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Assessment of challenges and strategies for driving energy transitions in emerging markets: A socio-technological systems perspective

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A B S T R A C T

The pursuit of improved quality of life standards has significantly influenced the contemporary mining model in the 21st century. This era is witnessing an unprecedented transformation driven by pressing concerns related to sustainability, climate change, the just energy transition, dynamic operating environments, and complex social challenges. Such transitions present both opportunities and obstacles. The aim of this study is to provide an extensive literature review on energy transition to identify the challenges and strategies associated with navigating transformations in energy systems. Understanding these transformations is particularly critical in the face of the severe consequences of global warming, where an accelerated energy transition is viewed as a universal remedy. Adopting a socio-technological systems perspective, specifically through the application of Actor Network Theory (ANT), this research provides a theoretical foundation while categorising challenges into five distinct domains and outlining strategies across these different dimensions. These insights are specifically tailored for emerging market countries to effectively navigate energy transition while fostering the development of resilient societies. Furthermore, our findings highlight that energy transition encompasses more than a mere technological shift; it entails fundamental changes in various systemic socio-economic imperatives. Through focusing on the role of social structures in transitions, this study makes a significant and innovative contribution to ANT, which has historically been criticised for its limited acknowledgement of social structures. Consequently, we propose an emerging market energy transition framework, which not only addresses technological aspects, but also integrates social considerations. This framework paves the way for future research and exploration of energy transition dynamics. The outcomes of this study offer valuable insights to policymakers, researchers, and practitioners engaged in the mining industry, enabling them to comprehend the multifaceted challenges involved and providing practical strategies for effective resolution. Through incorporating the social dimension into the analysis, we enhance the understanding of the complex nature of energy system transformations, facilitating a more holistic approach towards achieving sustainable and resilient energy transitions in emerging markets and beyond.

1. Introduction

Given that energy transition processes have received less attention concerning ongoing challenges and strategies for sustainable implementation, this study provides new insight into the body of literature by linking up two strands of the energy literature: technological dimensions of the energy shifts and the societal changes necessary for the transition to sustainable renewable energy consumption and production pattern free from environmental degradation (Zakari et al., 2022). The shift has become urgent in the wake of more frequent and severe climate change crises such as droughts, heat waves, floods, and rising sea levels (Zakari et al., 2022a; Zahoor et al., 2022; Zhang and Kong, 2022). A vast amount of literature has demonstrated the importance of renewable energy to a sustainable environmental system (Zhang and Kong, 2022; Liu et al., 2022; Liu et al., 2022), and the

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expected rising demand for critical transition minerals (Islam et al., 2022). The current paper focuses on energy system transition processes in emerging markets.

Such a study is timely as the world is seized with growing calls to work towards the International Energy Agency's net zero emissions by 2050 (IEA, 2023). This major shift has been called energy transition, defined as a shift in an energy system's condition that is more than the changes in a particular energy technology or fuel source (Islam et al., 2022). A significant change in the energy system primarily marks it. It is, therefore, associated with one or more causes linked to the system's scale, structure, economy, and even energy policy (Tzeremes et al., 2023). From an environmental perspective, energy transition is the process of transferring away from existing fossil energy systems represented by coal and petroleum toward renewable energy (Li et al., 2023). To achieve this objective, however, sacrifices must be made, as the transition necessitates the extraction of significant volumes of clean energy transition minerals to support the diverse technologies involved, such as solar photovoltaics (PV), wind turbines, storage facilities, and numerous others (Valero et al., 2021). A paradigm shift from fossil fuel-dependent non-renewable energy sources to clean and renewable energy production processes is required, yet it relies on metals and minerals (Islam et al., 2022). To understand the potential trajectory of the ongoing energy transition, it is vital to recognise that over the past 150 years, there have been at least two significant energy transitions. The first transition involved the shift from coal to gas and oil, while the current transition we are confronted with involves the transition from hydrocarbons to renewable energy sources (Li et al., 2023).

The main differences between the two phases of transitions are that the first transition was largely a traditional shift, understood in terms of fuel sources, such as the transition from wood to coal, coal to oil, driven by the need to accelerate industrialisation. In contrast, the current phase is propelled by the need to achieve sustainability (just energy transition where no one is left behind), necessitated by the climate change crises (Zakari et al., 2022a; Zahoor et al., 2022; Zhang and Kong, 2022). Therefore, in this review, we take a socio-technological systems perspective and argue the traditional framing of energy transitions as nothing other than technology shift looks naive at best. We further posit that transitions in fuels are inevitably accompanied by widespread social, economic, and political transformations that must also be factored into assessments of energy change (Rachidi et al., 2021). The implication of this is that energy transitions must be preoccupied more importantly with choices not so much between different fuels but between different forms of social, economic, and political arrangements built in combination with new energy technologies (Burke and Stephens, 2018; Miller et al., 2013). By so doing, we bring a novel perspective to our understanding of energy transition processes.

What seems to be clear is the difference between the energy transition trajectory experienced in the Global North and what it will look like in sub-Saharan Africa (Acheampong, 2023). Scholars have noted the contestation in ideologies and perceptions of how the transition should be rolled out. For example, Pedersen and Andersen (2023) remark on the conflict that erupted at both the conference of the parties (COP) to the United Nations Climate Convention (UNFCCC) or COP26 and COP27 between the Western and African governments as the former emphasised the need to reduce development finance for fossil-fuel projects. The scholars conclude that the controversy is testimony to the need to understand better how politics and power play a role in energy transitions in lower-income African countries (Acheampong, 2023). It is argued that the state and public utilities play a critical role, and so are civil society organisations and international financial organisations such as the World Bank and IMF (Power et al., 2016). For emerging markets, the energy transition trajectory is not clear, as extant literature is largely based on transition patterns in developed markets, which are technology-centric (Pedersen and Andersen, 2023). For developed contexts, where formal institutions are well developed, techno-centric transition projections are understandable. Yet, institutional voids in emerging markets make it necessary to investigate how socio-technical factors inform the just energy transition closely. While energy is generally accessible in developed countries, in Africa, there is still debilitating energy poverty (World Bank, 2023).

The other reason why it will not be possible to discuss the energy transition in emerging markets without leveraging a geopolitical lens is the important role of development organisations and Western private capital in financing the increased need for resource extraction and deployment of renewable energy sources (Li et al., 2023). Although emerging markets such as South Africa are endowed with critical raw materials (CRM) needed for the energy transition, manufacturing and production houses are in the West. Africa still lacks the technology and expertise for a successful transition without partnerships with the global village. However, the extant literature on energy transition is fragmented, lacking clear frameworks for emerging market contexts (Pedersen and Andersen, 2023). Research and practice approaches in the developed markets have largely reduced energy systems to remarkably narrow configurations of energy technologies, the prices at which these technologies can deliver energy in a useful form, and the carbon emissions they release (IEA, 2023). The result is stunted energy debates that systematically underemphasise the meaning and consequences of energy systems and their changes for human societies and provide limited opportunities for people other than energy engineers, bureaucrats, and economists to make influential contributions to energy policy deliberations (Miller et al., 2013; Tzeremes et al., 2023). This paper responds to calls for energy debates that are informed by robust empirical and theoretical inquiries into what current and future energy changes will mean for diverse groups of people across the planet (e.g., Burke and Stephens, 2018; Miller et al., 2013). For these reasons, this paper focuses on energy transitions from emerging markets, with a special focus on Africa. This also informs the sampling of literature for consideration.

The overarching objective of this paper is to propose a framework of energy transition for emerging markets faced with high endowments of CRM within a context of energy and socio-economic poverty, unemployment, and inequality. Therefore, the paper answers the following questions.

a) How is energy transition conceptualised from an emerging market standpoint?
b) What challenges must emerging markets overcome for a successful just energy transition?
c) How can emerging markets overcome various challenges to accelerate the sustainable energy transition?
d) What are the important outcomes a just energy transition should deliver?

After a thorough interrogation of these questions, the paper further outlines the just energy transition implications for emerging markets' skillsets, jobs, and community resilience. By addressing these important questions, the paper makes a significant contribution to the Actor Network Theory (ANT) by identifying and demonstrating that in addition to the widely leveraged four stages of translation, energy transition would require a distinct additional stage we label ‘institutionalisation’ to show the taken-for-granted necessary for just and sustainable energy transition in emerging markets, where institutional voids have been documented (Saeed et al., 2022). The paper tackles institutional dimensions of energy transitions, thereby adding a voice to addressing necessary and urgent calls to improve a theory often criticised for being institutionally blind (Marcon Nora et al., 2023). In addition to contributing to ANT, the paper makes a significant contribution to energy management literature by developing a framework of how the energy transition could pan out in emerging markets. This answers recent calls by scholars for more research that builds theory in emerging markets contexts (Morris et al., 2023), thereby leveraging the huge potential for novel theory development (Morris et al., 2023). At a more practical level, this study is significant as nations benefit from energy transition through enhanced economic growth and environmental sustainability (Liu et al., 2022).

That we have provided the background to this manuscript by outlining some of the challenges associated with energy transitions in emerging markets, potential differences with developed markets transitions, and the contributions the paper makes to Actor Network Theory and energy management literature, we next describe the review methods used.

2. Review methodology

The literature review in this paper is based on searches in WorldCat, a database linked to library collections across the world, and Google Scholar, combining search terms like ‘renewable energy’, ‘energy transition’, ‘just energy transition’, ‘community resilience’, ‘skills’, ‘jobs’, ‘critical raw materials’, ‘Africa’, and ‘development assistance’. Further, more in-depth searches were made on selected aspects of the socio-political-economy of energy and energy transitions in Africa and other emerging markets, as well as on the experiences of South Africa which is used as an example. The sampling relied on snowballing, where the researchers tracked related papers which either cited or were referenced by a focal paper (Wohlin, 2014). Only relevant papers from the search engine results were included for snowballing. The paper is presented in six sections, with the introduction highlighting the main research questions the review sought to answer and the main contributions of the study, a methods section which is followed by a conceptualisation of energy transition from a socio-technological systems perspective. Section four interrogates the key challenges emerging market actors face as they transition from non-sustainable energy systems to more sustainable ones. After scoping the key challenges, the review paper explores some of the strategies that could help emerging markets navigate the energy transition without worsening the current inequalities, poverty, and high levels of unemployment. The final section concludes the review and suggests possible avenues for future research.

3. Conceptualising the energy transition

The concept of “energy transitions” has been used so narrowly in policy discussions that it may no longer be appropriate for capturing the broad social consequences of energy systems change unless used more nuancedly (Miller et al., 2013; Acheampong, 2023). Within the existing literature, there is a notable disparity in the usage of the concept, revealing a crucial dichotomy. This dichotomy highlights the diverse perspectives on possible energy transitions, where some emphasise sustainability and climate change mitigation, while others prioritise resilience and climate change adaptation. This plurality of transitions showcases both convergences and divergences in the approaches taken to address our complex challenges (Hoppe and de Vries, 2019; Watari et al., 2021). The literature conceptualising energy transition as a struggle with sustainability and climate change mitigation has tended to focus more on the technology and how it can help reverse the effects of carbon emission (e.g., Energy Agency, 2021; Tzeremes et al., 2023). On the other hand, the scholars who emphasise resilience and climate change adaptability have tended to focus on how communities and stakeholders could be prepared to deal with the negative impacts of climate change, for example, farmers dealing with floods and droughts or employees dealing with job losses in the event of closures such as those associated with the transition from coal-fired energy plants (Owen et al., 2022; Valero et al., 2021).

These conceptualisations show us so much of an intertwining of technological shift and socio-political struggles as society and governments must deal with the inevitable new energy direction. In this paper, we argue that the transition is neither a technology-only nor a social-only dynamic (Burke and Stephens, 2018). It is a surging dynamic that encapsulates technological and social shifts that the 21st century society must tackle with intentionality. This argument is amplified by scholars who demonstrate how, for example, powerful and enduring socio-technical imaginaries shape the ways in which nation-states understand and allocate the risks and opportunities in large projects such as nuclear power (e.g., see Jasanoff and Kim, 2018). Similarly, energy transitions could be equally enabled and propelled by purely social conditions such as fantasies arising from energy sources (Sovacool and Brossmann, 2013). The social influence on energy transition could be seen when considering why bottom-up knowledge rather than the top-down dictates of policymakers and cultural brokers tend to yield substantive results (Phadke, 2013).

Together, the preceding arguments suggest that the energy transition is a socio-technology process to be understood through a socio-technological systems theoretical lens. To that end, this review is anchored on actor network theory and suggests that technology is not created on the one hand by innovators and passively adopted by active users. This is a remarkable insight in understanding energy transition, first as a technology shift, and second, one that does not have to be driven on different ends by innovators and adopters (Hess and Sovacool, 2020). Rather, there is integration of non-human and human actors to create a stable network of actors (Aka, 2019). Conceptualising the energy transition as a network building process that seamlessly involve the integration of all actors, human and non-human provides novel insights to unpack transition trajectories into the future (Marot et al., 2022). The implications of this change in conceptualisation include ensuring the collective engagement of stakeholders at every stage of the energy transition network building process (Marcon Nora et al., 2023). This process encompasses various phases, including problematisation, interessement or interposition, enrolment, and mobilisation (Akrich, 2023). During problematisation, the primary actor endeavours to identify the core issue at hand, determining the necessary knowledge claim required to address the problem, and identifying the actors that are essential within the network. According to Callon (1986) problematisation entails the main actor showing others what constitutes the problem at hand and convincing them that they have the ‘correct’ solution. In energy transition this could be a government showing the dangers of not attending to the carbon emissions and demonstrating why energy transition is the only viable solution, described in ANT as the Obligatory Point of Passage (OPP) to save the planet (Heeks and Stanforth, 2015). This stage involves a careful examination and articulation of the challenges and opportunities associated with the energy transition (Markon Nora et al., 2023). For energy transitioning emerging markets, the government could be the primary actor, envisioning the detrimental effects of inaction in the face of the impending devastating effects of global warming (Zakari et al., 2022). In several countries, these effects are already witnessed and well-articulated in government narratives to drive the energy transition agenda. For example, in South Africa, the government set up the Just Energy Transition Commission and is fostering partnerships to spearhead the process (Tyler and Mgoduso, 2022). Some of the global warming challenges include more frequent and severe droughts, floods, and heat waves. Once the problem has been identified and crystallised, the next step is interessement.

During interessement, the primary actors actively work toward building the network by engaging in negotiations with other actors, defining their respective roles within the network (Heeks and Stanforth, 2015). This phase entails fostering a shared understanding and agreement among the stakeholders regarding their involvement and contributions to the energy transition (Akrich, 2023). An essential process during the interessement phase is how the principal actors lock the others into place by interposing themselves, weakening the links of other actors to alternative interpretations and strengthening their focus on the problematized OPP (Heeks and Stanforth, 2015). This is seen in the energy transition by discrediting fossil fuels and even suggesting an ambitious target for eliminating hydrocarbons from the energy and electricity systems (Burke and Stephens, 2018; Miller et al., 2013). In South Africa, the government set an ambitious target to phase out coal-fired power stations (Muttitt et al., 2023). This weakens the links between power utility companies and coal-producing players. The government of South Africa has already started engaging with other actors, such as the alternative transition energy funders and generators (Marot et al., 2022). The users of alternative green energy are also considered in the process, for without critical uptake of the renewable energy, and behavioural change, the transition is slowed.

Once the negotiation process is complete, enrolment comes into play. At this stage, the actors involved willingly accept the roles assigned to them and actively enrol themselves in the network. What is important at this stage is acting, thus, the principal actors put interessement into practice by actions that define the roles that are to be played in enacting the OPP and the way in which the actors will relate to one another within the network (Heeks and Stanforth, 2015). This phase signifies a commitment and readiness to collaborate and work collectively towards achieving the goals of the energy transition. For example, if original equipment manufacturers agreed to the role of providing new equipment in the previous stage, the third stage involves putting to practice those roles by starting the production process. Meanwhile, the users are expected to starting shifting from fossil fuels to renewable energy sources. The main reason for a seamless integration of generation and use of energy is because energy is highly perishable, such that it should be used as it is generated (Muttitt et al., 2023). On the other hand, although the government may initiate funding of the energy transition, the other funders identified from the previous phase must start demonstrating commitment by funding to support the rolling out of equipment and infrastructure (Benlemlih et al., 2023). By emphasising action, the ANT phase of enrolment is, therefore, an essential part of the energy transition. Fourth, mobilisation occurs as external actors, often referred to as allies, extend their support to the network (Heeks and Stanforth, 2015). External funders and the international community of stakeholders could become integral to the energy transition efforts that started with the government and possibly other few local players. These allies recognise the importance of the energy transition and contribute their resources, expertise, or influence to bolster the efforts of the network (Muttitt et al., 2023). For this to succeed, the principal actors borrow the power of their passive agent allies and put themselves into positions of their representatives or spokespeople. During this important phase, actors dedicate their attention to monitoring of diverse interests so that they remain stable (O'Connell et al., 2014). Therefore, mobilisation amplifies the network's reach and impact, facilitating broader engagement and greater effectiveness in driving the energy transition forward (Marot et al., 2022). Through emphasising the significance of stakeholder participation and employing the framework of problematisation, interessement, enrolment, and mobilisation, the energy transition network can harness collective knowledge, resources, and support for a more comprehensive and successful transition process (Justesen and Mouritsen, 2011).

Although the original ANT assumes the four important processes of building a network, for this paper we propose a fifth process we label institutionalisation. Borrowing from institutional literature (e.g., Arranz and Arroyabe, 2023) we argue that institutionalisation is important in the emerging markets energy transition because there is a lot of work to be done for the energy network to stabilise and avoid dissidence or network collapse (Heeks and Stanforth, 2015). It involves a gradual shift not only in technology but behaviours and institutions, even after the actors are mobilised in the fourth process. Studies suggest the need for joint learning and institutionalisation of emerging energy systems to reach scale (Wahlund and Palm, 2022; Øvald et al., 2023). We argue that energy transition will be just and scalable, if it is institutionalised when green energy financing, production and consumption is embedded in the energy systems to the extent of being taken for granted. This is an important process considering that energy transition networks by nature are cultural constituted processes (Mützel, 2009).

Collectively, these five processes, we argue, constitute what is known as translation in the context of emerging market energy transition. Drawing on Latour's (1999a, p. 179) perspective, translation encompasses various aspects such as displacement, drift, invention, mediation, and the establishment of new connections that did not previously exist. It captures the transformative nature of the energy transition network-building process, where actors and stakeholders collaborate to navigate the complexities and challenges of transitioning to a sustainable energy system (Gatto, 2022). Translation involves the dynamic movement and reconfiguration of ideas, knowledge, interests, and resources within the network (Heeks and Stanforth, 2015). It entails the displacement of existing practices and the introduction of novel approaches to address the demands of the energy transition. Through this process, actors are prompted to adapt, evolve, and find innovative solutions, fostering the creation of new connections and relationships at both the social and the technology dimensions.

Drift is an inherent component of translation, signifying the subtle shifts and changes that occur as the network evolves (Latour, 1999a). It represents the fluidity and adaptability of the energy transition process, as actors continuously reassess and realign their roles, strategies, and objectives to navigate the evolving landscape (Pak et al., 2023). Invention plays a vital role in translation, referring to the generation of new ideas, concepts, and technologies that can propel the energy transition forward (Poddiakov, 2023). It involves the exploration of innovative solutions and the development of novel approaches that address the challenges and opportunities presented by the transition (Pak et al., 2023). Mediation is another aspect of translation, acting as a bridge that facilitates communication, negotiation, and collaboration among diverse actors within the network (Gatto, 2022). It enables the exchange of knowledge, perspectives, and resources, fostering collective decision-making and the formation of shared goals (Paddiakov, 2023). Ultimately, the translation process creates a link that establishes connections and relationships between actors, knowledge domains, and practices that were previously separate or disjointed to better implement energy transitions (Sillak and Vasser, 2023). It signifies the transformative power of collective action and collaboration in shaping the energy transition, forging new pathways towards a sustainable and resilient future energy system (Muttitt et al., 2023).

In this vein, energy transition is conceptualised as a shift in an energy system's condition, that is more than the changes in a particular energy technology or fuel source but marked by a significant change in the energy system and is therefore, associated with one or more causes linked to the system's scale, structure, economy, energy policy, behavioural usage patterns and processes through which all these are achieved (Wahlund and Palm, 2022). The value of analysing energy changes through the lens of socio-technological systems stems from the ability to expose important aspects of energy transformation that go unrecognised and unacknowledged in other analytical approaches (Mamidi et al., 2021; Miller et al., 2013; Watari et al., 2021). These include the social processes that stimulate and manage energy transformation, the social changes that accompany shifts in energy technologies, and the social outcomes that flow from the organisation and operation of novel energy systems (Miller et al., 2013).

Having conceptualised energy transition with the ANT lens, we now turn to exploring the challenges of energy transition that are applicable in emerging markets.

4. Challenges of emerging markets energy transition

The energy transition, like any other change process is riddled with challenges emanating from uncertainties related to choices that must be made in flow. The literature review has identified four key challenges that are presented with the illustration of examples in this section.

4.1. Lock-in problem

The lock-in problem is a significant challenge in energy transition research, as it involves the influence of inertia, path dependence, and enablement on the selection of courses of action. Path dependence, characterised by the inertia of prior choices, imposes constraints on future pathways due to self-reinforcing limits (Talebzadehhosseini and Garibay, 2022; Azam et al., 2023). These limits can include factors such as sunk investment costs, increasing returns, inter-relatedness of technologies, and network effects (Sánchez and Leadem, 2018). The concept of lock-in arises from path dependence and elucidates why new energy technologies, even if superior, sustainable, and economically feasible, may not be readily adopted (Araújo, 2014). Lock-in occurs when existing systems, infrastructure, and policies create barriers that hinder the adoption of alternative energy solutions. For instance, established energy systems heavily reliant on fossil fuels often have substantial investments and infrastructure in place (Sánchez and Leadem, 2018). This extensive infrastructure, coupled with the associated costs of dismantling or replacing it, poses a significant obstacle to transitioning to cleaner and more sustainable options (De La Peña et al., 2022; Zakari et al., 2022). Additionally, vested interests and dependencies on existing systems as actors dread the potential risks of stranded assets and economic losses, contribute to the lock-in problem, further impeding the adoption of innovative energy technologies (Goldstein et al., 2023).

Addressing the lock-in problem necessitates strategic interventions to overcome the inertia and constraints imposed by path dependence. These interventions can include the formulation and implementation of supportive policies, incentives for innovation and investment in clean energy, collaborative initiatives among stakeholders, and efforts to raise public awareness and support for sustainable alternatives (Gatto, 2022, Ali et al., 2023). Recognising and understanding the lock-in problem is important for effectively navigating the energy transition. Through identifying the barriers and developing targeted strategies to mitigate them, actors can facilitate the adoption of new energy technologies and overcome the resistance posed by existing systems (De La Peña et al., 2022). Overcoming lock-in is essential for unlocking the full potential of the energy transition and realising the benefits of a more sustainable and resilient energy future.

4.2. Energy dilemma and renewable energy transition

For emerging markets, important considerations when investigating energy transitions are the questions of energy security and energy equity, jointly referred in this paper as the energy dilemma. The definition of energy security has been elusive, but our literature review has identified some important themes to understand its conceptualisation. The diversity of themes highlights the contextuality of the definitions. From a national level of analysis, the themes are energy availability, infrastructure, energy prices, societal effects, environment, governance, and energy efficiency (Ang et al., 2015). According to Liu et al. (2022a,b,c) when a nation can meet its current needs and ensure the energy infrastructure's resilience and reliability, it can provide energy security, whereas access to reliable, affordable, and abundant energy is a fundamental tenet of energy equity.

What is observable in extant literature is the shift from explaining the resistance to new renewable energy in terms of existing energy technology regimes (for example see Azam et al., 2023) to increased attention to empirically unpacking the resistance of vested interests in and around public utilities (Demski et al., 2018). This argument is laid bare when considering the example of South Africa where Eskom, the public utility's resistance to non-hydro renewable energy has been associated with the existence of a minerals–energy complex constituted by reciprocal relations between mining industries, the energy sector, and related political interests in cheap energy produced from coal (Baker et al., 2014; Baker and Burton, 2018; Ting and Byrne, 2020; see also Hochstetler, 2020).

However, further exploring the case in question, the narrative often given, like in several other developing nations is that lower income African countries do not only suffer from public utility resistance but genuine concerns over energy security and deliberate attention on developing domestic sources of energy (Hassan et al., 2022). The need for energy security is not new although in the early transition it was primarily about securing oil and gas supplies, but now it is broadly about all forms of energy including electricity (Chester, 2010). The affordability, ease of availability and technological maturity of oil in some regions have contributed to the slow uptake of investment in renewable energy projects (Qadir et al., 2021). Therefore, it is argued that commercially viable endowments of fossil fuels provide a strong incentive for continued investment in these sources, especially in emerging markets characterised with energy poverty and alternative technology resource constraints (Zakari et al., 2022). The recent rise in oil and gas investment in Uganda, Ghana and South Africa, and continued coal investment in Zimbabwe further attest to this. Scholars have described this as the 'lock-in problem' (Kemp et al., 2007), resulting in continued reliance on existing energy sources and usages. In this vein, there is fear of worsening the energy crises in emerging markets, hence lock-in in traditional energy sources (Goldthau and Sovacool, 2012).

Fig. 1 shows that Africa in general and Sub-Saharan Africa particularly is grappling with energy poverty as the low levels of access to energy suggest. Even among developing regions, Sub-Saharan Africa still has lowest percentage of people with access to electricity despite other regions moving toward converging

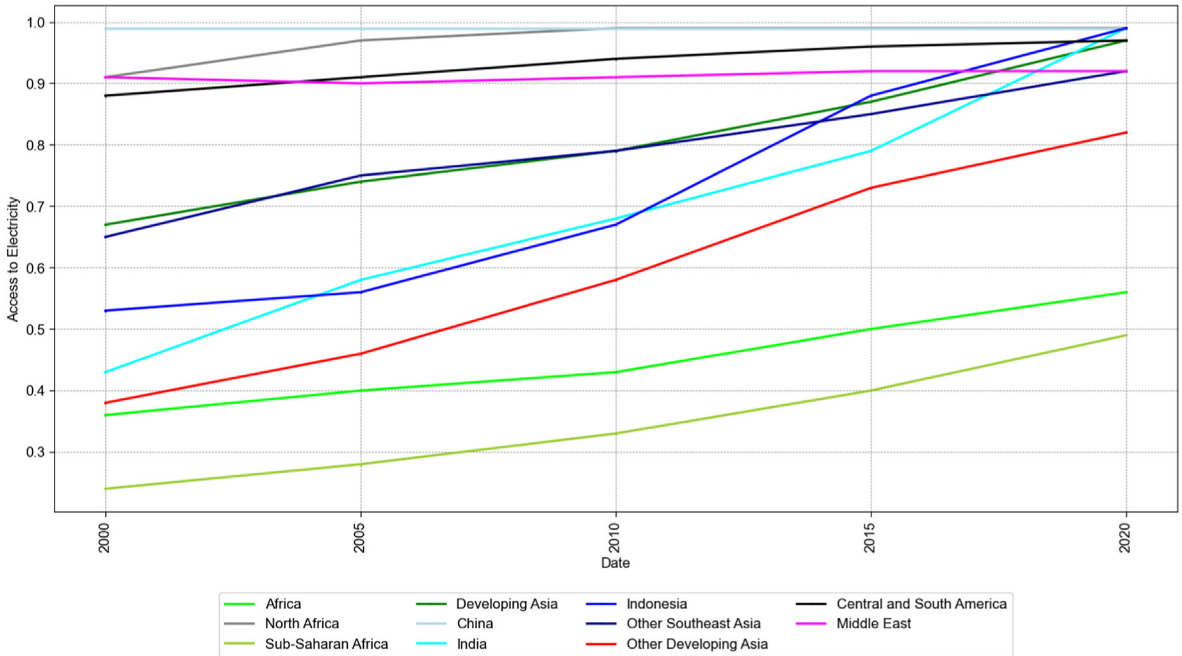

Fig. 1. The prevalence of energy poverty in selected developing countries, as indicated by regional proportion of access to electricity (World Bank, 2023).

above 90% electricity access.

The situation has been exacerbated by major conventional energy producers who have criticised the use of renewable energy renewable energy and portrayed it as costly and unpredictable (Geels et al., 2017). There are numerous biases against renewable energy with some 'doom-scholars' in different capacities thwarting the deployment of renewable energy by arguing that it is not feasible that renewable energy will meet the world's energy demand (Brook and Bradshaw, 2015; Harjanne and Korhonen, 2019; Heard et al., 2017). These pessimistic biases have impacted and indeed influenced public perception of renewable energy sources in terms of reliability, security, and affordability (Diesendorf and Elliston, 2018).

It is, therefore, proposed that:

Countries with commercially viable reserves of fossil fuels have a significant incentive to continue investing in these resources to ensure energy security. Consequently, this inclination towards maintaining fossil fuel reliance favours a gradual approach to the energy transition rather than a rapid one. The availability of abundant and economically viable fossil fuel endowments within a country creates a sense of security in meeting its energy needs. These resources can contribute to a stable energy supply, reducing dependence on external sources and potential energy vulnerabilities.

Balancing the need for energy security with the imperative for environmental sustainability requires careful consideration and the development of tailored strategies. This may include diversifying the energy mix, investing in research and development of renewable technologies, fostering international collaborations, and implementing policies that promote a just and inclusive energy transition.

4.3. Structural rigidities: financing, institutions, and the energy transition

Research on the interconnectedness of resource endowments, global markets and governance dynamics in the global north is well established (Energy Agency, I, 2021; Hoppe and de Vries, 2019). However, despite the important role of these factors in lower income countries, it remains unclear how they play out in the global south (Pedersen and Andersen, 2023). Traditionally, private investment has financed coal, oil and gas, and other non-hydro sources of energy, yet the recent spike in donor funding for renewable energy has been noticeable (Li et al., 2023). Thus, the role of funding cannot be neglected in the pace and direction of the energy transition. There is huge demand for finance to develop the much-needed infrastructure as emerging markets grapple with dilapidated powerlines which compromises energy security (Ang et al., 2015). The numerous breakdowns could result in compromised efficiency and effectiveness, even if investment were made to boost renewable energy generation.

Renewable energy generation and distribution requires very significant investments for generators and distribution channels to the end-users (Anantharajah and Setyowati, 2022). Traditionally, power generation was located close to the source of energy, for example hydropower stations, or closer to the end users as was the case with some thermal power stations. With the current rolling out of renewable energy, there is a huge opportunity to locate power generation closer to end users. However, that comes with social risk considerations and feasibility as much of the renewable energy technology requires large tracts of land (Ainou et al., 2023). The other challenge facing rollout of renewable technology is the fact that it is not always possible to conveniently utilise existing infrastructure, such as powerhouses and powerlines.

Furthermore, the question of security and vandalism is very high in emerging markets, factors less likely to be a consideration in the global north. A typical reason for investors shunning funding renewable energy projects is grid non-availability, a situation where there is electricity production, but the grid infrastructure cannot accommodate the additional power (Anantharajah and Setyowati, 2022). We call this problem *'weeding the forest'* because the power producer is generating energy which cannot be utilised. This is a common problem in emerging markets where existing infrastructure is either not available or is old, and therefore, experience costly frequent breakdowns (Belaïd, 2022). The problem gives rise to a situation where the electricity generated from a power producer goes to waste or is only partially purchased (Pilz and Al-Fagih, 2019).

Whereas significant investments in oil and gas have come from the private investment, much of non-hydro energy investment in sub-Saharan Africa could be traced to Western international financial players. South African institutional investors' holdings in coal, oil and gas companies in South Africa amount to USD 17.1 billion, ranking South Africa 19 out of 74 countries globally for the amount of money invested in fossil fuel companies (CER, 2023). Some examples of fossil investors in South Africa are the Government Employees Pension Fund, and Public Investment Corporation (CER, 2023), while renewable energy investments for the country received a boost following the International Partner Group (IPG) of five nations' pledge of $8.5 billion to support the country's transition investment plan from fossil fuels. However, the money is seen as inadequate to fund the transition and comes as a debt burden for South Africa. Some scholars observed that part of the broader renewable energy investment has geopolitical undertones (Yang et al., 2023). For example, the active investment of the USA through the U.S. International Development Finance Corporation (DFC) and the Power Africa initiative could be seen as a counter to the growing influence of China on the African continent (Bazilian et al., 2017).

As Fig. 2 shows, investment on renewable energy remain lower than fossil fuels in 2015 (a) and in 2021 (b). The other clear evidence is the static low investment in electricity networks when compared with the Asia Pacific, Europe, and North America.

From a public funding perspective, one structural rigidity emerges from fossil fuel subsidies where government measures are put in place to lower the price paid for fuel by consumers or to increase the price received by energy producers (Hayer, 2017). Several types of subsidy instruments are observed and differ between countries and can be classified into the following four categories: (i) direct financial transfers, (ii) preferential tax treatments, (iii) trade restrictions, i.e., import duties and tariffs; and (iv) regulations, i.e., price controls and rate caps (Qadir et al., 2021). Thus, governments across the world provide subsidised fossil fuels to incentivise the establishment of new industrial zones which is an important mechanism to accelerate economic growth and reduce income inequality in emerging markets (Al-Badi and AlMubarak, 2019; Alshehry and Belloumi, 2015; Howarth et al., 2017). However, such non sustainable energy subsidies are the main barriers to implementing clean energy projects (Erickson et al., 2017) through both limiting the production of renewable energy and increasing the demand for fossil fuels (UN, 2023). We argue for financial innovation, entailing the gradual removal of such subsidies and reallocation of funds to the promotion of renewable energy (Geels et al., 2017).

Some institutional rigidities emanate from information asymmetry where various stakeholders have different information about the same situation (Manjon et al., 2022). An example is the lack of information pertaining to the cost of deploying renewable energy when contrasted with the benefit of climate change mitigation. The cost of deploying renewable energy is declining with advent of new technology, yet policies in several countries remain fixated on old high-cost structures. As Fig. 3 shows, the cost of capital for a wide range of renewable energy sources has been declining from 2010 to 2018 according to figures from the IEA (2023). Private companies, including in the mining industry, for example, Sibanye-Stillwater in South Africa are taking advantage of the low capital cost to reduce their energy costs, improve power availability, lessen demand on the national grid and improve their carbon footprint by investing in solar projects (Mining Weekly, 2023) while governments remain stuck on subsidies of fossil fuels.

Following the preceding reasons, we propose that:

In the context of lower income African nations grappling with significant debt burdens, the availability of funding plays a significant role in determining the pace of their energy transition. These countries face unique challenges, as they strive to balance the urgent need for sustainable energy sources with the limited financial resources at their disposal. While funding can serve as a catalyst for accelerating the energy transition, the presence of underdeveloped policy frameworks presents a significant obstacle. The availability of adequate funding provides these nations with an opportunity to invest in renewable energy projects and infrastructure, thereby reducing their reliance on fossil fuels. Such investments not only contribute to addressing climate change and promoting environmental sustainability but also offer potential economic benefits,

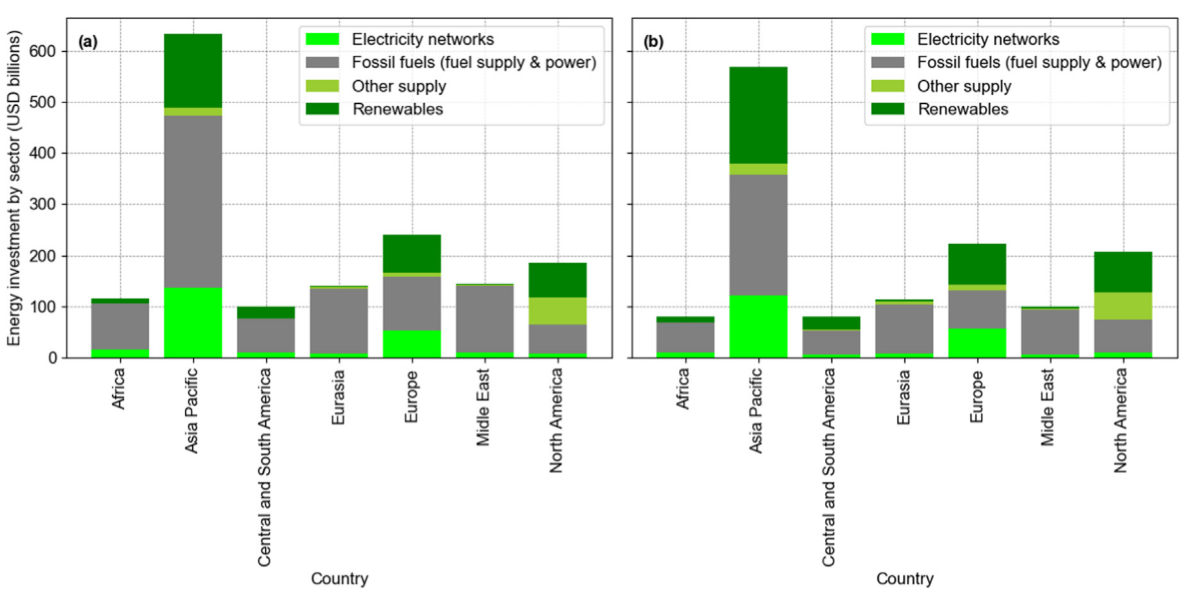

Fig. 2. Investment on renewable energy by regions (IEA, 2023). (a) shows investment in 2015, while (b) shows investment in 2021.

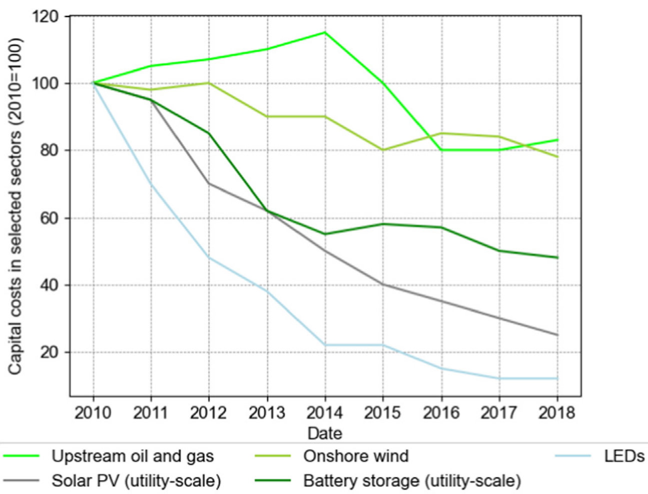

Fig. 3. Evolution of renewable energy generation costs over time. Source: International Energy Agency (IEA, 2023). Note: LEDs = light-emitting diodes, PV = photovoltaic. Capital costs represent the global weighted average costs of components or commissioned projects in the respective sectors. Solar PV and wind costs are based on calculations by IEA analysis using data from the International Renewable Energy Agency (IRENA, 2019).

including job creation and increased energy access. Therefore, financial resources can act as a powerful incentive, pushing these countries towards a more rapid energy transition.

4.4. Technology stunting: ICT, R&D and renewable energy transition

The role of ICT in energy transition is little understood as there has been limited research in this space (Li et al., 2023). However, evidence suggests that ICT is known to help countries to deliver on SDGs (Vyas-Doorgapersad, 2022), enhance energy efficiency via better management of energy resources (Zhao et al., 2016), and increase the share of renewable energy in the total level of energy consumption (Nguyen and Kakinaka, 2019), maximizing the production of renewable resources and to comfort the storage of electricity generated from renewable sources (Li et al., 2023; Tzeremes et al., 2023). Scholars argue that large capital investment requirements, low technological development, and information access are major obstacles in the renewable energy sector (e.g., Shahbaz et al., 2022). However, ICT has potential to enable countries to include renewable energy sources into the energy mix by diminishing social, knowledge, and technical barriers (Li et al., 2023). A country's ICT sector development is known to significantly impact increasing clean energy sources to ensure a sustainable future. It is important to highlight that there is debate as to the role of ICT in influencing co2 emission, because the results to verify that argument are inconclusive (Tzeremes et al., 2023).

Despite the ongoing debate, our literature review suggests that lack of investment in research and ICT is a major stumbling block to energy transition (Shahbaz et al., 2022; Hosan et al., 2022). In a landmark study, Shahbaz et al. (2022) employed panel data of 72 countries covering the period 2003–2019 to investigate the mediating effect of government governance, asymmetry, and heterogeneity between the digital economy and energy transition. The authors found that the digital economy positively affects energy transition by boosting the renewable energy consumption structure, generation structure, and by promoting governments' governance capabilities. An important finding from the study was that the digital economy positively contributes to renewable energy transition in the high-income countries, and there are regional heterogeneities in the impact of the digital economy on energy transition. Government governance was also found to have a mediating role in the relationship. Similarly, Qi et al. (2022) found that research and development investment leads to energy transition performance in terms of financial and non-financial performance. Studies in the European Union suggest that promoting energy patents in the transition is a contemporary need for a sustainable ecological solution (Chen et al., 2023), whereas studies in OPEC countries revealed that development of environment related technology (DERTI) activate the transition toward renewables (Niu et al., 2022). Together, these literatures underscore the important role of research, technology innovation and development in driving the energy transition through enabling renewable energy generation, storage, distribution, and usage options.

Building on these studies, we highlight literature from emerging markets which suggest paucity in R&D investment in these markets (Sun et al., 2023; Li et al., 2023). According to Luo and Zhang (2022) it was China's realisation that R&D expenditure intermediate as a new determinant for low carbon energy transition in Belt and Road Initiative economies, that propelled the energy transition. Similarly, Zhang and Kong (2022) found that when policies are instituted to drive energy transition, their boosting effect on renewable energy is overshadowed by resource allocation efficiency and technological innovation, which poses a serious challenge for emerging markets that lack efficiency due to stunted innovation.

Where attempts to digitise are made in emerging markets, new challenges have been experienced. For example, the threat of cybersecurity is on the rise for several countries and energy transition actors (Jakimowicz, 2022). Therefore, we argue that cybersecurity governance, which has not been widely covered in energy transition literature is an important consideration as economies digitalise for the just energy transition (Sanders et al., 2022). Specially, the convergence of Information Technologies and Operational Technology systems in industrial and public networks present several challenges related to availability, integrity, and confidentiality (Boeding et al., 2022). Cybersecurity governance are the processes and systems used to prevent damage, attack, or unauthorized access to the integrity and reliability of programs, data, and networks (Sanders et al., 2022). If cybersecurity governance is not prioritised, the energy transition is faced with serious risks (Jakimowicz, 2022; Sanders et al., 2022). For example, in February 2019, South Africa 's state-owned power company, Eskom, left a database, containing customer details, including partial credit card numbers exposed online and it is not clear the extent to which their over 5 million customers were affected by the cyber-threat (Olofinbiyi, 2022). What makes this a serious issue in South Africa is that the country was ranked as having the world 's third-highest number of cybercrime victims, with losses to cyber-attacks amounting to an estimated R2.2bn per year (Olofinbiyi, 2022).

Based on our analysis, we propose the following argument:

The lack of investment in Information and Communication Technology (ICT) development in emerging markets has a detrimental impact on the advancement of renewable energy transition. ICT plays a crucial role in enabling and optimizing renewable energy systems, facilitating efficient energy management, and promoting renewable energy integration into existing infrastructures. However, the inadequate investment in ICT development in emerging markets hinders their ability to fully leverage the potential of renewable energy sources. ICT solutions, such as smart grids, advanced metering systems, and data analytics, are instrumental in enhancing the efficiency, reliability, and flexibility of renewable energy systems. These technologies enable real-time monitoring, optimisation of energy generation and consumption patterns, and effective demand-side management. Additionally, ICT applications facilitate the integration of distributed energy resources and enable grid management strategies that support renewable energy sources.

4.5. Social dilemma

Our review of energy transition literature through a socio-technological lens reveals a social dilemma which addresses two often conflicting challenges: social impact and environmental sustainability (Liu et al., 2022). Although some scholars widely refer to the concept of energy trilemma, to describe the triple challenges of energy security, equity, and environmental sustainability (Khan et al., 2022; Shiraz et al., 2022), the additional burden of lost livelihoods for communities and employees is apparent in emerging markets when they transition from fossil fuels (Hampl, 2022). Thus, we chose to discuss the dilemma of social impact and environmental sustainability separately to underscore the importance of social issues in emerging markets which pose a huge risk to transition due to conflict over land use (Ghosh et al., 2022). The link between energy transition and sustainability is understood by considering the finding in literature that resources extraction is detrimental to the environment (Liu et al., 2022). It is argued that maintaining this balance in the era of rapid transitions to decentralized, decarbonized, and the digital system is challenging as it may risk trading off equally essential goals (Shiraz et al., 2022).

The estimation is that at least 30 energy transition minerals and metals (ETMs) form the material base for the energy transition, of which more than 50% is located on or near the lands of Indigenous and peasant peoples, two groups whose rights to consultation and free prior informed consent are embedded in United Nations declarations (Owen et al., 2022). This poses a significant challenge related to intersectionality with territories located in remote areas, mostly in developing countries (Jiskani et al., 2022). The projected rate of energy transition will certainly influence indigeneity, human modification of land, food production, water risk, conflict, and in the process compromising capacity measures for project permitting, consultation and consent (Islam et al., 2022; Owen et al., 2022).

Unless a deliberate effort is made to achieve a balance, there is a danger of overly focusing on social and environmental crisis associated with climate change at the expense of new impacts and dynamics associated with expanded resources extraction to support the transition (Huang et al., 2023). This is a likely outcome of the current scenario where considerations about the local effects of resource extraction are superseded by concerns about the possible severity of climate change and the urgent need to act (Jiskani et al., 2022). It is important to note that energy transition metals and minerals demand is projected to increase by as much as over 40 times for lithium and about 20–25 times for graphite, cobalt, and nickel (IMF, 2023). Although copper and iron are ubiquitous, an estimated demand rise of 275% for copper will lead to a giant leap in exploitation of this and other metals (Huang et al., 2023). For example, electric vehicle manufacturing requires several energy transition minerals including lithium, cobalt, and nickel, while deployment of hydrogen technology as an energy carrier will drive the demand for nickel and zirconium for electrolysers, and for platinum-group metals for fuel cells (Owen et al., 2022). What seems to be clear is that the growing demand for energy transition minerals and the accompanying rapid exploitation will intensify competition between climate change mitigations, environmental values, land use and the protection of land-connected peoples' rights (Huang et al., 2023).

Therefore, energy transition sparks debate about social dilemmas emanating from lack of clarity on the trade-offs between mitigating climate change impacts and the associated socio-economic costs to host communities (Zakari et al., 2022). It is important to take a collaborative approach to advancing the energy transition so that actions are coordinated with full participation of affected stakeholders to mitigate social and environmental threats to sustainability as enunciated in the United Nations Sustainable Development Goals 2030; Owen et al. (2022). Additionally, the capacities of political steering and governance (Kemp et al., 2007a) are limited because of several problems, for example, ambivalent national goals or priorities between climate change challenges and socio-economic progress; uncertainty about cause–effect relations and, distributed power of control (Funtowicz et al., 1998; Roe, 1998; Kemp et al., 2007a; Stepanov et al., 2023); political myopia; determination of short-term steps; and a danger of lock-in (Kemp et al., 2007; Kemfert et al., 2022).

Fig. 4 below shows the electricity generation by source in South Africa from 1990 to 2020. As seen from the graphs, coal is clearly the highest source of electricity generation, while wind and solar make an insignificant contribution. The dilemmas faced with government and other actors in the country is whether to prioritise energy transition goals or compromise transition commitments and ensure people and industry have electricity.

With energy transition comes the accelerated shutting down of coal powered stations. This is accompanied by huge burdens for developing nations from loss of employment, social networks, and livelihoods for host communities (Pedersen and Andersen, 2023). For example, at renewable energy plants the local communities are more vulnerable to the negative effects, such as noise pollution, landscape changes, and the potential for accidents, whereas communities that consume the same electricity are not situated near the plants, are less likely to experience such impacts (Nuru et al., 2022). Such unfair distribution of benefits and impacts leads people to neither support nor invest in the renewable energy sector (Bal et al., 2023). We argue for additional benefits to be provided to those residents directly affected due to their proximity to a renewable energy plant and distribution infrastructure, particularly in the case of wind and solar farms (Qadir et al., 2021).

Considering the arguments raised here, we proposed that:

Emerging markets government and other actors are faced with social dilemmas in an attempt to balance climate change demands for transitioning to cleaner sources of energy, yet such transition comes at a huge sacrifice and a risk of violating indigenous human rights. Dealing with these dilemmas calls for collaborative social innovation.

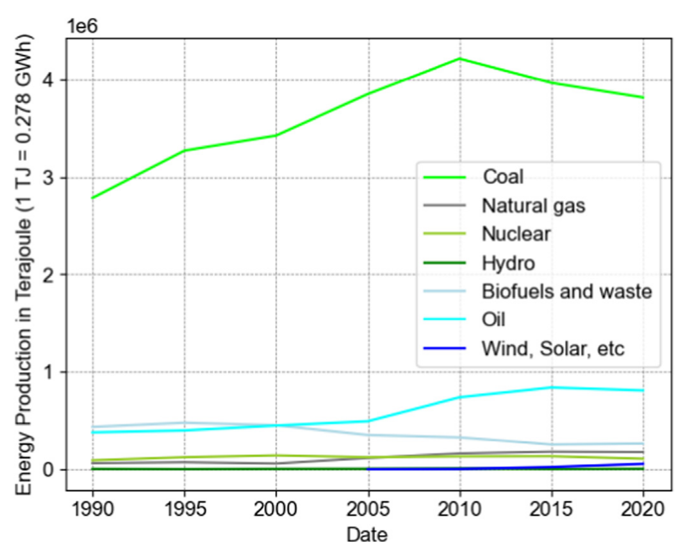

Fig. 4. South Africa's electricity generation over time (IEA, 2023).

5. Strategies for driving just energy transitions in emerging markets

What is undeniable is the fact that climate change affects every aspect of life on earth, including wildfires, flooding, heat waves and droughts, increasingly threatening human wellbeing and environmental health. As such the energy transition is probably the only way to serve the planet. However, this salvation is squarely hinged on metals and minerals which is the reason why accelerated mining is justified but should never be at the expense of society and the environment. This paper suggests some strategies drawn from literature.

5.1. Government commitment and institutional dynamism

Governance is an important predictor of natural resources price volatility (Liu et al., 2022). In a highly uncertain financial and political environment, companies, governments, and societies confront major policy and business choices regarding whether, where, and how much to invest in coal, natural gas, renewable energy, unconventional oil, and carbon sequestration projects respectively (Miller et al., 2013), which has a bearing on price volatility (Liu et al., 2022a,b,c). This is more so important considering the huge investments required for energy projects generally and especially renewable energy development (IEA, 2011). Although technological progress has seen the cost of developing wind and solar energy declining, there is growing scientific and political discourses motivating major policy initiatives and financial investments across the globe designed to foster the adoption of renewable energy technologies to reduce carbon emissions while creating green jobs (Ali et al., 2023). This is essentially due to the potential devastating impacts of climate change that the world is facing in the 21st century and beyond (IEA, 2023).

The potential and experienced impacts of climate change have seen tensions emerging around different approaches to building renewable energy plants and their implications for ecosystems, worker health, and communities, including utility-scale and community scale facilities and distributed energy systems. There is lack of clarity resulting from lack of policy or policy inconsistencies around transition energy approaches (Ali et al., 2023). Currently, for example, in South Africa there is ongoing debate whether to rapidly decommission coal powered stations as the country is grappling with an energy crisis characterised by socio-economic stressing loadshedding. This is why we call for both commitment and policy reforms to deal with the transition decidedly yet from a policy informed standpoint.

The question is not merely about whether there is policy to regulate the transition, but the policy must be crafted with the full participation of all stakeholders (Zahoor et al., 2022). This is important to avoid conflicts such as those emerging from other parts of the world. For example, in the USA the advent of new hydraulic fracturing or “fracking” technologies have enabled the extraction of natural gas from shale formations to drive prices to extraordinarily low levels, leading to gas replacement of coal. However, these developments gave birth to a new front in social conflicts over energy around concerns about the short-term health hazards of chemicals used in the fracking process, which are opaque to the public because of industry secrecy, and the still large ongoing carbon emissions associated with a surge in gas-fired electricity production, which perpetuates dependence on fossil fuels (Miller et al., 2013).

Similarly, even in cases where the transition is powered by exploitation of minerals and metals, lessons from The Lithium Triangles of Chile, Argentina, and Bolivia, in South America, and Zimbabwe, Namibia and Democratic Republic of Congo in Southern Africa demonstrate that the lithium extraction comes at a cost to society (Petavratzi et al., 2022; Vera et al., 2023).

The process used to extract and process lithium heavily draws underground water leading to livelihood costs to local communities in some of the world's worst water scarce semi-arid regions (Vera et al., 2023). It is therefore argued that there is need for stakeholder participation in drafting policies to drive the energy transition. A recent publication by the World Bank also suggests that government commitment and policy reform is an important precondition for successful energy transition. The call for policy reform is getting louder with the Bowen Basin Mining Club (BBMC) in Australia criticising The Queensland Strong and Sustainable Resources Communities Act of 2017 for focusing only on benefits for communities during resources entities operation periods, ignoring the long-term impacts on resources such as energy, water and food associated with closure and post mining ecosystems (BBMC, 2023). Although the world bank highlights these conditions as necessary globally, we argue that in emerging markets the need is even more pressing considering the inherent institutional voids that exist (Rafei et al., 2022).

What is clear from literature is that an energy transition is clearly underway, but the timing, pathways and forms are becoming more uncertain. For example, policy frameworks would need to address questions around whether to incentivise large scale utility generation of renewable energy or instead prefer community scale or even rooftop individual generation. Policy direction will have implications on mopping private investment in the sector because the appetite for private sector investing in renewable energy is found to heavily depend on policy frameworks (World Bank, 2023). This view is valid as energy industry practitioners and governments are grappling with policy frameworks to support financing energy transitions in several developing countries (Saadaoui and Chtourou, 2022). For example, mining industry entities in developing countries are deploying solar energy to minimise operation disruptions induced by loadshedding. Blanket Mine and Zimplats Mines in Zimbabwe are clear examples. However, they face challenges as there is no clear policy in terms of how they may distribute excess energy to the national grid nor receive compensation for the energy they generate should they wish to share with communities. Rallying all stakeholders to play an active role in the transition requires government commitment and advancing policy appropriately.

To this effect, there is need for emerging market governments to streamline processes to tackle bureaucracy which can be a major hurdle in the development of the renewable energy market, as witnessed in several countries where obtaining government approval for projects is often challenging, and projects are not always awarded based on merit (Zhao et al., 2016; Ali et al., 2023). Consequently, to avoid loss of confidence among potential investors there is need to establish policy with standard tariffs under an independent regulatory authority to encourage renewable energy investors to participate in clean energy projects. The authority could deploy standard testing and certification procedures for small power producers to promote a credible renewable energy market (Ji and Zhang, 2019).

Without appropriate policy, energy justice will be difficult to achieve because of the negative effects of renewable energy generation, such as huge solar farms allocated to large scale projects at the expense of local communities grazing land. An example is a large-scale solar farm in India whose energy in not accessed by locals because the voltage is too high for them, yet they suffer all the inconvenience associated with paving way for the new farm (Bryant et al., 2022). Therefore, a comprehensive policy design should address broader issues, considering four key parameters: (1) renewable energy potential assessment, (2) infrastructure development (Ali et al., 2023), (3) successful integration into the system (Li, 2022), and (4) implications on society and the environment (Liu et al., 2022a,b,c).

Together, the reviewed literature suggests that resources policies play a fundamental role in the protection and development of the benefits of sustainable resource use, management, and conservation (Zahoor et al., 2022). To build a robust policy framework calls for blending public and private policy processes, history, institutions, and current events (Bilal et al., 2022; Hassan et al., 2022; Taghizadeh-Hesary et al., 2022; Zakari et al., 2022a). This focus on context is important as it helps to pay attention to the various structural rigidities prevailing in emerging markets. For this reason, the government of Pakistan was recommended to build biogas facilities by adopting an economic strategy, owner training to build capacity for day-to-day operations in addition to providing professional technical assistance to enhance uptake of biogas technology (Ali et al., 2023).

5.2. Phased approach of energy systems transition

Several literature streams demonstrate how a phased approach could be a useful strategy in managing changes that are either triggered by systems dynamism in business strategy (Lyneis, 1999), technological transitions such as cloud migration (Rashmi and Sahoo, 2012), human factors in dealing with knowledge management (Horak, 2001) or other biological shifts such as medical treatment in patients (Mutebi, et al., 2020). In line with a socio-technology perspective, the energy system transition for emerging markets would benefit from phasing the human as well as the technological aspects of the changes. This is especially true considering the knowledge gaps that are inherent regarding the enrolment processes when people are expected to be part of the network of renewable energy users.

For example, people who are used to national grid supplied energy will need to adjust to the reality of microgrids and sometimes having to run their own system as is the case with solar and biogas energy (Ali et al., 2023). Within the ANT phases of translation, there is need for a phased approach so that projects are managed appropriately. The first step is to do a feasibility and needs analysis where a thorough analysis of the situation is warranted. This involves consideration of existing structural limitations in technology, infrastructure, renewable energy readiness, and energy poverty levels in the local area, or the country (Ali et al., 2023). Before phasing out coal power stations, for example, emerging nations must do a feasibility study of their energy generation capacity in line with the transition goals of a country (Husika et al., 2022). Next, there is need for a social and environmental impact assessment. One area that has resulted from energy transition is the increased demand for minerals and metals which are critical for the energy transition which has potential for far-reaching impacts on the environment and communities (Zakari et al., 2022). Scholars have acknowledged the serious impacts of lithium mining on underground water in semi-arid regions such as Namibia, Zimbabwe, and the Chile (Vera et al., 2023). Meanwhile, the rolling out of renewable equipment has impacts on the environment and on communities and may have cost implications where renewable energy comes at a higher cost to users (Yang et al., 2023).

The third process is phased implementation, where nations and users transition to renewable energy gradually by combining traditional energy sources with renewables until scale is reached before phasing out the traditional sources (Do and Burke, 2023). As already highlighted, timing is very important to ensure that generation expansion is aligned with usage, which calls for gradual behavioural shifts in energy consumption patterns. The shift entails not only changing energy types but behaviour, for example, regarding how people conserve energy. This calls for increased knowledge dissemination to educate the population for achieving critical mass of informed renewable energy users (Ali et al., 2023). The fourth process is control and monitoring which entails close follow-up to ensure that the planned processes are executed accordingly (Do and Burke, 2023). This also allows for fine-tuning of processes, for example, where it is realised that some estimated targets may have been unrealistic or in the event of unforeseen events emerging. A typical example was the Ukraine-Russia crisis which disrupted global energy supply chains and resulted in several countries having to revert to previously abandoned coal energy. Fig. 5 shows the waterfall model of a phased energy transition.

In line with the phased approach to energy transition, we propose the following:

In dealing with the lock-in problem associated with countries that are stuck in fossil energy a gradual phased approach would be ideal. The gradual energy transition approach acknowledges the complexities associated with shifting from fossil fuels to renewable and sustainable energy systems. It recognises the need to address various challenges, including technological limitations, infrastructure requirements, and economic considerations. By taking a gradual approach, countries can better manage the potential disruptions and uncertainties that may arise during the transition process.

Moreover, a gradual transition allows for a smoother adjustment for industries and communities heavily reliant on fossil fuels. It provides time for necessary adjustments, such as retraining the workforce, diversifying the energy mix, and implementing supportive policies and incentives. This measured approach aims to minimise any adverse socioeconomic impacts that may result from a sudden shift away from fossil fuels. While a gradual energy transition may provide short-term benefits in terms of energy security and managing economic concerns, it is essential to consider the long-term implications. The detrimental effects of climate change, environmental degradation, and the need to mitigate greenhouse gas emissions necessitate a more urgent and comprehensive transition towards sustainable energy sources.

5.3. Research and technological innovation

An idea commonly used in energy transitions is the concept of impedance of path dependence which argues that the transition advances following a path that progressively updates based on past experiences (Derkenbaeva et al., 2022). However, an alternative notion of path creation highlights the agency of entrepreneurs who at least in part define the flow of events (Dawson and Daniel, 2010; Inigo and Albareda, 2019; Rennings, 2000). Innovation is, therefore,

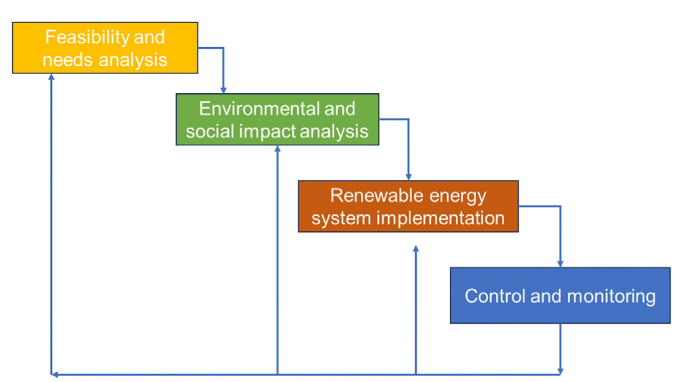

Fig. 5. A phased approach strategy of energy transition.

an important part of advancing the energy transition where alternative technologies are considered to mitigate the negative impacts of energy transition minerals exploitation and green energy deployment (Onifade and Alola, 2022). Some examples include research to advance waterless mining and minerals processing, minimum waste generation and mineral valorisation and advanced circularity (Vera et al., 2023). There is potential to look at alternative technology such as replacing copper cables with aluminium or other cheap and easily available materials to mitigate the risk of theft in developing contexts where electricity cables are at high risk of theft (Flores et al., 2018). It is expected that innovative technologies will play a key role in meeting the multifaceted goals of economic growth, poverty reduction, and tackling climate change in the context of energy in emerging markets (Liu et al., 2022a,b,c; Vyas-Doorgapersad, 2022).

Research and innovation are associated with high levels of risk, cost and uncertainty yet there is merit for governments to fund them because they enable countries to become self-reliant in renewable energy production (McDowall, 2018) by for example, producing their own solar panels and wind turbines, as is the case with Chinese wind plant manufacturers which have been largely dependent on the support of government R&D incentives (He, 2016). Fig. 6 shows the domination of China's government in investing in research and innovation in the renewable energy sector. Invariably, Africa and the 'rest of the world' governments are not paying much attention on research and development.

Although there is wide acceptance that with advancing technological innovation comes effective energy transition (for example, Ali et al., 2023), what literature is not giving due recognition is the central role of indigenous knowledge in the innovation process (Velasco-Herrejón et al., 2022; Hampl, 2022; Doyon et al., 2021). However, as Ottinger (2013) argues renewable energy could have as dire negative impacts on society as fossil fuels unless we gave greater credence to the "street science" of local communities within debates about the health and environmental concerns of wind power (Nikas et al., 2020). Street science is based on listening to the voice of communities on matters that affect them and genuinely dialogue with them for constructive collaborative decision making (Fjellheim, 2023; Hampl, 2022). For example, the technology around 'fracking' for gas and exploitation of lithium technology could be advanced with the contribution of local knowledge to better understand livelihoods patterns. The legal requirement for several countries is for a social and environmental impact assessment before a project starts, but in practice, the exercise has become a tick box exercise (Nikas et al., 2020).

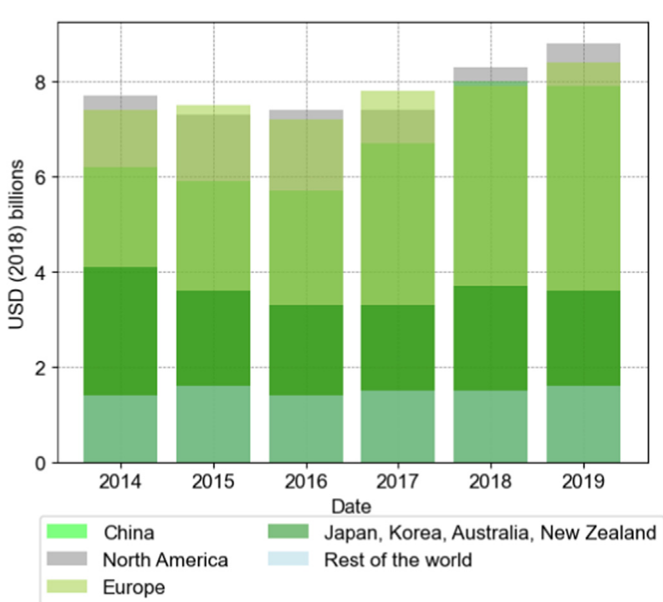

Fig. 6. Government spending on energy research, development, and deployment since 2014, including Preliminary 2018 Data (IEA, 2023).

In emerging economies, the role of citizens and activists in recasting the politics of energy has gathered traction as seen by their role in nuclear power in India (Bhadra, 2013). An example of how to seek more just outcomes for renewable energy developments could be seen from the "landscape symposium" model developed for engaging citizens in the decision-making process for wind power (Phadke, 2013). We argue, therefore, that learning is an integral concept that relates to energy transitions (Nikas et al., 2020). While learning generally implies improvement, based on novel, or accrued knowledge, it can be operationalised in a variety of ways, including experience curves and adaptive capacity for which local communities can play a key role, because the question of whose knowledge is considered relevant has profound consequences for the shape of energy systems (Miller et al., 2013; Velasco-Herrejón et al., 2022; Hampl, 2022; Doyon et al., 2021). Any technological innovation for energy transition should be assessed for its implications on people and the broader society because energy transitions may have impacts that span beyond technology and physical environments (Zakari et al., 2022).

Meanwhile, a study by Ali et al. (2023) found that the renewable energy projects' awareness through social media positively moderates the association between a) biogas plant maintenance barriers, b) financial support for biogas plants, c) economic and policy barriers, d) owner satisfaction with biogas, and the intention to adopt biogas technology in Pakistan. Thus, technology play an important role not only in influencing generation and distribution, but usage patterns, which are important for reaching scale. Following the proffered arguments, it is proposed, therefore, that:

The lack of investment in ICT development limits emerging markets' capacity to capitalize on the benefits offered by renewable energy technologies. However, ICT development fosters innovation and creates opportunities for new business models and market mechanisms in the renewable energy sector. Advanced ICT infrastructure and digital platforms enable the deployment of innovative financing models, such as peer-to-peer energy trading and crowd-funded renewable energy projects. These models can unlock additional sources of investment and foster greater participation from local communities, promoting the democratisation of renewable energy transition.

Addressing this challenge requires a concerted effort to prioritise and invest in ICT development in emerging markets. Governments, private sector entities, and international organisations should collaborate to create an enabling environment for ICT infrastructure deployment, including broadband connectivity, data centres, and digital skills development. Additionally, targeted financial mechanisms and incentives should be established to attract investments in ICT projects specifically tailored to support renewable energy transition in emerging markets. By bridging the gap in ICT development, emerging markets can unlock the full potential of renewable energy sources, improve energy efficiency, and accelerate the transition to a sustainable energy future. The integration of ICT solutions not only enhances renewable energy deployment but also drives economic growth, job creation, and technological innovation in these markets. Therefore, a strategic focus on ICT development, including cybersecurity is imperative to overcome the barriers hindering the advancement of renewable energy transition in emerging markets.

5.4. Social innovation

Extant literature suggests that the just energy transition will succeed when viewed as more than just technological innovation but a combination with social innovation. In the context of energy transition this paper defines social innovation as innovation that is social in its means and which contributes to low carbon energy transition, civic empowerment and social goals pertaining to the general wellbeing of communities (Hoppe and de Vries, 2018; Coy et al., 2021). It is characterised by innovative activities and services that are motivated by the need to meet a social need and are predominantly developed and diffused through organisations whose purposes are primarily social.

As noted in this paper, there are several social and behavioural barriers to energy transition that need to be overcome for a smooth transition. We identify social acceptance of renewable energy projects by communities, socio-political stakeholders, and the market as the leading barriers (Coy et al., 2021). These play an important role in informing the extent to which attitudes and values, strategies and policies, organisational structures and processes, delivery systems, and services throughout existing energy systems may hinder or support energy transitions. It is because of this social dimension that we argue for more than just technological innovation but harnessing new ways of collaboration, decision-making, and of mobilizing society (Miller et al., 2013). Since renewable energy technology is typically disruptive and bottom-up in nature there is need to address existing institutions, that often impede the development and diffusion of promising sustainable energy innovations (Wahlund and Palm, 2022).

However, through social innovation new ideas of meeting society goals are championed, for example, leveraging community energy and renewable energy cooperatives. When communities come together in energy cooperatives, they utilise new ways of decision making, in which technological developments go hand in hand with innovative ways of uniting different interests via cooperative decision making (Ang et al., 2015; Dawson and Daniel, 2010; Hoppe and de Vries, 2019). This addresses the social dilemma associated with energy transitions where benefits to one group of stakeholders could be at the expense of other sections' interests or rights. Some aspects of energy transition typically understudied are demographic (for gender aspects see Nikas et al., 2020) and behavioural components of energy use which usually must shift as part of the transition (Nikas et al., 2020). An example of initiatives to achieve this is green 'nudges', which is characteristically initiating subtle modifications in people's decision context to gently move them towards sustainable choices without changing monetary incentives or an option set itself (Wittmayer et al., 2022). Behavioural pattern changes are important considering that, for example, in Germany's transition, changes in policy could not deliver the desired carbon reduction targets due to industries such as manufacturing and transportation whose energy usage practices did not change (Schiffer and Trüby, 2018). An idea worth noting is that social innovation can be *individualistic*, looking at social innovation as local solutions to community problems that are not addressed by extant systems or *structural*, perceiving it in terms of institutional structures and context as key drivers of social innovation (Schlindwein and Montalvo, 2023; Nikas et al., 2020). Some important conditions Include (i) crises and opportunities; (ii) the agency of civil society; (iii) reconfiguration of social practices, institutions, and networks; and (iv) new ways of working that emerge from these reconfigurations.

We build on the work of Hochstetler (2020) who suggest that social innovation moves through a '4i' process, which consists of: (i) conceiving ideas, (ii) making an intervention, (iii) implementation, and (iv) resultant (social) impact. We add that these processes can only succeed with (iv) meaningful stakeholder engagement (Tyler and Mgoduso, 2022; Buana et al., 2023). These processes lead to the creation of long-lasting boundary spanning outcomes aimed at addressing societal needs by fundamentally changing the relationships, positions, and rules between stakeholders, including end-users, typically by open processes of participation, exchange, and collaboration (Markon Nora et al., 2023).

Taking an energy transition perspective, we argue that social innovation encompasses introducing new energy practices, for example, related to the likes of production, storage, distribution, and use, new behaviours, and relationships (Chen et al., 2023; Owen et al., 2022; Sillak and Vasser, 2023; Tyler and Mgoduso, 2022; Velasco-Herrejón et al., 2022) for supporting and managing social groups or new solutions that contribute to low carbon energy transition and at the same time to solving social problems, to attain social goals, like community empowerment, alleviating (energy) poverty, and increasing the general wellbeing of the community including building resilience for 'climate co-benefits' (Hoppe and de Vries, 2019). Meanwhile, the dance between technological innovation and social innovation is apparent as the advent of smart energy systems is driving social innovation, for example, new market models (like peer-to-peer trading of locally generated energy), new actor configurations, and coordinated citizen action like community energy is taking shape as the roles of private and institutional actors are evolving (Sillak and Vasser, 2023; Tyler and Mgoduso, 2022).

An example of social innovative initiative is the Integrated Community Energy Systems (ICES) where community energy plays a key role (Acosta et al., 2018). For emerging economies, ICES could be an important form of local energy system focusing on the collective use of distributed energy resources (Li et al., 2023). It is argued that they are socio-technical systems with high potential to advance local energy systems into socially inclusive, environmentally friendly energy systems that also stimulate local economies (Acosta et al., 2018). Some scholars have recommended equal distribution of renewable energy technologies across the urban and rural areas in African states, leveraging tactics like "green energy women" to act as local nodes which provide new knowledge and technology to other community members for wider impact to poor and remote households, many of which would otherwise lack power access (Zakari et al., 2022).

Reading from Fig. 7 it can be noted that deployment of low carbon technologies can contribute to a reduction in required energy production when combined with behavioural changes than just a technological approach. This, therefore, shows that social innovation will play an increasing role in the energy transition heading to the 2050 Net Zero Energy (NZE) scenario.

5.5. Financial innovation

While the era of fossil fuels is coming to an end due to their adverse impact on the climate, hope and expectations are rising for renewables. This underscores the need for increased investment in energy resources that meet the global demand without harming the already battered environment (Zakari et al., 2022). The World Bank (2023), in their 'Scaling Up to Phase Down' Roadmap argue that:

> "Without the means to fund an energy transition and network infrastructure, developing countries often pay more for electricity; they cannot access energy efficiency or renewable energy projects, and are locked into fossil fuel projects with high and volatile costs. In essence, they face a triple penalty for their energy transition that becomes a poverty trap".

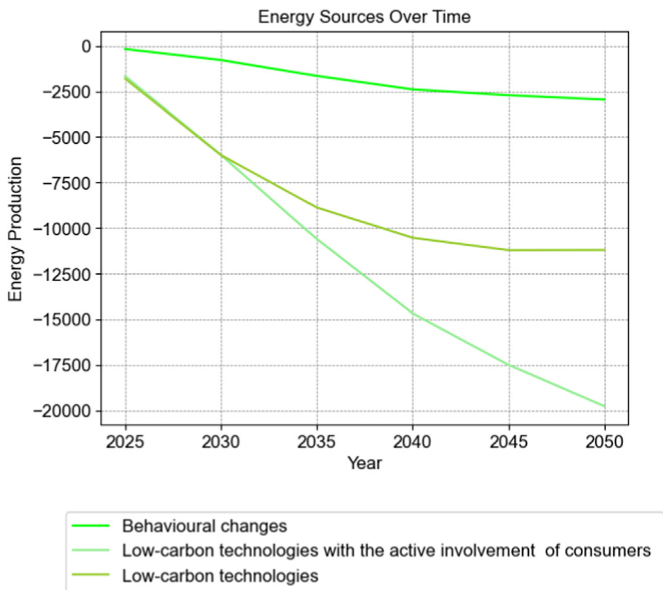

Fig. 7. The predicted contribution of low carbon technologies, behavioural changes and combined efforts of behavioural changes and low carbon technologies.

Clean forms of energy, such as solar, wind, hydro, hydrogen, and thermal power are both successful and readily available, yet investment in them has fluctuated over the past few years (Ainou et al., 2023; Ajadi et al., 2019; Anantharajah and Setyowati, 2022; Baker, 2021; Benlemlih et al., 2023).

One of the key reasons for this lacklustre attitude towards investment is the unwillingness of investors to take investment risk due to changes in policies and the amount of capital involved, which makes financing the energy transition arguably one of the biggest problems of the 21st century (Qadir et al., 2021).

While public financing of research and development (R&D) for renewable energy is needed to overcome the financing gap and to develop renewable energy technologies, there is need for increased private participation (De La Peña et al., 2022). For example, there was a significant difference in technology development when the R&D funding for renewable energy was reduced in Europe (Bointner et al., 2016a), yet technology improvement lowers the cost of renewable energy (Li et al., 2022), which ultimately helps to increase the level of investment in this sector due to anticipated higher returns (Olabi and Abdelkareem, 2022; Inigo and Albareda, 2019).

Private financing can play an important role in the energy transition when there is appropriate supporting policy and can take any of these innovative forms: (1) feed-in-tariffs (FiTs)- a policy designed to support the development of renewable energy sources by providing a guaranteed, above-market price for producers over a long-term contract (Zhang et al., 2023). Through this policy direction, the government has room to compensate green energy users who generate more energy than they consume (Zakari et al., 2022); (2) government financial incentives-this is a policy direction which allows the government to give private actors incentives to participate in the consumption and production of renewable energy (Zakari et al., 2022; Zhang et al., 2023). Some of the widely recommended incentives include green energy tax credits, grants, and green energy loan programs to finance renewable energy technologies and projects (Isah et al., 2023). For example, a renewable energy tax credit may be refundable or non-refundable (Curtin et al., 2017Curtin et al., 2017). If it is refundable, households get paid say 25% of their purchases of renewable energy equipment like solar panels. For non-refundable tax credit, energy generators have reductions of what they owe in taxes to the tune of their renewable energy investments (Curtin et al., 2017). In emerging markets there is need for supporting legislature to ensure the contracts are enforced and corruption is curbed.

Fig. 8 shows the declining trend of renewable energy investment from venture capital since 2008. Admittedly, 2008 is remembered for the global economic crises and the source of funding never recovered despite a sharp rise between 2004 and 2008. Another interesting observation from the graphs is that although government funding was higher than corporate funding of research and development, after 2016 there was a sharp increase in corporate investment on R&D above government investment. This suggests that as the energy transition unfolds, the government takes a more important role than industry, yet as time progresses corporate investment becomes more important. The main driver of private participation is a well-developed supportive legal framework.

We argue for a carrot and stick approach to the energy transition in emerging markets based on incentives for more investment in and usage of transition energy (Zhang et al., 2023), and penalties for continued investment and usage of dirty energy (Haji Esmaeili, Sobhani, Ebrahimi, Szmerekovsky, Dybing & Keramati, 2023). Fiscal and tax incentives in form of waiver of taxes and duties on the imports of renewable energy equipment to encourage progressive integration of renewable energy into the system is a key mechanism for promoting expansion (World Bank, 2023). For example, China implemented this policy with remarkable success to encourage the import of technologies that had not yet reached maturity in China (Zhao et al., 2016). Several other initiatives are proposed in literature, such as taxing fossil fuel generation, which increases the per-unit cost of unclean electricity generation and influencing the competition between the two power production technologies (Lipp, 2007). Another fiscal incentive is to provide loans at a minimal rate, specifically to construct renewable energy plants for residential use (Zhi et al., 2014).

However, in several emerging markets, this must be done gradually with intentionality to avoid exacerbating the energy poverty (World Bank, 2023). Similarly, some scholars have proposed the use of generated green energy to be used as digital currency, combining the idea of Fits, net metering (NM), and other market centred mechanisms to build resilient renewable energy systems by rewarding 'prosumers' (both producers and consumers)

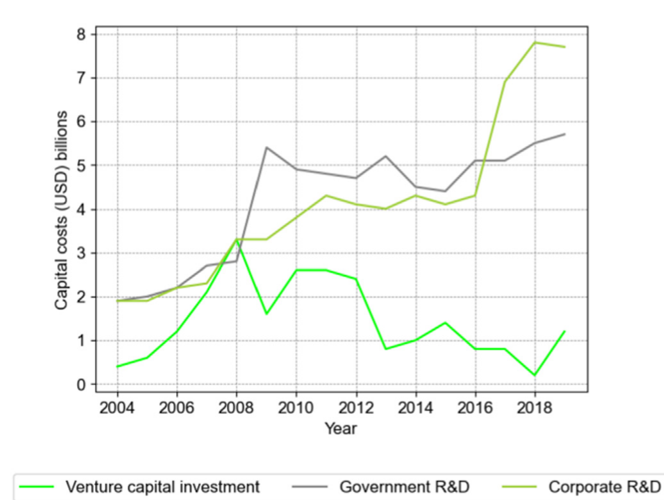

Fig. 8. The declining trend of renewable energy projects since 2008 (Frankfurt School-UNEP CentreBNEF, 2020).

(Mihaylov et al., 2019).

Institutional investors have been slow in joining the investment call due to the risks, lower returns and too long payback periods associated with renewable energy projects (World Bank, 2023). The need for huge investment is still something not to be wished away, giving rise to the need for new policies that favour collaboration (Bal et al., 2023; Sun et al., 2023). This is important considering that, for example, energy storage technologies require investment and cooperation among different stakeholders, such as the investor, consumer, and utility company (IEA, 2023). It is difficult to estimate the share of each stakeholder, which makes regulatory changes necessary to define how each stakeholder is charged/compensated (Bal et al., 2023). There is a close relationship between policy and private investment which suggests the need for policy design as a precondition for private funding (World Bank, 2023; Sun et al., 2023). Some scholars highlight the benefits of community renewable energy storage and suggest that the direct involvement of citizens through community storage increases the pace of the renewable transition and encourages individuals to invest in clean energy technologies (e.g., Parra et al., 2017).

Fig. 9 shows the step-by-step model of financial innovation in emerging markets energy transitions.

As depicted in Fig. 9, the main actors need to define the financial needs to meet the desired energy transition pace, which is followed by profiling the different financial sources of funds (Sun et al., 2023). There are typically three sources namely primary sources, which is funding such as that by the main actor like the government, secondary funding is the funding that is sourced from immediate actors that include the private sector, for example venture capital, withing a country or incentivising private users to invest in renewable energy (Zakari et al., 2022), and tertiary sources such as the global energy transition funders (Qaiser, 2022), including the World Bank or European Union countries which partly funded South Africa and other African countries' transition (Tyler and Mgoduso, 2022). To secure the funds, some creative mechanisms include withdrawing fossil energy subsidies and investing the funds in renewable energy projects (Sendstad et al., 2022). Once the funding has been secured, there will be need to service the financial obligations and for that reason, nations need to be careful when receiving secondary and tertiary funding as the interest rates could be expensive which could lead to debt crisis (Tyler and Mgoduso, 2022). The diagram shows feedback loop where results of control and monitoring inform the adjustments of different stages of the model. Having outlined the different challenges and proposed strategies for dealing with them, the paper turns to building a framework of energy transition in emerging markets. Based on the arguments raised in this section, it is proposed that:

The impact of funding on energy transition outcomes in lower income African nations is tempered by the prevailing underdeveloped policy frameworks. Inadequate policy frameworks fail to provide clear guidelines, incentives, and regulations that encourage a shift towards renewable energy sources. As a result, despite the availability of funding, the investment landscape remains tilted towards continued investment in fossil fuels, perpetuating the existing energy infrastructure and hindering progress towards a sustainable energy future. Addressing this challenge requires a comprehensive approach that combines targeted funding mechanisms with the development of robust policy frameworks. By aligning financial resources with supportive policies, these nations can effectively navigate the complexities of energy transition. This approach will not only enable the accelerated adoption of renewable energy technologies but also foster the creation of a sustainable and resilient energy system, capable of meeting the needs of their populations while mitigating the adverse impacts of climate change.

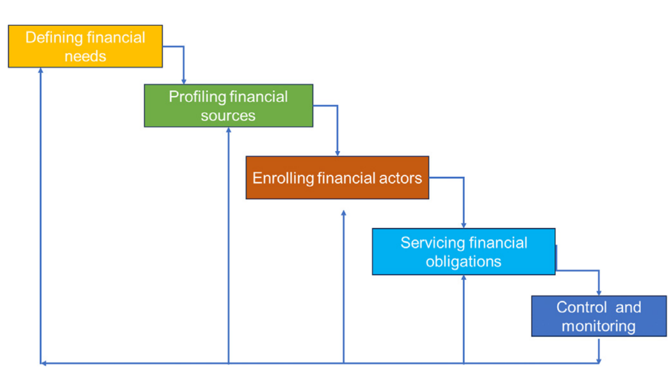

Fig. 9. The financial innovation model for energy transitions.

5.6. *Towards a dynamic framework of just energy transition in emerging markets*

Building on the findings of our literature review, we integrate literature to build a framework of just energy transition in emerging markets which are characterised by several challenges. Fig. 10 is a theorisation of the arguments delivered in the review. We draw from ANT (Latour, 1999a) to propose that the energy transition succeeds when the starting point is the *problematisation* process involving principal actors leading the processes by identifying the common problem facing the actors (Aka, 2019; Akrich, 2023; Pak et al., 2023; Hess and Sovacool, 2020; Justesen and Mouritsen, 2011).

In the context of energy transition this could be the government and other actors, such as the mining industry leading the identification, and communication of the debilitating effects of global warming, and biodiversity loss to other actors (Heeks and Stanforth, 2015; Zakari et al., 2022). There is, therefore, need to proffer energy transition as the Obligatory Passage Point to saving the planet (Aka, 2019). As demonstrated in the literature, this stage calls for *government commitment to a collaborative energy transition* (Miller et al., 2013; Tyler and Mgoduso, 2022; Power et al., 2016). When the government is committed, energy transition succeeds because the government is the traditional custodian of the environment and expectation is for it to lead the transition (World Bank, 2023). In collaboration with other principal actors, the government could champion *social innovation* so that the transition is beyond technological change but encompasses change in behaviour, attitudes and habits around energy generation, usage, and systems (Hoppe and de Vries, 2018). At this point, it is important to overcome *social dilemmas*, which may otherwise prevent translation to the next phase of the transition (Owen et al., 2022). This underscores the need for energy transition which takes care of the societal needs and environmental sustainability (Zakari et al., 2022).

The next phase of translation is *interessement* which involves principal actors locking the others into place by interposing themselves, weakening the links of other actors to alternative interpretations and strengthening their focus on the problematized OPP (energy transition) (Callon, 1986; Aka, 2019; Akrich, 2023; Pak et al., 2023; Hess and Sovacool, 2020; Justesen and Mouritsen, 2011). At this point, transition to green energy is communicated as the only way out and fossil fuels are portrayed as destructive to the environment (Heeks and Stanforth, 2015; Zakari et al., 2022). Government commitment demonstrated in the problematisation phase drives government funded investment to lead the transition (IEA, 2023; Wang et al., 2022). The investment would cover research and development, technological innovations, expansion of

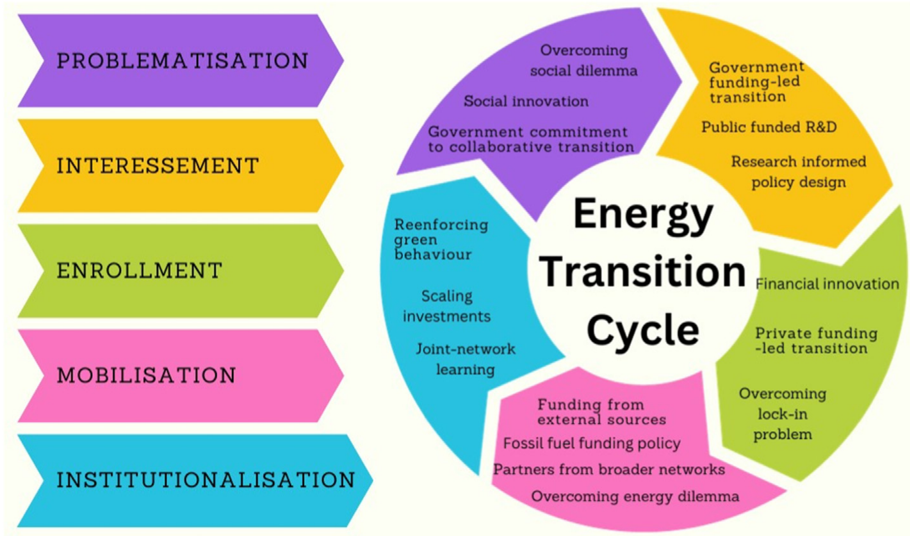

Fig. 10. Emerging market dynamic energy transition framework.

ICT supported by strong cybersecurity governance and policy development (Arranz and Arroyabe, 2023).

By so doing the energy transition network starts taking shape as more actors start to see merit in *enrolling* into the network, which is the third phase of the energy transition (Latour, 1999a). This is the phase when the principal actors put *interessement* into practice by actions that define the roles that are to be played in enacting the OPP (energy transition) and the way in which the others will relate to one another within the network (Callon, 1986; Aka, 2019; Akrich, 2023; Pak et al., 2023; Hess and Sovacool, 2020; Justesen and Mouritsen, 2011). For example, the roles of private industry players, communities, mining companies, and public players, such as the national utility actors are given specific roles to play, be it in terms of production, distribution, or responsible usage (LaMonaca and Ryan, 2022). Leveraging R&D, and policy design, which was done in the previous phase, there is *enrolment* of actors, including those playing a significant funding role (IEA, 2023; LaMonaca and Ryan, 2022). Therefore, private actors, sometimes as private public partnerships become the leading source of funds for the energy transition as they may eclipse government funding at this phase (IEA, 2023; Aleluia et al., 2022). It is important to point out that policies and all commitments must be for a just energy transition, guided by social innovation (Miller et al., 2013). Social innovation entails crafting alternative jobs and skills for employees working in transitioning environments in addition to building resilient communities (Ningrum et al., 2022; Muttitt et al., 2023; Nikas et al., 2020; Nuru et al., 2022). This also entails finding innovative land uses and a changing economic and social systems in former fossil fuel mining environments, while the extraction of energy transition minerals is done responsibly in emerging mining zones (Owen et al., 2022; Ningrum et al., 2022; Muttitt et al., 2023; Nikas et al., 2020). Lock-in problems are overcome by collaborative efforts of enrolled actors as they gradually take a phased approach to energy transition (Lyneis, 1999; Rashmi and Sahoo, 2012; Horak, 2001; Mutebi et al., 2020; Ali et al., 2023; Yang et al., 2023).

The phase of mobilisation is when other external actors join the network attracted by the momentum generated from past phases of the transition journey (Heeks and Stanforth, 2015). It is important for the principal actors to borrow the force of their passive agent allies and turn themselves into their representatives or spokespeople (Heeks and Stanforth, 2015; Aka, 2019; Akrich, 2023; Pak et al., 2023; Hess and Sovacool, 2020; Justesen and Mouritsen, 2011). This is when, for example, mining industry players take the initiative to drive energy transition in the communities, supporting government or local authorities' efforts (Blinova et al., 2022). The roles of government, local authorities and large-scale private companies are integrated in emerging markets when it comes to sustainable development. The mining industry in South Africa is already driving energy transition by investing significantly in alternative energy sources, for example Sibanye-Stillwater, Rio Tinto Richards Bay and South 32 are some of the leaders in leveraging the opportunity presented by the OPP of energy transition in support of government efforts (e.g., Mining Weekly, 2023). A key feature of this phase is the gradual, phased addition of external funders and revisiting of funding policy of fossil fuels (World Bank, 2023). It would be useful for the transition process to be gradual to balance energy poverty and the commitment of actors to a just energy transition (Rashmi and Sahoo, 2012; Horak, 2001; Mutebi et al., 2020; Ali et al., 2023; Yang et al., 2023).

Fig. 10 gives a detailed just energy transition framework for dynamic emerging market. Although processes are presented in different segments to show the processes, it is important to note that the processes are dynamic and once initiated, they perpetuate to the subsequent phases. For example, social innovation is required from start and all the way, and government funding does not end at the beginning of the transition but rather continues as other funding sources add to the already existing sources.

As the network mobilises, the process results in stability where human and non-human actors find themselves comfortable with each other (Heeks and Stanforth, 2015). The network then shifts to the next level which we proposed in this paper based on a wide review of institutional literature (Arranz and Arroyabe, 2023) suggesting that for energy transition to be scaled, there is need to achieve taken-for-granted status, a process we labelled *institutionalisation* as the fifth phase of the just energy transition process in emerging markets. Literature has highlighted the importance of institutional change in energy transitions (Milchram et al., 2019). Institutionalisation is important for emerging markets because renewable energy and the technology involved in supporting Operational Technology and Information Technology are not yet institutionalised as people still lack affordable basic electricity access (IEA, 2023; Markard, 2018). The process involves leveraging joint regulatory and social learning to scale behavioural change and new technological innovation (Milchram et al., 2019; Vazquez and

Hallack, 2018). Learning is important to keep the momentum going in the face of lacking basic digital and other skills in some communities. Thus, there need for training to skill and to upskill communities and employees who work in phasing out fossils is emphasised in literature (Banerjee and Schuitema, 2022; Bray et al., 2022).

6. Conclusions and direction for future research

The world is grappling with the adverse effects of climate change such as heat waves, veld fires, incessant droughts, floods, and the rising sea level. These challenges have had a significant toll on society and the environment, which has prompted the global community to call for urgent action to reverse the debilitating scourge. What is clear, though, is the huge surge in demand for renewable energy minerals and metals. The rising demand has a potentially serious impact on society because this review suggests that the transition seems to be more than just a technology shift as it involves changes in the ways in which people and the energy technology integrate to avoid the impeding global climate catastrophe. As such the transition will leave a trail of increased inequality, unfair distribution of the benefits and impacts of the transition for source communities and user communities.

The review identifies five challenges that emerging markets need to deal with and include the lock-in problem, energy security, structural rigidities, technology stunting and social dilemmas. For the transition to be just and avoid burdening the already battered communities, this paper proposed five strategies, namely, phased and gradual transition, government commitment and institutional dynamism as a precondition to create a conducive investment environment for private sector participation, research and technological innovation to create intentionality driven self-sufficiency and home grown solutions, social innovation to enable a transition that builds the resilience and support of local communities through meaningful stakeholder engagement, and financial innovation to ensure financial investment that leverages private and public sources, including local communities through community cooperatives.

In doing that the paper has made significant contributions to the energy body of knowledge by proposing a theoretical framework for just energy transition in emerging markets. The framework extends the actor network theory by suggesting a fifth phase labelled institutionalisation to highlight the importance of institutions in these contexts. Drawing from this paper, we propose some future research directions.

Future research could test the proposed framework against emerging market countries undergoing transition. This is an important research direction as there is currently scarce research on the direction, pace, and impacts of energy transitions in emerging economies. Another stream of research could be to look at strategies for building resilient societies in the face of the energy transition. This review has exposed some important insights by finding that the energy transition is not merely a technology shift but has socio-economic impacts which require the deployment of socio-technology systems thinking to tackle. We also suggest that alternative theories be tested to give a fuller understanding of the transition processes and outcomes. Some of the promising theories could be the legitimacy theory to interrogate the legitimacy of the just energy transition because it has emerged as a controversial concept, considering that it is not a piece of legislature nor a theoretical perspective, rendering it fluid. This study deliberately reviewed the energy dilemma of energy security and equity on one hand and the social dilemma of social impacts and environmental crises. Future studies could look at the combined role of these challenges, as a quadrilemma, on energy transitions.

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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.

References

Acheampong, A.O., 2023. Governance, credit access and clean cooking technologies in Sub-Saharan Africa: implications for energy transition. J. Pol. Model. 45 (2), 445–468.
Acosta, C., Ortega, M., Bunsen, T., Koirala, B.P., Ghorbani, A., 2018. Facilitating energy transition through energy commons: an application of socio-ecological systems framework for integrated community energy systems. Sustainability 10 (2), 366.
Ainou, F.Z., Ali, M., Sadiq, M., 2023. Green energy security assessment in Morocco: green finance as a step toward sustainable energy transition. Environ. Sci. Pollut. Control Ser. 30 (22), 61411–61429.
Ajadi, T., Boyle, R., Strahan, D., Kimmel, M., Collins, B., Cheung, A., Becker, L., 2019. Global trends in renewable energy. UN environment program. Frankfurt School. Retrieved from. https://www.fs-unep-centre.org/wp-content/uploads/2020/06/GTR_2020.pdf. on 20/10/2023.
Aka, K.G., 2019. Actor-network theory to understand, track and succeed in a sustainable innovation development process. J. Clean. Prod. 225, 524–540. https://doi.org/10.1016/j.jclepro.2019.03.351.
Akrich, M., 2023. Actor network theory, bruno Latour, and the CSI. Soc. Stud. Sci. 53 (2), 169–173.
Al-Badi, A., Al Mubarak, I., 2019. Growing energy demand in the GCC countries. Arab J. Basic Appl. Sci. 26 (1), 488–496.
Aleluia, J., Tharakan, P., Chikkatur, A.P., Shrimali, G., Chen, X., 2022. Accelerating a clean energy transition in Southeast Asia: role of governments and public policy. Renew. Sustain. Energy Rev. 159, 112226.
Ali, S., Yan, Q., Razzaq, A., Khan, I., Irfan, M., 2023. Modeling factors of biogas technology adoption: a roadmap towards environmental sustainability and green revolution. Environ. Sci. Pollut. Control Ser. 30 (5), 11838–11860.
Alshehry, A.S., Belloumi, M., 2015. Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia. Renew. Sustain. Energy Rev. 41, 237–247.
Anantharajah, K., Setyowati, A.B., 2022. Beyond promises: realities of climate finance justice and energy transitions in Asia and the Pacific. Energy Res. Social Sci. 89, 102550.
Ang, B.W., Choong, W.L., Ng, T.S., 2015. Energy security: definitions, dimensions, and indexes. Renew. Sustain. Energy Rev. 42, 1077–1093. https://doi.org/10.1016/j.rser.2014.10.064.
Araújo, K., 2014. The emerging field of energy transitions: progress, challenges, and opportunities. Energy Res. Social Sci. 1, 112–121.
Arranz, C.F., Arroyabe, M.F., 2023. Institutional theory and circular economy business models: the case of the European Union and the role of consumption policies. J. Environ. Manag. 340, 117906.
Azam, W., Khan, I., Ali, S.A., 2023. Alternative energy and natural resources in determining environmental sustainability: a look at the role of government final consumption expenditures in France. Environ. Sci. Pollut. Control Ser. 30 (1), 1949–1965.
Baker, L., 2021. Procurement, Finance and the Energy Transition: between Global Processes and Territorial Realities. Environment and Planning: Natural Space. Advance online publication. https://doi.org/10.1177/2514848621991121.
Baker, L., Burton, J., 2018. The politics of procurement and the low-carbon transition in South Africa. In: Handbook of International Political Economy of Energy and Natural Resources. Edward Elgar Publishing), pp. 91–106.
Baker, L., Newell, P., Phillips, J., 2014. The political economy of energy transitions: the case of South Africa. New Polit. Econ. 19, 791–818.
Bal, M., Stok, M., Bombaerts, G., Huijts, N., Schneider, P., Spahn, A., Buskens, V., 2023. A fairway to fairness: toward a richer conceptualization of fairness perceptions for just energy transitions. Energy Res. Social Sci. 103, 103213.
Banerjee, A., Schuitema, G., 2022. How just are just transition plans? Perceptions of decarbonisation and low-carbon energy transitions among peat workers in Ireland. Energy Res. Social Sci. 88, 102616.
Bazilian, M., Sovacool, B., Moss, T., 2017. Rethinking energy statecraft: United States foreign policy and the changing geopolitics of energy. Global Policy 8 (3),

422–425.
Belaïd, F., 2022. Implications of poorly designed climate policy on energy poverty: global reflections on the current surge in energy prices. Energy Res. Social Sci. 92, 102790.
Benlemlih, M., Jaballah, J., Kermiche, L., 2023. Does financing strategy accelerate corporate energy transition? Evidence from green bonds. Bus. Strat. Environ. 32 (1), 878–889.
Bhadra, M., 2013. Fighting nuclear energy, fighting for India's democracy. Science as Culture 22 (2), 238–246.
Bilal, Khan I., Tan, D., Azam, W., Tauseef Hassan, S., 2022. Alternate energy sources and environmental quality: the impact of infation dynamics. Gondwana Res. https://doi.org/10.1016/j.gr.2021.12.011.
Blinova, E., Ponomarenko, T., Knysh, V., 2022. Analyzing the Concept of Corporate Sustainability in the Context of Sustainable Business Development in the Mining Sector with Elements of Circular Economy. Sustainability 14 (13), 8163.
Boeding, M., Boswell, K., Hempel, M., Sharif, H., Lopez Jr., J., Perumalla, K., 2022. Survey of cybersecurity governance, threats, and countermeasures for the power grid. Energies 15 (22), 8692.
Bointner, R., Pezzutto, S., Grilli, G., Sparber, W., 2016a. Financing innovations for the renewable energy transition in Europe. Energies 9 (12), 990.
Bray, R., Montero, A.M., Ford, R., 2022. Skills deployment for a 'just'net zero energy transition. Environ. Innov. Soc. Transit. 42, 395–410.
Brook, B.W., Bradshaw, C.J., 2015. Key role for nuclear energy in global biodiversity conservation. Conservation Biology 29 (3), 702–712.
Bryant, G., Ghosh, D., Morcom, J., Pillail, P., 2022. India's enormous solar park was meant to help poor communities. But it left the landless stricken. The Conversation. Retrieved from. https://theconversation.com/indias-enormous-solar-park-was-meant-to-help-poor-communities-but-it-left-the-landless-stricken-189789. on 20/10/2023.
Buana, Y., Mursitama, T.N., Abdinagoro, S.B., Pradipto, Y.D., 2023. Stakeholder engagement by power system experts of Indonesia electricity sector for sustainable energy transition. Int. J. Energy Sect. Manag. 17 (3), 474–488.
Burke, M.J., Stephens, J.C., 2018. Political power and renewable energy futures: a critical review. Energy Res. Social Sci. 35, 78–93.
Callon, M., 1986. Some elements of a sociology of translation: domestication of the scallops and the fishermen of St. Brieuc Bay. In: Law, J. (Ed.), Power, Action, and Belief: A New Sociology of Knowledge? Routledge, London, pp. 196–223.
CER (Center for Environmental Rights), 2023. New data reveals extent of South African investors' fossil fuel holdings. Retrieved on 15 June 2023 from. https://cer.org.za/news/new-data-reveals-extent-of-south-african-investors-fossil-fuel-holdings.
Chen, J., Huang, S., Kamran, H.W., 2023. Empowering sustainability practices through energy transition for sustainable development goal 7: the role of energy patents and natural resources among European Union economies through advanced panel. Energy Pol. 176, 113499.
Chester, L., 2010. Conceptualising energy security and making explicit its polysemic nature. Energy Pol. 38, 887–895.
Coy, D., Malekpour, S., Saeri, A.K., Dargaville, R., 2021. Rethinking community empowerment in the energy transformation: a critical review of the definitions, drivers and outcomes. Energy Res. Social Sci. 72, 101871.
Curtin, J., McInerney, C., Gallachóir, B.Ó., 2017. Financial incentives to mobilise local citizens as investors in low-carbon technologies: A systematic literature review. Renew. Sustain. Energy Rev. 75, 534–547.
Dawson, P., Daniel, L., 2010. Understanding social innovation: a provisional framework. Int. J. Technol. Manag. 51 (1), 9. https://doi.org/10.1504/IJTM.2010.033125.
De La Peña, L., Guo, R., Cao, X., Ni, X., Zhang, W., 2022. Accelerating the energy transition to achieve carbon neutrality. Resour. Conserv. Recycl. 177, 105957.
Demski, C., Poortinga, W., Whitmarsh, L., Böhm, G., Fisher, S., Steg, L., Pohjolainen, P., 2018. National context is a key determinant of energy security concerns across Europe. Nat. Energy 3 (10), 882–888.
Derkenbaeva, E., Vega, S.H., Hofstede, G.J., Van Leeuwen, E., 2022. Positive energy districts: mainstreaming energy transition in urban areas. Renew. Sustain. Energy Rev. 153, 111782.
Diesendorf, M., Elliston, B., 2018. The feasibility of 100% renewable electricity systems: A response to critics. Renew. Sustain. Energy Rev. 93, 318–330.
Do, T.N., Burke, P.J., 2023. Phasing out coal power in a developing country context: insights from Vietnam. Energy Pol. 176, 113512.
Doyon, A., Boron, J., Williams, S., 2021. Unsettling transitions: representing Indigenous peoples and knowledge in transitions research. Energy Res. Social Sci. 81, 102255.
Energy Agency, I, 2021. Review 2021 Assessing the Effects of Economic Recoveries on Global Energy Demand and CO2 Emissions in 2021 Global Energy. International Energy Agency. Retrieved from. www.iea.org/t&c/.
Erickson, P., Down, A., Lazarus, M., Koplow, D., 2017. Effect of subsidies to fossil fuel companies on United States crude oil production. Nature Energy 2 (11), 891–898.
Fjellheim, E.M., 2023. Wind energy on trial in saepmie: epistemic controversies and strategic ignorance in Norway's green energy transition. Arctic Review on Law and Politics 14, 140–168.
Flores, F.U., Seidman, D.N., Dunand, D.C., Vo, N.Q., 2018. Development of high-strength and high-electrical-conductivity aluminium alloys for power transmission conductors. In: *Light Metals 2018*. Springer International Publishing, pp. 247–251.
Frankfurt School-UNEP Centre/BNEF, 2020. Global Trends in Renewable Energy Investment 2020. http://www.fs-unep-centre.org. (Accessed 20 June 2023).
Funtowicz, S., Ravetz, J., O'Connor, M., 1998. Challenges in the use of science for sustainable development. International Journal of Sustainable Development 1 (1), 99–107.
Gatto, A., 2022. The energy futures we want: a research and policy agenda for energy transitions. Energy Res. Social Sci. 89, 102639.
Geels, F.W., Sovacool, B.K., Schwanen, T., Sorrell, S., 2017. Sociotechnical transitions for deep decarbonization. Science 357 (6357), 1242–1244.
Ghosh, D., Bryant, G., Pillai, P., 2022. Who wins and who loses from renewable energy transition? Large-scale solar, land, and livelihood in Karnataka, India. Globalizations 1–16.
Goldstein, J.E., Neimark, B., Garvey, B., Phelps, J., 2023. Unlocking "lock-in" and path dependency: a review across disciplines and socio-environmental contexts. World Dev. 161, 106116.
Goldthau, A., Sovacool, B.K., 2012. The uniqueness of the energy security, justice, and governance problem. Energy Pol. 41, 232–240.
Haji Esmaeili, S.A., Sobhani, A., Ebrahimi, S., Szmerekovsky, J., Dybing, A., Keramati, A., 2023. Location allocation of biorefineries for a switchgrass-based bioethanol supply chain using energy consumption and emissions. Logistics 7 (1), 5.
Hampl, N., 2022. Consume less or grow sustainably? Matching energy systems with Indigenous worldviews in Panama. Regional Studies, Regional Science 9 (1), 412–424.
Harjanne, A., Korhonen, J.M., 2019. Abandoning the concept of renewable energy. Energy policy 127, 330–340.
Hassan, S.T., Batool, B., Zhu, B., Khan, I., 2022. Environmental complexity of globalization, education, and income inequalities: new insights of energy poverty. J. Clean. Prod. 340 (August 2021), 130735. https://doi.org/10.1016/j.jclepro.2022.130735.
Hayer, S., 2017. Fossil Fuel Subsidies. EPRS: European Parliamentary Research Service, Belgium. Retrieved from. https://policycommons.net/artifacts/1339186/fossil-fuel-subsidies/1948628/. on 21 Oct 2023. CID: 20.500.12592/dzf5th.
He, D.X., 2016. Coping with climate change and China's wind energy sustainable development. Advances in Climate Change Research 7 (1–2), 3–9.
Heard, B.P., Brook, B.W., Wigley, T.M., Bradshaw, C.J., 2017. Burden of proof: A comprehensive review of the feasibility of 100% renewable-electricity systems. Renew. Sustain. Energy Rev. 76, 1122–1133.
Heeks, R., Stanforth, C., 2015. Technological change in developing countries: opening the black box of process using actor–network theory. Dev. Stud. Res. 2 (1), 33–50.
Hess, D.J., Sovacool, B.K., 2020. Sociotechnical matters: reviewing and integrating science and technology studies with energy social science. Energy Res. Social Sci. 65, 101462.
Hochstetler, K., 2020. Political Economies of Energy Transition: Wind and Solar Power in Brazil and South Africa. Cambridge University Press.
Hoppe, T., De Vries, G., 2018. Social innovation and the energy transition. Sustainability 11 (1), 141.
Hoppe, T., de Vries, G., 2019. Social innovation and the energy transition. Sustainability 11 (1). https://doi.org/10.3390/su11010141.
Horak, B.J., 2001. Dealing with human factors and managing change in knowledge management: a phased approach. Top. Health Inf. Manag. 21 (3), 8–17.
Hosan, S., Karmaker, S.C., Rahman, M.M., Chapman, A.J., Saha, B.B., 2022. Dynamic links among the demographic dividend, digitalization, energy intensity and sustainable economic growth: empirical evidence from emerging economies. J. Clean. Prod. 330, 129858.
Howarth, C., Viner, D., Dessai, S., Rapley, C., Jones, A., 2017. Enhancing the contribution and role of practitioner knowledge in the Intergovernmental Panel on Climate Change (IPCC) Working Group (WG) II process: Insights from UK workshops. Climate Services 5, 3–10.
Huang, Q., Khan, G.D., Yoshida, Y., 2023. Assessing health and dietary issues of households displaced due to the aynak copper mine project, Afghanistan. Extr. Ind. Soc. 15, 101299.
Husika, A., Zecevic, N., Numic, I., Dzaferovic, E., 2022. Scenario analysis of a coal reduction share in the power generation in Bosnia and Herzegovina until 2050. Sustainability 14 (21), 13751.
Inigo, E.A., Albareda, L., 2019. Sustainability-oriented innovation dynamics: levels of dynamic capabilities and their path-dependent and self-reinforcing logics. Technol. Forecast. Soc. Change 139, 334–351. https://doi.org/10.1016/j.techfore.2018.11.023.
Isah, A., Dioha, M.O., Debnath, R., Abraham-Dukuma, M.C., Butu, H.M., 2023. Financing renewable energy: policy insights from Brazil and Nigeria. Energy Sustain. Soc. 13 (1), 1–16.
Islam, M.M., Sohag, K., Alam, M.M., 2022. Mineral import demand and clean energy transitions in the top mineral-importing countries. Resour. Pol. 78, 102893.
Jakimowicz, A., 2022. The energy transition as a super wicked problem: the energy sector in the era of prosumer capitalism. Energies 15 (23), 9109.
Ji, Q., Zhang, D., 2019. How much does financial development contribute to renewable energy growth and upgrading of energy structure in China? Energy Policy 128, 114–124.
Jiskani, I.M., Moreno-Cabezali, B.M., Rehman, A.U., Fernandez-Crehuet, J.M., Uddin, S., 2022. Implications to secure mineral supply for clean energy technologies for developing countries: a fuzzy based risk analysis for mining projects. J. Clean. Prod. 358, 132055.
Justesen, L., Mouritsen, J., 2011. Effects of actor-network theory in accounting research. Accounting. Audit. Account. J. 24 (2), 161–193.

Kemfert, C., Präger, F., Braunger, I., Hoffart, F.M., Brauers, H., 2022. The expansion of natural gas infrastructure puts energy transitions at risk. Nat. Energy 7 (7), 582–587.
Kemp, R., Rotmans, J., Loorbach, D., 2007a. Assessing the Dutch energy transition policy: how does it deal with dilemmas of managing transitions? J. Environ. Pol. Plann. 9 (3–4), 315–331. https://doi.org/10.1080/15239080701622816.
Kemp, R., Rotmans, J., Loorbach, D., 2007b. Assessing the Dutch energy transition policy: how does it deal with dilemmas of managing transitions? J. Environ. Pol. Plann. 9 (3–4), 315–331.
Khan, I., Zakari, A., Dagar, V., Singh, S., 2022. World energy trilemma and transformative energy developments as determinants of economic growth amid environmental sustainability. Energy Econ. 108, 105884.
LaMonaca, S., Ryan, L., 2022. The state of play in electric vehicle charging services–A review of infrastructure provision, players, and policies. Renew. Sustain. Energy Rev. 154, 111733.
Li, N., Hakvoort, R.A., Lukszo, Z., 2022. Cost allocation in integrated community energy systems—performance assessment. Appl. Energy 307, 118155.
Latour, B., 1999a. For David Bloor... and beyond: A reply to David Bloor's. Studies in history and philosophy of science 30, 113–130.
Li, W., Cao, N., Xiang, Z., 2023. Drivers of renewable energy transition: the role of ICT, human development, financialisationsation, and R&D investment in China. Renew. Energy 206, 441–450. https://doi.org/10.1016/j.renene.2023.02.027.
Lipp, J., 2007. Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. Energy policy 35 (11), 5481–5495.
Liu, H., Alharthi, M., Atil, A., Zafar, M.W., Khan, I., 2022a. A non-linear analysis of the impacts of natural resources and education on environmental quality: green energy and its role in the future. Resour. Pol. 79, 102940.
Liu, H., Khan, I., Zakari, A., Alharthi, M., 2022b. Roles of trilemma in the world energy sector and transition towards sustainable energy: a study of economic growth and the environment. Energy Pol. 170, 113238.
Liu, H., Saleem, M.M., Al-Faryan, M.A.S., Khan, I., Zafar, M.W., 2022c. Impact of governance and globalization on natural resources volatility: the role of financial development in the Middle East North Africa countries. Resour. Pol. 78, 102881.
Luo, S., Zhang, S., 2022. How R&D expenditure intermediate as a new determinants for low carbon energy transition in Belt and Road Initiative economies. Renew. Energy 197, 101–109.
Lyneis, J.M., 1999. System dynamics for business strategy: a phased approach. Syst. Dynam. Rev.: J. Syst. Dynamic. Soc. 15 (1), 37–70.
Mamidi, V., Marisetty, V.B., Thomas, E.N., 2021. Clean energy transition and intertemporal socio-economic development: evidence from an emerging market. Energy Econ. 101. https://doi.org/10.1016/j.eneco.2021.105392.
Manjon, M.J., Merino, A., Cairns, I., 2022. Business as not usual: a systematic literature review of social entrepreneurship, social innovation, and energy poverty to accelerate the just energy transition. Energy Res. Social Sci. 90, 102624.
Marcon Nora, Alberton, A., Ayala, 2023. Stakeholder theory and actor-network theory: The stakeholder engagement in energy transitions. Business Strategy and the Environment 32 (1), 673–685.
Markard, J., 2018. The next phase of the energy transition and its implications for research and policy. Nat. Energy 3 (8), 628–633. https://doi.org/10.1038/s41560-018-0171-7.
Marot, A., Kelly, A., Naglic, M., Barbesant, V., Cremer, J., Stefanov, A., Viebahn, J., 2022. Perspectives on future power system control centers for energy transition. J. Modern Power Syst. Clean Energy 10 (2), 328–344.
McDowall, W., 2018. Disruptive innovation and energy transitions: is Christensen's theory helpful? Energy Res. Social Sci. 37, 243–246.
Mihaylov, M., Rădulescu, R., Razo-Zapata, I., Jurado, S., Arco, L., Avellana, N., Nowé, A., 2019. Comparing stakeholder incentives across state-of-the-art renewable support mechanisms. Renewable energy 131, 689–699.
Milchram, C., Märker, C., Schlör, H., Künneke, R., Van De Kaa, G., 2019. Understanding the role of values in institutional change: the case of the energy transition. Energy Sustain. Soc. 9, 1–14.
Miller, C.A., Iles, A., Jones, C.F., 2013. The social dimensions of energy transitions. Sci. Cult. 22 (2), 135–148. https://doi.org/10.1080/09505431.2013.786989.
Mining Weekly, 2023. Retrieved on 27 June 2023 from. https://www.miningweekly.com/article/solar-projects-help-support-miners-gold-pgm-operations-2022-12-01.
Morris, S., Aguilera, R.V., Fisher, G., Thatcher, S.M., 2023. Theorizing from emerging markets: challenges, opportunities, and publishing advice. Acad. Manag. Rev. 48 (1), 1–10.
Mutebi, M., Anderson, B.O., Duggan, C., Adebamowo, C., Agarwal, G., Ali, Z., Eniu, A., 2020. Breast cancer treatment: a phased approach to implementation. Cancer 126, 2365–2378.
Muttitt, G., Price, J., Pye, S., Welsby, D., 2023. Socio-political feasibility of coal power phase-out and its role in mitigation pathways. Nat. Clim. Change 13 (2), 140–147.
Mützel, S., 2009. Networks as culturally constituted processes: a comparison of relational sociology and actor-network theory. Curr. Sociol. 57 (6), 871–887.
Nguyen, K.H., Kakinaka, M., 2019. Renewable energy consumption, carbon emissions, and development stages: Some evidence from panel cointegration analysis. Renewable Energy 132, 1049–1057.
Nikas, A., Lieu, J., Sorman, A., Gambhir, A., Turhan, E., Baptista, B.V., Doukas, H., 2020. The desirability of transitions in demand: incorporating behavioural and societal transformations into energy modelling. Energy Res. Social Sci. 70, 101780.
Ningrum, V., Chotib, Subroto, A., 2022. Urban community resilience amidst the spreading of coronavirus disease (COVID-19): a rapid scoping review. Sustainability 14 (17), 10927.
Niu, X., Zhan, Z., Li, B., Chen, Z., 2022. Environmental governance and cleaner energy transition: evaluating the role of environment friendly technologies. Sustain. Energy Technol. Assessments 53, 102669.
Nuru, J.T., Rhoades, J.L., Sovacool, B.K., 2022. Virtue or vice? Solar micro-grids and the dualistic nature of low-carbon energy transitions in rural Ghana. Energy Res. Social Sci. 83, 102352.
Olabi, A.G., Abdelkareem, M.A., 2022. Renewable energy and climate change. Renew. Sustain. Energy Rev. 158, 112111.
Olofinbiyi, S.A., 2022. A reassessment of public awareness and legislative framework on cybersecurity in South Africa. Science: Juridical Sci. 2 (20), 34–42.
Onifade, S.T., Alola, A.A., 2022. Energy transition and environmental quality prospects in leading emerging economies: the role of environmental-related technological innovation. Sustain. Dev. 30 (6), 1766–1778.
Ottinger, G., 2013. The winds of change: environmental justice in energy transitions. Science as Culture 22 (2), 222–229.
Øvald, C.B., Callegari, B., Nybakk, E., 2023. The role of power and future resources in the institutionalisation of the Norwegian oil economy. Energy Res. Social Sci. 96, 102930.
Owen, J.R., Kemp, D., Lechner, A.M., Harris, J., Zhang, R., Lèbre, É., 2022. Energy transition minerals and their intersection with land-connected peoples. Nat. Sustain. https://doi.org/10.1038/s41893-022-00994-6.
O'Connell, B., Ciccotosto, S., De Lange, P., 2014. Understanding the application of Actor-Network Theory in the process of accounting change. In: Critical Perspectives on Accounting Conference. Canada, Toronto. July 7-9.
Pak, N.A.H., Ismail, S., Mohd Alwi, N., 2023. Translation of the management control system in a privatised solid waste management network. J. Account. Organ. Change. 19. https://doi.org/10.1108/JAOC-08-2021-0100Che.
Parra, D., Swierczynski, M., Stroe, D.I., Norman, S.A., Abdon, A., Worlitschek, J., O'Doherty, T., Rodrigues, L., Gillott, M., Zhang, X., Bauer, C., 2017. An interdisciplinary review of energy storage for communities: Challenges and perspectives. Renewable and Sustainable Energy Reviews 79, 730–749.
Pedersen, R.H., Andersen, O.W., 2023. A contested agenda: energy transitions in lower-income African countries. Energy Pol. 175. https://doi.org/10.1016/j.enpol.2023.113496.
Petavratzi, E., Sanchez-Lopez, D., Hughes, A., Stacey, J., Ford, J., Butcher, A., 2022. The impacts of environmental, social and governance (ESG) issues in achieving sustainable lithium supply in the Lithium Triangle. Mineral Econ. 35 (3–4), 673–699.
Phadke, R., 2013. Public deliberation and the geographies of wind justice. Sci. Cult. 22 (2), 000-000.
Pilz, M., Al-Fagih, L., 2019. In: IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm). (1–6) IEEE.
Poddiakov, A., 2023. Creativity of creativity researchers: invention of problems and experimental objects to study thinking. Integ. Psychol. Behav. Sci. 57 (1), 43–64.
Power, M., Newell, P., Baker, L., Bulkeley, H., Kirshner, J., Smith, A., 2016. The political economy of energy transitions in Mozambique and South Africa: the role of the Rising Powers. Energy Res. Social Sci. 17, 10–19.
Qadir, S.A., Al-Motairi, H., Tahir, F., Al-Fagih, L., 2021. Incentives and strategies for financing the renewable energy transition: A review. Energy Rep. 7, 3590–3606.
Qaiser, I., 2022. A comparison of renewable and sustainable energy sector of the South Asian countries: an application of SWOT methodology. Renew. Energy 181, 417–425.
Qi, X., Guo, Y., Guo, P., Yao, X., Liu, X., 2022. Do subsidies and R&D investment boost energy transition performance? Evidence from Chinese renewable energy firms. Energy Pol. 164, 112909.
Rachidi, N.R., Nwaila, G.T., Zhang, S.E., Bourdeau, J.E., Ghorbani, Y., 2021. Assessing cobalt supply sustainability through production forecasting and implications for green energy policies. Res. Pol. 74, 102423.
Rafei, M., Esmaeili, P., Balsalobre-Lorente, D., 2022. A step towards environmental mitigation: how do economic complexity and natural resources matter? Focusing on different institutional quality level countries. Resour. Pol. 78, 102848. https://doi.org/10.1016/J.RESOURPOL.2022.102848.
Rashmi, M.S., Sahoo, G., 2012. A five-phased approach for the cloud migration. Int. J. Emerg. Technol. Adv. Eng. 2 (4), 286–291.
Rennings, K., 2000. Redefining innovation-eco-innovation research and the contribution from ecological economics. Ecol. Econ. 32. Retrieved from. www.elsevier.com/locate/ecolecon.
Roe, E., 1998. Taking Complexity Seriously. Policy Analysis, Triangulation and Sustainable Development. Kluwer Academic Publishers, Boston.
Saadaoui, H., Chtourou, N., 2022. Do institutional quality, financial development, and economic growth improve renewable energy transition? Some Evidence from Tunisia. J. Knowl. Econ. 1–32.
Saeed, A., Riaz, H., Baloch, M.S., 2022. Institutional voids, liability of origin, and presence of women in TMT of emerging market multinationals. Int. Bus. Rev. 31 (4), 101941.
Sánchez, D.G., Leadem, D.A., 2018. Energy transition and path dependence: the case of Costa Rica. Rev. Geográfica América Cent. 3 (61E), 281–295.
Sanders, P., Bronk, C., Bazilian, M.D., 2022. Critical energy infrastructure and the evolution of cybersecurity. Electr. J. 35 (10), 107224.
Schlindwein, L.F., Montalvo, C., 2023. Energy citizenship: accounting for the heterogeneity of human behaviours within energy transition. Energy Pol. 180,

113662.
Sendstad, L.H., Hagspiel, V., Mikkelsen, W.J., Ravndal, R., Tveitstøl, M., 2022. The impact of subsidy retraction on European renewable energy investments. Energy Pol. 160, 112675.
Shahbaz, M., Wang, J., Dong, K., Zhao, J., 2022. The impact of digital economy on energy transition across the globe: the mediating role of government governance. Renew. Sustain. Energy Rev. 166, 112620.
Shiraz, H.G., Vagin, M., Ruoko, T.P., Gueskine, V., Karoń, K., Łapkowski, M., Abrahamsson, T., Ederth, T., Berggren, M., Crispin, X., 2022. Towards electrochemical hydrogen storage in liquid organic hydrogen carriers via proton-coupled electron transfers. J. Energy Chem. 73, 292–300.
Sillak, S., Vasser, M., 2023. How might we co-design energy transition policy in old industrial regions? Environ. Pol. Govern. 33 (2), 139–152.
Sovacool, B.K., Brossmann, B., 2013. Fantastic futures and three American energy transitions. Science as Culture 22 (2), 204–212.
Stepanov, I., Makarov, I., Makarova, E., Smolovik, E., 2023. Climate change and challenges to sustainable development in the Russian Arctic. Climatic Change 176 (4), 39.
Sun, G., Li, G., Dilanchiev, A., Kazimova, A., 2023. Promotion of green financing: role of renewable energy and energy transition in China. Renew. Energy 210, 769–775.
Taghizadeh-Hesary, F., Zakari, A., Yoshino, N., Khan, I., 2022. Leavering on Energy Security to Alleviate Poverty in Asian Economics. The Singapore Economic Review, Singapore, pp. 1–28. https://doi.org/10.1142/s0217590822440015.
Talebzadehhosseini, S., Garibay, I., 2022. The interaction effects of technological innovation and path-dependent economic growth on countries overall green growth performance. J. Clean. Prod. 333, 130134.
Ting, M.B., Byrne, R., 2020. Eskom and the rise of renewables: regime-resistance, crisis and the strategy of incumbency in South Africa's electricity system. Energy Res. Social Sci. 60, 101333.
Tyler, E., Mgoduso, L., 2022. Just energy transitions and partnerships in Africa: a South African case study. Meridian Econ. 10.
Tzeremes, P., Dogan, E., Alavijeh, N.K., 2023. Analyzing the nexus between energy transition, environment and ICT: a step towards COP26 targets. J. Environ. Manag. 326. https://doi.org/10.1016/j.jenvman.2022.116598.
Valero, A., Valero, A., Calvo, G., 2021. Summary and critical review of the International Energy Agency's special report: the role of critical minerals in clean energy transitions. Rev. Metal. (Madr.) 57 (2). https://doi.org/10.3989/REVMETALM.197.
Vazquez, M., Hallack, M., 2018. The role of regulatory learning in energy transition: the case of solar PV in Brazil. Energy Pol. 114, 465–481.
Velasco-Herrejón, P., Bauwens, T., Friant, M.C., 2022. Challenging dominant sustainability worldviews on the energy transition: lessons from Indigenous communities in Mexico and a plea for pluriversal technologies. World Dev. 150, 105725.
Vera, M.L., Torres, W.R., Galli, C.I., Chagnes, A., Flexer, V., 2023. Environmental impact of direct lithium extraction from brines. Nat. Rev. Earth Environ. 4 (3), 149–165.
Vyas-Doorgapersad, S., 2022. The use of digitalization (ICTs) in achieving sustainable development goals. Glob. J. Emerg. Market Econ. 14 (2), 265–278.
Wahlund, M., Palm, J., 2022. The role of energy democracy and energy citizenship for participatory energy transitions: a comprehensive review. Energy Res. Social Sci. 87, 102482.
Wang, S., Sun, L., Iqbal, S., 2022. Green financing role on renewable energy dependence and energy transition in E7 economies. Renew. Energy 200, 1561–1572.
Watari, T., Nansai, K., Nakajima, K., Giurco, D., 2021. Sustainable energy transitions require enhanced resource governance. J. Clean. Prod. 312. https://doi.org/10.1016/j.jclepro.2021.127698.
Wittmayer, J.M., Hielscher, S., Fraaije, M., Avelino, F., Rogge, K., 2022. A typology for unpacking the diversity of social innovation in energy transitions. Energy Res. Social Sci. 88, 102513.
Wohlin, C., 2014. Guidelines for snowballing in systematic literature studies and a replication in software engineering. In: Proceedings of the 18th international conference on evaluation and assessment in software engineering, pp. 1–10.
World Bank, 2023. Scaling up to Phase Down: Financing Energy Transition in Developing Countries. Retrieved on 28 June 2023 from. https://www.worldbank.org/en/news/press-release/2023/04/20/.
Yang, Y., Xia, S., Qian, X., 2023. Geopolitics of the energy transition. J. Geogr. Sci. 33 (4), 683–704.
Zahoor, Z., Latif, M.I., Khan, I., Hou, F., 2022. Abundance of natural resources and environmental sustainability: the roles of manufacturing value-added, urbanization, and permanent cropland. Environ. Sci. Pollut. Control Ser. 29 (54), 82365–82378.
Zakari, A., Tawiah, V., Khan, I., Alvarado, R., Li, G., 2022. Ensuring sustainable consumption and production pattern in Africa: evidence from green energy perspectives. Energy Pol. 169, 113183.
Zakari, A., Khan, I., Tawiah, V., Alvarado, R., 2022a. Reviewing the ecological footprints of Africa top carbon consumer: a quantile on quantile analysis. Int. J. Environ. Sci. Technol. 2017. https://doi.org/10.1007/s13762-021-03904-z.
Zhang, D., Kong, Q., 2022. Green energy transition and sustainable development of energy firms: an assessment of renewable energy policy. Energy Econ. 111, 106060.
Zhang, R., Lee, M., Huang, L., 2023. Grid parity analysis of photovoltaic systems considering feed-in tariff and renewable energy certificate schemes in Hong Kong. Renew. Sustain. Energy Rev. 181, 113326.
Zhao, Y., Song, Z., Li, X., Sun, Q., Cheng, N., Lawes, S., Sun, X., 2016. Metal organic frameworks for energy storage and conversion. Energy Storage Mater. 2, 35–62.
Zhi, Q., Sun, H., Li, Y., Xu, Y., Su, J., 2014. China's solar photovoltaic policy: An analysis based on policy instruments. Appl. Energy 129, 308–319.