private passenger vehicles, its application in freight transport can be accelerated as a practical solution for reducing emissions in this sector (Moriarty & Honnery, 2019).

3.3. Policy Implications

3.3.1. Global Enablers

International cooperation is crucial for phasing out fossil fuels, yet the challenge lies in determining how to effectively achieve this. Broadly, two main approaches—top-down and bottom-up—have been identified in the literature. Advocates of the bottom-up approach emphasize promoting local technologies and manufacturers rather than imposing expensive new technologies. Strong international cooperation between developed and developing nations is essential to ensure mutual benefits and equitable transitions. This cooperation can be fostered through technology push and demand driven mechanisms[6], research and development (R&D) initiatives, and educational programs on energy transition.

Technologies innovated in developed countries are often prohibitively expensive for developing nations, necessitating collaboration to bridge this gap. This can be achieved through joint R&D projects, academic programs focused on equitable energy transitions, and vocational training. Synchronizing the technological capabilities of developed countries with the resource endowments of developing nations is also critical. For example, sunlight in tropical Africa could be harnessed for solar energy, while mountainous areas in Asia offer potential for wind energy. Bhattarai et al. (2022) suggest that shifting energy-intensive industries from rich to poor countries could temporarily reduce energy demand; however, this is not a sustainable long-term solution.

Building innovative supply-side policies is equally crucial. Collaborative governance structures, such as stakeholder commissions, can address conflicts in the transition. For instance, Germany's Commission on Growth, Structural Change, and Employment facilitated the phase-out of coal by 2038, offering financial compensation to affected regions. While the outcome faced criticism, Hauenstein et al. (2023) found that trust-building and behind-closed-door discussions played a significant role in overcoming obstacles, despite external pressures and a lack of alternatives. Such approaches demonstrate the importance of inclusive governance frameworks in facilitating transitions away from fossil fuels (see also Lægreid et al., 2023). Moreover, phasing out of fossil fuels highlights the importance of community spirit, trust, and a transparent legal framework for successful collaborations between industries, contrasting with citizen cooperatives where finance and environmental attitudes play a key role (Eslamizadeh et al., 2020).

The case of Ecuador's Yasuní National Park referendum highlights the complexities of national versus global priorities. Expert elites in Ecuador advocated for leaving fossil fuels underground to protect biodiversity, while political elites shifted from supporting non-extraction with compensation to opposing extraction bans without compensation (Alarcón, 2024). This reflects a broader tension in the Global South, where resource-dependent economies struggle to balance development goals with global sustainability demands. International collaboration must address these conflicts through equitable solutions that align national and global

[6] See (Reda et al., 2021) for more detail specially for building owners.

objectives. Furthermore, investor-State arbitration, while compensating for stranded fossil fuel assets, should avoid unjust enrichment (Hailes, 2023).

Another key strategy is to focus on stopping the expansion of fossil fuel production and infrastructure as an immediate step. Fergus et al. (2024) argue for building a global norm against new fossil fuel projects, which is vital for achieving the goals of the Paris Agreement. Economically, investing in renewable energy infrastructure and implementing supportive policies can drive growth. Socially, ensuring the equitable distribution of renewable energy benefits, particularly to marginalized groups, is essential for a just transition (Yu et al., 2024).

Institutional strength is a critical enabler for the energy transition. Ramirez et al. (2022) identify weak governance as a significant barrier in Colombia, where social unrest, violence, and inequality undermine energy democracy. They argue that green investments should go beyond market opportunities and contribute to institution building. Strengthening governance structures is thus vital for ensuring the success of renewable energy initiatives.

Global geopolitical events also impact energy transitions. Kuzemko et al. (2022) examine the effects of Russia's 2022 invasion of Ukraine on Europe's energy policy. The crisis accelerated clean energy adoption in Europe but created challenges for phasing out fossil fuels, especially in the Global South. The resurgence of the state as a key energy actor underscores the need to balance energy security with sustainable and equitable transitions.

Policy mechanisms can also play a significant role in phasing out fossil fuel subsidies. Nowag et al. (2021) propose using EU State Aid rules to implement measures like a "Fossil Fuel Inquiry" and enhance civil society advocacy for climate policy enforcement. Despite such initiatives, 11 countries, responsible for 83% of the EU's emissions, along with the EU's budget and public banks, continue to allocate over €21 billion annually to support coal, oil, and gas production. Of this total, €2.6 billion is specifically dedicated to coal phaseout efforts (Gençsü et al., 2020). Effective media narratives are necessary to garner public support and ensure the success of the transition (Arsenault & Le Billon, 2022).

Legal and economic challenges also need attention. Zheng (2024) highlights the potential conflict between phasing out fossil fuel production and the risk of breaching investment treaties protecting foreign fossil fuel investments. Lujala et al. (2022) examines factors influencing national efforts to limit fossil fuel production, noting that wealthier nations are more likely to implement constraints, while fossil fuel dependence and OPEC membership hinder such actions. These findings provide valuable insights for future supply-side climate initiatives.

In conclusion, phasing out fossil fuels requires a multifaceted approach that integrates global enablers, supply-side policies, demand-side policies, and equitable international cooperation. Key strategies include fostering R&D collaboration, building inclusive governance frameworks, strengthening institutions, and creating global norms against fossil fuel expansion. Addressing legal, economic, and social barriers is essential to ensure that the transition is not only effective but also just, orderly and equitable. By aligning national development goals with global sustainability objectives, the international community can take meaningful steps toward a fossil-free future.

3.3.2. National implementation

Pension funds

Pension funds in the US and EU have gradually integrated climate considerations into their investment strategies over the past two decades, shaped by the Kyoto Protocol, Copenhagen

Accord, and Paris Agreement. While these funds have increasingly acknowledged climate risks, their impact on phasing out fossil fuels remains limited due to complacency and acceptance of superficial actions by fossil fuel companies. McDonnell (2024) argues that for pension funds to significantly contribute to fossil fuel phase-out, they must radically redefine their role, adopt clearer frameworks, and align their investments with the Paris Agreement to drive meaningful change.

Phase out fossil fuel subsidies

Subsidies play a significant role in both hindering and facilitating the phasing out of fossil fuels. On the one hand, removing fossil fuel subsidies offers short-term benefits, such as reduced government spending and improved fiscal space for reinvesting in renewable energy projects. However, without strong climate policies in place, the removal of subsidies can lower fossil fuel prices, making them more attractive and potentially slowing the transition to low-carbon alternatives (Schwanitz et al., 2014). In countries like Indonesia, where fossil fuel subsidies are prevalent, partial subsidy removal (e.g., 25%) can increase poverty in the short term. Yet, reallocating the saved funds to government spending on social programs can slightly reduce poverty. A full subsidy removal combined with fund reallocation may help reduce poverty further, but mark-up pricing for energy could undermine these benefits (Dartanto, 2013). But, removing energy subsidies is not enough; improving the energy mix is also needed (see Hartono et al. (2020), and revenues from shifting subsidies to other sectors may be important in this regard

In Germany, despite renewable energy growth, stagnating greenhouse gas emissions highlight the challenges of phasing out coal, especially given traditional stakeholder alliances and the destabilization of established energy systems. The study suggests that phasing out coal should be linked to structural support for affected regions to avoid social and economic disruption (Leipprand & Flachsland, 2018). In high-income countries, fossil fuel subsidies misalign with global climate goals, contributing to negative socio-economic and environmental impacts. Gradually phasing out these subsidies and redirecting funds toward green energy investments like solar panels (Singh et al., 2023), improving macroeconomic performance, reduce inequality, support renewable energy policies, and socio-technical transition (Xu, 2021). However, renewable energy subsidies must be carefully designed to minimize potential distributive effects (Monasterolo & Raberto, 2019).

Transitions across multiple fossil fuels

The transition away from fossil fuels involves complex challenges and requires careful consideration of various strategies, technologies, and socio-economic impacts. A bottom-up analysis of Finland's 2019 energy system shows that replacing coal, oil, natural gas, and peat through electrification would require at least doubling power production. The specific increase depends on the technologies used, particularly whether hydrogen or electric drives are adopted in the transport sector (Michaux et al., 2023).

Several transition scenarios have been explored, including a fully renewable energy transition and an advanced fossil and nuclear transition, which emphasize the potential pathways and trade-offs involved (Foran, 2011). In the context of decarbonization goals, cross-subsidies in electricity pricing have been discussed, although these are not explicitly tied to fossil fuels or equity (Yang & Liang, 2023). Fossil fuel production disproportionately harms marginalized communities through pollution and climate change, often exacerbating systemic racism. This calls for the implementation of phase-out strategies that integrate public health and equity

considerations to ensure that the most affected groups are supported in the transition (Donaghy et al., 2023).

Additionally, phasing out fossil fuel industries is seen as essential to reducing overall fossil fuel consumption. This approach has implications beyond energy transitions and calls for broader strategies that consider the socio-economic dynamics of affected regions and sectors (McDowall, 2022). In South Korea, studies show that phasing out fossil fuel subsidies and increasing renewable energy subsidies could support the country's energy transition, though the details and outcomes of such policies remain complex (Park et al., 2021). Phasing out fossil fuels also leads to significant shifts in residential energy systems in Europe, with widespread electrification of the residential sector being one of the most prominent changes (Salim et al., 2024). Furthermore, fossil fuel dependence is often tied to elite power structures, highlighting the role of political and economic elites in shaping energy transitions (Shriver et al., 2022).

Just Energy Transitions

The concept of “Just Transition" aims to ensure that the shift to a low-carbon economy is both equitable and inclusive, addressing the social, economic, and political challenges faced by communities and workers affected by this transition. In South Africa, the Just Transition Feasibility Framework (JTFF) is proposed to assess the country’s energy transition. This framework highlights the socio-political challenges of moving from fossil fuel-based energy systems to renewable energy, emphasizing the need for broader inclusivity in policies that focus not only on renewable electrification but also on empowering local communities. The JTFF suggests that without addressing the needs of workers and communities, the energy transition could exacerbate inequalities, particularly in regions dependent on fossil fuel industries (Mirzania et al., 2023).

In sub-Saharan Africa (SSA), a diverse set of frameworks and policies for just transition has been put forward by governments, NGOs, and multilateral institutions. A review of 75 non-academic Just Transition documents reveals the varied approaches taken to support the region's energy transitions. These documents highlight different policy proposals and frameworks, each reflecting the unique socio-economic and political contexts of the countries involved. This diversity underscores the complexity of implementing a Just Transition in SSA, where factors such as poverty, access to energy, and employment depend heavily on the energy sector. The need for careful planning and inclusive policies is crucial to ensuring that the transition does not leave behind vulnerable populations (Ullman & Kittner, 2024).

Addressing the political economy of fossil fuel Transitions

Addressing the political economy of fossil fuel transitions involves recognizing the varying political costs associated with phaseout policies in different countries. In Norway, pro-phaseout parties have not experienced significant losses in support, suggesting that fossil fuel phaseout policies may not be politically costly in countries with strong social welfare systems. However, the political costs of such policies could be much higher in countries with weaker social safety nets, where voters may feel more vulnerable to the economic disruptions caused by energy transitions (Egli et al., 2023). In this context, the social and economic impacts of fossil fuel phaseout must be carefully managed to ensure that vulnerable populations are supported during the transition, which may require tailored policies based on the country’s political and economic landscape.

The political economy of fossil fuel transitions also varies depending on a country's level of wealth and governance transparency (Lægreid et al., 2023). For instance, members of the Powering Past Coal Alliance (PPCA), who are wealthier and have more transparent governments, face lower political and economic costs when phasing out coal. This is in contrast to major coal consumers like China and India, where the costs of transition are higher due to economic dependencies on coal and less transparent governance (Jewell et al., 2019). In Alberta, Canada, a key issue in the transition is the lack of capacity in provincial ministries to develop robust renewable energy policies. A network is working to address this by providing policy analysts and lawmakers with relevant information on the health impacts of coal and best practices in renewable energy, helping to build the necessary capacity for a successful low-carbon transition (Lysack, 2015).

3.4. Limitations and future research directions

We considered a sub-section on where these transitions might be headed. However, we did not include literatures on renewable energy and energy efficiency, for example, as this is a very large body of work; and relates to other parts of the GST decision, and so are beyond our scope.

Future research might integrate literature reviews on tripling renewable energy and doubling energy efficiency, with that on equitable fossil fuel transitions

And as noted in reviews of literature on case studies, lesssons to be drawn from case studies deserve further attention, taking care to identify what might be applicable in other contexts (such as higher levels of poverty and inequality), and what is context-specific.

4. Conclusion

4.1. Review of literature on complex problem for relevant and novel insights

In this working paper, we have assessed the multifaceted problems in transitioning away from fossil fuels – what this might mean for different countries and how can the multilateral regime play a catalytic role – as introduced in our research question (section 1). In section 2, we reported in detail on a systematic literature review of papers in the Web of Sciences database, as outlined in section 2. Our systematic literature review identified 130 papers, and we have in the narrative part drawn on a few more. These papers contain very rich information, and no summary can include all the useful findings. We analysed the studies identified, exploring the literatures for tried-and-tested approaches and novel insights. The findings show that the problems in transitions away from fossil fuels are not straightforward.

In Section 3, we highlighted these insights and approaches for transitions away from coal and oil & gas, respectively, and on policy implications. In reviewing the literature, we considered both equity and science, and short- and long-term perspectives, which are all important considerations in the GST decision.

In concluding this working paper, we offer reflections based on our analysis. To address these complex multifaceted problems, giving attention to different contexts and understanding the timing of transitions will be important. Very rapid transitions are necessary, but disruptive – and addressing equity (in distributional and procedural dimensions) and socio-economic development is crucial. Governance, institutions, norms, transparency, indicators and – last

but not at all least – a wide range of actors are needed to Implement equitable fossil fuel transitions.

4.2. Context and timing matters

The challenge of transitioning away from fossil fuels is global, but will not happen at the same time or in same way in different places. It is well understood that the timing of phase-outs will differ for different context – without detracting from the urgency of phasing out as soon as possible, where possible.

The literature assist in providing further nuance to such broad statements. Studies suggest a sequence, to first halt new activities on fossil fuel, and then phase out existing facilities. The stop on new fossil fuel should be as widespread as possible, given that we are in a climate crisis. There will be some exceptions to this rule, with a compelling argument being to spend the few remaining fossil fuels that can be burned without exceeding 1.5°C where they contribute most to human welfare (as distinct from prioritising least cost). So, in poorer countries that are highly dependent on fossil fuels, there is case for some more time.

However, the need to transition remains. The phase down and eventual phase-out of existing fossil fuel facilities depends on time, place and fuels. Given the complexity, it is not surprising that various authors arrived at different conclusions. There are studies that advocate for the immediate shutdown of fossil fuel-fired power plants, while others warn of the adverse effects on goods and services production. Phasing shut-down of coal-fired power plants, rather than immediately, to enable a controlled decline in coal-sector employment and giving workers time to find new livelihoods. Interestingly , among studies that investigate early coal phaseout, some find that – on its own – this may fail to meet long-term climate goals, unless accompanied by other measures such as carbon price and broader decarbonization efforts. Most studies would tend to support a context-sensitive approach to decarbonization, consider the socio-economic realities of different regions, timing and different fuels. In the literature on transitions away from oil and gas, a recurring recommendation is removing producer subsidies for extraction of oil and gas.

Studies on timing of transitions in energy and transport systems have noted acceleration, and identified technological, policy, economic, and social determinants for such shifts.

The literature on fossil fuel transitions includes many case studies. Given the importance of context, such case studies are helpful, to understand important matters from patterns of fossil fuel production and / or consumption to political economy dynamics. However, care should be taken to generalize from individual and localized cases.

4.3. Equity and socio-economic implications

Rapid transitions are necessary to address the climate crisis. Yet very rapid change is disruptive, and capabilities to address distributional equity may be exceeded.

How to address the political economy implications of rapid transitions? Based on our reading of the literature, we would argue that, at any pace of change, all sustainable development goals should be met. In the context of fossil fuels, ensuring access to affordable, reliable, sustainable, and modern energy for all by 2030 (SDG7) is highly relevant, and eradicating poverty and reducing inequality between and within countries is required SDGs 1 and 10.

While SDGs provide a useful lens at global scale, the literature clearly points to the importance of local dimensions. Transitions are less costly, including to workers and communities, if social

welfare systems are strong. More specific and active policies and measures to needed to address social-economic implications. Compensation and skills redevelopment are proactive measures that are supported by the literatures.

Workers and communities should determine their own future, if fossil fuel transitions are to be called just. Procedural equity is an abstract term, but the includes practical ideas. On procedural equity, too, case studies are helpful in understanding specific contexts. Some insights from various studies include suggestions to build on just transition framework that addresses local challenges while fostering national benefits. Inclusive processes, such as commissions across countries as different as Germany and South Africa, seek to build consensus across a wide range of stakeholders. There is much support in the literature on considering governance and institutions, including the norms and visions they seek to implement.

4.3. Governance, institutions and norms

Multilateralism, international cooperation and collaborative governance are more important than ever, generally, in era of fragmentation. Many countries are divided internally, and conflict and adversarial competition are shaping international relations in 2025.

Good governance and institutions are important – but what do they mean for equitable fossil fuel transitions more specifically? Some authors suggest using existing institutions to focus this new challenge, while others explore whether new institutions need to be established. Whether existing or new, it seems most authors find institutions specifically for transitioning away from fossil fuels are very important. An interesting notion is that instutions should do three things: a) set strategy, b) build consensus / mediate conflict, and c) coordinate implementation.

Setting norms is also important at global scale. There is a literature that suggests that norms aginst fossil fuels should be adopted. Some authors in this literature argue for a new treaty, a Non Fossil Fuel Proliferation Treaty; while other studies cuation about the time and effort required for new negotiations, and recommend strengthening the norm-setting function of the UN climate regime. Rather different kinds of treaties are investment treaties. These tend to protect the interests of fossil fuel companies – and changing these would be worht further research.

Actors, in the sense of organisation and individuals promoting change, are obviously important. Beyond the usual actors (UN bodies, civil society, etc.), the studies reviewed here also point to actors not typically thought of as change agents. The suggestions that oil and gas lawyers are well placed to assist with equitable fossil fuel transitions seems novel to us. Like all good ideas, it merits further research and testing in practice.

The literature suggests developing criteria and indicators to measure the equity of transitions away from fossil fuels. Such criteria need to track progress in the transitions – how to measure phase out and phase down, across coal, oil and gas. And indicators that track the distributional implications, measures to ensure fairness, and the processes that deliver them, are needed. As in other dimensions, context will matter, and it is likely not helpful to identify single indicators, but rather multiple indicators and way track progress.

4.5. Final remarks

Ten years after the adoption of the Paris Agreement, it is time to accelerate implementation. Transitioning away from fossil fuels is a multifaceted challenge that demands

context-specific solutions and international cooperation. There is not one size fits all, and the rich literature on country case studies is important for each set of national circumstances. However, this transition cannot succeed without robust political systems and public willingness that actively support a just, orderly, and equitable process.

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