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Barriers to powering past coal: Implications for a just energy transition in South Africa

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ABSTRACT

The feasibility of South Africa's just energy transition, as dictated by the speed of phasing out coal and scaling up renewables, will rest on a range of techno-economic, socio-political, and socio-technical factors. Interactions between these dimensions of the transition carry significant implications for energy justice. In response, this paper proposes the Just Transition Feasibility Framework (JTFF) to better evaluate how feasibility constraints may impact South Africa's energy transition ambitions, and its more recent commitments to energy justice. Drawing on qualitative findings from interviews with South African energy experts, the study provides critical insights on the national- and community-scale implications of current energy policies. The analysis highlights socio-political constraints related to the Renewable Independent Power Producer Programme (REI4P) which aggravate energy vulnerabilities and misrecognition of places. In addition to strategically tackling a range of techno-economic and socio-technical constraints which are seen to exacerbate distributive injustice, the South African government should extend the 50 km radius scheme of the REI4P to a wider and more inclusive regional basis. Foremost, policy interventions must seek to realign South Africa's Minerals Energy Complex towards a just transition pathway committed to renewable electrification, community empowerment, and sustainable socio-economic structures.

Abbreviations: ANC, African National Congress; CCS, Carbon Capture and Storage; CET, Coal Elimination Treaty; CEPs, Community energy professionals; CO_2, Carbon dioxide; COP, Conference of the Parties; COSATU, Congress of South African Trades Unions; EJM, Energy Justice Metric; ED, Enterprise Development; FDI, Foreign direct investment; FIPs, Feed-in premiums; FIT, Feed-in tariff; GDP, Gross Domestic Product; GHG, Greenhouse gas; IAMs, Integrated assessment models; IEA, International Energy Agency; IPPs, Independent Power Producers; JET, Just Energy Transition; JETP, Just Energy Transition Partnership; JTF, Just Transition Fund; JTFF, Just Transition Feasibility Framework; JTM, Just Transition Mechanism; JTP, Just Transition Platform; KZN, KwaZulu-Natal; LFFU, Leave Fossil Fuels Underground; MACs, Mining affected communities; NUM, National Union of Mineworks; NUMSA, National Union of Metalworkers; OECD, Organization for Economic Cooperation and Development; PAS, Political Action System; PPCA, Powering Past Coal Alliance; REI4P, Renewable Independent Power Producer Programme; SED, Socio-economic development; SDGs, Sustainable Development Goals; SIPs, Sensitive intervention points; UNFCCC, United Nations Framework Convention on Climate Change.

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1. Introduction

Despite international efforts dedicated to phasing out fossil fuels [1,2],[4] coal accounted for over one-third of global electricity generation in 2021, raising associated carbon dioxide (CO_2) emissions to record levels [3].[5] Moreover, and further counteracting climate change mitigation scenarios [4–6], 40 % of the growth in global CO_2 emissions in 2021 was attributed to the resurgence of coal [7]; wherein developing nations accounted for over 60 % of greenhouse gas (GHG) emissions, with a rising trend [3]. Given current market trends which entail declining demand in mature markets balanced by strong growth in emerging Asian economies [8], the International Energy Agency (IEA) predicts that coal consumption will remain unchanged through to 2025 [3,9]. Thus, the sense of urgency associated with rapidly reducing global coal production cannot be overstated, leading to recent calls from Australian scholars for a Coal Elimination Treaty (CET) to accelerate the coal phase-out [10].

While global alliances [2] and treaties [11] remain critical for accelerating strong divestment in fossil fuels [12], translating pledges to reduce coal into meaningfully national action faces several barriers, which extend beyond political obstacles [13–15]. These barriers can be analysed through the lens of 'feasibility constraints', which "functions as a boundary concept through which different dimensions of energy policies can be discussed across disciplines and between different stakeholders" [16]. To the above point, two recent studies [17,18] in *Nature Climate Change* concluded that current 1.5 °C-compatible low-carbon pathways for coal phase-out exceed "even the most optimistic interpretations of real-world ambitions" [19]. Furthermore, Muttit et al. [18] report that to meet the IPPC 1.5 °C limit, China, India, and South Africa[6] would need to phase-out coal twice as fast as historically observed "for any power technology in any country, relative to system." Furthermore, South Africa would need to reduce its share of coal generation at a rate of approximately 30 % each decade to meet the IPPC 1.5 °C limit [18].[7]

Compounding the feasibility of achieving deep decarbonisation in coal-dependent nations such as South Africa [20] is the growing challenge of aligning the processes and outcomes of the clean energy transition to notions of fairness and equity [21–25], or in other words "implementing energy justice" [[26]:2]. Relatedly, the notion of a 'just transition'[8] has been discussed since the 1970s; coinciding with a period when labour unions in the United States sought support for workers in heavy industries whose jobs were endangered by environmental regulations [27–29]. In more recent times, discussions around energy justice and just transition have become increasingly politicised [8,30–32]. Scholarly contributions increasingly acknowledge how formerly colonised states of the Global South forego policy autonomy due to global climate change pressures [33], with recent datasets quantifying the extent to which the burden of long-term coal-phase out responsibilities will fall unequally on non-OECD countries, foremost China and India [34].

Ahead of COP22[9] in Marrakech, the United Nations Framework Convention on Climate Change (UNFCCC) published its technical paper, *Just transition of the workforce, and the creation of decent work and quality jobs* [35] – words written into the preamble of the Paris Agreement and ratified in 2016 [11]. In the intervening years between COP21 in Paris and its most recent iteration, COP27 in Sharm el-Sheikh [36], the notion of a 'just transition' has remained on the international climate policy radar [31,37]. In a message delivered to the Powering Past Coal Alliance (PPCA)[10] on March 2nd, 2021, UN Secretary-General Guterres advocated foremost for the phasing out of coal power to meet climate ambitions, but also stressed the importance of implementing a just transition [38]:

> We have a collective and urgent responsibility to address the serious challenges that come with the speed and scale of the transition. The needs of coal communities must be recognised, and concrete solutions must be provided at a very local level.
>
> [39]

However, following opposition from India,[11] China, and the United States [36,40], COP26 in Glasgow saw the notion of a coal 'phase-out' softened to a coal 'phase down' [41]. This remains the status quo in the lead up to COP28 in Dubai.

Several countries, predominantly in the Global North, have appointed the equivalent of a *Just Transition Commission* (JTC) as part of their energy transition policy [31,42].[12] Beyond the Global North, South Africa has emerged as a first mover, following the announcement of its Just Energy Transition Partnership (JETP) at COP26, which is supported by a consortium of donor countries [43]. More recently, South Africa published its Just Transition Framework in June 2022, ahead of launching its Just Energy Transition (JET) Investment Plan in November 2022. While the policy trajectory and its rich nomenclature appear to coalesce, Heffron and McCauley [31] report deficiencies in just transition policy measures which risk locking in fossil fuel dependency in the European Union (EU). In parallel, scholars have documented the dangers associated with current just transition pathways perpetuating economic risks and energy injustices in major coal producing countries, such as South Africa [44] and jurisdictions within Germany, Canada, and Australia [45].

Bridging the gap between dynamic 'feasibility spaces' [14] and 'justice in energy transitions' [46], this study draws on these respective literatures to examine prospects for *powering past coal* [1] in South Africa, which holds a unique position among nations in the race against climate change (see Section 2). Following recent examples in the literature [13,17,47], this paper adopts the language of feasibility constraints [14,16,48] to assess techno-economic, socio-political, and socio-technical barriers to phasing out coal and scaling up renewables in South Africa. Applying an energy justice approach [25,49], the main objective of the paper is to better understand how feasibility constraints may influence prospects for a just energy transition in South Africa.

Specifically, we identify sensitive intervention points (SIPs) [50], where policy measures can be enacted to support post-carbon transitions [50] and climate change targets [51], in alignment to distributive, procedural, and recognition justice [25]. According to Farmer et al.

[4] Notably, the Powering Past Coal Alliance (PPCA) was launched in 2017 at the UNFCCC Conference of the Parties, with government and business members committing to "phasing out existing unabated coal power generation and a moratorium on new coal power generation without operational carbon capture and storage" [2,241].

[5] In 2021, global energy related greenhouse gas (GHG) emissions from coal stood at around 37.4 % of total GHG emissions (~15.3 gigatonnes of CO_2 equivalent), nearly matching the combined emissions from oil (~26.2 %) and natural gas (~18.3 %) [7].

[6] Alongside Indonesia [81], these countries stand apart as coal dependent G2 Member States, states [242], with each country sourcing at least 60 % of its electricity generation from coal [82].

[7] Compared to ~20 % for China and ~25 % for India.

[8] For example, McCauley and Heffron [21] characterise the just transition in terms of "a fair and equitable process of moving towards a post-carbon society."

[9] Conference of the Parties.

[10] A coalition of national and subnational governments, businesses and organisations working to advance the transition from unabated coal power generation clean energy.

[11] At COP27, India called for a phase down of fossil fuels, as opposed to coal specifically, which failed to make the final COP27 text. Only the European Union and the United Kingdom supported the proposal [40].

[12] Notably, European Union Member States are currently navigating aspects of the Just Transition Mechanism (JTM), such as the Just Transition Fund (JTF) and the Just Transition Platform (JTP) [224], which can be regarded as examples of best policy practices to date [31].

[[50]:132], SIPs may enable a "kick to the current state of the system" or "a shift in the underlying system dynamics." In this paper, we follow the example applied by van Voss and Rafaty [[6]:2] to China's coal phase-out, where SIPs are described as "relatively minor but well-targeted interventions [which] can generate major behavioural changes and nonlinear shifts towards achieving climate mitigation goals."

In response, this paper proposes the Just Transition Feasibility Framework (JTFF) to assess interactions between feasibility constraints and energy justice. The framework is operationalised to the South African context through an exploratory, qualitative approach which synthesises findings from primary and secondary data. Primary data results are derived from a series of expert interviews ($N = 13$), while secondary data results are sourced from a narrative literature review on energy justice in South Africa. We triangulate these results through qualitative and quantitative analysis. Our study adds to a small but growing qualitative evidence base on just transition in South Africa. Critically, the proposed framework can be replicated to examine the feasibility of implementing a just transition in other countries, particularly fossil fuel dependent nations in the Global South [52–54] where coal regimes are yet to be destabilised [55].

The paper is structured as follows to fulfil its aims and objective. In the next section, we provide a background to the South African energy system and outline issues which may derail conditions for a socially fair, decarbonisation pathway. Next, Section 3 reviews the energy justice literature on South Africa and related materials. Section 4 presents the methodology, while Section 5 introduces our analytical framework. The sixth and seventh sections report and discuss the results. We conclude by summarising key findings and highlighting recommendations for policies and future research.

2. Background

South Africa shares a turbulent history of social and environmental injustices [56]. Following the end of apartheid in 1994, the country's fossil-based energy system and lack of environmental governance have prolonged issues of poverty, inequality, and pollution [57–59]. Scholars such as Baker et al. [20] and Barnes [60] describe how South Africa's just transition is complicated by its unique legacies of apartheid, social unrest, poverty, unemployment, and structural crisis in the energy sector, which dictate much of its political landscape. Foremost, through these trials and tribulations [61,62], the coal sector has become increasingly unviable, not just on environmental grounds, but also economically and socially [63,64].

South Africa's regional economy has already suffered from mine downscaling in the past [65,66]. Specifically, the Matjhabeng region – located approximately 550 km southwest of Mpumalanga, South Africa's mining capital – suffered extreme job losses when mines started to be closed following the end of the global gold boom in 1989, from which it is yet to recover [65,66]. Nel et al. [67] document how nearly 100,000 jobs were lost during the 1990s in the Free State Goldfields in Mathjabeng. Similarly, areas in the northern KwaZulu-Natal (KZN) region – once one of the country's primary coal belts – effectively collapsed during the 1990s [67]. In such regions, constraints on investment and development, the migration of skilled workers, and ostracisation by the business community have seen towns in the coal-rim cluster such as Dundee approaching socio-economic extinction [67]. Critically, South Africa has a high unemployment above 40 % and a Gini-Coefficient of 0.63, with the Covid-19 pandemic worsening its recent socio-economic performance [63].

Amid these pressures, South Africa is among the most coal dependent economies in the world [47,68], relying on coal as a key source of foreign currency reserves [63,69]. Notably, South Africa is the largest producer of coal in Africa [70], exports around 30 % of its domestic coal production by volume [63], and holds the fifth largest recoverable coal reserves in the world [71]. Consequently, it is the largest emitter of CO_2 on the African continent [72] and the second most carbon-intensive economy in the world. Conversely, it boasts the largest solar capacity in Africa [73] and the highest national electrification rate in Sub-Saharan Africa (~86 %) [74,75].[13]

Currently, South Africa's total energy supply (TES) remains dominated by coal (~72.9 % in 2020) while renewables account for around 1.1 %. By comparison, coal now constitutes just a small fraction of TES in a country such as the United Kingdom (~3.5 %) [76], which has phased out most of its coal-fired power stations [77], while the Netherlands presents an illustrative case of coal phase-out through mechanisms of "industrial upgrade and regional renewal" [55]. At present, coal accounts for around 90 % of electricity generation in South Africa while renewables account for a small fraction (~6.6 %).[14] Notwithstanding, the government aims to decommission 34 GW of coal-fired capacity [78] and install 18.2 GW of renewable energy capacity by 2030 [79,80].

In sum, the South African power sector is characterised by extreme coal dependency (see Figs. A1 and A2) – rivalling other coal giants such as China, India, and Indonesia [81] among countries in the G20 [82], while lagging far behind leading countries in the PPCA [2,34]. Supporting this synopsis, Lamb and Minx [47] categorise South Africa as a 'coal-dependent development' country,[15] facing a range of feasibility constraints: high coal share, high CO_2 emissions, oil and gas rents, inadequate climate legislation, fossil fuel subsidies, corruption, insufficient democratisation, and lack of climate awareness. Other authors [63,83] have highlighted similar factors in selecting South Africa as a key case study for just transition scholarship, while the country's underlying energy challenges are well documented in the literature [84,85].

3. Literature review

3.1. Trends in just transition scholarship in South Africa

Research focusing on South Africa's just transition has increased since the turn of the decade [60,63,70,83], supplementing a rich literature established throughout the 2010s [20,58,86–88]. We trace the earliest seminal contribution to Winkler and Marquand's 2009 study on actions for supporting a just transition pathway at near-, medium- and long-term timescales [[89]:48], which called for "a paradigm shift in industrial policy" to support a low-carbon economy. Despite a recent uptake on just transition studies in South Africa (see Section 3), limited qualitative research has been undertaken drawing on primary data from expert interviews [60,83,90,91]. More common qualitative research methods on this topic include literature review [20,92,93], case studies [89,94,95], or content analysis [96]. Applying a mixed methods research approach [97–99], Hägel et al. [95][16] found that the political influence of Eskom[17] (the country's electricity utility) and labour unions, coupled to economic dependence on coal, constrain prospects for transitioning to renewable energy and implementing Sustainable Development Goals (SDGs) 1, 8 and 10.

[13] Moreover, among African countries, Adenle [73] estimates that South Africa has the largest with potential for concentrating solar power of 43,275 TWh/year, for solar PV of 42,243 TWh/year and for wind of 41,195 TWh/year.

[14] Hydropower accounts for ~2.6 % of TES, followed by wind (~2.5 %) solar PV (~1.5 %) and solar thermal (~0.6 %). Continuing with the comparison of the UK, the difference is stark: coal accounted for just 2.4 % of electricity generation in 2021, while wind power accounted for nearly 21 %, with solar PV representing a small share of the total (~4.0 %) [76].

[15] Alongside emerging economies such as China, India, Turkey, Russia, and other countries from the former Soviet Union and Eastern Block. The study classifies other countries as either, oil and gas states, fragile states, fractured democracies, or wealthy OECD.

[16] Case studies and statistical analysis.

[17] Eskom owns approximately 92 % (42 GW) of the total installed power capacity [157].

Overall, much of the empirical research on just transition, both within [20,74,100–104] and beyond South Africa, has followed a quantitative approach focused on techno-economic factors [20,74,100–102]; mirroring developments in the literature on feasibility constraints of national energy transitions [105–107]. Most feasibility studies[18] quantify the impact of technical and economic factors constraining a specific technology diffusion pathway [108–110], but fail to integrate the socio-political dimension of energy transitions [18,105,111]. As noted by Burton et al. [[112]:6], much of the policy discussion in South Africa still focuses on techno-economic feasibility, as opposed to "the need for policies to manage the transition." As a result, there remains a marked knowledge gap in understanding the perspectives of key stakeholders and socio-political factors actively shaping the configuration of South Africa's just transition. Qualitative research approaches such as interviews and focus groups can help bridge this gap, by providing a direct means for better understanding the interactions between key constraints and specific actors involved in the energy transition.[19]

3.2. Scopus search

To complete the literature review, we carried out the following search in Scopus for title, abstract and keywords: "just transition" OR "energy justice" OR "just energy transition" AND "South Africa." The search returned 39 journal article results ($N = 52$), with the earliest dating to 2009 [89]. Following a screening check of journal abstracts, seven papers were excluded for not meeting the inclusion criteria (i.e. South African context and focus on just energy transition). Snowball sampling was then employed to retrieve any additional journal articles, which included five studies ($N = 37$). Given that one study dated to 2009 and two studies were retrieved from 2023, Fig. 1 shows the search results for the period 2014–2022, indicating that over 70 % of the studies were published after 2020. Our search results highlight that just transition scholarship on South Africa is steadily growing.

To help interpret the search results, we used the bibliometric software tool, VOSviewer, to examine the co-occurrence network of keyworks across the dataset [113]. Given the relatively small sample size, we set the co-occurrence between keywords to one, which resulted in 100 connected items (total 120), composed of 20 individual clusters (see Fig. 2). The largest clusters contained 10 items (Cluster 1 and Cluster 2), while the smallest cluster contained two items, composed of *Mpumulanga* and *regional resilience*. We also note the keyword *minerals-energy complex* in Cluster 19 (see Section 6.1). Notably, *energy justice* and *just transition* formed two of the main clusters, while smaller clusters were formed around *energy transition*, *renewable energy*, and *coal*, among others. Across the clusters, the median number of items was 4 ($M = 5.0$; $SD = 2.3$).

As a further check of developments in the literature, we created an overlay visualisation of the results to check research trends over time (see Fig. 3). The results highlight the recent surge in just transition scholarship, as suggested by Fig. 1, with emerging interest in *environmental justice*, *climate goals*, and *green transition*, among other themes.

3.3. Review of qualitative fieldwork

A further review of the retrieved studies ($N = 37$) revealed an underrepresentation of qualitative research methods focusing on primary data collection, with only eight studies (~22 %) employing interviews or workshops with stakeholders directly involved in South Africa's energy transition (i.e. working and living in South Africa). Across this subsample, the studies of Cock et al. [64] and Kalt [114] focused on coal phase-out, while the work of Funder et al. [91], Cantoni et al. [90] and Jaglin [115] focused on the renewable energy transition. The three remaining studies [60,63,83] encompassed both sides of the just transition, in line with our approach. We draw upon this mini review to better contextualise recent findings in the literature and to lay the groundwork for our discussion (see Table 1).

Cock [64] considers thee distinct social spaces of the energy transition, entailing different priorities of resistance which remain deeply contested: mining affected communities (MACs) concerned with dispossession of land and livelihoods for local communities; environmental justice organisations prioritising climate change mitigation; and labour unions grappling with employment insecurity and related socio-economic impacts. The author contends that deeper connections are needed between these three social spaces to develop a coherent vision of a just transition, which is fully aligned to narrowing inequalities [64]. Furthermore, MACs fear that a just transition will contract their livelihoods, both in relation to employment and the loss of a market for informal sector activities. Notwithstanding, there is general awareness concerning the polluting effects of mining on the local environment and its adverse health impacts [64].

Kalt [114] finds that unions with an orientation towards social justice are better aligned to developing transformative transition strategies that enable coalitions with environmental groups and facilitate bottom-up participatory processes. To this point, Räthzel et al. [[116]:516] document how "the centrality of labour has been simultaneously a driving force for change as well as a barrier to a fundamental reconsideration of the relationship between labour and nature" in South African society.[20] Foremost, coal unions are concerned about whether renewable energy policies link environmental benefits with employment opportunities [114].

Cantoni et al. [90] report rife procedural injustices in Qandu-Qandu, an informal peri-urban settlement in Cape Town, where residents have limited access to governance mechanisms for securing basic energy rights; existing in an effective 'scalar limbo' between urban grid connection and rural electrification programs. Energy injustices were further observed in relation to the installation of solar mini grids, namely, distributive injustice related to the incompatibility between the electricity system and commercial appliances, and recognition injustice due to political manipulation and dismissal of energy needs. The authors [[90]:9] conclude that "the spatiality and place-based granularity of the energy landscape becomes crucial when considering the facets of energy justice."

Analyzing the impacts of solar PV adoption in South Africa's Western Cape, Jaglin [115] observed three transitional pathways at play: resistance towards the development of private residential PV connected to the municipal grid (in Swellendam); pragmatic approaches and experimental trials towards implementing renewables set by the municipality, but constrained by a lack of managerial competence and absence of a feed-in tariff (FIT) for businesses (in Mossel Bay and George); and municipality support for renewables with regulatory backing, but internal conflict among different city departments disputing the best way to prioritise environmental commitments (in Cape Town). These findings point to the importance of local authorities as 'steering agents' for a just transition, which remains underexamined in the literature [92,117].

Todd and McCauley [83] develop a taxonomy of barriers to examine the challenges facing South Africa's just transition, focused on the following aspects: governmental national, municipal, industrial, institutional, and labour barriers. Notably, interviewees reported a lack of

[18] For example, studies using integrated assessment models (IAMs).

[19] Here, following Jewell and Cherp [[14]:4], we infer that a constraint should be contextualised according to the specific actor whose action is being constrained. The authors provide the following examples: "an investor considering a renewable energy project is constrained by the project's profitability while a policy maker considering a ban on coal power is constrained by the potential loss of employment among her electorate."

[20] The authors conducted 25 life-history interviews with environmentally engaged, trade unionists in South Africa.

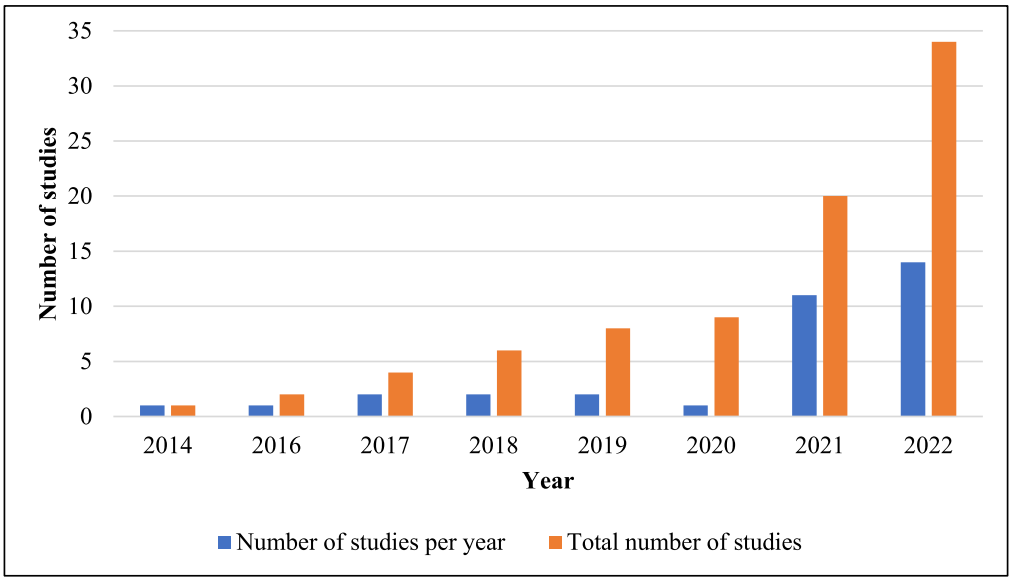

Fig. 1. Scopus search results by year (2014–2022).

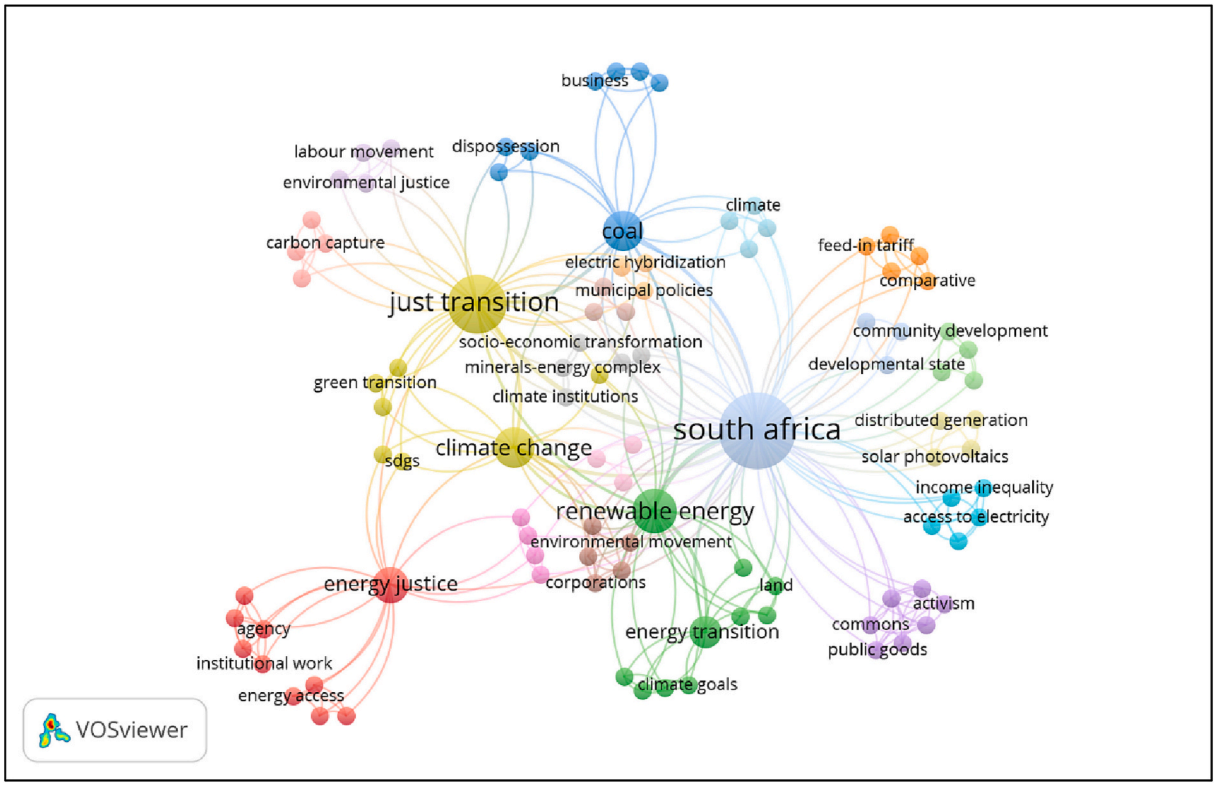

Fig. 2. Network visualisation of keywords in Scopus dataset: co-occurrence threshold one.

cohesion between national and municipal government and lack of funding for renewable energy projects, among other constraints. The study demonstrates a lack of strategic direction for major municipalities such as Cape Town and Durban, and documents how local communities struggle to buy electricity from independent power producers (IPPs) in Cape Town. The authors [83] advocate for more commitment towards building "a powerful coalition of constituents" to support the just transition, through harnessing the power of large-scale municipalities to encourage distributed renewable energy. Other studies shed light on the motives and influence of key stakeholders in the transition [63], the role of community energy professionals (CEPs) [91], and pluralities of meaning associated with energy justice in South Africa [60].

4. Material and methods

4.1. Research design and data collection

We applied a qualitative case study exploratory approach [83,118,119], triangulating results from semi-structured expert interviews ($N = 13$) and literature review findings. Following the example

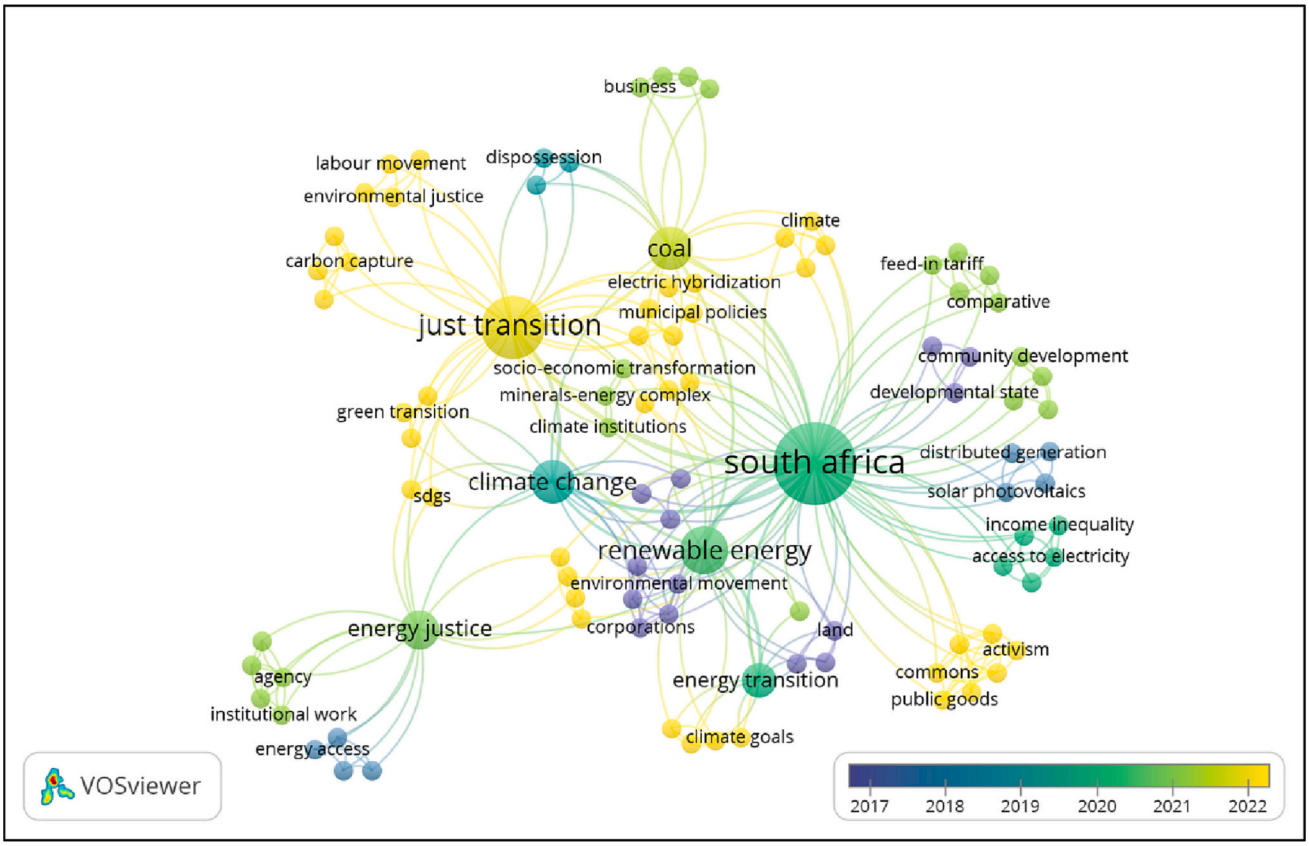

Fig. 3. Overlay visualisation of keywords in Scopus dataset: co-occurrence threshold one.

of Funder et al. [91], our "small sample" approach helped facilitate a "fine-grained, in-depth inquiry" into the topic [[120]:483], with each interview lasting approximately 30 to 35 min, on average. Following our previous engagement with the case study [121,122], we selected interviewees based "on the key parameter of experiential relevance" [[83]:3], through a combination of purposive and snowball sampling techniques. Snowball sampling is appropriate when the population of interest is hard to reach, which proved the case in this study.[21]

In total, four socio-economic development officers, three directors of community development and wellness programmes, and two renewable energy developers were interviewed, in addition to four interviews with associated key stakeholders (see Fig. 4). In this respect, our sample composed of actors with more direct involvement in the renewable energy side of the transition, as opposed to the coal phase-out. We prioritised engaging with renewable energy experts, since this stakeholder group remains underrepresented in the literature [83,91,115], as reflected in Table 1. While addressing this underrepresentation gives rise to a potential limitation in the sample, we compensate by cross-checking our results on coal perspectives against qualitative findings retrieved in the narrative literature review, alongside recent case study evidence on South Africa [55].

Research and interview questions were developed through the authors' research experience with energy transitions in the Global South and specified through an initial review on energy justice in South Africa (both academic and grey literature materials). The lead author conducted the interviews between June and September 2020 via Zoom, using probing techniques to encourage rich insights from respondents. An interview guideline was formulated to help direct the discussion, thereby maintaining a similar structure throughout all interviews. All interviews were recorded and subsequently transcribed following consent from the interviewees.

As shown in Table 2, questions focused on South Africa's coal industry and developments around the phase-out, national energy policy, the Renewable Energy Independent Power Producer Program (REI4P), and implications of the transition on local communities and wider society (i.e. probing for energy justice-related impacts). As discussed in Section 6.2, REI4P is a competitive tender process (i.e. an auction-based energy procurement scheme) designed to increase renewable energy projects [123] and manage the socio-economic disruption caused by the implementation of these projects [58].

4.2. Data analysis

Interviewer transcripts were processed and codified in NVivo12 qualitative data analysis software [124], thereby identifying nodes and sub-nodes to help isolate patterns from the data, adhering to the principles of thematic analysis [125]. This process generated four nodes composed of a total of 11 sub-nodes. In reviewing the results, we detected 180 codes across the sample ($M = 13.85$, $SD = 1.72$), which were further analysed in terms of their relative frequency (i.e. number of specific references per node) to better evaluate the data. This approach provided a means for systematically exploring and condensing the data into meaningfully items [126]. Thereafter, the lead researcher and one of the co-authors reviewed each code multiple times to ensure reliability, while identifying specific commonalities and differences across the data. The final thematic structure produced by NVivo12 was judged to be representative of both sides of the research question: feasibility constraints to phasing out coal and accelerating the uptake of renewables.

We supplemented this method with a conversion process of manual

[21] Unfortunately, the original plan to organise expert workshops during a field visit to South Africa was cancelled due to the Covid-19 pandemic.

Table 1
Summary of qualitative literature on just transition in South Africa.

Study	Research aims and objective	Qualitative, primary data collection methods	Key findings and conclusions
[64]	Examines resistance to coal mining that is emerging from three different social spaces: MACs, environmental justice organisations, and the labour movement	• Six workshops in MACs • N = ~50 per workshop; 2015–2019[a] • In-depth face-to-face interviews • *N* = 12; 2015–2019	• Despite heavy constraints, initiatives involving resistance to coal are building a 'counterpower' that confronts inequality, promotes solidarity, and envisions a post-carbon future • The just transition should adhere to an inclusive, participatory process, which is part of a national conversation on the transformation of our society
[91]	Examines the dilemmas and constraints facing CEPs, seeking to facilitate dialogue and collaborative activities in South Africa's renewable energy communities	• In-depth, semi-structured interviews with actors involved in the implementation of South Africa's REI4P *N* = 15; April 2014–February 2015 • In-depth, semi-structured interviews with economic development managers *N* = 10; 2018–2020	• CEPs face challenges in pursuing personal ideals within a corporate context, making a difference from a marginalised position, and delivering results without practice frameworks • CEPs should be understood and analysed in view of their individual agency, as opposed to mere extensions of their corporation
[83]	Examines policy preventing the large-scale implementation of renewables in South Africa	• Semi-structured interviews with energy experts *N* = 28; May–June 2018	• The weakness of the state electrical utility, Eskom, was identified as the primary barrier counteracting renewable energy policy in South Africa, followed by lack of political commitment • Lack of cohesion between national and municipal government, the political power of the mining industry and unions, and lack of availability for renewable energy projects were identified as additional barriers
[114]	Examines two country cases of labour-environmental conflict around coal transitions (South Africa and Germany); investigating labour union responses to the 'green transition'	• Problem-centred interviews with a range of union representatives • N = 21; 2019–2020	• Unions may strategically adopt oppositional, reactive, affirmative or transformation transition strategies, which is guided by an imperative to protect or expand their power resources • Social justice-orientated unions are more likely to develop transformative strategies and support the energy transition
[63]	Aims to identify the main actors, their main objective, and the contextual factors shaping South Africa's energy transition	• Expert interviews with representatives from governmental institutions, businesses, and civil society (*N* = 21; August–December 2020)	• The four main objectives shaping the energy transition are: energy availability; maintaining profitability of the coal sector; environmental and climate protection; and reducing inequalities and employment insecurity • Interviewees expect the coal sector to continue constituting a key source of national and community-level income throughout the near future
[90]	Examines the situation of energy access and energy injustices in the peri-urban peripheries of Cape Town, South Africa, and Ouagadougou, Burkina Faso	• Interviews with governance actors (*N* = 22), energy and development-related civil society organisations (*N* = 11), scholars (*N* = 7), and residents of Quandu Quandu (*N* = 14): *N* = 54; February 2020–June 2021	• Planned scale, scope, and technological design of solar energy projects in peripheral areas are critical to determining whether and how a project will benefit local communities • Fragmented access to energy produces 'socio-natural hazardscapes of informality', which exacerbate energy injustices across space and time
[115]	Analyses effects of solar PV adoption by high-income households and businesses in the Western Cape, South Africa, on the hybridisation of urban electricity systems and the ability of municipalities to drive a just transition	• In-depth interviews with municipal engineers and technicians, solar equipment developers and installers, and mangers of commercial premises with solar PV • *N* = 18, August–September 2018	• Decentralised solar technologies threaten the surpluses generated from charges paid by grid customers, reducing capacity for the municipality to subsidise electricity services for the poor and support other essential services • Municipalities are implementing a variety of local arrangements to better control distributed electricity generation, aiming to avoid a post-carbon transition model that otherwise risks creating a new energy divide
[60]	Investigates pluralities in the meaning of energy	• Ethnographic research conducted in MACs in Mpumalanga and	• The concept of 'net justice' and 'struggle against justice'

(*continued on next page*)

Table 1 (*continued*)

Study	Research aims and objective	Qualitative, primary data collection methods	Key findings and conclusions
	justice to examine the diffuse and general policy-orientated desires in the just transition and force attention to the question of: 'justice for whom?'	KwaZulu-Natal Provinces, and other parts of South Africa • Semi-structured interviews with actors from civil society, government, the private sector, labour and community members • $N = 80$, November 2018–March 2020.	within the assemblage analysis reveal qualitatively different interpretations and meaning for different actors • More net energy justice does not balance out other types of injustice, while the energy transition is teleologically and ontologically variable

[a] Personal communication with author (February 12th 2023).

coding, wherein the captured nodes and sub-nodes were translated into the language of feasibility constraints. Three sub-factors or individual constraints were identified for the techno-economic and socio-technical dimensions, compared to five for the socio-political dimension. Thus, our research approach followed an iterative and non-linear process, which is the hallmark of thematic analysis [127]. Notwithstanding, this approach entails varying degrees of subjectivity in terms of transforming the established codes to align with the conceptual framework. We minimised this influence through further rounds of validation between the author team to establish the most representative breakdown of feasibility constraints.

5. Analytical framework

5.1. Feasibility constraints

Feasibility constraints facing the global energy transition [105] have been explored in recent contributions from Hyun et al. [13], Lamb and Minx [47], and Jewell and Cherp [14], among others [8,18,128,129]. Muttitt et al. [[18]:144] describe how 'socio-political feasibility' reflects the political efforts required to "overcome multiple and complex social inertias;" characterised by 'soft' and 'probabilistic' constraints [14], such as insufficient institutional capacity, exposure to corruption, lack of democratic norms, and social resistance [14,20,47].[22] By contrast, techno-economic constraints involve 'hard' factors such resource scarcity and lack of infrastructure [14]. Critically, most studies have adopted a primarily techno-economic focus, failing to address social acceptance and non-financial issues, which may be equally significant as techno-economic constraints [105,130]. Additionally, feasibility constraints facing decarbonisation pathways are usually examined at a global or continental level in techno-economic models, leaving national contexts underexplored [13].

Taken together, feasibility constraints can be seen to reflect the co-evolving nature of national energy transitions [55]: interacting across techno-economic (energy flows and markets), political (political action), and socio-technical (knowledge and social practices) systems [131]. Thus, decarbonisation pathways can be rendered infeasible by constraints within any of these dimensions [14]. For example, Jain and Jain [75] identified the main constraints facing the future of renewable

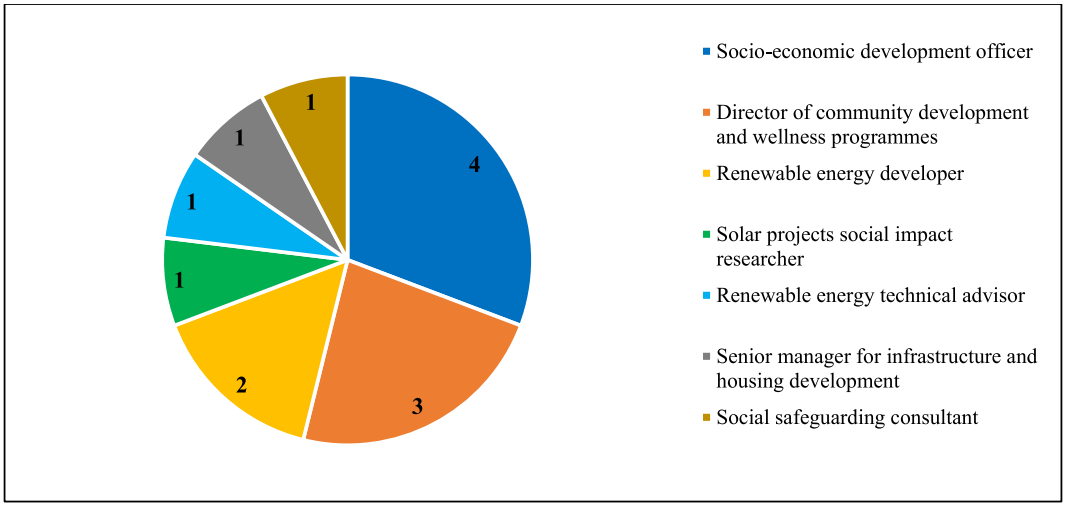

Fig. 4. Composition of interviewees ($N = 13$).

Table 2
Overview of interview structure.

Interview stage	Objectives
Introduction	Ice breaker with the interviewee; presenting the interviewer and research topic and expectations for the interview
Background	Confirming the interviewee's credentials; learning about the interviewee's background and experience with the South African energy sector
Coal sector and phase-out (1)	Learning about South Africa's coal industry, its history, present, and prospective future
Coal sector and phase-out (2)	Learning about barriers and drivers to phasing out coal; impacts on local communities, wider society, and the economy
Renewable energy transition (1)	Learning about the socio-economic impacts of renewable energy development; the development of domestic and small-scale renewable energy projects; barriers and drivers to developing small-scale and community-owned renewable energy projects
Renewable energy transition (2)	Evaluating the success of the REI4P to date; assessing employment prospects and risks associated with the energy transition
Reflections and closing remarks	Inviting additional comments on the topic and final reflections on South Africa's energy policy and potential for a just transition
Conclusion	Finalising the interview, thanking the interviewee, and requesting contacts for further interviews and networking recommendations for future fieldwork

[22] Within this dimension also exists 'hard' institutional constraints such as legislation, and 'soft' institutional constraints such as lobbying [111].

energy in South Africa as lack of grid infrastructure and electricity supply (techno-economic), political volatility and misaligned energy strategies (socio-political), and shortage of technical skills (socio-technical). Nacke et al. [55] examined coal phase-out in South Africa in view of its technological, industrial, and regional systems, which together compose its Political Action System (PAS), reporting risks of prolonged lock-in and potential conditions for sustaining the coal regime.

Drawing from the recent work of Todd and McCauley [83] and earlier contributions to energy transitions scholarship [14,131,132], we define a feasibility constraint as follows:

> A parameter of the energy transition – linked to the techno-economic, socio-political, or socio-technical dimension – which impedes or delays the phasing out of fossil fuels and the uptake of low-carbon energy sources and technologies at the national, regional, community or individual level.

As specified within the 'three perspectives' framework on national energy transitions [131], and supported by Todd and McCauley's 'taxonomy of policy barriers' [83], it is critical to emphasise that feasibility constraints (or 'barriers') interact dynamically and in many instances amplify each other's impact on constraining the energy transition [131] and coal phase-outs [55]. Additionally, there is a pressing need to understand "architectures of constraint" at the national level, which can be defined as "combinations of political economic factors that are mutually reinforcing and highly resistant to intervention" [[47]:1]. Identifying such architectures may assist policymakers in better identifying SIPs for expediting coal phase-outs [6] and diminishing 'tensions in the transition' [92] and within energy justice [33]. Such efforts may contribute positively to expanding what Jewell and Cherp [14] coin as the *feasibility frontier*: a dynamic space which is reconfigured over time as technologies, infrastructures, institutions, and cultures evolve.

The feasibility frontier [14] can be used as a tool to map future fossil fuel declines onto historical precedents [34,133]. Applying this tool, Bi et al. [134] argue that coal phase-out policies depend on national and global dynamics, with the former proving less likely to accelerate policy mechanisms in countries such as China and India before 2050. Vinichenko et al. [34] also find that national dynamics are less effective in triggering the diffusion of coal phase-out pledges to reach non-OECD countries and non-PPCA members such as China, India, Indonesia, and South Africa. Additionally, global dynamics have the capacity to expand or shift the feasibility frontier, whereas national dynamics correspond to a country's movement within the frontier itself [34]. These dynamics suggest that coal phase-out in countries such as South Africa will be at least partially, if not highly contingent, on global forces influencing energy policies, systems, and markets. In parallel, new growth mechanisms would most likely be needed to accelerate the deployment of renewables [107].

5.2. The three tenets of energy justice

McCauley et al. [23] stress the extent to which conceptualisations of energy justice remain the subject of increasing contestation and ongoing exploration. This paper only engages directly with the latter point. In acknowledging a plethora of viable approaches [23,46,135,136] and the absence of a common definition or single framework for just transitions [29], this analysis adopts the more traditional lens of the 'three tenets' framework [25], which operationalises distributive, procedural, and recognition justice as the respective pillars of just transition pathways [21,137]. In contrast, other scholarly contributions aim to shift the discourse around these three dimensions of energy justice [60,138,139].

In doing so, our approach adheres to the same foundations demarcated by Cantoni et al. [90], wherein an 'epistemic warning' was given regarding the application a "Western theorisation of the energy justice concept",[23] which may be at odds with divergent communities across a country such as South Africa. Foremost, the just transition should account for realities on the ground [140], so that the emerging narrative can minimise the risk of exacerbating existing or creating new energy injustices. As Sovacool et al. [141] caution, low-carbon transitions can otherwise risk creating new forms of energy injustice and vulnerabilities, while failing to address underlying "structural drivers of injustice in energy markets and the wider socio-economy."

Distributive justice connects to issues regarding access to and affordability of energy services, and the siting of energy infrastructure [22,49,142], thereby entailing an inherent techno-economic and spatial dimension. Distributive injustices occur when the social good and ills of an energy resource of technology are misallocated across society [22,23]; accounting for co-benefits and externalities of energy systems [137], as well as temporal variations in effects to future generations [23]. Recognition justice calls for fair representation, freedom, and safety for all individuals [143], countering forms of political hegemony, cultural domination, disrespect, and violence [22,144], which can be classified as different manifestations of 'non-recognition'. Recognition is 'post-distributive' in the sense that inequalities need to be understood in relation to their social impacts [145], which can be achieved by identifying which parts of society are impacted by energy injustices and reflecting on who qualifies as a legitimate 'energy victim' [146].

Lastly, procedural justice connects the former tenets by calling for a mix of formal and informal contributions to decision-making processes [23]. The focus here is on the "informational aspects of energy developments to achieve social goals" [[137]:10], advocating for inclusive and equitable stakeholder participation in the planning of rules and laws [22]. Crucially, and comparable to the three perspectives framework [131], the energy justice tenets interact dynamically with one another [30,49]. Notably, scholars have developed tools such as the Energy Justice Metric (EJM) [27], to better capture the dynamics of energy justice across different national contexts [147], while exploring a range of conceptual approaches to understand just transition in different contexts [46,148]. However, to the authors' knowledge such metrics are yet to be developed and applied to measuring parameters of just transition mechanisms (see Section 8).

5.3. The Just Transition Feasibility Framework

Despite the need to assess the feasibility of just transitions in countries throughout both the Global North and South, energy justice is yet to be examined through a conceptual approach that explicitly internalises parameters of techno-economic, socio-political, and socio-technical constraints to the discussion. However, Rempel and Gupta [149] approach this direction in a recent study based on a scoping review of the Leave Fossil Fuels Underground (LFFU) literature which ranks institutional feasibility, cost effectiveness, environmental effectiveness, and justice and equity. Additionally, Hanto et al. [63] systematised their qualitative analysis of contextual factors influencing South Africa's low-carbon transition under techno-economic, institutional, and discursive categories. In alignment to the literature on feasibility constraints [14], Hanto et al. [63] focus on complex interactions between actors with different objectives. Following semi-structured interviews and field observation in hydropower sites, Islar et al. [16] contributed to the energy justice literature on the Global South by examining a range of feasibility constraints impacting Nepal's energy transition. Accounting for the influence of China and India in the region, the authors demonstrated the importance of geopolitical, biophysical, and ethical

[23] A case in point regarding Western hegemony is the recent qualitative systematic review of Shelton et al. [243], which referred to the United States, Australia, and Europe in the abstract.

constraints facing Nepal [16]. Jaglin [[115]:28] argues that South Africa's just transition should account for "local geographic, physical and socio-political specificities," while Nacke et al. [[55]:4] stress the importance of implementing coal phase-out "without serious negative consequences for affected vulnerable groups."

Such contributions set the conceptualisation of a Just Transition Feasibility Framework (JTFF) in motion. Against this background, Fig. 5 unifies feasibility constraints and justice tenets within a single framework, which can be applied empirically to national and cross-country case studies to enrich just transition scholarship. Through the JTFF, we crystallise recent approaches in the literature, providing a novel contribution which can complement outputs such as the just transition management framework [150] and EJM [27].

6. Results

This section operationalises the JTFF to the context of the South Africa, based on primary data collected through interviews with energy experts engaged with the country's just transition pathway. In doing so, we recognise and extend previous contributions in the literature which have identified multiple barriers confronting this vision [75,83]. Section 6.1 focuses on techno-economic constraints, while Sections 6.2 and 6.3 turn attention to the socio-political and socio-technical dimensions. Section 6.4 summarises the key findings.

6.1. Techno-economic constraints

Techno-economic constraints facing South Africa's just energy transition revolve around interactions between its economic dependence on coal, lack of energy infrastructure, and market risks for investing in renewable energy projects.

6.1.1. Supply-side coal dependency and economic capacity

Given South Africa's immense dependence on coal, a prospective phase-out – while technically achievable – is severely constrained by supply-side dynamics and associated economic forces [128], which presents the main risk to prolonging lock-in and the status quo of the coal regime [55]. Most of South Africa's coal reserves (~9.8 Gt) are in the Central Basin (comprising the Witbank, Highveld, and Ermelo Coalfields), with smaller reserves located in the Waterberg Coalfield (~3 Gt) [151]. Exploiting additional reserves, primarily in the Waterberg Coalfield – which is conditional on other techno-economic factors such as water resources and rail infrastructure – remains a key political objective of the South African government and Eskom [151,152], which threaten to counteract the just transition discourse.

South Africa's main mining region, Mpumalanga, is underperforming across several economic indicators when compared to the national average [128], underlining the need for an energy transformation. At present, South Africa remains in a precarious position in terms of its economic capacity, which refers to "the availability of resources to support low-carbon technologies or to compensate for losses incurred by phasing out carbon-intensive technologies" [[14]:5]. From the outset, it is apparent that specific policies will be needed to assist MACs such as Mpumalanga, which are set to incur higher negative impacts from the energy transition [88].

Against this backdrop, one socio-economic development officer warned of threat to Witbank, one of the main coal mining sites in Mpumalanga:

> *It is one of the areas where most of the coal stations and coal generation stations are, and I think it is feasible for renewable projects. Government should ensure that this specific area is not killed by the removal of such a big industry.*
>
> (R8)

Another officer expressed concerns over macro-economic impacts:

> *When you look at areas like Mpumalanga in South Africa, the majority of the GDP from that community derives from coal fired production. So, if you move the country away from coal, what happens to the economic structure of communities such as Mpumalanga and Limpopo? Provinces such as those two are heavily reliant on coal.*
>
> (R11)

South Africa's energy transition will also be influenced by its underlying economic development and future energy demand. Unlike European nations such as Germany and Italy – with commitments to phasing out coal [153,154] but declining population trends [155] – South Africa has a growing population [156,157] which intensifies its future demand for energy [63,157,158]. In view of long-term contracts committing coal supplies to Eskom, nationwide coal dependency could be sustained for decades to come [151,159]. Accounting for techno-economic factors such as existing coal reserves and the influence of the mining sector on Gross Domestic Product (GDP), Ohlendorf et al. [160] report that energy experts anticipate South Africa's operating coal capacity will be maintained until at least 2040. Fundamentally, the South African energy system is characterised by extreme path dependency and foreseeable lock-in [55], whereby the country's coal

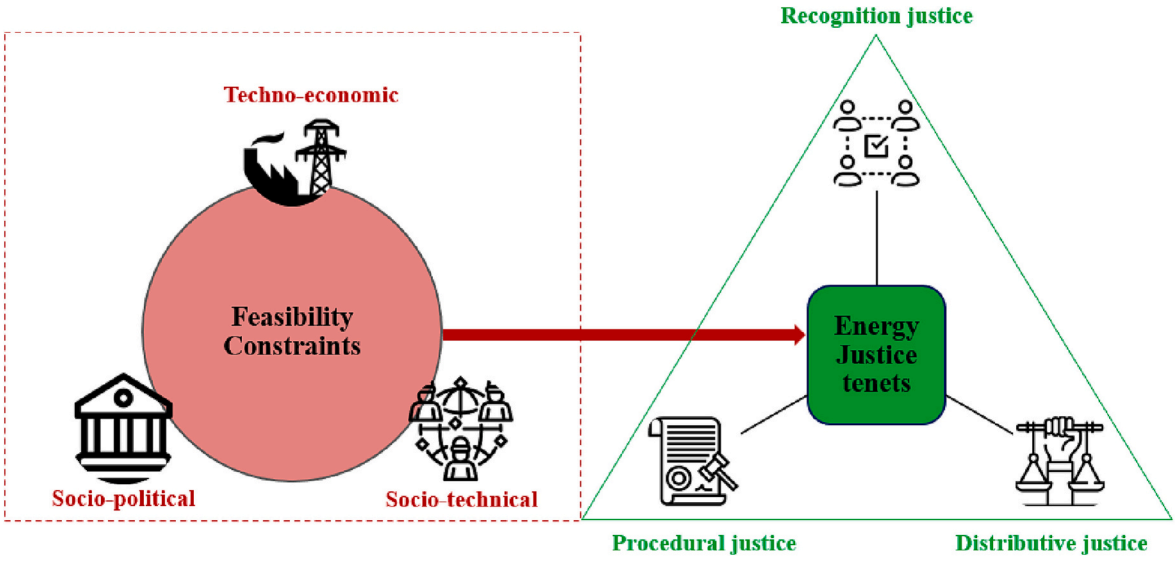

Fig. 5. The Just Transition Feasibility Framework.

phase-out and wider energy transition will be conditioned by its historical pattern of energy production [34,133].

Overall, around 80 % of interviewees cited economic dependence on coal as the main techno-economic constraint slowing the transition to renewable energy, as reflected by South Africa's so-called 'Minerals Energy Complex' [161]; "a powerful technological and political symbiotic relationship between these two central pillars of the South African economy [83]," wherein commodity extraction supports elite regimes [60]. As summarised by Kirshner [162], this complex "holds substantial economic, political and socio-technical influence." Reflecting on the country's energy crisis, a renewable energy developer highlighted South Africa's supply-side challenge [63], which intersects with the power of coal unions and political lobbying (see Section 6.2):

> *Coal will remain the backbone of energy supply and an energy source in South Africa for a long time. In addition, we have quite an abundance of coal in South Africa and a heavy reliance on coal as a primary source for energy production. And because of that, we have a firmly established coal-powered sector resistant to renewable energy*.
>
> (R13)

Similarly, a renewable energy technical advisor cited South Africa's fossil fuel dependency and the need for diversification, "…*that concentration needs to be managed and we need to divert to other sources of energy*" (R2). However, managing the transition is further impeded by insufficient infrastructural capacity to accommodate renewables into the energy grid.

6.1.2. Lack of infrastructural capacity

As reported by Barnes [60], a significant portion of South Africa's energy transition dynamics play out across top-down planning for infrastructure and industry, focused on 19 strategic infrastructure projects. South Africa relies on a heavily centralised energy system; burdened by an ageing coal fleet and infrastructure that is failing to meet electricity demand [63,157,163,164]. In the words of one respondent, "*our biggest challenge in South Africa is to look at our energy structure, structural infrastructure*" (R1). The infrastructure challenge interacts directly with the political landscape, given that the coal-based "*electricity distribution and generation network have been inherited from regime to regime*" (R1), with limited efforts towards breaking Eskom's long-held standing as a dominant regime-incumbent [55,128,165]. At present, South Africa's renewable energy transition remains stifled by inadequacies at the level of its national energy infrastructure, which were detailed by around 40 % of interviewees. For example, one socio-economic development officer explained the situation as follows:

> *The main issue would be the issue of grid availability and grid stability for renewable energy connection to the grid. Some of the highest resourced areas for renewable energy do not necessarily have an existing grid availability*.
>
> (R9)

Another officer referred to the lack of capacity across the distribution grid as the main "*macro-level barrier*" facing the deployment of renewable energy (R4). With the existing grid infrastructure, most renewable energy-generated power will be lost during the transition and distribution process [166], which constrains investment prospects for securing large-scale renewable energy projects.

Shortfalls in electricity generation capacity have also exacerbated the frequency and severity of power outages [167–169]. Rational "load shedding"[24] has been repeated in South Africa in recent years, hampering the national economy [169] and leading to an increase in residential fires [168]. This crisis became entrenched in South Africa's energy system following Eskom's failure to perform infrastructure maintenance, which led to public announcements in January 2015 that load shedding could recur for several years [168]. More recently, in December 2019, Eskom implemented "Stage 6" electricity cuts (~6 GW of production shed) for the first time in its history, grinding parts of the country and its coal sector to a halt [167].[25] In the words of Hofstatter, [170], *the plunder of Eskom and other parastatals almost sank South Africa*, while proliferating the neo-patrimonial governance legacy of the Zuma presidency [171].[26]

Six interviewees made explicit reference to load shedding, with one respondent emphasising its ongoing impact, "…*as we talk now, this week we started load shedding again…because Eskom has got problems of maintenance with some its stock*" (R6).

Another respondent lamented this reality:

> *I must tell you, in South Africa at the moment, Eskom is not reliable at all I'm sorry to say. We've had power outages; we've had them really bad. Last year, we sat without electricity for 12 h at a time when they had load shedding and things like that.*
>
> (R3)

All interviewees in this sub-group (R3, R5, R6, R10, R11, R12) concurred that load shedding was one of the principal drivers for renewable energy uptake, with two respondents explicitly stressing the need for solar and battery storage solutions to help keep "*businesses open*" and "*households running*" (R5, R6). On this note, it should be stressed that renewable energy uptake remains largely privileged to companies and households with adequate financial resources, which bodes ominously for the promise of a just transition [115]. Furthermore, the deployment of rooftop solar PV is marginal compared to large-scale, grid-connected projects [115], which constrains the overall growth of solar and its ability to close the energy gap. In related work on energy justice in Burkina Faso, Cantoni et al. [172] document how such factors may contribute to a situation of "unattainable proximity" to electrification.

Critically, lack of infrastructure capacity is likely to prevent opportunities for prosuming [173], acting as a further deterrent to renewable energy uptake. In response, a social safeguarding consultant admitted that it was unclear whether this was strictly down to policy constraints, or more of a technical issue:

> *…I have read about how many, for example, private farmers who have built solar grids…are not able to connect to feed back into the grid…so there is a lost opportunity there. Is it because of infrastructure capacities, or is it because they* [*Eskom*] *do not want to have competition or someone to pay*?
>
> (R5)

Surprisingly, only one interviewee (R5) referenced the intermittency of renewables [174] and the need for electricity storage solutions [175] to support South Africa's contribution towards delivering the global energy transition [176]. Such solutions are particularly pressing in South Africa where a sustainable electrification scheme is needed to support around 3.5 million households living without access to modern energy [177].

In view of techno-economic constraints and associated interactions with the political and market landscape, transitioning to renewable energy will be delayed until necessary investments are made to upgrade electricity infrastructure, alongside implementing technical solutions for renewable energy deployment. Building infrastructure capacity would help promote opportunities for prosuming and market competition, should the necessary policy measures be put into effect. However, investments in renewables can also aggravate energy injustices depending on how the process is handled by policymakers, as exemplified by Vega-Araujo and Heffron [178] in their analysis of the impact

[24] Otherwise referred to as rolling electricity blackouts.

[25] Previously, load shedding had reached up to Stage 4 (~4 GW).

[26] 9 May 2009 to14 February 2018.

of transmission grid expansion on indigenous people in La Guajira, Colombia.

6.1.3. Investment risks in renewables

A further techno-economic constraint facing South Africa's clean energy transition is high investment risks due to a lack of strong funding mechanisms to support investment in renewable energy projects.[27] In most cases, renewable energy support schemes only provide revenue, for example, the REI4P enables a platform for projects to sell their electricity back to Eskom through a power purchasing agreement (PPA). While the REI4P has helped decrease the commercial risks associated with renewable energy projects, it has fallen short of attracting sufficient market competition from local investors and financial institutions [94,121].

A senior manager for infrastructure and housing development highlighted this constraint: "*The South African economy is very, very small, so there is not much opportunity for renewable energy enterprises to grow. The opportunities for them are very limited in our area*" (R12). Eskom's ongoing financial and operational crisis [63], wherein it is struggling to service $30 billion of debt [179,180],[28] further constrains investment opportunities, as documented by a social safeguarding consultant:

> *Eskom is undergoing substantial financial stress at the moment, and they are getting almost double-digit annual electricity price increases. So, financing renewable energy projects for them would be a huge challenge.* (R5)

A socio-economic development officer commented on the investment risks and financial constraints facing small-scale solar projects:

> *People are trying to do certain things, but its relatively cost ineffective to build a four-megawatt or a five-megawatt plant for a local community if the input cost is higher than the output cost of the project.* (R9)

Having discussed hard techno-economic constraints related to coal dependency and lack of infrastructure, and comparatively softer factors concerning investment risks and financial constraints towards scaling upwards renewable energy capacity, the next sub-section examines socio-political constraints facing South Africa's just transition.

6.2. Socio-political constraints

Socio-political constraints facing South Africa's just energy transition rest primarily on interactions between its current institutional capacity and level of administrative integrity, alongside policy support levels for renewable energy, linking to the implementation and monitoring of the REI4P.

6.2.1. Insufficient institutional capacity and support for renewable energy

Institutional capacity can be defined as "the ability to see through a policy given the present of diverse interests…signalled by the quality of governance and political stability" [[14]:5]. In the South African context – wherein a multitude of diverse interest are represented by an array of stakeholders – institutional capacity remains lacking amid a strong presence of 'regulatory capture', defined by the "the entanglement of ostensibly independent regulatory agencies in the interests that they are supposed to be regulating" [[181]:156].

Given the monopolistic structure of its energy market – attributed principally to the position of Eskom – South Africa has an intense path dependency on coal, which the government firmly maintains by subsidising the coal industry under the premise of energy security and economic development [182]. In the words of Araújo [[183]:118], path dependence refers to "inertia of prior choices constraining future pathways, based on self-reinforcing limits like sunk investment costs; increasing returns; inter-relatedness of technologies; and network effects." This description typifies the South African energy system, wherein Eskom clings to the strategy of an incumbent [55,128,165] by seeking to maintain the status quo through "resisting change and creating inertia" [[63]:165]. Incumbent actors such as Eskom have the capacity to slow down national energy transitions and can threaten to collapse an emerging innovation system, such as decentralised solar technologies [115,184].

Burton et al. [182] observe that coal subsidies supporting Eskom are likely to remain in place, since they operate largely invisibly to the public. This sense of 'lock-in' [185], which sustains South Africa's path dependency [63], is exemplified by attempts to ramp up of coal operations in the provinces of Mpumalanga and Limpopo, which undermine climate change commitments [186–188]. Investments into new coal sites signify a lack of political commitment to the clean energy transition [182], delaying the pace at which renewables can grow to potentially rival the fossil-based energy regime [107,162,189]. Insufficient institutional capacity and lack of policy support for renewables were cited by around 60 % of interviewees as the main socio-political constraints facing the transition:

> *There seems to be a little political will to move the government policy towards renewable energy. There still seems to be much focus on coal generation, which in my view, is primarily related to the perception that coal creates more jobs. For many government policy decisions, the focus is to keep coal stronger in the mix.* (R5)

A renewable energy technical advisor further described how the government is facilitating the ramping of coal operations, counteracting the need for energy policies compatible with climate change targets [14,190]:

> *Some mines are closing because they reached the end of the viability, the lifespan. Then they start with new ones. There are always new players coming in. Initially, there was only one new mine, and they started developing the second mine and finally, the third mine, called Gamsberg Mine, started operation about two and a half years ago.* (R2)

Prospects for powering past coal [1] are further constrained by the presence of regulatory capture within the South African government, corresponding to a range of corruptive practices at the administrative level. Around 30 % of interviewees described this phenomenon, underscoring the lack of administrative integrity across governmental departments as per their interactions with Eskom:

> *The problem is that we only have a sole utility, Eskom. All the corruption involved with Eskom and the coal mines and the various deals with political parties, family members and stuff like that is, in my opinion, the main barrier.* (R6)

A renewable energy technical advisor alluded to the sense of regulatory capture and associated corruption pervading the energy system:

> *The main challenge with the transition away from coal is that many of these coal mines belong to people involved with politicians. As you may be aware, lots of corruption has been happening in South Africa in recent years.* (R2)

In response, Field [191] argues that the South African government should build institutional capacity by integrating "key public and private stakeholders with structural and procedural protection" to help counteract regulatory capture.

[27] Thus, investment risks to the renewable energy sector can be seen to be caused by a specific policy constraint regarding the REI4P.

[28] Eskom's debt is estimated to be 8 % of South Africa's GDP [83].

6.2.2. Red-green tensions and corruptive practices

Hanto et al. [100] conclude that South Africa's supply-side energy crisis, and the techno-economic constraints described in Section 6.1 stem from the government's sustained investment in coal power stations and failure to liberalise the power sector,[29] to which deep routed corruption must be added as a principal socio-political constraint. For example, a regional economic development officer recounted how corruptive practices have impacted the implementation of the REI4P:

> *What we found is that some of the small businesses in the local communities are 'double dipping'. They're moving between plants and presenting proposals and then they get funds for the same project, so they get double funding from different plants.*
>
> (R1)

Sovacool [123] document how corruption risks in South Africa broadly extend from tender rigging, collusion, and anti-competitive behaviour to misallocation of public contracts and diverting of public spending, as well as land grabbing practices and procurement processes.

The corruptive nature of South Africa's energy politics has attracted international media attention, following an attempt on the life of Andre de Ruyter on December 13, 2022 [192,193]. de Rutyer became chief of Eskom in December 2019, seeking to root out endemic corruption and mismanagement at the company [193]. His agenda aligned closely to accelerating the energy transition by confronting socio-political constraints which have stifled South Africa's economy [192,193]. However, on December 8, 2022, the Minister of Mineral Resources and Energy, Gwede Mantashe, accused de Rutyer of "actively agitating for the overthrow of the state" [193]. de Rutyer was the victim of an alleged cyanide poisoning attempt on December 14, following his resignation the previous day [192]. Within a few days of these events, the ruling African National Congress (ANC) party transferred control of Eskom to Mantashe, a self-proclaimed "coal fundamentalist" [193]; raising new question marks over the course of South Africa's just transition [194].

Speaking to some of corruption risks identified in the literature [74,123], a social safeguarding consultant articulated the extent to which coal unions dictate the trajectory of South African energy policy, or lack thereof:

> *…the unions are extremely powerful in South Africa; they have got a lot of impact on industry. The coal mining industry and the mining industry in general has got very militant and very active unions in it. Again, the government knows that it needs the unions on good terms with them. So, if there is going to be job loss related to scaling down coal and not replacing that with long-term sustainable jobs in renewable energy, then that is going to cause immense opposition from the unions themselves. We have seen how that can bring the country to its knees before.*
>
> (R5)

The potential trade off in employment security remains at large in South Africa, given that the bulk of renewable energy jobs for locals are short-term and low skilled positions that end after the construction phase is completed [114].

Cock [64] describes this dichotomy in terms of 'red-green tensions', whereby the labour movement insists there should be no job losses for the sake of a just transition, while the opposition contends that the phasing out of coal and a shift to renewables is imperative to this cause. Notably, the National Union of Metalworkers (NUMSA) took the government to court in 2018 to prevent the signing of Round 4 agreements for the REI4P [64], which proved unsuccessful [83]. Likewise, as the largest affiliate of the Congress of South African Trades Unions (COSATU), the National Union of Mineworks (NUM) has rallied strongly to protect mining jobs [64].

One interviewee reflected on the predicament, "*…keep in mind you've still got a lot of organised people in certain positions, how do you keep those people satisfied when they are about to lose money*?" (R9). Related to environmental tensions, an economic development officer cautioned that climate change denial could prove the greatest social barrier to South Africa's clean energy transition: "*What about all the people out there* [outside of the renewable energy industry]? *For them, it's like we don't need CO_2 reduction, we want energy, so coal is good*" (R9). Such perspectives reveal how the political strength of mining unions constrains "energy justice outcomes" [83], while shaping public perceptions of the just transition.

6.2.3. Lack of transparency and monitoring mechanisms for REI4P

Under the REI4P, large-scale renewable energy producers must allocate 1 to 1.5 % of their revenue to socio-economic development (SED) and enterprise development (ED) schemes within a 50 km radius of the renewable energy project site [58].[30] Renewable energy companies task these responsibilities to economic development managers and their teams. Although their actions on the ground can potentially facilitate more positive conditions for implementing a just transition, Funder et al. [91] document how managers usually have limited agency and may encounter constraints when trying to balance company interests and community needs. Overall, the REI4P can be characterised as "a case of enrolment of the private sector in community development within the renewable energy sector" [91].

To date, arguably, the REI4P has proved somewhat successful in expanding renewable energy production [157] but has largely failed to establish a domestic manufacturing sector [114]. This shortcoming has limited opportunities for long-term high-quality jobs in the renewable energy sector for South Africans [114]. Interviewees concurred that mostly low-skilled job opportunities are available during the construction phase of projects, while high-quality jobs for operating and maintaining renewable energy assets remain limited. However, there were also mixed perceptions of the REI4P. Some respondents (R2, R8, R11) described positive impacts including community trust funds, private sector engagement and investment in infrastructure, community, and rural development, as well as educational and skills training programmes for local communities and businesses. By comparison, other respondents critiqued these schemes for failing to address socio-economic inequities. Foremost, respondents explained that the stipulated 50 km radius restriction exacerbates the unequal distribution of socio-economic benefits, wherein some communities receive over-funding for renewable energy projects, while others beyond this radius are excluded and forego job opportunities:

> *The biggest problem with renewable energy projects is they are very close together. What is happening is this 50 km radius – the labour-sending area – only about four solar plants cover 50 km. Certain areas are being extremely over-funded, while others are not having anything done.*
>
> (R3)

Next, two main issues were cited: (1) lack of transparency regarding the implementation process of the REI4P and its implications (~38 % of interviewees); and (2) insufficient monitoring mechanisms for the REI4P (~54 %). To the first point, one respondent explained the need for clearer legislation: "*In the Western Cape they have one or two tenders for CSP* [Concentrated Solar Photovoltaic] *plants awarded, but it's still some legislative issue because the government hasn't come out clearly on a white paper to say, yes you can, or no you cannot*" (R9). Another respondent lamented the shortcomings of the REI4P, "*…there are some specifications, but it doesn't give much detail. There isn't much regulation as to how exactly, around health for example, should an IPP implement socio-economic development*" (R4).

[29] Likewise, Cock [64] states that "the real issue is the privatisation of such energy."

[30] In the assessment of company bidding, 70 % of the scoring addresses the price, while 30 % addresses required contributions to SED and ED schemes [91].

Moreover, respondents explained that there is no structured strategy in place for evaluating local communities' specific needs before investing REI4P revenues in SED and ED schemes. One interviewee explained how "*the developers have been overwhelmed by the lack of clarity in their economic development initiative that the Government is pushing for*" (R13). Furthermore, interviewees explained that developers tasked with managing SED and ED schemes lack access to information about government plans and strategies for community investment. The director of a community development and wellness programme explained how "*there is not much information cascading down to these communities where the government wants to start developing these REIPPs within the Northern Cape*" (R7). One renewable energy developer framed the lack of grassroots planning as follows:

> *So, the government did not concentrate on evaluating the community issue from the bottom level, so the renewable energy companies did not look at that and say, "We want to leave a legacy. What type of legacy would you want to have? So, let's plan it… we have an opportunity to intervene in poverty, inequality, and unemployment. How will we do it?*"
>
> (R10)

Interviewees recommended that the provincial government should instead identify community issues and demands at the local level. Moreover, the provincial government should design individual investment plans based on key criteria linked to renewable energy developments and coal mine closures, such as local area unemployment, poverty rates, inequality, and other socio-economic issues. For example, a solar projects social impact researcher explored alternative solutions, citing the need for more investment in education and training:

> *I think a more effective approach, would be rather to put it into skills and education, something that could be long-term developed, rather than just paying a dividend to shareholders, which I think might accentuate the poverty trap in some senses*.
>
> (R6)

Relatedly, another interviewee highlighted how local people responsible for disbursing REI4P funds lack the necessary training to formulate ideas and take strategic decisions:

> *The really big issue that's been in discussion for several years now is the Community Trusts, how they are set up. Are people equipped to manage so much money without really any real background or training? They are just normal members from the community. How do they decide where the money goes?*
>
> (R1)

Moreover, a social safeguarding consultant highlighted political interference and bureaucratic problems in the management of the schemes, as one of the main constraints to spending these funds effectively and equitably:

> *There is a lot of political interference in these programmes as well. In one of the projects that I was monitoring, they were trying hard to do good socio-economic and enterprise development, but they had to get permission from government departments. The department just never responded. They tried to launch this programme for two years, but the department never came on board*.
>
> (R5)

This commentary reflects a lack of monitoring mechanisms for evaluating the impacts of SED and ED schemes. On paper, the schemes are meant to be monitored by the government via "quantitative minimum criteria" such as community ownership of at least 2.5 % of equity in the associated renewable energy company, alongside more aspirational targets for community development [91].

The underlying issue remains a lack of community participation in developing and implementing renewable energy projects in South Africa. One socio-economic development officer (R4) elaborated on the links between the local municipality and Eskom under the current arrangement, calling for a more robust policy mechanism that "*would protect or allow the municipalities to get access to electricity from IPPs that are sitting with their area*:"

> *I think what needs to be done is to engage the local municipalities…we get to benefit that local community by having them access electricity from the plant directly; instead, what is happening is we have an IPP in a local municipality still buying electricity from Eskom. And that's why they end up owing Eskom a lot of electricity*.
>
> (R4)

On this subject matter, a renewable energy developer (R10) provided a detailed explanation of the ramifications of community disengagement in hindering the effectiveness of the SED and ED schemes (see Table 3). These observations reflect the processes by which weak governance mechanisms can block community participation in the development and implementation of renewable energy projects. For example, studies focused on wind power in the global North [195] and European offshore wind power [196] explore how 'blocking mechanisms' such as 'soft' institutional constraints may offset the renewable energy development and deployment. By contrast, 'harder' mechanisms such as feed-in-tariffs (FITs), auctions, feed-in premiums (FIPs), and investment subsidies etc. [197] should incentivise development and protect consumers [198], at least in principle.

Having discussed techno-economic and socio-political constraints, the next section completes this part of the analysis by reviewing the implications of socio-technical constraints on energy justice and the potential for a just transition in South Africa.

6.3. Socio-technical constraints

Socio-technical constraints facing South Africa's just energy transition revolve around interactions between knowledge systems and social practices, which manifest in relation to employment risks, social capital, and community engagement.

6.3.1. Skills and manufacturing capability shortage

South Africa's renewable energy industry is heavily dependent on foreign direct investment (FDI), with a mix of European, Chinese and US manufacturing companies dominating the construction of solar projects nationwide [199]. Consequently, local enterprises struggle "to compete

Table 3
Deficits in the socio-economic and enterprise development schemes of the REI4P.

Constraints	Insights from a renewable energy developer (R10)
Lack of community participation in early stages	*Community participation…is essentially basic in the initial stages of devising or talking together about what type of projects and how those projects are being developed; instead of just getting people from outside to come and implement the projects.*
Misperceptions among the local community	*So, community participation in the developments, or in the setting up of projects by these companies has been limited because communities did not know, they just saw these companies say, "Okay, we have money we want to spend, we'll build a school, we'll build you an early child development centre, we'll give you shoes," but the community did not have a say, that much, in terms of what projects should be implemented.*
Lack of consultation processes and monitoring mechanisms	*There is no real monitoring by the government on whether these targets being set are being met. I am not seeing any monitoring around tracking continuously on whether socio-economic and enterprise development are viable. Is it feasible? A lot of the companies go with these pie-in-the-sky ideas, and they do not succeed because nobody is there to advise them.*

with international companies in productivity and labour costs" [[121]:10]. Close to 80 % of interviewees reflected on the socio-technical constraints associated with these market dynamics: citing a deficit in relevant skills and manufacturing capability for developing renewable energy projects without foreign involvement. Another interviewee (R3) flagged how the combination of foreign corporate players and weak institutional capacity gives rise to an autocratic setup of renewable energy in local communities, highlighting the links between socio-political and socio-technical dimensions, and associated market factors.

According to one socio-economic development officer, South Africa lacks "*the skills of counties like Spain and other European countries where they are very much advanced with renewable energy technology and there are lots of skills available*" (R8). Other respondents drew comparisons to the coal sector, with a social safeguard consultant explaining the status quo, "*we have a firmly established mining sector in the country with very rich experience and history and a very long and firmly established value chain. We don't have the equivalent in the renewable energy sector and that becomes a problem*" (R5). A socio-economic development officer echoed this viewpoint, specifying the problem in terms of job losses to the manufacturing sector:

> *The renewable energy industry in South Africa is still in its infancy. We are not yet competitive in that sector. So, if you move the jobs and you move away from coal-fired generation, what is the alternative that renewable energy will provide in terms of manufacturing?*
>
> (R11)

Furthermore, the recognised skills shortage can negatively impact consumer confidence and social trust in renewables following their deployment, as further explained by the same interviewee, "…*you see, there have been some challenges regarding the management of and also the maintenance of some of the solar components that have been installed on domestic units in remote areas*" (R11). Among other factors such as socio-cultural attitudes [200], insufficient labour capacity to meet operational and maintenance demands for renewable energy technologies (RETs) can spark social resistance and weaken consumer acceptance [132,201].

6.3.2. Employment insecurity, lack of community engagement and social resistance

Deficits at the level of knowledge transfer and social practices in relation to renewable energy development present a socio-technical constraint to South Africa's just transition. These deficits may contribute towards social resistance against renewables from MACs. Opposition may likewise arise from within non-mining communities which are at risk of suffering regional despondence following coal phase-outs [55]. In some cases, the absence of a strong domestic niche for South Africa's renewable energy sector is associated with negative community impacts; stemming from the socio-economic and cultural conflicts that arise due to an influx of foreign workers. Interviewees cited employment insecurity as a principal issue, with one respondent flagging the widespread concern that renewable energy may "*steal local jobs*" (R6). Social resistance is aggravated when local workers have a misperception about prospective skill requirements, as recounted by one interviewee:

> I remember there was a bit of a disruption in terms of foreigners coming in and taking local jobs because they would see a welder welding – without knowing that it was highly technical welding and required technical skills and knowledge – and the local community thought that is just standard welding and they could do it.
>
> (R5)

Although potentially challenging, one of the interviewees suggested that disruptive impacts could be better mitigated if the South African government encouraged local workers to collaborate more closely with foreign workers in renewable energy developments:

> That's a tough one because, obviously, some countries like Spain and Germany have the skills related to the energy that is needed. They do add value to the country and renewable energy. But to stop the disruption, I would think maybe add incentives for them to positively include local people, local skills, local expertise.
>
> (R6)

As elaborated by a renewable energy technical advisor, communities typically have high expectations for renewable energy projects, but these hopes are not grounded in proper information regarding project size and associated socio-economic impacts:

> I think one of the main challenges is that the plants are fairly small. We're talking 10, 50, 75 and 100 MW plants. Opportunities for employment around these plants is for highly skilled people. That's only around the maintenance areas where lower skilled and semi-skilled people could be employed.
>
> (R2)

The interviewee further communicated how a backlash can be created against renewables when benefits fail to materialise for individuals and the local community:

> *The resistance was based on a misunderstanding and miscommunication regarding community expectations. Communities' understanding of benefits from these plants was that they're going to get cash and it's the end of poverty for them.*
>
> (R2)

Regarding training schemes, the director of a community development and wellness programme made a case for "*better communication and decision-making from bottom-up and from top-down*" (R3) to help bolster community engagement and local support for renewables. Similarly, a renewable energy developer recommended increasing "advocacy and awareness" (R13) regarding the reality of renewable energy projects and potential socio-economic benefits; inferring the need to distinguish clearly between impacts associated with the incumbent coal industry and renewable energy sector. Indeed, one socio-economic development officer relayed the sense of fear among local workers facing potential redundancy due to coal phase-out:

> *There has been some resistance to adopting renewable energy in South Africa because most people felt they would lose their jobs and they would not be reskilled to take up new jobs in renewable energy or any other sector of society.*
>
> (R4)

Moreover, the temporal nature of most renewable-energy related jobs may fail to provide an alternative long-term and sustainable source of income for redundant coal miners:

> *South Africa is sitting with a lot of investment and money running through the coal industry. In a coal plant you will always have the steady job of mining the coal, so you will always have work for miners. But if you close that mine and now suddenly have an energy plant like a solar plant, which only has 18 months of the construction phase, this means only 18 months of jobs for local people.*
>
> (R9)

However, analysts contend that "with appropriate long-term planning, many dislocated workers can readily find work in related sectors, minimising near-term effects from dislocations" [202]. Notwithstanding, the scope for relocating workers is likely to be highly context specific. For example, oil and gas workers may have the necessary skills for transferring into carbon capture and storage (CCS) projects [203] and the emerging 'hydrogen economy' [204,205]. By contrast, replacement jobs for former coal industry employees may face significant sacrifices such as lower salaries [206–208], alongside potential geographical relocation due to disparities between areas of renewable energy investment and coal mines, as evidenced by other country cases

[209–211]. Interviewees identified these risks, for example, a social safeguarding consultant linking logistical and geographic factors to distributive injustice:

> Even though renewable energy might create jobs, sustaining jobs in the coal area matters. So, the coal truck drivers will all lose their jobs in Mpumalanga. And even though twice as many jobs are being created in the Northwest, there will still be a lot of job loss in coal regions such as Mpumalanga.
>
> (R5)

A lack of social capital further compounds spatial inequities and the marginalisation of vulnerable communities in the context of South Africa's just transition aspirations. Fraser [94] investigates social capital in relation to large-scale solar energy projects; questioning whether the small IPP programme is sufficient for rectifying socio-economic disparities and cautioning that inequalities in solar siting may perpetuate distributive injustice during South Africa's ongoing national electrification programme [212]. The underlying risk is that communities with weak social capital lack resources to prevent environmental and social harm [94].

6.4. Summary of findings

The analysis of feasibility constraints reveals distinct patterns across techno-economic, socio-political, and socio-technical dimensions. Across the three dimensions, a total of 11 barriers were identified and quantified by evaluating the responses of interviewees. Fig. 6 summarises the results, showing techno-economic constraints in brown (M = 69.2, SD = 7.7), socio-political constraints in red (M = 49.2, SD = 14.0), and socio-technical constraints in orange (M = 61.5, SD = 20.4).[31]

Supply-side coal dependency (techno-economic) and *skills shortage* (socio-technical) were the most frequently discussed sub-constraints, while *lack of community engagement* (socio-technical) *and social resistance* and *corruption* (socio-political) received less comparatively less focus from interviewees. While confined to a relatively small sample size, the analysis supports previous findings which suggest that techno-economic constraints may be the most critical factor facing South Africa's just transition, and its decarbonisation aspirations in general [47,160].

We reviewed this quantitative finding at a further level by subsuming the two REI4P-related variables (*lack of transparency for implementation* and *insufficient monitoring mechanisms*) under one measure, which increased the weighting of the socio-political constraint dimension to 61.5 % (equal to the socio-technical dimension). This adjustment affected the statistical results for the sample (M = 63.8, SD = 18.1), but retained techno-economic constraints as the most cited feasibility dimension. Based on this assessment, we conclude that among interviewees, socio-political and socio-technical constraints were perceived to carry a similar impact level in determining South Africa's potential for phasing out coal and scaling up renewables, while the techno-economic dimension is the most critical determinant shaping the country's emerging feasibility frontier [14,34,133].

7. Discussion

7.1. Energy justice implications of feasibility constraints

At the national scale, South Africa's economic dependence on coal aggravates conditions of macro-economic instability, which entail severe socio-economic consequences for parts of the population, as reflected by significant disparities between and within regions of the country [88,128]. Conditions for perpetuating distributive injustice remain rife, especially in MACs such as Mpumalanga and Limpopo. As documented by Barnes [60], these regions have declined into 'stranded communities', underscoring a legacy of 'settler-colonial dynamics' of extraction and exploitation. Fear of marginalisation and socio-economic deprivation are heightened in MACs such as Ermelo (one of the main mining towns in Mpumalanga) where residents report procedural injustice due to a lack of consultation [213].

South Africa's embedded mineral complex and the prevailing grip of Eskom on its energy system entail procedural injustices through the guise of neo-patrimonial governance [123], wherein corruptive practices and regulatory capture offset opportunities for greater stakeholder participation in energy projects and bottom-up initiatives. Interviewees identified prevailing conditions of social hierarchy and inequality regarding access to and affordability of renewable electricity. This situation gives rise to energy vulnerabilities [214,215], while diminishing opportunities for community renewable energy and prosuming. Furthermore, although South Africa is endowed with abundant solar and wind resource potential, renewable energy projects are constrained by their techno-economic parameters, which see many of the best sites for solar and wind projects located beyond the country's main coal belts. The spatial dynamics of renewable energy deployment may give rise to 'friction zones' which entrench existing inequalities and invoke recognition injustice [58]. Notably, distributive inequities stem from the 50 km radius restriction of the REI4P, which by default is an exclusionary system. The current system feeds into spatial injustices which need to be overcome to support a just transition [115].

Specifically, our analysis reveals the interaction between macro- and micro-level energy injustices caused by the REI4P, wherein the 50 km restriction creates socio-economic disparities across regions, and between communities and households. Earlier work from McEwan [58] also identified spatial injustices linked to the legally defined zones of the REI4P and its zones of SED and ED impacts, which may force territories into "uneasy co-existence" with risks of new power struggles and distributive injustices. As discussed by Monyei et al. [49], resource and spatial distribution influence the configuration of distributive and recognition injustices in off-grid, rural South Africa, while nationwide there are risks of the just transition failing to de-territorialise looming spatial injustices [60].

The analysis highlights sizeable risks associated with the unequal geographical distribution of socio-economic costs and benefits [216]. These inequalities threaten to amplify the income gap between coal-reliant regions and other areas, while also creating new 'renewable energy divides' between communities. Exacerbating the peripheralisation of both rural and peri-urban communities [217] poses a stark threat to South Africa's vision for a just transition, especially if investment risks in renewable energy projects fail to be managed to the benefit of local communities.[32] At present, cost-benefit analysis dictates that commercial risks are mainly viable for foreign investors, leaving local communities with limited access to finance, resources, and land, at the fringes of renewable energy investment and ownership [58]. The socio-economic landscape and market dynamics of renewable energy generation, supply, and consumption give rise to local energy injustices, which disrupt community empowerment, energy security, and wealth creation [218]. Specifically, the built-in tendency for the REI4P to transnationalise renewable energy projects and constrain community ownership predominates, offsetting the rate of knowledge transfer and development of a domestic supply chain for renewables [58]. If reversed, South Africa would have stronger capabilities to assume a leadership role in the manufacturing and potential export of renewable electricity in sub-Saharan Africa [219,220]. Meanwhile, fossil fuel subsidies prevent the

[31] Across the sample, we reported the following results: M = 58.0, SD = 15.9.

[32] Gloubchikov and O'Sullivan [216] define an energy periphery as "places that are systematically disadvantaged through the whole energy system due to their inferior position within the asymmetrical spatial distribution of economic, political and symbolic resources and capabilities."

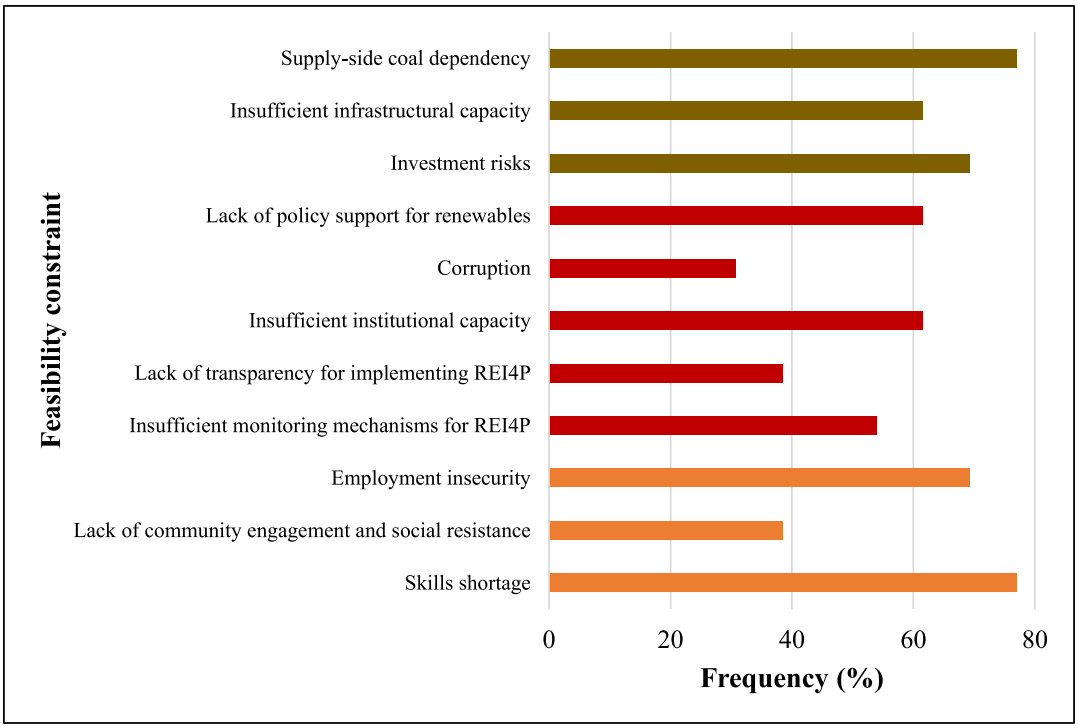

Fig. 6. Ranking of feasibility constraints by dimension based on coding of interview data.

renewable energy sector from competing effectively with the coal industry [182], thereby undermining the foundations of a just transition.

Procedural injustices remain embedded in South Africa's current energy transition pathway, as reflected by largely top-down policies and lack of public participation, both at the national and community level [20,92,199]. Renewable energy policies are yet to receive the necessary level of support and implementation to challenge the fossil-fuel regime, with access to renewable electricity constrained by Eskom's protective regime. Procedural injustices take hold in the guise of corruption and regulatory capture, with interviewees documenting how political interference derails community plans and ambitions for transitioning to renewable energy. Moreover, the current arrangement around renewable energy procurement fails to bridge pervasive income inequality, thereby tasking the government with a greater challenge to address employment risks and wage differentials, as part of its just transition commitment [160].

The just transition is further stifled by softer issues such as a lack of policy transparency and coherency regarding the REI4P, deficits in access to information for renewable energy planners and local communities, and insufficient training mechanisms for SED and ED officers to fulfil the mandate of the REI4P. This undesirable mix of constraints – contributing towards an underlying deficit in structural and procedural protection for rural, urban, and coal communities alike – deepens the potential for employment insecurity and related socio-economic risks, while disempowering local communities and threatening the livelihoods of future generations. Specifically, renewable energy-based employment entails a pronounced gap between high- and low-quality jobs, with the former attributed mainly to foreign workers. Furthermore, available jobs in the renewable sector are often short-term and may require relocation, as compared to permanent jobs in the mining sector.

While well intentioned, the SED and ED mandates of the REI4P remain only partially fulfilled, at best. Underlining these shortcomings, is a lack of both implementation and monitoring mechanisms to target and track welfare benefits. From the outset, these benefits appear to be generic and non-specific to the community of interest, with key areas such education and healthcare often neglected by the schemes. Such a situation speaks not only to procedural and distributive injustice but carries intergenerational implications, as future generations may see their livelihoods decline [221–223]. The needs of the local community are misrecognised while local participation in renewable energy remains hampered, feeding into conditions for proliferating energy injustice. Moreover, marginalised communities remain devoid of solar investment [94], undermining the premise of a just transition to see 'no one left behind' [224,225].

7.2. *Sensitive intervention points for supporting a just transition*

The analysis demonstrates how feasibility constraints interact dynamically with parameters of energy justice, whereby these interactions configure the scope of South Africa's just transition ambitions. To complete the study, we link our findings to specific policy strategies which could help diminish feasibility constraints and elevate energy justice. Cantoni et al. [90] describe how specific 'entry points' should be targeted to counteract energy injustices, while other scholars have discussed a range of interventions [47,226]. Here, we adopt the language of *sensitive intervention points* [6,50,51] to communicate policy recommendations aligned to "seizing opportunities" for a just transition [227].

Table 4 identifies intervention points based on results from the interview data and supporting discussions in the academic and grey literature. Our suggestions internalise Snell's [228] assessment that a just transition requires "an interventionist state committed to social partnership and union involvement," among other factors which support procedural justice and related energy justice tenets. Critically, securing energy justice will be complemented by seizing viable opportunities for achieving structural change across other sectors of the economy, such as manufacturing, transport, agriculture, and tourism [128,189,225].

8. Conclusions

This study provides key guidance to South African policymakers, and other stakeholders engaged with just transition mechanisms in coal-dependent countries, while advancing scholarly discussions on energy justice in the Global South. Applying the JTTF, we analyse interactions between feasibility constraints across three distinct dimensions of South

Table 4
Sensitive intervention points for addressing just transition feasibility constraints.

Dimension	Feasibility constraint	Sensitive intervention points
Techno-economic	• Supply-side coal dependency	• Develop a comprehensive strategy to accelerate the unbundling of Eskom • Enact success metrics for objectively evaluating just transition performance and progress across the coal value chain • Support investments in new technologies and industrial clusters, including development of a domestic supply chain for green hydrogen and electric vehicles • Develop strategies for implementing economic diversification at the national and sub-regional level
	• Insufficient infrastructure capacity	• Support Eskom's ambition to deliver a 'step change' in grid investments by accelerating the decommissioning of ageing coal plants, thereby unlocking grid capacity and potential for renewable energy deployment • Develop a Master Plan dedicated towards building local supply chains for building new generation and transmission capacity • Attract new investment into upgrading the country's infrastructure and electricity grid, alongside debt financing for Eskom
	• Investment risks	• Create a more competitive market environment for renewable energy investment by increasing subsidies • Attract new business partners from democratic countries to diversify FDI in South Africa's energy system
Socio-political	• Lack of policy support for renewables	• Renewable energy expansion should be accompanied by policies dedicated to increasing electricity access in marginalised communities • Policies should better support rooftop solar PV • Introduce new legislation to support the expansion of renewables across different regions, specifying place-based targets and timelines
	• Insufficient institutional capacity	• Incentive structure for better coordination between governmental departments • Develop dispute-settlement mechanisms to alleviate tensions between political factions and coordinate more cohesive institutional action
	• Corruption	• Counteract regulatory capture and corruption through the passing of new legislation which holds stakeholders accountable for impeding just transition mechanisms • Implement a Just Transition Tribunal (JTT) to bring perpetrators to justice and establish a new benchmark in social and environmental justice
	• Lack of transparency for implementing REI4P	• Improve mechanisms for information disclosure and dissemination to local stakeholders regarding REI4P policy
	• Insufficient monitoring mechanisms for REI4P	• Develop a continuous monitoring scheme, whereby REI4P representatives publish and discuss the impacts of their work on a regular basis and identify ways to increase the effectiveness of SED and ED measures
Socio-technical	• Employment insecurity	• Develop a database to log the details of mining-affected workers in respect to location, job type and other relevant socio-economic indicators • Develop adequate compensation and investment schemes for MACs including retirement packages and targeted welfare measures • Promote stakeholder participation in identifying viable pathways for job resettlement in MACs, using a needs-based assessment approach • Enhance regional diversification opportunities by integrating just transition mechanisms across other key sectors of the economy such as manufacturing, transport, agriculture, and tourism
	• Lack of community engagement and social resistance	• Enhance levels of community representation by encouraging membership-based organisations in local communities to help counteract recognition injustice • Promote exchange of ideas and evidence within local communities by nominating village representatives to represent key concerns around the just transition to strengthen feelings of security, safety, and freedom • Mobilise support and collective action in MACs and other communities impacted by renewable energy deployment (within the 50-km radius of the REI4P zone and surrounding areas) • Call upon the media to better publicise processes around the just transition and promote knowledge and awareness about climate change and decarbonisation
	• Skills shortage	• Mobilise local knowledge for just outcomes which account for a diversity of energy cultures[a] • Implement training schemes in MACs, rural communities, and other marginalised areas which reflect access to electricity and account for employment-related risks

[a] The Energy Cultures Framework [244] recognises that "distinctive clusters of knowledge, belief, behaviour and material objects (as held by individuals and groups) will have some bearing on the way energy is used, along with the more decentred influences."
Source: Based on [6,22,90,128,225,227,229].

Africa's national energy transition [131] and discuss implications for implementing energy justice.

Our analysis supports several recent findings in the literature [49,63,83,115], and moreover, empirically reinforces three emerging aspects of energy justice scholarship: distribution of vulnerabilities [215,230], energy peripheries [217,231], and misrecognition of places [90,172]. At the local level, we highlight an underexamined dimension of distributive and recognition injustice linked to the influx of foreign workers. This situation constrains the growth of South Africa's renewable energy labour force and sees local communities marginalised or excluded from just transition processes, which can give rise to social resistance against renewables. Foremost, our results study draws attention to both the national- and community-scale implications 50 km radius policy specified by the REIP4. By standardising the scheme, local needs and different identities are potentially overlooked and the risk of energy vulnerabilities is increased. In response, we advocate for 'place-based approaches' to the study of just energy transitions, which more directly account for inequalities embedded in energy-related decisions [232] and the relationship between "space, place, and justice" [233]. As A Starting point, we recommend that the South African government

extend the current scheme to a regional basis, which would better support conditions for a socially just transition through a more spatially inclusive approach.

In parallel, decisive measures should be taken to increase environmental awareness throughout the country by means of educational programs and media campaigns. Climate change and energy awareness play a critical role in helping to acclimatise the public to just transition pressures, serving to offset conditions for social resistance. Social acceptance and the drive towards building a renewable energy labour force are intrinsically linked to socio-cultural and informational factors. However, the justice implications of reducing both socio-political and socio-technical constraints will rest upon addressing techno-economic factors, foremost, in relation to South Africa's supply-side coal dependency, as well as its lack of infrastructural and grid capacity, which present market risks to scaling up renewable energy capacity.

Findings from this study can help inform decision-making in other coal-dependent countries in the Global South such as Colombia [234], China [6], India [235], Indonesia [236], the Philippines [237], Vietnam [238], and beyond [239]. Further cross-comparative research [47,55,160] is needed to explain convergent and divergent techno-economic, socio-political, socio-technical, and contextual factors shaping decarbonisation pathways and just transition mechanisms in carbon-intensive economies. For example, mirroring our findings in South Africa to an extent, climate protection in Indonesia is yet to enter the public consciousness [240], while political lock-in and regulatory capture undermine the decarbonisation agenda in countries such as Vietnam [238] and China [6], to name but a few. In India, scepticism and concern remain over the feasibility of renewables to meet baseload electricity demand, while higher levels of investment are urgently needed to support renewable energy targets [235]. Cross-comparative studies will help contribute towards more robust national policies and transnational strategies aligned to the just transition [63], while supporting empirically-grounded policy sequencing for enacting feasible coal phase-out pathways [55]. Following the recent contribution of Vinichenko et al. [34],[33] energy transition scholars should identify suitable parameters for examining a 'just transition feasibility frontier'. Mapping the dynamic feasibility space of just transitions in different countries and regions including the Global South can serve as a powerful corollary to the EJM [27,147], which has been mostly applied to cases in the Global North.

Finally, to help enrich the just transition discourse and advance deeper conceptual and empirical understanding of the topic, we encourage the integration of 'restorative justice' in future studies to broaden the scope of the JTFF. At its core, restorative justice, as advanced by Heffron and McCauley [139], encourages society to reflect on past injustices and find ways to overturn historic damages incurred by individuals, communities, and the environment, thereby striving to heal the people and the land [227]. Notably, both South Africa's Presidential Climate Commission [227] and National Business Initiative [225] draw upon the tenets of procedural, distributive, and restorative justice, wherein recognition justice is subsumed under the first pillar. Internalising restorative justice into the just transition discourse vis-à-vis an assessment of feasibility constraints can help illuminate the pertinence and potence of prospective policy interventions.

CRediT authorship contribution statement

Pegah Mirzania: Investigation, Conceptualization, Methodology, Data Curation, Visualization, Writing – Original Draft, Writing – Review & Editing. **Joel A. Gordon:** Conceptual Framework, Data Analysis, Visualization, Writing – Review & Editing. **Nazmiye Balta-Ozkan:** Investigation, Conceptualization, Project Administration, Funding Acquisition, Writing – Review & Editing. **Ramazan Caner Syan:** Conceptualization, Writing – Original Draft, Writing – Review & Editing. **Lochner Marias:** Project Administration, Writing – Review & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A

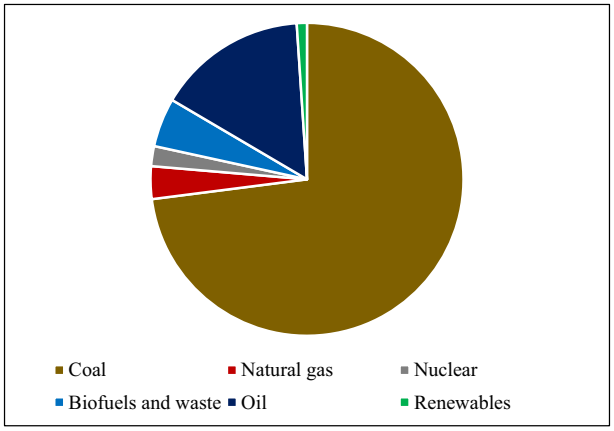

Fig. A1. Percentage of energy supply by source in SA, 2020 [76].

[33] See Fig. 3 in their study: The evolution of the feasibility space for coal phase-out pledges.

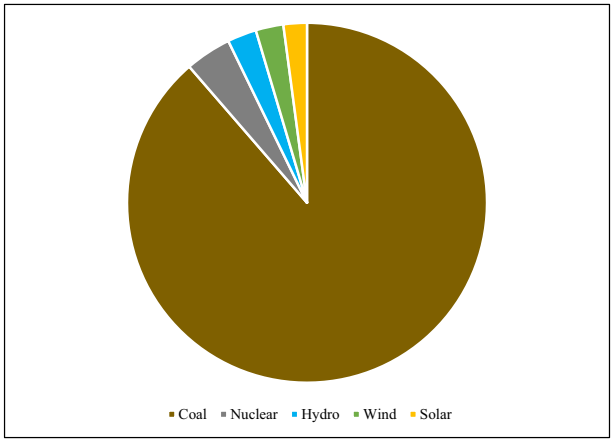

Fig. A2. Percentage of electricity generation by source in South Africa, 2020 [76].

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