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ADVANCED REVIEW

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Equitable, effective, and feasible approaches for a prospective fossil fuel transition

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Abstract

Most fossil fuel resources must remain unused to comply with the Paris Agreement on Climate Change. Scholars and policymakers debate which approaches should be undertaken to Leave Fossil Fuels Underground (LFFU). However, existing scholarship has not yet inventoried and evaluated the array of approaches to LFFU based on their effectiveness, equity, or feasibility. Hence, this review article asks: *What lessons can we learn from reviewing scholarship on proposed approaches to leaving fossil fuels underground (LFFU)?* We identify 28 unique LFFU approaches, of which only 12 are deemed environmentally effective (e.g., fossil fuel extraction taxes, bans and moratoria, and financial swaps); eight involve moderate-to-high (non-)monetary costs, and only four are deemed entirely just and equitable. Of the 12 environmentally effective approaches: only three were deemed cost-effective (regulating financial capital for fossil fuel projects, removing existing fossil fuel subsidies, and bans & moratoria); merely four were deemed equitable (asset write-offs, retiring existing fossil infrastructure, pursuing court cases/litigation, and financial swaps); and all were deemed institutionally problematic in terms of their feasibility (six were challenging to implement as they threatened the vested interests of powerful stakeholder groups). Moreover, the reviewed scholarship draws heavily on empirical studies of how these LFFU approaches can be optimized in European, North American, and Chinese contexts; fewer studies have explored the effectiveness and fairness of LFFU approaches in the South and/or in a North–South context. Future research should particularly focus on North–South fossil fuel financial flows, which have received comparatively little attention.

This article is categorized under:
The Carbon Economy and Climate Mitigation > Decarbonizing Energy and/or Reducing Demand

KEYWORDS
climate change, climate justice, climate policy, fossil fuels, fossil transition

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1 | INTRODUCTION

Unabated fossil fuel combustion is a leading driver of climate change (IPCC, 2014, 2019), hence curbing average global warming to 1.5–2°C above pre-industrial levels—an objective (Article 2.1a) of the Paris Agreement on Climate Change (UN, 2018)—requires substantially phasing out fossil fuels (McGlade & Ekins, 2015; Welsby et al., 2021). However, as of 2019, approximately 80% of global primary energy demand was met using fossil fuels (Johnsson et al., 2019), and fossil fuel production rates grew through 2020 to the point that the "budget" of burnable fossil fuels compliant with the 1.5°C goal may be overshot by 120% by 2030 (SEI, 2020).

Leaving Fossil Fuels Underground (LFFU) in compliance with these goals will generate *stranded assets* potentially worth up to $200 trillion (Linquiti & Cogswell, 2016); these are physical (e.g., machinery, infrastructure), financial (e.g., equity, debt), natural (e.g., oil reserves), human (e.g., employment), and social (e.g., communities) assets that will be prematurely devalued as fossil fuel production is halted (see Bos & Gupta, 2018, 2019; Caldecott et al., 2013). This could lead to a shrinking of the global economy by $1–4 trillion (Mercure et al., 2018) threatening *both* the financial institutions that invest in fossil firms (Christophers, 2019; Gunningham, 2020; Rempel & Gupta, 2020) who may therefore oppose a fossil fuel phase-out, *and* non-financial actors who depend on fossil fuels for their livelihoods, like coal miners and diesel-power consumers (e.g. Rempel & Gupta, 2021).

Policies must clearly eradicate this fossil-intensive trend, but how exactly can we LFFU? Scholars present possible *approaches to LFFU* (e.g., Lazarus et al., 2015; Lazarus & van Asselt, 2018; Le Billon & Kristoffersen, 2019); however, few have systematically compiled the array of proposed LFFU approaches (c.f. Gaulin & Le Billon, 2020), and none have evaluated them based on their *effectiveness*, *equitability*, and *feasibility and/*or accounted for the challenge of stranded assets. Hence, we ask: *What lessons can we learn from reviewing scholarship on proposed approaches to leaving fossil fuels underground (LFFU)?*

This review article presents our method (Section 2), a comprehensive (though not exhaustive) list of LFFU approaches (Section 3), an analysis of each approach based on its effectiveness, equitability, and feasibility (Section 4), and a discussion on geospatial and other trends across the reviewed literature (Section 5), before drawing conclusions (Section 6).

2 | METHODS

The Paris Agreement is a demand-side treaty focusing on *emissions* rather than fossil fuel supply (Asheim et al., 2019); it does not even mention "fossil fuels"! Consequently, most climate policy instruments *indirectly* address the fossil fuel industry by debating, for instance, the *carbon* price (Lazarus & van Asselt, 2018) rather than that of coal, oil, or gas. Hence, we define an *LFFU approach* broadly as "a policy, instrument or measure with the explicit goal of taking climate action and that may directly or indirectly diminish fossil fuel production or consumption."

We undertook a *scoping review* (Munn et al., 2018; Pham et al., 2014) of LFFU approach scholarship. We searched the *Scopus* database using the command: TITLE-ABS-KEY ("fossil fuel" AND ["transition" OR "approach" OR "demand-side" OR "supply-side" OR "policies"]) AND (LIMIT-TO (PUBYEAR, >2014),[1] which yielded 6826 unique hits. After limiting the search to relevant subject areas (e.g., social science, economics, law), 1674 hits remained. These results were further screened by assessing the abstracts and conclusions of each paper in relation to the posed research question (see Section 1); this resulted in a long list of 121 papers. Twenty-two papers were discarded as their focus deviated from ours[2] and 16 papers[3] were added while analyzing this filtered selection, leading to a final list of 115 papers.

Five papers (Gaulin & Le Billon, 2020; Lazarus et al., 2015; Lazarus & van Asselt, 2018; Le Billon & Kristoffersen, 2019; Mutezo & Mulopo, 2021) reviewed LFFU approaches, but (1) these papers focused predominantly on supply-side instruments, (2) neglected innovative, niche, and unique alternatives, and (3) only Le Billon and Kristoffersen (2019) produced a framework to evaluate supply-side LFFU approaches using equity/justice criteria, but do not apply it. Although our search is from 2015 onwards, we examined previous assessments of climate policy scholarship (Ekins et al., 2019; IPCC, 2007, 2014). We use these papers as the point of departure for our more comprehensive review.

We categorized LFFU approaches as *economic*, *regulatory* (Lazarus et al., 2015; Le Billon & Kristoffersen, 2019), or "*other*" for niche approaches, and by "type" [either fossil fuel *demand restrictive (DR) or supply restrictive (SR)*, or *demand supportive (DS) or supply supportive (SS)*]. The latter focuses on encouraging substitution of fossil demand and supply, respectively, building on Green and Denniss (2018).

We identified 28 approaches and evaluated them using four dimensions adapted from the framework in Chapter 13 of the IPCC (2007) report (Table 1). *Environmental effectiveness* assesses whether an approach is successful in LFFU;

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TABLE 1 Scoring system used to evaluate the identified LFFU approaches

	Environmental effectiveness	Cost effectiveness	Justice and Equity	Institutional feasibility
Score	Does it directly LFFU at its respective level of governance?	How much does it cost to implement, financially or otherwise?	How are implementation costs and stranded assets allocated and accounted for?	Is the approach novel, complex, and will it be resisted?
+	Likely LFFU	Relatively low implementation costs	Costs borne by governments, firms, financiers, or other rich and capable actors, AND the approach directly and explicitly allocates stranded assets to firms, financiers, governments, or other rich and capable institutional actors	Not novel or complex and therefore not resisted; no organization of vested interests and hence not resisted
0	Potentially LFFU	Some implementation costs	Costs borne by governments, firms, financiers, or other rich and capable actors, but the approach ignores the accompanying stranded assets	Either novel, complex, or there is some organization of vested interests and likely met with some resistance
–	Very unlikely LFFU	High implementation costs	Costs borne by under-resourced and under-represented fossil dependents, and stranded assets are unaccounted for	Very novel, complex, with vested interests organized and thus likely to be met with heavy resistance

Source: original, adapted from IPCC (2007).

cost effectiveness assesses the potential monetary *and* non-monetary (i.e., administrative, logistical, time, personnel) costs of a given approach; *justice and equitability* assess who likely wins or loses from an approach and who likely incurs the inevitable financial, physical, natural, human, and social stranded assets; finally, *institutional feasibility* assesses the potential resistance to an approach, which (building on IPCC, 2007) depends on the novelty, complexity, and *vested interests* that actors may have in a given approach.

We assessed each approach in isolation, acknowledging that in practice mixes of approaches will be adopted (Section 5). Evaluating approaches in isolation is challenging because, inter alia, the *outcome* vis-à-vis effectiveness and equity vary in different contexts (as Skovgaard & van Asselt, 2019 show in terms of fossil fuel subsidy reform). However, it is useful to consider the shortcomings and possibilities that each LFFU approach *may bring* to different policy mixes. Thus, this review does not draw definitive conclusions and recommendations about LFFU approaches; rather, it: (1) sheds light on the multidimensional and implicit ramifications of LFFU approaches for policymakers, financiers, investors, and civil society; and (2) allows for a comparison of various LFFU approaches across multiple categories.

Finally, we adopt the UNEP GEO-6 framework for qualifying our confidence (Ekins et al., 2019) in the scores we assign to each approach. We rank each approach's score as either (ibid, p. 626):

- *Inconclusive (Inc)* if there is "no or limited evidence and no clear consensus";
- *Unresolved (Un)* if "multiple independent studies exist but conclusions do not agree";
- *Established but Incomplete (EbI)* if there is a "general agreement although only a limited number of studies exist but no comprehensive synthesis"; or
- *Well Established (WE)* if "multiple independent studies... agree"

Such ranking depends on the frequency with which the approach was discussed in the scholarship (see rightmost column in Table 2) and the level of (dis)agreement pertaining to the effectiveness, equitability, and feasibility of each approach across the reviewed scholarship.

3 | INVENTORY OF LFFU APPROACHES

This section presents and briefly defines our inventory of 28 unique LFFU approaches (see Table 2).

TABLE 2 Inventory of identified approaches to LFFU, organized by type and dimension

Category	Type	Approach	Discussed in
Economic	DR	Carbon Emissions Tax	Cairns (2018); La Rovere (2020); Baldwin et al. (2020); van der Ploeg and Rezai (2018); Rozenberg et al. (2020); Kopytin et al. (2020); Kalkhul et al. (2020); Le Billon and Kristoffersen (2019); Armstrong (2019); King and van den Bergh (2018); Pregger et al. (2019); Paterson (2020); Sinn (2012); Evans and Phelan (2016); Gunningham (2020); Mutezo and Mulopo (2021); Lazarus et al. (2015); Sovacool and Geels (2016); Gaulin and Le Billon (2020); Piggot et al. (2018); Newell and Simms (2019); Faehn et al. (2017); Green and Denniss (2018)
		Fossil Fuel Import Tax	Lazarus and van Asselt (2018); York and Bell (2019)
		Border Tax Adjustments	Rocchi et al. (2018); Trachtman (2017)
		Tradeable Emissions Permits	Caldecott and Dericks (2018); Lohman (2012); Armstrong (2019); Paterson (2020); Sinn (2012); Lazarus et al. (2015); Sovacool and Geels (2016); Gaulin and Le Billon (2020); Erickson et al. (2018); Green and Denniss (2018);
	DR + SS	Feebate Programmes	Rozenberg et al. (2020); Plötz et al. (2019)
	SR	Tradeable Production Quotas	Le Billon and Kristoffersen (2019); Lazarus et al. (2015); Lazarus and van Asselt (2018); Green and Denniss (2018)
		Fossil Fuel Production/Extraction Tax	York and Bell (2019); Sinn (2012); Foster et al. (2017); Christophers (2019); Mutezo and Mulopo (2021); Lazarus et al. (2015); Erickson et al. (2018); Piggot et al. (2018); Faehn et al. (2017); Lazarus and van Asselt (2018); Green and Denniss (2018); Le Billon and Kristoffersen (2019); Richter et al. (2018)
		Fossil Fuel Subsidy Removal	Johnsson et al. (2019); Yuan et al. (2019); Coady et al. (2019); Le Billon and Kristoffersen (2019); Paterson (2020); Monasterolo and Raberto (2019); Christophers (2019); Lin and Xu (2019); Mutezo and Mulopo (2021); Chepeliev and Mensbrugghe (2020); Lazarus et al. (2015); Gaulin and Le Billon (2020); Erickson et al. (2018); Newell and Simms (2019); Piggot et al. (2018); Lazarus and van Asselt (2018); Green and Denniss (2018); Collier and Venables (2015); Geels et al. (2017)
		Fossil Fuel Export Tax	Sinn (2012); York and Bell (2019); Nalule (2020); Lazarus et al. (2015); Piggot et al. (2018); Lazarus and van Asselt (2018)
	DS + SS	Green Finance and Subsidies for Alternatives	Baldwin et al. (2020); Rozenberg et al. (2020); van der Ploeg and Rezai (2018); van der Ploeg (2020); Chapman et al. (2018); York and Bell (2019); Sinn (2012); Monasterolo and Raberto (2019); Ringsmuth et al. (2016); Escobar et al. (2020); Foster et al. (2017); Evans and Phelan (2016); Johnstone et al. (2017); Gunningham (2020); Mutezo and Mulopo (2021); Ediger (2019); Healy and Barry (2017); Lazarus et al. (2015); Newell and Mulvaney (2013); Sovacool and Geels (2016); Erickson et al. (2018); Asheim et al. (2019); Green and Denniss (2018); Collier and Venables (2015); Geels et al. (2017)
"Other"	SR	Divestment	Le Billon and Kristoffersen (2019); Rempel and Gupta (2020); Gupta et al. (2020); Ayling and Gunningham (2017); Paterson (2020); Chapman et al. (2018); Christophers (2019); Healy and Barry (2017); Lazarus et al. (2015); Gaulin and Le Billon (2020); Piggot et al. (2018); Lazarus and van Asselt (2018)
		Engagement	Rempel and Gupta (2020); Gupta et al. (2020); Gunningham (2020)
		Asset Write-Off	Gupta et al. (2020); Rempel and Gupta (2021)

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TABLE 2 (Continued)

Category	Type	Approach	Discussed in
		Expanding Investor Understanding to Innovatively Regulate Investors	Christophers (2019); Gunningham (2020); Mutezo and Mulopo (2021); Healy and Barry (2017); Newell and Simms (2019); Piggot et al. (2018)
		Blockades	Le Billon and Kristoffersen (2019); Healy and Barry (2017); Gaulin and Le Billon (2020)
		Court cases/litigation	Gaulin and Le Billon (2020); Burger and Wentz (2018)
		Finance Swap and Compensation	Le Billon and Kristoffersen (2019); Armstrong (2019); Lazarus et al. (2015); Gaulin and Le Billon (2020); Erickson et al. (2018); Newell and Simms (2019); Lenferna (2018); Piggot et al. (2018); Faehn et al. (2017); Eichner and Pethig (2019); Harstad (2012); Lazarus and van Asselt (2018); Geels et al. (2017)
		Unionization	Evans and Phelan (2016); Mutezo and Mulopo (2021)
Regulatory	DR	Promoting Energy Efficiency Improvements	Sinn (2012); Evans and Phelan (2016); Mutezo and Mulopo (2021)
		Capping Growth of Electrical Sector	York and Bell (2019); King (2012)
		High emissions/efficiency standards, building codes, and regulations	Lazarus et al. (2015); Erickson et al. (2018); Green and Denniss (2018); Pollin and Callaci (2018)
	SR	Bans and moratoria	Johnsson et al. (2019); Kalkhul et al. (2020); Vogt-Schilb and Hallegatte (2017); Le Billon and Kristoffersen (2019); York and Bell (2019); Johnstone et al. (2017); Lazarus et al. (2015); Gaulin and Le Billon (2020); Piggot et al. (2018); Asheim et al. (2019); Newell and Simms (2019); Piggot et al. (2018); Lazarus and van Asselt (2018); Green and Denniss (2018); Geels et al. (2017)
		Full climate-related information disclosure and emissions accounting	Gunningham (2020); Lazarus et al. (2015); Piggot et al. (2018); Lazarus and van Asselt (2018)
		License/permit suspensions	Johnsson et al. (2019); Kalkhul et al. (2020); Vogt-Schilb and Hallegatte (2017); Johnstone et al. (2017); Sovacool and Geels (2016); Erickson et al. (2018)
		Limiting state good provisioning	Lazarus et al. (2015); Erickson et al. (2018); Lazarus and van Asselt (2018)
		Retire/phasing-out existing fossil-intensive infrastructure	Chapman et al. (2018); David (2018); Mutezo and Mulopo (2021); Sovacool and Geels (2016)
	SR + DR	Regulating Financing Capital for Fossil Fuel Projects and Infrastructure	Best (2017); Nalule (2020); Kulagin et al. (2020); Johnstone et al. (2017); Christophers (2019); Gunningham (2020); Mutezo and Mulopo (2021); Lazarus et al. (2015); Piggot et al. (2018); Lazarus and van Asselt (2018); Geels et al. (2017)
		Environmental Impact Assessment of forthcoming fossil projects	Lazarus et al. (2015); Green and Denniss (2018)

Abbreviations: DR, demand restrictive; DS, demand supportive; SR, supply restrictive; SS, supply supportive.

3.1 | Economic

Economic approaches include a **Fossil Fuel Production/Extraction Tax**, taxing producers rather than consumers. This taxes financial assets or the capital income generated, thereby influencing production (Sinn, 2012). Sinn (2012, p. 217) elaborates:

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> The tax on financial assets, or, equivalently, on the capital income earned on these assets, would prompt the resource owners to leave a larger part of their wealth below ground, tilting their private wealth portfolio in the direction of a socially optimal portfolio with less man-made capital and more natural capital. The carbon resources would be extracted more slowly, as the extraction and price paths would have to flatten.

A **Carbon Emissions Tax** is levied on the emitted CO_2 or CO_2e (carbon dioxide equivalent—see e.g., Lohman, 2012) allocated to the emitter (i.e., fossil fuel consumers), also known as a Pigouvian tax (e.g., Cairns, 2018; Paterson, 2020). It assumes that market failure externalized the "'real' costs of [greenhouse gas] emissions and thus intervention is needed to 'internalise' these costs" (Paterson, 2020, p. 5). A **Tax on Imported Fossil Fuels** raises the price and decreases the demand for fossil fuels (e.g., Lazarus & van Asselt, 2018; York & Bell, 2019). For example, India has a "tax on locally produced and imported coal at a rate of INR 400 [about USD 6] per tonne" (Piggot et al., 2018, p. 2). An alternative is a **Border Tax Adjustment (BTA)**, which enables a country to increase tariffs on imported goods produced in countries or regions lacking climate policies or carbon pricing (Rocchi et al., 2018, p. 127; Trachtman, 2017). A **Fossil Fuel Export Tax** taxes exports rather than imports, disincentivizing fossil fuel extraction by taxing the producer (Lazarus & van Asselt, 2018; Richter et al., 2018). Like with production/extraction taxes, such taxes "aim to remove distortions created by subsidies [and] to reflect the full social cost of extraction activities" (Lazarus et al., 2015, p. 7).

More complex approaches include **Tradeable Emissions Permits (TEPs)** and Cap-and-Trade schemes, which involve commodifying and distributing tradeable *emissions* permits across fossil *consumers* through gratis allocation or auctions (usually through grandfathering; Lohman, 2012), and once distributed, permit holders can buy and sell permits depending on their own targets and the marginal cost of reducing their own carbon footprint. These *emissions* permits limit fossil fuel consumption, not production. Alternatively, **Tradeable Production Quotas (TPQs)** can curtail fossil fuel supply by capping fossil fuel extraction and production, and "production permits" are allocated or auctioned among producers (e.g., Le Billon & Kristoffersen, 2019).

Fossil Fuel Subsidy Reform removes existing direct (i.e., monetary) and indirect (e.g., tax breaks) subsidies from the government which make fossil fuel production competitive by externalizing its socioecological and economic costs; removing such subsidies would partly shift the "true costs" of producing fossil fuels to producers.

Green Finance and Subsidies for Fossil-Alternatives, including "green bonds", finance for research and development (e.g., Gunningham, 2020; Monasterolo & Raberto, 2019), "green" subsidies (directly through, e.g., cash transfers, indirectly through, e.g., tax breaks or Feed-in-Tariffs; Gaulin & Le Billon, 2020, p. 892) and allocating funds and resources to support "community-centric entrepreneurship" (Mutezo & Mulopo, 2021, p. 11), can increase the competitiveness of low-carbon technologies (e.g., Gaulin & Le Billon, 2020), including fungible fuels, photosynthetic energy systems, hydrogen fuel cells (Ringsmuth et al., 2016), and more conventional renewables like solar PV and wind. **Feebate Programs** combine carbon emission taxes on "energy-inefficient equipment" (a "fee") with a "rebate" (e.g., subsidy) for fossil alternatives or "new energy-efficient equipment" (Rozenberg et al., 2020, p. 2). Allegedly, feebates can "avoid stranded assets in their extreme form" as they "do not tie a new cost to the utilization of existing capital" (ibid, p. 3). Feebates are typically discussed for the transport sector, where the "fee" would apply to petrol/diesel cars and the "rebate" to cars with near-zero emissions (Plötz et al., 2019).

3.2 | Regulatory

While many of the above economic mechanisms need to be embedded in regulatory approaches, we now discuss purely regulatory approaches. A popular option is promulgating **Stricter Emissions/Efficiency Standards**, which includes emissions caps, prohibiting, regulating certain types of technologies, and broader regulations, for example, on new infrastructure projects or setting building codes (Ericksen, Lazarus, & Piggot, 2018; Erickson et al., 2015). States can also pursue **Energy Efficiency Improvements** by allocating permits & licenses that replace *either* high-emitting projects with lower-emitting alternatives, *or* replace projects with a low Energy Return on Investment (EROI) with one with a greater EROI (see e.g., Lazarus et al., 2015).

Permission for a new infrastructure project is often subject to an **Environmental Impact Assessment (EIA)**.[4] Including GHG emission criteria in EIAs may enable regulators to conduct "[c]omprehensive emissions assessment in

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environmental impact review of new fossil fuel supply projects" (Lazarus et al., 2015, p. 10). This could enable more efficient fossil fuel governance. Note that following an EIA, companies must prepare environment management plans to reduce their pollutants, which include GHGs, and therefore may indirectly target fossil fuels.

Similarly, companies and their investors and financiers could be required to provide **Full Climate-Related Information Disclosure and Accounting**, which could include financed fossil fuel projects and infrastructure and their carbon footprints; the latter is more commonly disclosed. With full fossil fuel-related disclosure, regulators are able to better monitor current and expected fossil fuel production at intra- and international levels.

Fossil fuel exploration and production firms require licenses, permits, or concessions before production. States could **Suspend Existing Licenses or Permits**, or explore options to revoke, terminate, or forgo renewing licenses and/or permits to fossil fuel producers. However, this often requires the state to compensate the producer—which can hamper implementation (see Section 4.2.5). Such a suspension could, for instance, reduce California's oil production by 70% over a 10-year period (Erickson, Lazarus, & Piggot, 2018). **Bans and moratoria** prohibit producing certain kinds of fuel (e.g., from a particular reserve) or using certain methodologies (e.g., fracking in Tunisia and France) within the authority's jurisdiction (Le Billon & Kristoffersen, 2019, p. 1081; Geels et al., 2017, p. 16). Note that "certain moratoria have no legislated end date, essentially acting as de facto bans" (Gaulin & Le Billon, 2020, p. 891). Such approaches are being adopted in Costa Rica, Belize, France, Canada, the United States, Denmark, and New Zealand (Erickson, Lazarus, & Piggot, 2018; Le Billon & Kristoffersen, 2019, p. 1081),[5] though of these, only Canada and the US are significant fossil fuel producers (Le Billon & Kristoffersen, 2019, p. 1081).

Capping the Growth of Electrical Grid limits electricity production and "is essentially a moratorium on the growth of the energy sector" (York & Bell, 2019, p. 43). Since 80% of 2019 primary energy demand was met with fossil fuels (Johnsson et al., 2019), implementing an upper limit to the energy produced can reduce demand for fossil fuel and therefore LFFU. This assumes that if "we simply add renewables to an ever-growing energy mix, then we have the negative impacts of renewables in addition to the carbon emissions of the fossil-based system" (King, 2012, p. 2).

Two indirect regulatory options also exist. States can **limit the provisioning of public goods** used by fossil producers, like water and land (Lazarus et al., 2015; Lazarus & van Asselt, 2018), which would hamper the ability of fossil fuel producers to maintain their business-as-usual practices. Since the coal supply chain is water-intensive (in mining and power plants; Luo & Otto, 2014), reducing water access can constrain coal production. Moreover, **financial capital can also be regulated**; this is needed as central & commercial banks have heavily invested in fossil fuel projects (Gunningham, 2020, p. 14). Regulating such financial capital would elevate the cost of capital for "capital-intensive energy production" (Best, 2017, p. 76), and establish a governance structure threatening the ability to raise funds on (inter)national markets for fossil projects (Gunningham, 2020).

3.3 | "Other"

We classify "Other" approaches as those that can be taken by the state in addition to other actors, like civil society or investors and financiers. On the financial side, **Expanding Investor Understanding** through four key tropes (subjectivity, economism, temporality, and convention—see Christophers, 2019) can yield innovative financial approaches to LFFU, including a "multi-faceted approach to reducing short-termism [by] tying key management long term incentives to carbon emissions reductions" and "mandat[ing] the 'gating' (i.e., the practice of temporarily blocking withdrawals from an investment fund) of products with medium or long-term investment horizons" (Gunningham, 2020, p. 8); expanding fiduciary duty; and creating "substantially decarbonized" indices to accommodate conventional passive investing (Gunningham, 2020, p. 12).

Other options for financers include **Divestment**, or the act of selling (often) liquid fossil fuel assets (e.g., common shares, convertible bonds), typically by an institutional shareholder (like pension funds), so as to reduce risks, gain reputation and stigmatize the fossil fuel industry. **Engagement**, in contrast, is an approach used by investors to leverage their shareholder power to sway the behavior of fossil fuel companies. A problem with divestment is that it creates new vested interests; however, in current governance systems, **Asset Write-Off** (where shareholders "write-off" their fossil fuel-related equity and incur the devaluation costs themselves) is not yet possible (Gupta et al., 2020; Rempel & Gupta, 2021).

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Civil society can employ **Blockades** through social movements to physically hamper the extraction, production, and/or distribution process or anywhere along the supply chain (Gaulin & Le Billon, 2020), though mostly they "block fossil fuel extraction at its source" (Healy & Barry, 2017, p. 454; Le Billon & Kristoffersen, 2019, p. 1080). Blockades accompany other protests and are supported by public information and petitions (Le Billon & Kristoffersen, 2019, p. 1080). Similarly, **Labor Unions** can mobilize to pressure a company, bank, or an industry more broadly to change their business practices through (1) *business unionism*, "which seeks mutual gains between business, workers and union interests"; (2) *social-democratic/movement unionism*, "which seeks to socialize the capitalist economy to moderate market forces to achieve social justice and equity"; and (3) *radical unionism*, "which seeks to mobilize social–political forces to promote working-class interests and an alternative non-capitalist society" (Evans & Phelan, 2016, p. 335).

Beyond blockades and unions, civil society groups often pursue **Litigation** and demand that courts halt fossil fuel exploration and production within their jurisdiction on grounds of human rights violations, air pollution, and driving climate change (Gaulin & Le Billon, 2020). The recent verdict against Shell shows (Baazil & Lombrana, 2021) that multinationals are not immune to aggressive climate action. Litigation can also be used by companies to obstruct fossil fuel phase-outs, when companies demand compensation from governments for prematurely phasing out their contracts, permits, concessions, or licenses, like nuclear power plant owners suing the German government for forcing their closures (Bos & Gupta, 2019).

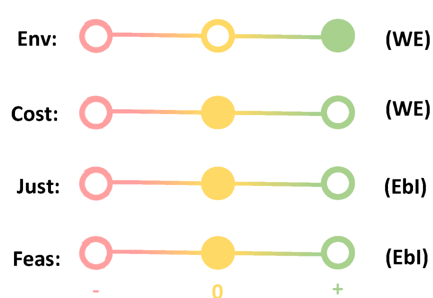
Ceasing fossil fuel activities often brings costs to governments, investors, producers, and consumers. This can be addressed through **Finance Swaps and Compensation**, where international actors compensate citizens, companies, or governments for the opportunity costs of not developing their own resources "based on the sovereign right of individual states to develop their resources, and the opportunity cost associated with renouncing this right" (Le Billon & Kristoffersen, 2019, p. 1079). Financial swaps would evoke "pay-to-preserve policies", in which "a sub-global coalition… purchases profitable fossil-fuel deposits from non-signatories to keep them in the ground" (Eichner & Pethig, 2019, p. 398). An example is the Yasuni-ITT initiative of the Ecuadorian government, where ex-president Rafael Correa proposed banning oil production from the Ishpingo–Tambococha–Tiputini (ITT) block in the Yasuni National Park in exchange for $3.6 billion from the international community—equivalent to half of the reserve's net-present value in 2007 (Kingsbury et al., 2018; Larrea & Warnars, 2009; Vallejo et al., 2015). Suspicions about the legitimacy and intentions of the Correa administration's plan ultimately led to its failure (Kingsbury et al., 2018); this "should strike a note of caution about the difficulty of mobilizing funds for compensation from the international community" (Newell & Simms, 2019, p. 8).

4 | ANALYSIS: EFFECTIVENESS, EQUITABILITY, AND FEASIBILITY

Sections 4.1–4.3 individually assess each LFFU approach using the criteria from Table 1 in Section 2, and Section 4.4 compares the assessments across all approaches, summarized in Figures 1 and 2. Note that the figures in Sections 4.1–4.3 evaluate each approach based on their Environmental and Cost Effectiveness (Env & Cost, respectively), Equitability and Justice (Just), and Feasibility (Feas), and subsequently denote whether each evaluation is Well Established (WE), Established but Incomplete (EbI), Unresolved (Un), or Inconclusive (Inc) using the criteria from Section 2.

4.1 | Economic

4.1.1 | Fossil fuel production/extraction tax



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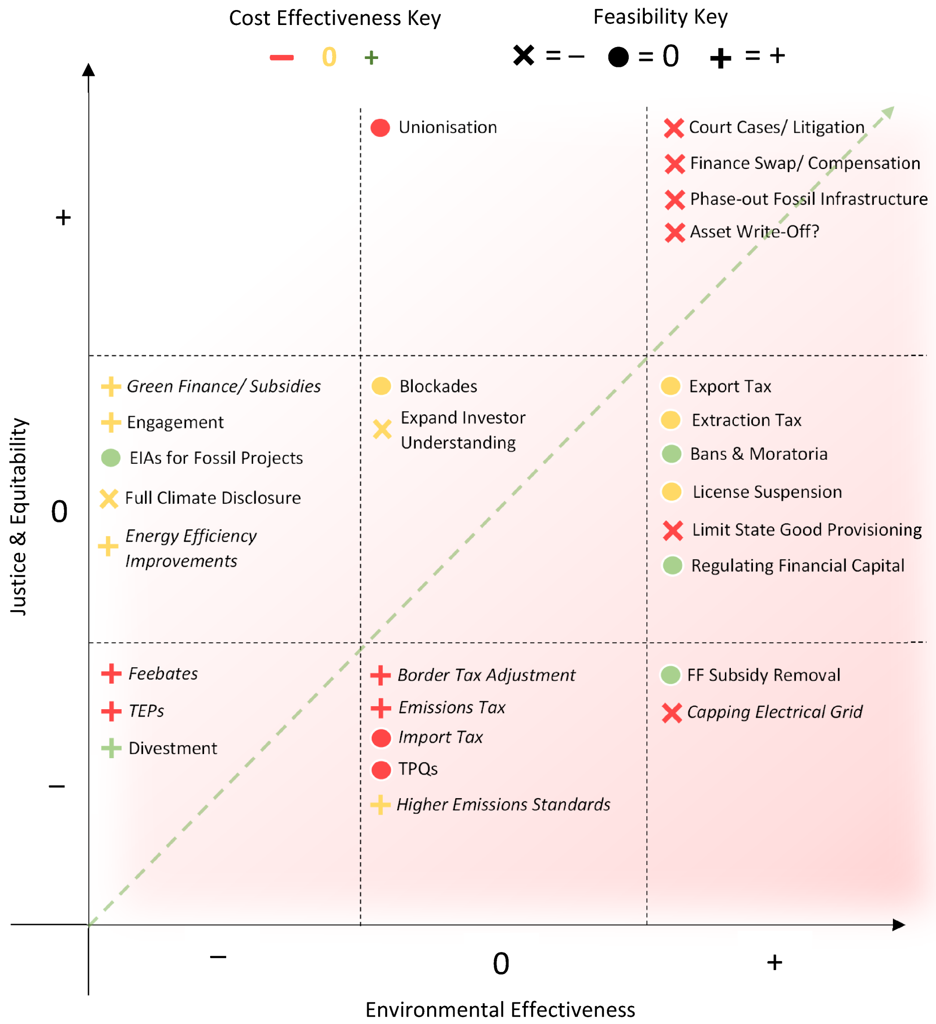

FIGURE 1 Compilation of all LFFU approach scores

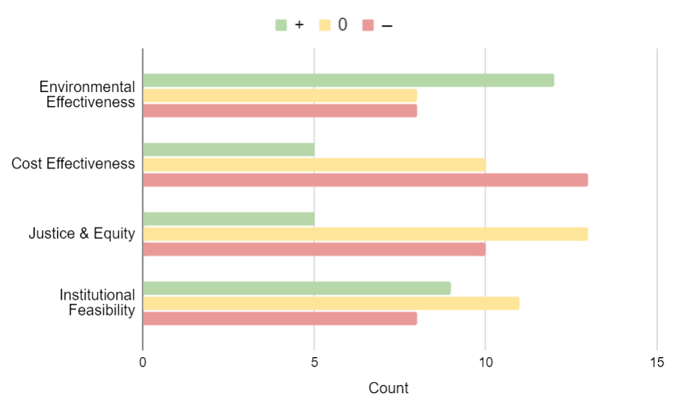

FIGURE 2 Summary of overall scores, by category

Carbon pricing has lower impacts on production than, for example, the market price of fossil fuels (Le Billon & Kristoffersen, 2019), indicating that a production tax can be environmentally effective *only* if it is significant enough to financially disincentivize the fossil fuel producer. Such a competitive tax rate is dependent on nations (Sinn, 2012, p. 219, *emphasis added*).

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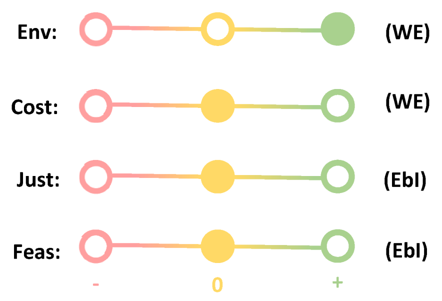
harmoniz[ing] their tax systems in order to avert triggering a competition that would see their tax rates engaging in a race to the bottom… [otherwise] each country would have an incentive to underbid its neighbors to attract more capital at their expense, and in the end, the source taxes would be eroded.

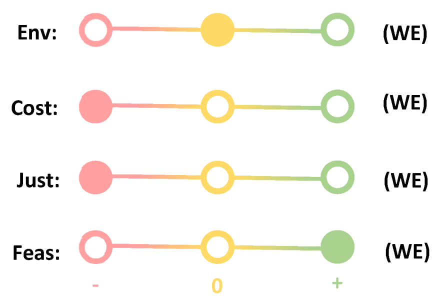
A production/extraction tax has administrative and logistical costs. That said, unifying frameworks like those of the Organization for Economic Co-operation and Development (OECD) may enable synchronizing such taxes (Sinn, 2012). Finally, since such a tax allocates costs directly to fossil fuel producers rather than consumers (Section 4.1.3), but on its own does not address the related stranded resources, infrastructure, and jobs, it is only partially just.

4.1.2 | Fossil fuel export tax



Running in parallel with production/extraction taxes, an export tax may be environmentally effective if levied "by a coalition of major exporters", while a "unilateral export tax has little impact" (Richter et al., 2018, p. 43). Moreover, a "nation that taxes coal exports but not domestic consumption… might reduce coal consumption and emissions globally but, by indirectly encouraging domestic consumption, increase its own" (Lazarus & van Asselt, 2018, p. 5), suggesting that an effective export tax must come in tandem with an effective domestic production/extraction or consumption tax; it is therefore somewhat complex to design and implement effectively. Moreover, an export tax resembles a production/extraction tax as it allocates the implementation costs directly to fossil fuel exporters, which are typically multinational conglomerates or state-owned enterprises, but makes no effort to govern accompanying stranded assets.

4.1.3 | Carbon emissions/consumption tax



The environmental effectiveness of emissions taxes is "modest when their coverage is patchy, and when carbon-intensive industries can, therefore, shift to 'emission havens' elsewhere" (Armstrong, 2019, p. 672). Moreover, Sinn (2012, p. 221) notes that "the externality that has to be fought depends on the stock of carbon in the atmosphere, whereas the tax advocated is on the flow of carbon emitted." That is (ibid),

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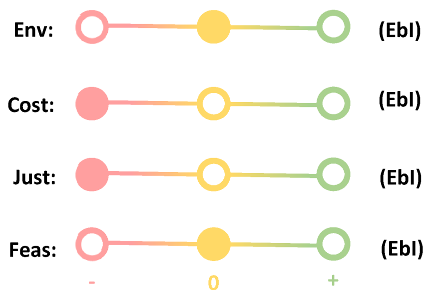
> [a] correctly designed Pigouvian tax would have to track the polluters responsible for the stock of anthropogenic carbon in the air and would have to burden their share in this stock with an annual tax whose rate should, in each year, equal the marginal damage that would be caused by a small increment to this stock… no one has ever proposed or analyzed such a carbon tax—probably because administering it would be far too demanding, since it would be necessary to trace the tax debtors over hundreds if not thousands of years after they emitted the carbon.

Most agree that "conventional carbon taxes might not be able to shape expectations on future climate policy" as they externalize the socio-ecological costs (Kalkhul et al., 2020, p. 15) and are difficult to design. Some nations like Norway have introduced emissions taxes decades ago but have been largely unsuccessful in curbing domestic oil production, and may imply similar outcomes when other producers follow suit, like Canada (Kopytin et al., 2020). Global South countries are also adopting such taxes such as South Africa and Ivory Coast (Mutezo & Mulopo, 2021, p. 6). Moreover, a carbon emissions tax could exacerbate and reproduce inequalities as it would (Kashwan, 2021, p. 8)

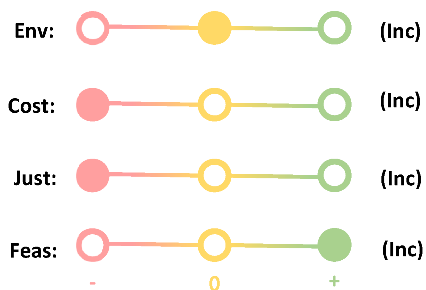
> affect poor and/or racial minority households very differently compared to others. Unless subsistence items, such as food, water, and energy were protected from the inflationary effects of carbon taxes, even a moderate level of the carbon tax could make these items too expensive for the poor in the United States.

4.1.4 | Fossil fuel import tax



The conditions for an effective import tax on fossil fuels would mimic those of a consumption/emissions tax; namely that *a coordinated and temporally-sensitive system* is necessary to tax fossil fuel imports. However, demand-side policies such as this bear major shortcomings, and hence, "[i]ncreasing the price of… importing fossil fuels through a carbon fee and dividend system… may need to be implemented alongside other supply-focused approaches to increase its impact" (York & Bell, 2019, p. 43). Moreover, the same equity considerations apply as in Section 4.1.3, namely that consumers are unjustly allocated the costs of the approach and no stranded asset considerations are made for the exporting nation.

4.1.5 | Border tax adjustments



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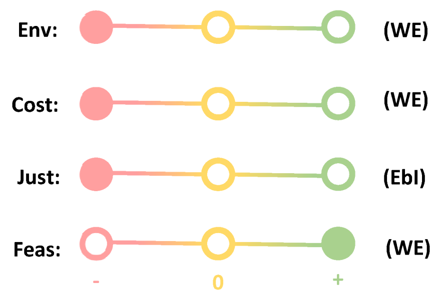
Since BTAs are an expansion of fossil fuel import taxes, our assessment is similar to that in Section 4.1.4. However, BTAs cast a much wider net and therefore tax a more expansive group of imported and carbon-intensive consumer goods, which de facto allocates an even greater burden to consumers than a more simplistic tax on imported fossil fuel. As such, it is comparatively even more unjust and inequitable.

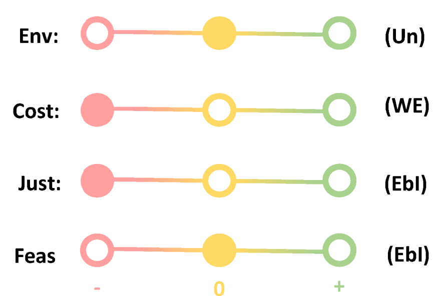
4.1.6 | Tradeable emissions permits



A "cap-and-trade system indeed would be an efficient regulatory system if it were equally applied to all sectors of the economy, because it determines the one uniform price of CO_2 emissions. In fact, however, it is applied only to electric power generation and a few other sectors" (Sinn, 2012, p. 186). TEPs and cap-and-trade schemes will only be environmentally effective if they are adopted on a global level across all economic sectors, otherwise, leakage issues and manipulation will persist (see Section 5).

However, TEPs and cap-and-trade schemes have proven to be nothing more than a novel arena for capital accumulation and gargantuan profitability (Lohman, 2012)—partially or substantially because TEPs are typically handed out gratis, often via grandfathering—and are "used by producers to try to maintain oil production and insulate it from demands about more fundamental policy reform including supply-side restrictions" (Gaulin & Le Billon, 2020, p. 891). In the early phases of the EU Emissions Trading System (ETS),[6] "handouts given to only ten of Europe's intensive industrial users of fossil fuels exceed the total EU budget for environment" (Lohman, 2012, p. 93); moreover, "[m]any European corporations sell or charge their customers for surplus emissions rights that they receive gratis under the EU ETS, *ploughing the proceeds back into fossil-fuelled business as usual*" (Lohman, 2012, p. 92–93, *emphasis added*).

4.1.7 | Tradeable production quotas



TPQs are theoretically more promising than TEPs in their environmental effectiveness since a properly devised TPQ scheme would establish a strict upper limit on fossil fuel production. However, problems include: "agreement on overall production, quasi-universal participation, a fair system of quota trading, a potential queue system for new projects, and revenue allocation consistent with the overall objective of reducing emissions *so that revenues are not reinvested in*

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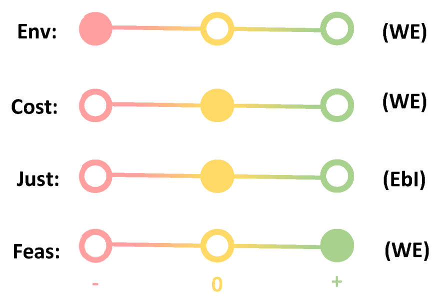
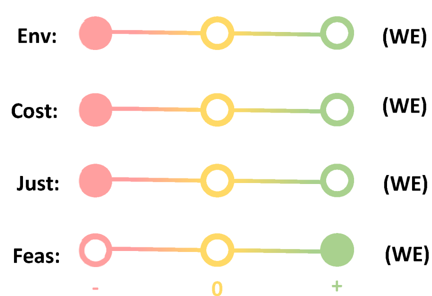
carbon-intensive projects and lifestyles" (Le Billon & Kristoffersen, 2019, p. 1080, *emphasis added*). Altogether these considerations would render TPQs potentially quite costly (monetarily and otherwise) and subject to contestation given their novelty and complexity; moreover, TPQs may be subject to the same manipulation and exploitation as their emissions counterparts (Section 4.1.6) given their design similarities, posing suspicions vis-à-vis the extent to which they will be equitable on any fronts.

4.1.8 | "Green finance" and subsidies for fossil fuel alternatives



Direct (monetary) subsidies for fossil fuel alternatives stood at some $100–120 billion in 2013 (Monasterolo & Raberto, 2019), and institutional investors continue promoting "green bonds" and "green investments", though their legitimacy is often questioned (Rempel & Gupta, 2020). Individually, these mechanisms are "entirely useless, as the overall amount of CO_2 emissions is determined by the cap alone" (Sinn, 2012, p. 186). Moreover, subsidies for "bioelectricity and feed-in tariffs supporting solar power and wind turbines", for instance, have "become expensive flops" because "saving of fossil energy is completely neutralized by the additional use of fossil fuels triggered by this price reduction in other countries" (Sinn, 2012, p. 186). Even Germany, a successful user of renewable energy, has faced questions over the "affordability of the feed-in-tariff[s]" (Chapman et al., 2018, p. 188). York & Bell (2019, p. 41) note that "growth in non-fossil fuel energy only had a very modest effect on curbing fossil fuel use, where it took between four and thirteen units of non-fossil energy to displace one unit of fossil energy". Banking on fossil alternatives alone may spur an "Energy Addition" rather than an "Energy Transition", where renewable sources are added to the existing (dirty) grid while total fossil fuel combustion remains virtually unscathed (York & Bell, 2019).

4.1.9 | "Feebates"



Given its hybrid nature, the effectiveness, equitability, and feasibility of a feebate program depend on those for carbon emissions taxes (see Section 4.1.3) and fossil-alternative subsidies (see Section 4.1.8), which are similar to one

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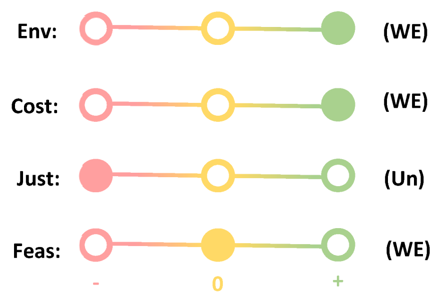
another. Carbon emissions taxes are slightly more environmentally effective than green subsidies, but in this analysis, we err on the side of caution and assign the more pessimistic score to the feebate approach.

4.1.10 | Fossil fuel subsidy reform

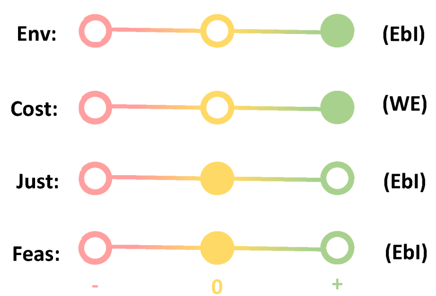


Removing fossil fuel subsidies is mostly effective and feasible with few administrative hurdles (e.g., Lazarus & van Asselt, 2018). Its environmental and cost effectiveness depends on the extent to which indirect (non-monetary) subsidies—like tax credits—are accounted for since indirect subsidies are likely much larger than direct ones (Le Billon & Kristoffersen, 2019). Monetary and direct subsidies for fossil fuel production in 2015 was ±$50–100 billion globally, while those for consumption hit roughly $500 billion; however, "broadly defined… [they] amount[ed] to an estimated *$5.13 trillion* in 2015, of which 81% results from the unaccounted costs of air pollution, climate change impacts and broader vehicle externalities" (Le Billon & Kristoffersen, 2019, p. 1078, *emphasis added*; Coady et al., 2019).

Since subsidies for fossil fuel *consumption* outweigh those for *production* tenfold, removing such subsidies will disproportionately impact consumers rather than producers, following suit with the inequitable narratives pertaining to, for example, emissions and import taxes (Sections 4.1.3 and 4.1.4).

4.2 | Regulatory

4.2.1 | Regulating financial capital



A strict cap must be set on the aggregate amount of capital available for new fossil energy if such a regulation is to be environmentally effective. Best (2017, p. 76) explains that

> [w]hen there is a larger supply of aggregate financial capital available, greater competition between capital providers helps to lower the cost of capital. This lower cost of capital benefits all borrowers in an economy, with the largest benefits accruing to capital-intensive sectors that are more sensitive to cost of capital changes, including energy producers.

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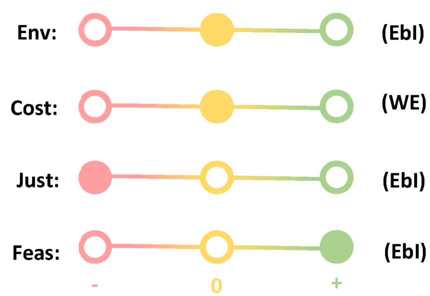
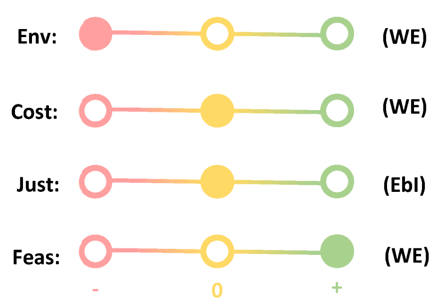
Furthermore, the conditions regulating the allocation of financial capital to fossil fuel projects must: be clear-cut; omit loopholes; and be internationally recognized and adopted. Otherwise, "high-carbon companies could bypass the tightening of prudential policy in one jurisdiction by raising funds on the international financial markets, unless such policies are implemented across all major jurisdictions" (Campigli et al., 2018, p. 6, quoted in Gunningham, 2020, p. 16). Some banks have pledged to remove coal-related financing (e.g., EIB, 2019) though similar measures for oil and gas are less prominent, indicating that this less novel approach may be gaining traction.

4.2.2 | Higher emissions standards



Raising efficiency standards may also be lucrative for regulators: the US federal government may save $1.3 billion annually by tightening such standards by some 30% (Pollin & Callaci, 2018). This demand-side approach may fail if similarly tight emissions standards are not adopted universally; "less productive jurisdictions [choose] inefficiently lax emissions standards" to "manipulate the return on capital" (Eichner & Pethig, 2018, p. 191) and "boost its export revenue" (ibid, p. 192). Assuming this obstacle is overcome, it can be relatively cost-effective. However, given its demand-side nature, raising emissions standards could allocate costs directly to consumers, making it more expensive for households to afford housing or transportation.

4.2.3 | Promoting energy efficiency improvements



This in theory allows for replacing higher-emitting processes (like lignite coal combustion) with lower-emitting fossil processes (like combusting "fracked" gas). Improving energy efficiency at the intra- and international level can only effectively LFFU when "more efficient" fossil fuels cannot be used to replace "less efficient" variants. Moreover, calls to improve energy efficiency with Bioenergy with Carbon Capture and Storage (BECCS) must also be rejected, given the unproven, uneconomical, and socio-ecologically hazardous state of BECCS technology (Hubacek & Baiocchi, 2018; Kefford et al., 2018; Mo et al., 2018; Rodriguez et al., 2017; van der Ploeg &

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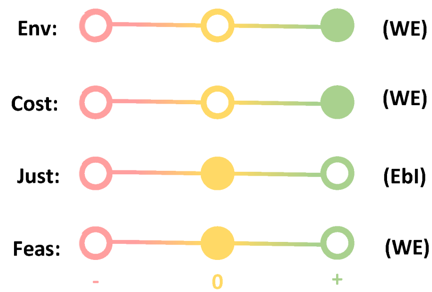
Rezai, 2018). The OECD (2020) Export Credit Arrangement includes efficiency regulations, but does not meet the conditions above as they allow for BECCS integration *and* new fossil projects in exchange for decommissioning older and dirtier ones.

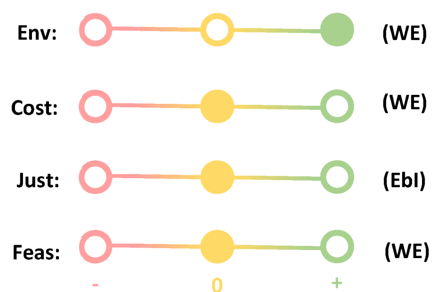
4.2.4 | Bans and moratoria



Bans and moratoria can be environmentally and cost-effective as they target fossil fuel supply at the source; particularly moratoria are "potentially the most effective supply-side initiatives, since they suspend the extractive activities, with or without compensation for affected fossil fuel companies" (Gaulin & Le Billon, 2020, p. 895). Examples of successful bans on fossil fuels include "Costa Rica, Belize, and France, with Ireland possibly joining this group," though [n]one of these countries… are significant producers" (Le Billon & Kristoffersen, 2019, p. 1081).

One obstacle for a ban or moratorium on fossil fuel production is the accompanying opportunity costs; governments and firms could forgo billions—if not trillions—in sales, export, and tax revenues (e.g., Kartha et al., 2018) and related jobs. Moreover, since circa 85% of proven oil and gas reserves are outside Europe and North America (BP, 2020), "Global South" governments may resist bans which deprive them of their "Right to Development" (e.g., Armstrong, 2019; Gupta & Chu, 2018). Hence, one condition for the feasibility of a ban/moratorium is an accompanying allocation of resources to compensate (particularly nonindustrialized countries) for their forgone opportunity to develop national resources (see Section 4.3.8).

4.2.5 | License and permit suspensions



Operating somewhat analogously to bans or moratoria, suspending licenses or permits tied to fossil fuel production may directly and effectively curtail fossil fuel production. However, suspending licenses and permits may violate concessions agreements and/or bilateral/multilateral investment treaties already established that previously granted firms permission to extract and commercialize coal, oil, and gas resources, which could result in

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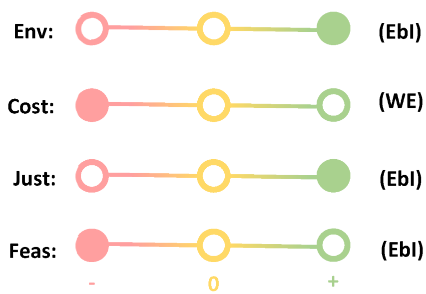
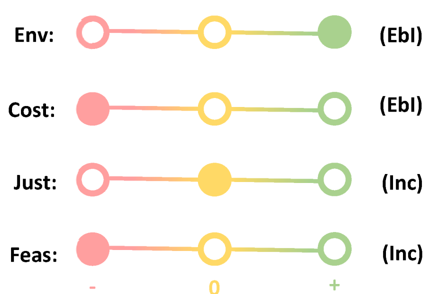
governments facing exorbitant compensation claims for loss of (i.e., stranded) revenue (Le Billon et al., 2021). That said, “this option is administratively feasible” (Erickson, Lazarus, & Piggot, 2018), but compensation claims may put a disproportionate burden on poorer countries. Like bans or moratoria, suspending licenses or permits for fossil production by neglecting the stranded assets may also allocate their burden onto poorer fossil fuel dependents.

4.2.6 | Retire/phase-out fossil fuel infrastructure



“[E]arly retirement well before [an]... investment has been recouped is unlikely to proceed without strong economic incentives, regulatory measures, and/or compensation” (Kefford et al., 2018, p. 295). That is, firms that have invested in fossil projects and infrastructure with life expectancies into the mid- to long-term may demand compensation for prematurely devaluing their assets. In 2021, the German utility provider, RWE, sued the Dutch government in response to its coal phase-out law in 2019 (ICSID, 2021); RWE claims the Dutch government is violating the Energy Charter Treaty and is requesting €2 billion in compensation for damages and lost revenues (Verbeek, 2021). Despite these feasibility and cost constraints, this approach is relatively unique in directly and explicitly governing stranded physical assets.

4.2.7 | Limiting state good provisioning



States grant fossil fuel producers rights to use public land and water through concessions, permits, and contracts to explore and produce fossil fuels. Revoking such rights may breach those contracts and lead to arbitration and disputes at the international level (Bosch, 2021), analogous to the above-mentioned RWE lawsuit (Section 4.2.6). However, unlike early fossil infrastructure retirement, limiting state good provisioning does not explicitly tackle the accompanying stranded assets.

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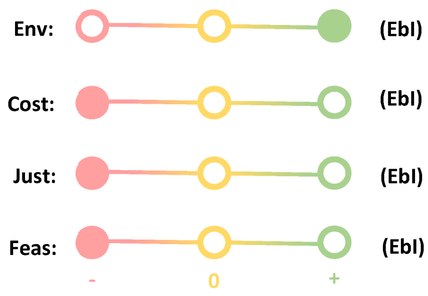
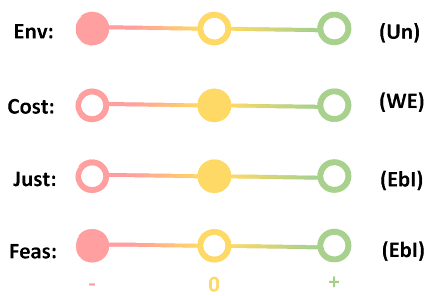
4.2.8 | Capping the electrical grid



In theory capping, the electrical grid could effectively limit fossil fuel demand and therefore the quantity supplied. However, there will be "tremendous resistance" from "embedded technocrats who have built today's grid" (King, 2012, p. 4). Thus, economic, legal, and compensatory considerations must be addressed if states decide to cap a provincial, regional, or national electrical grid. Furthermore, nations with energy poverty/insecurity—like South Africa (Memane et al., 2019)—may oppose such restrictive measures without guarantees that international resources will be mobilized to ensure universal, affordable and sustainable energy access from low-carbon alternatives. Capping the grid would disproportionately allocate costs and stranded assets to under-resourced and underprivileged fossil dependents.

4.2.9 | Full climate-related disclosures



Full international climate accounting and disclosure is necessary but is in itself ineffective because "within current international carbon accounting standards, curtailing supplies does not count as a full contribution to mitigation, since emissions are territorially accounted for at the location of consumption rather than production" (Le Billon & Kristoffersen, 2019, p. 1075—also see Section 2); however, the Paris Agreement itself has "several elements through which the need to limit fossil fuel supply can be addressed" (Piggot et al., 2018, p. 3), such as a "global stocktake… tracking measures targeted at fossil fuel extraction" to help align with Article 2.1a (Piggot et al., 2018, p. 7).

The Task Force on Climate-Related Financial Disclosures, a coalition of 31 asset managers with joint assets under management of ±$140 trillion, have pledged to improve relevant financial disclosures pertaining to climate-related investments, but these declarations have thus far been met with no substantive or meaningful action (Gunningham, 2020, p. 7):

> it is doubtful whether the TCFD recommendations, even if mandated, will prove to be a game changer. On the contrary, it may well be that this framing has lulled policymakers—And [Central Banks and Financial Regulators] in particular—into a mistaken sense that information disclosure and risk management is *all* that is necessary to enable financial actors to play their part in a low carbon transition? Unfortunately, there is evidence that this is not the case.

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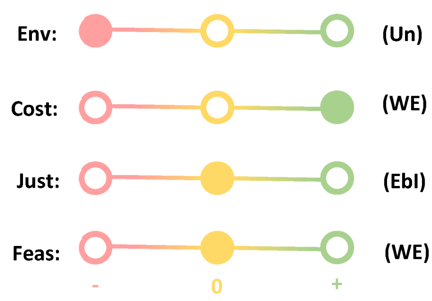
4.2.10 | Environmental impact assessment of forthcoming fossil projects

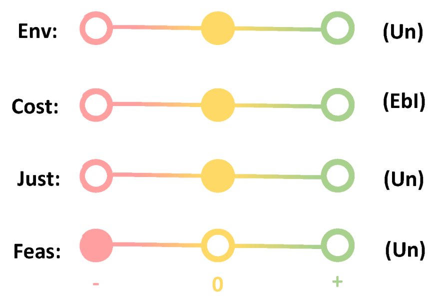


For effective EIAs, financial, economic, and environmental information must be fully and transparently disclosed (Section 4.2.9) else the assessment will be misinformed. Such assessments are rendered moot unless a rigid upper cap is introduced at the (inter)national level for fossil fuel production meeting safe socio-ecological requirements (similar to Sections 4.2.1 and 4.2.9), otherwise, fossil-intensive projects can proceed despite rigorous assessments.

That said, EIAs are "have relatively low administrative and transaction costs" because the "commodities to be accounted for (especially coal and oil)… are typically already measured by firms for existing administrative purposes such as resource tax liability assessment and compliance with local environmental license conditions" (Green & Denniss, 2018, p. 77), suggesting that an economic and legal framework is already in place to enable such comprehensive assessments.

4.3 | "Other"

4.3.1 | Expanding investor understanding to innovatively regulate finance



Whether an innovative approach to regulating financial actors for LFFU will be environmentally effective rests on whether the four aforementioned tropes are understood and challenged (Christophers, 2019; Section 3.3). For instance, modernizing the legal and fiduciary obligations of investors to include accountability and responsibility for fossil-related climate damage experienced by shareholders resulting from investments can revamp the "economism" trope that plagues the existing investor paradigm. Alternatively, financial assets and pay-outs can be "gated" and tied to long-term, climate- and fossil-related milestones, challenging their myopic temporality (Gunningham, 2020). However, this is administratively and logistically challenging, given the conventionality and conformity that investors and financiers have historically and continue to operate with (Christophers, 2019).

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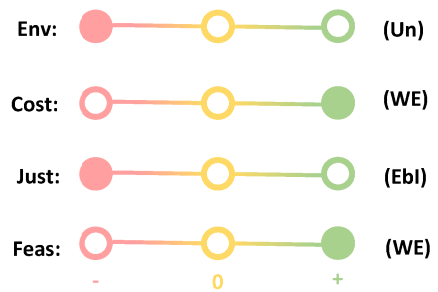
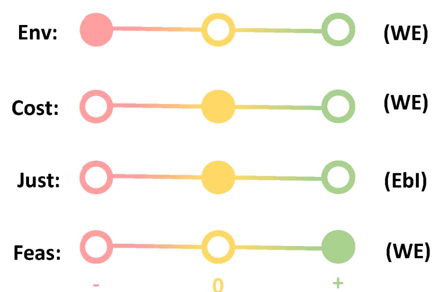
4.3.2 | Divestment



Many have praised the fossil fuel divestment movement (FFDM) for "successfully" accruing tens of trillions of dollars in pledged divestments from fossil firms (e.g., Healy & Barry, 2017; Paterson, 2020). The movement has successfully stigmatized the industry, questioned the legitimacy of fossil fuel investments (Healy & Barry, 2017; Piggot, 2018), and has "contributed" to climate action "through moral activism" (Gaulin & Le Billon, 2020, p. 895).

However, "divestment has had a very limited direct effect on fossil fuel production so far" (Gaulin & Le Billon, 2020, p. 895), because, inter alia: (1) "[m]any fossil fuel producers, especially those organized through large state-owned companies like national oil companies in the Middle East, are relatively insulated from external financial leverage, including from Western investment funds that constitute the vast majority of divesting organizations" (Le Billon & Kristoffersen, 2019, p. 1079); (2) although socio-political pressure may prompt investors to acknowledge the socio-ecological implications of their investment and subsequently divest, investors predominantly account for the financial risks posed by the climate emergency, and would "divest" if it were both the financially sound decision and aligned with their fiduciary duty (Christophers, 2019; Rempel & Gupta, 2020); (3) divestment very marginally (if at all) increases the cost of capital to fossil fuel producers (Gunningham, 2020); and (4) divestment implies sales to new investors, sending-off prospective stranded financial assets (i.e., common shares that may very well devalue as fossil fuels are phased out), it de facto reallocates the burden of governing stranded assets elsewhere, potentially to less capable financial institutions from the Global South (Gupta et al., 2020).

4.3.3 | Engagement



Shareholders have not yet effectively engaged through their shareholder responsibility with the companies in which they holds shares. Engagements with fossil firms have been scarce, and the few reported instances have almost entirely been reactionary in addressing, for example, oil spills rather than proactively pushing for LFFU (Rempel & Gupta, 2020), rendering the approach environmentally ineffective. Moreover, engagement costs the institutional

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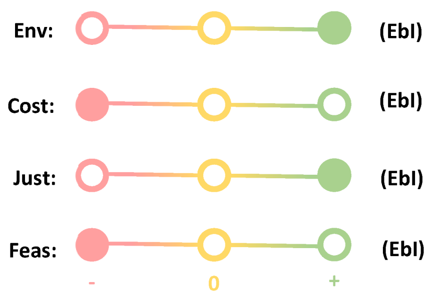
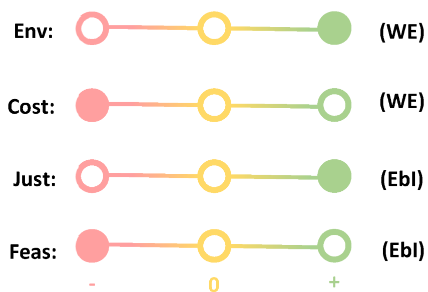
shareholder time and resources in opening a continuous dialogue with the fossil fuel producers, though these costs fall entirely on the shareholders.

4.3.4 | Asset write-off



By writing off their already existing fossil-related equity, institutional and major shareholders could stigmatize and disincentivize further investment in the fossil sector, and by doing so they would directly incur the implementation and stranded asset costs themselves (Gupta et al., 2020; Rempel & Gupta, 2021), rendering the approach relatively equitable. However, this would imply that relevant shareholders absorb hundreds of billions in financial costs by conducting such a write-off, which will be heavily contested under the premise that it may contradict traditional understandings of fiduciary obligations (Rempel & Gupta, 2020). Moreover, this may send share prices skyrocketing and inadvertently benefit fossil fuel producers, raising serious concerns vis-à-vis this approach's equitability—though these intricacies remain unexplored in the existing scholarship and the broader asset write-off mechanism must be unpacked in future research.

4.3.5 | Court cases and litigation



Not only can litigation consume both time and financial resources, but also some judges may claim lack of jurisdiction since the issues raised "should be addressed by the executive and legislative (otherwise known as the "political") branches of government and not the judiciary", as some US judges have recently ruled (Burger & Wentz, 2018, p. 398). Plaintiffs must therefore carefully devise a legal strategy before bringing a fossil producer to court, else the litigation process may stall and actions for LFFU may delay. If successful, however, favorable verdicts can demand that reparations are paid or fossil-intensive infrastructure be adequately decommissioned, in theory allocating the stranded asset burden to firms, governments, and/or financiers and can establish a precedent that can lead to changes in the policy landscape.

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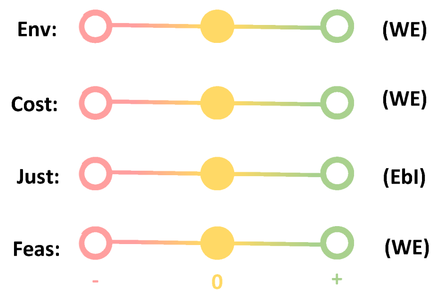
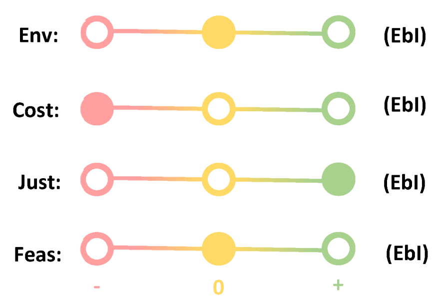
4.3.6 | Blockades



"From a sample of 57 well-documented blockades across the world, 21% led to a cancellation of the targeted project, 25% to a suspension, and 54% did not prevent the continuation of the project" (Gaulin & Le Billon, 2020, p. 895). Those that were successful typically targeted projects at their early stage of development "rather than… fossil fuel production already in place" (Gaulin & Le Billon, 2020, p. 896), suggesting that blockades may successfully prevent a fossil project from unfolding if CSOs or NGOs are able to mobilize both physical and digital movements swiftly and with urgency from the time that plans for a forthcoming project have been revealed or have leaked until the proposed projects begin materializing. Conditions for effective blockades include: available human resources for both organizing and participating; timely access to complete and transparent fossil fuel project-related information; and a society with civic space to protect activists against powerful incumbents.

Anti-fossil fuel blockades have been dispersed globally, with 5–10 reported instances in each continent since 2000—though mostly concentrated in Latin America, North America, and India (Gaulin & Le Billon, 2020), suggesting that there is no particular dearth in human resources or CSOs in any one location. However, nondisclosure and secrecy mechanisms that are built to protect financiers and investors (Gunningham, 2020) result in both lacking and lagged information that hampers the speed with which CSOs can mobilize.

4.3.7 | Unionization



Unions are not environmental groups, and their predominant concern—particularly for labor unions—is that an energy transition should not jeopardize the jobs of existing direct and indirect employees of the fossil fuel industry (Evans & Phelan, 2016), echoing original calls for a "Just Transition" since the 1990s (Kartha et al., 2018; Pollin & Callaci, 2018; Teske, 2019a, 2019b). Therefore, the most critical condition dictating a union's success in LFFU is *ensuring that more than ample resources are allocated to both generate new, low-carbon employment opportunities and retrain existing workforces to thrive in these new roles*.

Some research indicates that "spending $1 million on clean energy investments generates about seventeen jobs across all sectors of the U.S. economy, while spending the same $1 million on maintaining the existing fossil fuel infrastructure produces only about five jobs" (Pollin & Callaci, 2018, p. 2). Moreover, the renewable energy sector typically

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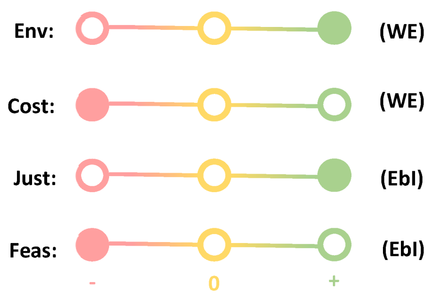
requires more specialized skills than a low-skilled coal miner, which will require mobilizing mammoth funds for retraining programs to sway labor unions to LFFU.

4.3.8 | Financial swaps



Trust in and transparency from the host government is imperative for an effective financial swap to LFFU. The predominant factor that led to the Yasuni-ITT initiative's demise was the "lack of guarantees from the Ecuadorian government that the oil would, in fact, stay underground" (Martin & Scholz, 2014: para 5; quoted in Kingsbury et al., 2018, p. 9–10). But, a larger problem is that it may be financially impossible to compensate the world for leaving such a huge amount of fossil fuels underground, and the success of Yasuni would have opened the floodgates for such compensation claims. The question is—who is to pay for these claims—a handful of richer countries, philanthropists, or the fossil fuel conglomerates?

4.4 | LFFU approach comparison

Figure 1 compares different scores across all 28 approaches and Figure 2 summarizes the overall scores. Figure 1 is constructed so that an approach that meets all criteria (i.e., earning a "+" for all four dimensions) would be displayed in the top-right cell with a green "+" marker, though no approach earned such a score. Moreover, the gradient shading in Figure 1 highlights the uneven distribution across different scores, with fewer just and equitable approaches compared to environmentally effective approaches, and only four approaches classified as cost-effective (green colored).

Twelve of the 28 approaches are deemed environmentally effective as they likely will LFFU (rightmost column of Figure 1); these are predominantly (7/12) regulatory approaches, though some (4/12) are more economic in nature, like fossil fuel production/extraction and export taxes. Of these 12, only one (capping the electrical grid) is demand-side, and as such, we posit that supply-side approaches tend to more effectively LFFU. Conversely, eight approaches are deemed environmentally ineffective (leftmost column of Figure 1); these are typically demand-driven approaches subject to exploitation, like TEPs, and target promoting fossil-fuel alternatives rather than curtailing fossil fuel production at the source.

Most (9/12) environmentally effective approaches bear moderate-to-high (non-)monetary costs (yellow and red markers in Figure 1). For instance, asset write-offs may cost shareholders tens of billions in stranded financial assets; pursuing litigation measures will cost ample human resources and time; and suspending licenses/permits may spark lawsuits between fossil-producing firms and states in the event that concessions are breached. Only five are low-cost approaches vis-à-vis their implementation[7]; a ban or moratoria is relatively inexpensive for a state to implement, for instance; similarly, a shareholder is able to somewhat effortlessly divest their equity, though of course, this comes at an environmental cost seeing as divestment is unlikely to LFFU and is therefore environmentally ineffective.

Only five approaches meet our criteria for justice and equitability, of which four are simultaneously environmentally effective (top-right cell in Figure 1). This is because only these five approaches acknowledge the stranded assets that inevitably accompany LFFU, even though many approaches do in fact allocate the cost of implementing a particular approach to richer and more capable actors; for instance, a tax on fossil fuel *extraction* places the burden on fossil producers (meeting one criterion), but neglects the stranded asset dimension. Conversely, retiring and/or

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decommissioning existing fossil-intensive infrastructure addresses the stranded physical assets associated with LFFU. Overall, however, it seems that justice considerations are generally side-lined in favor of the pursuit for effectiveness.

Finally, eight approaches yielded low institutional feasibility scores given that they would likely be met with significant resistance due to their novelty or complexity, or due to the vested interests of affected actor groups; of these eight, six pertained to approaches that were simultaneously environmentally effective. For instance, financial swaps will likely be contested by the international community due to the precedent it sets, the lack of clarity of what the "international community" means, and the corrupt nature under which the Yasuni-ITT initiative was underpinned (Section 3.3). Of the remaining 20 approaches, 11 are partially institutionally feasible and 9 are deemed institutionally feasible, as they are more conventional and readily discussed (particularly the latter), like carbon emissions taxes or divestment, which have been on the climate agenda now for decades (both of which are environmentally ineffective).

5 | DISCUSSION

Each of the identified approaches is subject to complications vis-à-vis "carbon leakages" and "green paradoxes" (for more see Baldwin et al., 2020; Edenhofer et al., 2020; Foster et al., 2017; Le Billon & Kristoffersen, 2019; Sinn, 2008, 2012; van der Ploeg & Rezai, 2018). One proposed way to mitigate against leakages and green paradoxes is through "globally coordinate[d] climate change policy" (Foster et al., 2017, p. 259), since climate change "cannot be successfully resolved in the absence of effective global governance" (Cole, 2011, p. 1). A supply-side treaty is needed, which could involve forming a "coalition of the willing" (Cole, 2011; Piggot et al., 2018) to effectively restrict global fossil fuel supply; the Fossil Fuel Non-Proliferation Treaty (FF-NPT) has been proposed to play this role (Newell & Simms, 2019, p. 4–5). Altogether, a "supply-side climate treaty could notably help tackle the problem of free riders and insure against a failure of the Paris Agreement" (Gaulin & Le Billon, 2020, p. 889), though such a treaty could lead to the collapse of financial markets given the sums invested in fossil fuel. International cooperation arises neither spontaneously nor instantaneously, though; it will be imperative that first movers lead the charge by adopting effective and equitable LFFU approaches, after which said approaches can be evaluated and subsequently diffused at the global level.

Moreover, individually, any approach for LFFU will be ineffective and inequitable; considering *policy mixes* across different dimensions and levels of governance is critical. Supportive and restrictive policy mixes across various energy types can create a "policy apparatus for incumbency", which can "by counterpoint with Schumpeter's (1942) highlighted process of 'creative destruction'—be considered '*destructive re-creation*'" (Johnstone et al., 2017, p. 148, *emphasis added*). "Rather than the incumbent configuration being subject to destruction, it is instead re-created by destructive pressures that instead bear on emerging niche innovations (like renewable technologies and energy efficiency improvements)", which the authors show has hoisted the UK's incumbent nuclear energy and natural gas sectors while boxing out niche renewable challengers (ibid, p. 148).

Considering mixes of approaches to LFFU is therefore imperative to sculpt an effective and equitable fossil fuel phase-out, and moreover, as the above-mentioned (Johnstone et al., 2017) paper exemplifies, trade-offs between the effectiveness (and equitability, feasibility) of various LFFU approaches within a selected mix must be taken into account. Recall that our analysis aimed to shed light on the multidimensional implications that accompany any LFFU approach, so that key actors (policymakers, investors, and civil society) can sculpt mixes that mitigate against shortcomings (Section 2). For instance, divestment has limitations vis-à-vis equitability, but as noted, it has certainly been successful in stigmatizing the fossil industry (Section 4.3.2); perhaps divestment strategies could be adapted and coordinated, so that designated "buyers" immediately *write-off* the acquired assets, while designated "sellers" use the freed capital to *finance fossil alternatives*, *phase-out existing infrastructure*, and *for finance swaps*. Forthcoming research should consider drawing on Johnstone et al. (2017) and exploring how the broader range of LFFU approaches that we have identified have unraveled in different contexts and which trade-offs these mixes have yielded.

6 | CONCLUSION

Our scoping review of 115 recent papers aimed to identify lessons on approaches to leaving fossil fuels underground (LFFU). We compiled a menu-list of 28 approaches for LFFU and assessed them using the adapted IPCC (2007) framework for environmental effectiveness (*how likely will it LFFU?*), cost effectiveness (*how high will the (non-)monetary implementation costs be?*), justice and equitability (*who will incur the implementation costs and accompanying stranded*

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fossil fuel assets?), and institutional feasibility (*how novel and complex is the approach*, *and to what extent will it be contested?*).

We found that only 12/28 approaches were likely environmentally effective while seven approaches were unlikely to LFFU. The remaining eight approaches were considered potentially effective for LFFU, which included carbon emissions taxes, border tax adjustments, and higher emissions standards—see Section 4.4. Of the 12 environmentally effective approaches, only three were deemed cost-effective (regulating financial capital for fossil fuel projects, removing existing fossil fuel subsidies, and bans & moratoria), and merely four were deemed equitable (asset write-offs, retiring existing fossil infrastructure, pursuing court cases/litigation, and financial swaps). This paucity in equitable approaches arose because very seldom do the proposed LFFU approaches even acknowledge the accompanying stranded fossil fuel assets, let alone explicitly aspire to allocate them to rich and capable actors. None of the environmentally effective approaches were entirely institutionally feasible, though this should not deter or dismiss any given approach, but should act as a fair warning of prospective the challenges and friction that may arise in implementing it.

Interestingly, we noticed few papers on *suasive* approaches (e.g., raising public awareness of government subsidies) and broader legal issues, like bilateral investment treaties and policy freezes. The former is likely as scholars have recently tended to focus on supply-side policies for LFFU (Section 2); the latter is arguably the case because the publications included in this review (bar one—Burger & Wentz, 2018) did not predominantly originate from legal journals, suggesting that the regulatory and economic approaches to LFFU merit a more strenuous analysis from a legal perspective.

Many of the particularly mainstream LFFU approaches (e.g., carbon taxes) were discussed predominantly (though not entirely) in the context of the Global North, for example (inter alia), **in the UK** (e.g., Bebbington et al., 2020; Caldecott & Dericks, 2018; Johnstone et al., 2017), **Norway** (Bang & Lahn, 2019; Kopytin et al., 2020; Marsden et al., 2019), **and the US** (e.g., Hubacek & Baiocchi, 2018; Kefford et al., 2018; van de Graaf, 2018; van der Ploeg & Rezai, 2018), among others. Empirical research covering the Global South is steadily growing, with Muldoon-Smith and Greenhalgh (2019, p. 60) calling for a move "beyond the mostly Western European and North American perspectives" and others corroborating (Ansari & Holz, 2020; Bos & Gupta, 2018). Recent studies have adopted explicit and contextualized focuses on Africa's fossil fuel political economy (e.g., Mutezo & Mulopo, 2021; Nalule, 2020), and certain approaches have been extensively studied in a Southern context—like blockades (see, e.g., Bond, 2018; Temper et al., 2018), finance regulation (e.g., Baker, 2015b) and fossil-alternatives (e.g., Baker, 2015a)—though "developing" countries are often encouraged to forgo the temptation of commercializing their fossil fuel reserves and "leapfrog" into a low-carbon future (e.g., da Silva & Delgado, 2018; Gupta & Chu, 2018; La Rovere, 2020).

Gaulin and Le Billon's (2020) Fossil Fuel Cuts database encompasses fossil fuel supply-side measures undertaken across 107 nations, though it admittedly spans only a subset of the LFFU approaches that we identify (Table 2); forthcoming research may consider building on this momentum to gradually expand the focus of the state-of-the-art using a broader spectrum of LFFU approaches and with a greater focus on the "Global South" (and particularly in a North–South context), perhaps through case studies that unpack which approaches are implemented in which contexts, and test for determinants of adoption in each case.

Two additional knowledge gaps have surfaced. First, there is an overwhelming lacuna in the role that regulating and innovating finance plays in LFFU, as Christophers (2019, p. 759) corroborates:

> Indeed, there is a dearth of knowledge about how the finance sector at large approaches climate change issues more generally, in significant part because those academics with the best access to finance professionals—scholars of finance—have shown extraordinarily little interest in the topic…of more than 20,000 articles published in the leading twenty-one finance journals between 1998 and June 2015, only twelve (0.06 percent) were related substantively to climate change.

Second, and building on the first, seldom are financially oriented LFFU approaches discussed in an *international*, *North–South context* or in relation to a global responsibility and accountability for *past* fossil fuel-related finance flows (the latter alluding to the stranded financial asset narrative, see Section 1). That is, fewer studies acknowledge or unpack the "North–South" geopolitics and financial flows that hoist the hegemonic fossil fuel empire; Nalule (2020, p. 262) acknowledges this in noting that "European countries do not always act so 'green' in Africa and abroad" in spite of "green" domestic policies. This is peculiar given that Article 2.1c of the Paris Agreement (UNFCCC, 2015) explicitly calls on nations to "[make] finance flows consistent with a pathway towards low greenhouse gas emissions". The bulk of the identified approaches are somewhat domestically bound, and as a result, it is difficult to ascertain the degree to

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which the identified LFFU approaches will be effective, equitable or feasible beyond rich countries in the Global North. Future research could explore how these 28 identified LFFU approaches interact with and acknowledge international fossil fuel financial flows, particularly in a North–South context, and perhaps consider developing innovative approaches that more explicitly do so. Finally, identifying appropriate policy mixes is critical to developing effective, legitimate, equitable, and cost-effective plans to LFFU and combat the climate emergency.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTIONS

Arthur Rempel: Conceptualization (equal); data curation (lead); formal analysis (lead); investigation (lead); methodology (equal). **Joyeeta Gupta:** Conceptualization (equal); data curation (supporting); formal analysis (supporting); funding acquisition (lead); investigation (equal); methodology (equal); project administration (lead).

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ENDNOTES

[1] We selected publications from 2015 onward to align with the adoption of the Paris Agreement and since previous IPCC reports have assessed the literature prior to their publication.

[2] For example, some papers conducted case studies on hydropower or smart-grid prospects in, for example, India, which only use fossil fuels as a point of departure but do not engage with the fossil fuel political economy.

[3] These papers were cited in other analyzed papers but were exclude for being before 2015—our cut-off date.

[4] In the past, these did not mandate reporting on GHGs as these were not considered pollutants.

[5] And Spain as of very recently (Ioualalen, 2021)

[6] The EU ETS is the only globally functioning trading scheme to date.

[7] This is not surprising given that the fossil fuel phase-out may cost as much as $200 trillion (Linquiti & Cogswell, 2016).

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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