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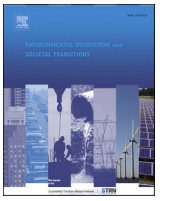

Conceptualising energy geographies in East Africa: A research agenda for exploring spatial dimensions of renewable energy transitions

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ABSTRACT

This study contributes to the understanding of the spatiality of energy transitions in the East African Community (EAC) and to cross-regional conceptual learning. It is situated at the intersection of Sustainability Transitions and Energy Geography. Building on a conceptual framework developed by energy geographers, we conduct a conceptual review and examine the production of locations, landscapes, territories, and territoriality in the EAC. The study considers spatial differentiation and embedding across scales as preconditions for and outcomes of the shift to low-carbon energy systems. It examines how expanding energy infrastructure and related land-use changes transform livelihoods and daily spaces. The review provides a conceptual framework and language for a collective research agenda on EAC energy geographies, highlighting the complementarities and divergences between concepts in the two fields. The region's heterogeneity suggests multiple pathways and overlapping territories, which remain central to energy politics, a situation not yet as visible in high-income countries.

1. Introduction

Energy geographers are currently engaged in a dialogue with colleagues in the field of Sustainability Transitions (ST), discussing the topic of societal transitions to sustainable energy systems. Traditionally, Energy Geography (EG) is concerned with studying energy infrastructural development, energy distribution and transport. EG deals with environmental impacts and risks, spatial patterns of investment and consumption, supply chains and markets, and use patterns and their determinants from a spatial, regional or resource management perspective (Solomon et al., 2004). Additionally, it explores how energy technology diffuses within and between nations and maps regional variations in energy distribution and uses (Calvert, 2016).

ST, on the other hand, is a relatively interdisciplinary field dominated by scholars from other backgrounds – especially sociology, science and technology studies, industrial economics, innovation studies, and engineering. This field studies historical and current innovation processes and societal change in various sectors, such as energy, water, waste management, agro-food, and transport

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(Fuenfschilling & Binz, 2018; Ghosh et al., 2021; Köhler et al., 2019; Welie et al., 2018). It analyses how concerns around unsustainable modes of production and consumption drive ambitions to enact fundamental change in society in the direction of "sustainable development" – yet the meaning of this remains highly contested (Frantzeskaki et al., 2012).

Geographical perspectives are increasingly influencing ST as a field. Valuing context-sensitive analysis and care in translating (rather than copying) conceptual insights, Geography of Sustainability Transitions (GeoST) scholars have criticised tendencies of universalism (Mans, 2014). Others have highlighted the need for care in exporting concepts and frameworks (Cherunya et al., 2020; Ghosh et al., 2021; Welie et al., 2018). As a perspective, GeoST insists on the importance of contextual conditions (policies, institutions, norms, and culture). It highlights socio-spatial processes, such as cross-scale networks, that make up the spatial fabric of transitions (Hansen & Coenen, 2015; Truffer et al., 2015). The intra-field debate has stimulated context-sensitive development of the two current dominant approaches in the ST field: the multi-level perspective (MLP) and technological innovation systems (TIS) (Coenen et al., 2012; Hoicka et al., 2021; Raven et al., 2012; Truffer et al., 2015).

Both EG and ST converge in many ways: the exploration of the ongoing attempts at transforming energy systems to mitigate climate change, preventing loss of biodiversity and resource depletion, decarbonising the global economy, and reducing poverty (Bridge et al., 2013; Köhler et al., 2019). This study is situated at their intersection where an emerging body of work seeks to complement the strong attention to temporality in the ST field with attention to how ongoing transitions to sustainable energy systems involve changes in the geographical organisation of supply and demand-related activities and the spaces in which they are embedded (Bulkeley et al., 2014; Castán Broto & Baker, 2018); and to the "geographical elements of continuity and change" (Bridge et al., 2013, p 333).

With this conceptual review, we aim to contribute to the understanding of the spatiality of energy transitions in the East African Community (EAC) and to lay a conceptual basis for energy geographies from the region. We do so by reviewing work in ST and EG and engaging with a framework proposed by Bridge et al. (2013, p 331) to "assess the geographical implications of a transition towards low-carbon energy". Applying the framework to the EAC context has the benefits of: providing a conceptual scope for an emerging field; analysing its relevance and usefulness in a cross-regional dialogue and; adding nuance and deepening the understanding of EAC energy transitions. We draw on the wider region-specific literature to explore how concepts match the empirical literature. This results in complementary dimensions and themes, which may have been overlooked in the conceptualisation based on and empirical application of the concepts to contexts in the Global North.

The framework is anchored on six key concepts with the aim of providing "conceptual language for systematically working through the spatialities of energy transition"(Bridge et al., 2013, p 339): location, landscape, territory and territoriality, spatial differentiation, scale and scaling, and spatial embeddedness and path-dependency. These concepts are embedded in the wider field of energy geography, where scholars have partially or entirely applied the framework (Baptista, 2018; Dahlmann & Lindeque, 2017; McEwan, 2017). The concepts are explicitly proposed as entry points to invite scholarly exchange and cumulatively richer understandings of space and spatial change. However, cross-field dialogue comes with the risk of conceptual misunderstandings and incoherence. We thus review how scholars who situate their work within the fields of EG or ST define and empirically apply each concept. This highlights where the use of concepts overlaps, complements and diverges to the extent that scholars mean fundamentally different things.

The review further shows that a coherent and encompassing energy geography from the EAC region is missing. Apart from some historical work (Boamah, 2020; Sergi et al., 2018), few studies have adopted a spatial perspective on energy transitions as the *primary* lens for understanding the preconditions for and implications of the transition to renewable energy. Some studies have partially dealt with the geography of energy transitions in the EAC (Ahlborg, 2018; Aly et al., 2019; Bhamidipati & Hansen, 2021; Boamah, 2020; Koepke et al., 2021; Ulsrud et al., 2018). Furthermore, substantial literature concerning renewable energy development in the EAC exists beyond the spatially framed studies. This literature, situated in other fields, covers different politico-economic and social aspects of energy transitions and development in the region (Baker, 2023; Brunet et al., 2021; Karekezi & Kimani, 2004; Koepke et al., 2021; Newell & Phillips, 2016; Ockwell & Byrne, 2016; Pedersen, 2016). Focusing on social relations between actors, these studies show that transitions are diversified and depend on socio-spatial settings, resources, history, technological capabilities, institutions, regulations, norms, and culture. Whilst an exhaustive review of the broader literature is outside of our scope, we will nevertheless incorporate examples from it. This is to situate work that make use of the specific concepts in a broader discussion on the spatiality of energy transitions in the EAC region.

Further scholarly exchange can highlight challenges in large-scale Western energy models now facing competition from decentralised supply modes despite their successful export and adoption in the EAC (Kirshner et al., 2020). These challenges necessitate a critical examination of regional energy transformations. The incumbent regime,[1] entrenched in policy but weakly materialised, co-exists with traditional energy regimes using biomass and liquid fuels (Baptista, 2018), resulting in a 'splintered regime' marked by spatial and social divisions and fragmented energy services (Lawhon et al., 2018; Welie et al., 2018). The EAC energy sector provides an interesting case where heterogeneous practices complement or compete with one another in terms of their occupation or performance of functions in time and space. This complexity shapes current trajectories.

Furthermore, the land-extensive character of renewable energy production will change the role of rural areas, with a significant impact on rural populations and natural environments. This makes rural areas play a central role in emerging energy geographies with their shifts in power dynamics and relational dependencies (Naumann & Rudolph, 2020). New spatialities are also shaped by parallel processes such as renewable energy financialisation, digitalisation, resource competition and the global policy drive to mitigate climate change and restructure the material foundation of the economy. This paper takes initial steps to analyse the evolution of spaces

[1] A sociotechnical regime forms a deep structure and stable component of an existing sociotechnical system. It refers to a semicoherent set of rules that orient and coordinate the activities of social groups that reproduce various elements of the sociotechnical systems (Fuenfschilling & Binz, 2018)

created by the coexistence of incumbent and emerging energy systems, sketching the contours of a regional EG research agenda.

The rest of the paper is organised as follows. Section 2 outlines the methodology for conducting the review. Section 3 reviews the main concepts and themes proposed by Bridge et al. (2013), using literature from the EAC region to explore nuances, differences, and complementarity at the interface between EG and ST. Section 4 discusses the research agenda for collective energy geographies in the EAC and concludes with highlighting conceptual insights of relevance to the broader literature on energy transitions and future pathways.

2. Methodology

2.1. Qualitative literature review

In our research, we adopt a qualitative approach to establish a knowledge base at the intersection between EG and ST, specifically for the EAC. Motivated by our interest in energy geographies from the region, we use search strings to identify a "core" body of geographical work that we can situate in a wider discussion. The approach follows a methodology similar to that used by (Haddad et al., 2022) and the PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Tawfik et al., 2019), commonly used in systematic literature reviews, such as the one conducted by Kungl & Hess (2021). While qualitative, the approach belongs to the family of systematic reviews, that according to Mengist et al., (2020), help map and assess the state of the art in a specific field or topic, furthering knowledge development.

The PRISMA approach summarises heterogeneous knowledge from different disciplines (Tricco et al., 2018). Following the PRISMA process, we develop a research protocol that consists of the following steps: 1) specification of the research goals and questions; 2) the choice of components in the interface between ST and EG; 3) determination of inclusion and exclusion criteria; 4) identification of search strategies; 5) charting of the results; 6) discussion of the results, and provision of conclusions and recommendations (Al Harthi et al., 2020). The organisation of the stages listed above is somewhat different from Al Harthi et al. (2020). Instead, it is tailored to our research aim and the conceptual nature of the review based on an already established framework. The focus is on identifying search strategies and sorting articles during the research process (Raj et al., 2022).

2.2. Geographic scope of the review

This review covers the EAC region, which is susceptible to controversies both geopolitically and academically due to differences in researchers' demarcation of the area.[2] The historical context of political unions and physical conditions also contribute to the contentious nature of defining the boundaries of this region. We have defined the scope of the EAC regional intergovernmental organisation to encompass the countries Burundi, Kenya, Rwanda, Tanzania, Uganda, South Sudan and the Democratic Republic of Congo (DRC). This definition is motivated by the existence of harmonised interconnections of electricity infrastructure through the EAC cross-border electrification programme, the EAC energy security policy framework, the EAC development strategy (2022–2026), and the EAC vision 2050 (Ockwell & Byrne, 2016). The DRC was omitted in the search string because it joined the federation in April 2022. So far, it has not yet implemented sectoral policies of the federation.

2.3. Review process

A search protocol was developed to provide a review process that covers the intersection between the EG and ST literature, focused on the EAC region. This protocol included three overlapping bodies of work: ST, EG, and energy transitions in Africa. In the EG field, we utilised the existing Bridge et al. (2013) framework. From the ST field, we concentrated on two key concepts: "sustainability transition" and "energy transition". In the third body of literature about energy transition in the region, our search went from global to EAC specifically. We aimed to include energy research that does not necessarily use the "transition" label yet evidences energy system change in the region. The search incorporates keywords such as "sustainable energy", "renewable energy", "electrification", and "bioenergy" for the EAC region. Fig. 1 shows how the searches transition from broader to regionally-specific searches, aiming to identify the core intersection of the three bodies of work and the four interfaces across the bodies of literature. It also indicates the interrelated fields and the interfaces included in the scope.

The search strings (see Appendix 1) were initially developed in March 2022 with multiple rounds of testing of variations in search terms. They were revised in January and December 2023 based on review comments. The authors replicated the searches and agreed upon the reasoning behind it. All search strings were implemented using Scopus, the largest online database of peer-reviewed published research articles (Haddad et al., 2022).

By focusing on only peer-reviewed articles and books, the aim was to map published literature that theorises or empirically contributes to the conceptualisation of the interface between EG and ST at the global, African, regional (East Africa), and national

[2] For example, some authors such as Mihayo & Kombe (2022) consider the East African region to be composed of 3 countries: Uganda, Tanzania, and Kenya. The Webster's dictionary defines the East Africa area as comprising Tanzania, Kenya, Uganda, Rwanda, Burundi, and Somalia. In contrast, The Collins dictionary definition considers Eastern African countries as former economic and political federations dismantled in the 1970s. The United Nations Statistics Division scheme identifies the following countries as belonging to the Eastern Africa region, Indian Ocean island countries and Southern African countries: Zimbabwe, Zambia and Malawi.

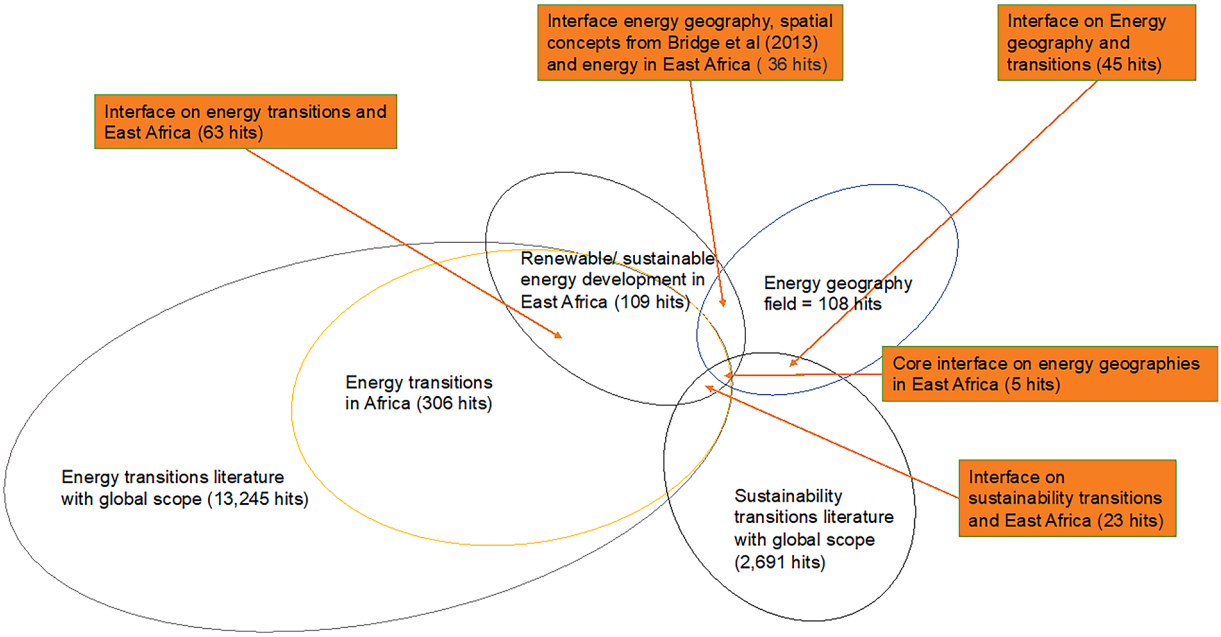

Fig. 1. Key search terms used to establish the interfaces between studies labelling themselves as Energy Geography (in green colour), Energy Transitions (in yellow), Sustainability Transitions (in blue) and where they meet in East Africa-specific literature, with search hits from Scopus search. The sizes of circles are not proportional to number of hits.

levels (individual countries). We also identified additional documents (articles and reports) via snowball sampling, which were included to contextualise the review.

The search strategy of establishing interfaces has two strengths. Firstly, it provides a clear core for building a regional perspective where EG and ST literature converge, from which we may broaden out to relevant work that does not necessarily label itself as "energy geography" or "sustainability transitions". Secondly, this allows us to access the broader literature. This helps to select and incorporate highly relevant publications, building the base of evidence for understanding energy transitions at the East African level or within individual countries. In addition, it provides a point of reference regarding the size of different bodies of literature and comparisons with other countries on the continent. Finally, this search strategy aimed also to access a conceptual literature that approaches the six key concepts at the global level. To capture this breadth of publications, no restriction was put on either year or field of publication. A weakness of the strategy is that the six concepts and selected search strings impose a quite narrow frame in comparison to the broader energy literature from the region and well as within the ST field. This means the review is not exhaustive and a different scope—that includes ST studies beyond energy, or studies from other parts of Africa) may yield important insights now missing. We see this as a modest attempt at providing a "basic conceptual language" (Bridge et al., 2013, p 339) for collectively developed energy geographies from the region.

The search generated a total sample of 281 documents (total hits from the six searches including the identified core, four interfaces and the EAC energy literature), including articles, book chapters, research notes and conference papers. Retrieved data for this sample was exported as CSV files and opened in MS Excel for further screening. From this sample, we removed duplicates (N=34), topics deemed irrelevant, i.e., those which do not relate to either energy geography or energy transitions but refer to energy within, for example, agriculture and sanitation (N=56), conference papers (N=29), and editorial and field notes (N=2). After this exclusion, 160 abstracts remained for screening (see Appendix 2).

2.4. Selection process

In the next step, abstracts from all documents were screened to retain documents that were relevant to both the aim and scope of the review. The first author completed an initial sorting to remove documents outside the scope (see Appendix for further details). This stage was followed by a session wherein the first and second authors double-checked and discussed articles considered for exclusion. The authors jointly identified the selection criteria and the threshold for inclusion/exclusion of publications in the research. This resulted in the following eligibility criteria: 1) geographical, 2) conceptual, and 3) empirical relevance (for further detail see Appendix1).

Geographically, articles about EAC or individual member countries were deemed relevant (Burundi, Kenya, Rwanda, South Sudan, Tanzania, and Uganda). Conceptually, the focus was directed towards publications that conceptualised energy geography and transition using the framework by Bridge et al. (2013) or partially extended or applied the framework empirically in any world region. The motivation of the review was to expand the framework, enhance its concepts and broaden the empirical base of evidence by learning

across regions. For empirical relevance, the screening focused on the documents providing substantial empirical evidence on energy transition for the EAC and individual member countries. We excluded documents that provided hypothetical scenarios from modelling, prediction and static mapping of energy resources. This was because these studies do not inform the state of the art regarding the situation for regional transitions and sectoral development.

Documents were selected for full reading if they met at least two out of the three criteria, resulting in 76 from the list. We used a snowballing technique to identify additional literature to help situate this core body of work in the broader debate, both conceptually and empirically. The analysis of the sample follows a deductive[3] content analysis method in that it builds on an existing theoretical framework that we use as a starting point to organise the analysis and then build on to test or expand the theory (Thomas, 2006).

3. Review of spatial concepts for exploring energy transitions in East Africa

In the following review, we first introduce each concept as it is understood by EG and ST scholars. Based on this, we review how EAC-specific literature engages with and contributes to understanding the concepts at the interface between the two fields.

3.1. Location: Changing the proximity of rural areas through a scramble for resources

Location is explained in both absolute and relational terms. The absolute characteristic of a location refers to fixed geographical coordinates (latitude and longitude) (Bridge et al., 2013), as well as the type of energy infrastructure and its use in various places (Naumann & Rudolph, 2020). Relative location, on the other hand, is a highly dynamic variable. It denotes the networks and relationships between specific locations and their roles in the global economy. Relative location also reflects the way interactions between locations affect the sociotechnical dimensions of energy systems (Baptista, 2018). 'Relational proximity' is used to describe the changing nature of these relationships in the form of flows of energy (e.g., transmission networks), goods, knowledge and finance that decrease the relative distance as compared to other locations (Bridge et al., 2013). Baptista (2018) extends this concept to explain how location-specific energy production and distribution and actor networks influence global economic relationships, and shape socio-technical systems and energy transition prospects.

ST scholars emphasise the particularity and singularity of place in driving how locations shape the geographies of socio-technical (energy) transitions (Hansen & Coenen, 2015). The two strands of literature are complementary: While ST scholars emphasise place specificity (the unique contexts) in terms of political and institutional context, the idea of proximity is prominent in EG literature. Naumann & Rudolph (2020) describe that the extraction of resources can increase the importance and connectivity of rural areas with other places in national energy systems. Decentralised energy systems decrease absolute and relative proximity between urban centres and rural hinterlands. In contrast, the expansion of large-scale centralised systems may increase the absolute distance yet create new proximities between places of production and consumption along supply chains (Paul, 2018).

In the context of the EAC, the demand for energy resources generates new fixed locations and shifts in relational location within and beyond the region. This places rural areas at the centre of energy plans and strategies, drawing state and international private and state interest, resources, knowledge and finance. Governments in the region are prioritising widespread economic transformation and this draws the region into a trans-national scramble for new energy resources for large-scale electricity generation (Aly et al., 2019; Brunet et al., 2021). Fossil fuels remain a focus for electricity generation and industrialisation support, but there is growing interest in renewable energies from international donors and investors (Brunet et al., 2021; Newell & Phillips, 2016; Rodríguez-Manotas et al., 2018). The discovery of fossil fuel deposits has attracted investments from countries like China and other Asian nations, enhancing the proximity between them and the EAC (Bofin & Pedersen, 2017; Dye, 2020; Shen, 2020). China and the EAC are also linked by investments in solar PV supply chains (Groenewoudt et al., 2020). The relationship with Western donors and investors is increasingly built around renewable energy investments, mirroring their reluctance to finance carbon-intensive projects. This relationship remains predicated on the neoliberal market paradigm and involves changes in rural areas' positionality, with land value increasing for specific rural locations with identified wind and solar potential. This, in turn, draws these areas into transnational linkages of capital flows and energy resources (Newell & Phillips, 2016). Rising powers like Brazil and India are also contributing to the development of large-scale renewable energy systems (Shen, 2020).

For rural areas and populations, scholars highlight a tension in their positionality in the global realm, with multiple emerging proximities and networks. Dynamics of financialisation lead to changes and diversification of energy systems, creating various trajectories (Munro et al., 2022). In economic geography terms, rural areas are the primary location of the financialisation processes where corporate actors and conventional state authorities invest in few but large-scale energy production plants and draw financial gains from their exploitation (Brunet et al., 2021; Klagge & Nweke-Eze, 2020). This increases the relative proximity of rural to urban areas through flows of electricity and money. However, funding for decentralised and small-scale solutions such as micro-grids, small units of solar PV, pico-solar and solar torches have long been oriented around energy access goals and linked to donor-funded development projects (Ojong, 2022). These solutions are implemented by churches and governments in public service programs to electrify rural health care and educational institutions (Cross & Neumark, 2021; Ockwell & Byrne, 2016).

Looking specifically at the solar PV market, studies show a multiplication of fixed locations and, similarly, multiple proximities (Baker, 2023; Bhamidipati & Hansen, 2021; Ockwell & Byrne, 2016). These are achieved through both large-scale investments and

[3] In contrast, an inductive qualitative analysis approach would create and operationalise broad analytical categories based on themes in the documents analysed in an iterative process (McCrory et al., 2020).

private sector-led decentralised solar PV initiatives, which connect centres with high energy demand. Supply chains for solar products are emerging in major and small cities. In addition, solar PV repair workshops have emerged to bring both livelihoods and health risks (Cross & Murray, 2018).

The sector's transformation relies on customer affordability and entrepreneur capacity to distribute hardware (Cross & Neumark, 2021; Davy et al., 2022). As a result, Kenya has become a central hub in the regional PV supply network (Davy et al., 2022; Ockwell & Byrne, 2016). Underlying this market-based diffusion and financial model is the increasing involvement of transnational actors and donor support (Bhamidipati et al., 2019; Ockwell & Byrne, 2016).

A parallel process of financialisation is extending to grassroots levels, connecting citizens to international funding through remittances, mobile banking (Onsongo, 2019), and prepaid meters. This trend is closely interconnected with the adoption of solar PV and financial technologies (Cross & Neumark, 2021). This enhances the proximity between urban companies and rural customers. As a result, dependency relations between rural users and international actors are increased. Furthermore, this market does not address the access gap in economically peripheral areas and among marginalised groups with low energy demand (Koepke et al., 2021).

A somewhat different dimension of relative proximity is illustrated by literature studying community-level impacts from energy projects related to positionality and a sense of "someone's place in the world" (Ferguson, 2006). Regional studies detail place-specific encounters between new infrastructures and services across different scales. The arrival of new grids and/or solar PV affects everyday social and economic practices. It changes the locations and meaning around "one's place in the world" as an individual and community. This extends to diverse energy-related activities such as cooking, socialising and doing business. Additionally, it influences the meaning, sense of belonging in, and use of outdoor and indoor spaces, affecting family life, public space and participation in village matters (Ahlborg, 2018; Boamah, 2020; Ulsrud et al., 2018).

Electrification connects rural users to marketplaces and the broader economy and generates political, economic, and geographical relations. It changes mobility patterns and the time, labour, and value nexus. Moreover, it affects information chains, including connections to global spaces through practices such as entertainment. However, the traditional rural-urban divide has shifted, with a new divide emerging within villages between affluent households that can afford to connect to the grid or buy good-quality solar PV and those unable to afford any form of electricity (Boamah, 2020; Grimm et al., 2017).

In summary, the application of the location concept reveals different transition dynamics across the EAC, showing how large-scale infrastructures – both fossil fuel and renewable energy based and small-scale renewable energy systems – draw rural areas closer to economic and institutional centres and into international networks and funding flows. New multi-scalar proximities are shaped by investment in decentralised energies and grassroots initiatives that can reduce, maintain or create new relations of dependence. These insights demonstrate the relevance of attending to both fixed and relative locations in understanding and addressing energy challenges within the EAC as well as in other regions where the rural-urban relationship is increasingly complex. The regional literature, seen through this lens, highlights changing proximities across all levels of society and persistent exclusion despite geographically denser infrastructural networks.

3.2. Energy landscapes: A relational perspective on energy practices and land use change

The concept of 'energy landscape' extends from a specific location to a situation in which energy systems transform the physical landscape and its embedded immaterial dimensions (political, institutional, emotional, and historical) (Calvert et al., 2019). The concept of landscape holds an inherent vagueness in geography that is also seen in EG, where it takes on multiple meanings. Bridge et al. (2013) have offered a comprehensive definition that captures the diverse meanings of the energy landscape, describing it as an assemblage of natural and cultural features across space, and the history of their production and interactions. Similarly, other authors, such as Baptista (2018) and Kirshner et al. (2020), describe the energy landscape as the constellations of activities and sociotechnical linkages associated with energy capture, conversion, and distribution. Additionally, Calvert et al. (2019) and Baka & Vaishnava (2020) position landscape transformation as a central aspect of structural change in energy systems. Consistent with Huber (2015), they emphasise the significance of material landscapes, livelihoods, and social values "drawn from or embedded in these landscapes"(Calvert et al., 2019, p 191) as well as political acceptance and contestation.

The EG perspectives differ significantly from the understanding of the metaphor 'landscape' in the ST field, which is associated with the MLP framework (Hansen & Coenen, 2015). This distinction demonstrates the importance of not conflating these concepts. In the MLP framework, the landscape is viewed as a macro-environment where broader contextual developments occur beyond any actor's influence (Brunet et al., 2021; Geels, 2011). This "landscape" refers to a certain combination of scale and the characteristic of being external to the "regime". Empirical examples illustrate the politico-institutional pressures for change, such as the growing awareness of climate change, discourse on climate policies and mechanisms, and the urgent need for the unserved population to access modern energy services (Rodríguez-Manotas et al., 2018).

The geographical concept with its diverse meanings is applied in some studies from the region. Given the uneven spatial coverage of electricity services, the landscape reflects the coevolution of multiple energy systems. Hence, Baptista (2018) suggests conceptualising the energy landscape through historical socio-technical dimensions and various fuels (Calvert et al., 2019). National policymakers focus their electrification efforts on socio-economic transformation, industrialisation, and economic growth. Unlike the substantial literature on landscape effects and social resistance to new energy projects in Europe, these are not a primary concern. The main landscape issue is deforestation due to firewood and charcoal production, which modernising energy systems aims to solve (Doggart et al., 2020; Munro & Bartlett, 2019; Murphy, 2001). Electrification and new biofuels are adding to the energy mix rather than replacing existing sources (Amigun et al., 2011). The phenomenon of energy stacking (Choumert-Nkolo et al., 2019) explains the trajectory from a lack of services to a heterogenous regime rather than a homogenous one. This makes energy landscapes multi-layered

and socio-materially distinct from the geographical context that has dominated landscape discussions in ST and EG.

Despite expected environmental and social consequences, new infrastructures are often perceived as more beneficial than detrimental (Aalders et al., 2021; Bhamidipati & Hansen, 2021). However, energy projects are often implemented with little political attention to their landscape integration. In Rwanda, this presents challenges, particularly regarding the nexus between land use, water resources, and livelihoods. For instance, upstream-downstream conflicts can arise from siltation affecting hydropower stations (Gasore et al., 2021). This highlights the need for stricter land and water use regulations. In some cases, as seen in Tanzania, institutional buildings follow the installation of hydropower plants (Mdee, 2017). As a result, new and contested land and water use rules emerge, materially altering the landscape.

Existing literature makes no clear distinction between location and landscape, rather these appear to be intertwined. Boamah, (2020) takes a relational perspective to examine how energy systems are driven by expectations and demands, producing specific outcomes in particular locations. The study explains factors that push residents to contest the grid systems and adopt SHS in Kenya: attachment to their homeland, spatial inaccessibility, and poor grid quality. Munro & Bartlett (2019) apply the concept of "bricolage" to explore multi-layered energy landscapes in low-income communities that face poor grid service. Communities devise their own 'post-modern' energy systems by assembling all resources in their vicinity (regulated, unregulated solar PV, solar lanterns, batteries, and torches). Factors such as local energy poverty, political malpractice in-state utilities, and expectation of business opportunities (Munro & Bartlett, 2019; Ockwell & Byrne, 2016) outweigh global discourses and the politics of climate change.

International policy pressures to mitigate climate change exemplify the macro-level pressures that the MLP framework labels as "landscape pressures". While the concept is not geographical, it directs attention to pressures for change that are external to energy systems and national political priorities in the region, yet influence the development trajectories. Volatility of oil prices, developments of carbon markets and funding mechanisms, and geopolitical considerations influence energy policy in the region, yet there are also broader pressures for change that originate at the local level – especially where public perception, acceptance and resistance to new energy projects are shaped by localised effects on landscapes and livelihoods. New energy systems are entangled in land access, livelihood activities, and aspirations to a better life. Public support for rural electrification may weaken if grid expansion fails to deliver. For example, Brunet et al. (2021) document mixed social acceptance of a large-scale solar power plant in Rwanda, which provides employment but does not give locals access to electricity. Problems with blackouts and poor quality of grid services also incur economic and social costs that undermine trust in the large-scale systems (Hartvigsson et al., 2015).

Seen through the analytical lens of material landscapes, livelihoods and social values (Calvert et al., 2019), the EAC appears as a region aspiring to transform into an industrialised landscape, away from the landscape shaped by small-scale agriculture. There is strong policy and public support for infrastructural expansion and large-scale energy projects, driven by the access gap and unmet demand for cheap and reliable energy provision to fuel economic transformation in a region experiencing rapid urbanisation and youth unemployment (Dye, 2020; Muchunku, 2024). The weaknesses of the current regime combine with demographic shifts to drive transformation, and this still weighs heavier than unmet expectations at specific locations in the energy system. By contrasting the EG landscape with the MLP landscape pressures, our attention is directed towards the cumulative material effects on landscapes and livelihoods, as well as public support and resistance to specific energy pathways. Thus, while the "landscape" concepts in EG and the MLP framework are not compatible, an analysis of landscape transformations in the EAC benefits from the ST field's attention to sources of destabilisation to the current splintered regime.

3.3. Territory and territoriality: Control and influence in energy systems spaces

Territory, defined as the outcome of processes involving bordering, bounding, and enclosure, establishes distinct inside/outside divides (Gailing et al., 2019). Economic and political actors, including states, firms, communities, and households, employ strategies of partition and integration to assert authority and commercial power (McEwan, 2017). A classic illustration of the territory is one characterised by boundaries aligning with the nation-state, serving as a power container—a concept termed as "topographical" territory by Sánchez-Zamora et al. (2014). This type of territory stands out due to its spatial continuity and coherence. Importantly, territory is not confined solely to the nation-state; it may also be localised or transboundary.

Furthermore, Gailing et al. (2019) highlight the creation of regional energy governance spaces as an embodiment of territory. The delineation of such territories is influenced by actors' political agendas, visions, policies, and plans, in conjunction with material infrastructures. A related concept, the 'topological' territory, extends beyond bounded spaces to include extended and transboundary flows of resources and influence. These are facilitated by networks of infrastructures, actors, and nodes (Thomas & Erickson, 2021). Despite their significance, both topographical and topological forms of territory and territoriality are seldom explored in GeoST literature. The possession and control of energy territories involve struggles and negotiations. They are maintained and expanded via lobbying, networking, and mobilisation of actors for acceptance or contestations (Baptista, 2018; Bhamidipati & Hansen, 2021; Ockwell & Byrne, 2016). The practices involved in appropriating, governing, and controlling space by political, legal, and socio-economic means and strategies constitute 'territoriality' (Bridge et al., 2013). Controlling the space involves integrating actors, excluding others, and resisting the intrusion of competitors in the territory (Raffestin & Butler, 2012). While there are very few analyses of energy transitions in the EAC that adopt territoriality as a primary analytical lens, the research by Cormack & Kurewa, (2018) constitutes an exception. It uses the concept of territoriality to analyse how the implementation of the wind energy project in Turkana, Kenya, has contributed to the increased exclusive claims to the land driven by the desire to access benefits such as employment opportunities and corporate social investments.

The concept of topological territories is particularly salient for understanding the regional context. Within this context, existing energy regimes are fragmented, poorly aligned and overlapping, and the institutionalisation level is relatively low (Munro &

Samarakoon, 2022). The majority of the population in the region relies on bioenergy sources that are often unregulated, or part of an illegal sector (e.g. charcoal production) (Munro & Bartlett, 2019). Moreover, the markets for kerosene and diesel are weakly regulated in rural areas. This offers possibilities for intrusion into the state-controlled territory, by intersecting off-grid territories, or by theft or sabotage. Electricity theft is a relatively widespread phenomenon that can be understood as a reaction to unaffordable services, grids that pass by without connecting the people underneath, and a reluctance to pay for unreliable services (de Bercegol, 2022; Ngowi et al., 2019; Winther, 2012). In informal settlements, the absence of reliable grid services results in the use of solar PV and diesel generators. However, it also leads to the dominance of illegal practices as the prevalent mode of territoriality. For instance, studies by de Bercegol & Monstadt (2018) and Njoroge et al. (2020) show the existence of cartel networks that circumvent and sabotage the implementation of government strategy to provide affordable grid electricity in Kibera and Mathare (Nairobi).

Off-grid energy services complement and compete with the national grid. Solar panels are increasingly sold or leased to urban and rural customers. Transactions around solar panels engage company-customer relations, governed by contracts and pre-paid meters, along with software that can cut off users for non-payment or rule-breaking (Cross & Neumark, 2021). This dynamic creates a market for unregulated fake solar products (Baker, 2023; Groenewoudt et al., 2020). According to Groenewoudt et al. (2020) and Muchunku et al. (2018), low-quality and fake solar products offer swift and inclusive access. In contrast, regulated high-quality solar products, while more reliable than fake ones, have exclusive access and involve supplier control over user behaviour. Solar PV companies are also becoming regional or multinational utilities as they expand their customer networks (Baker, 2023). With an international footprint, these utilities challenge state sovereignty over off-grid energy territories, influence traditional grid operators, and assert a strong position in the political decision-making arena (Ockwell & Byrne, 2016).

In EAC energy transitions, policies and practices of electricity provision and access are territorial in both topographic and topological senses. In the current expansion of national grids, state actors use strategies (territoriality) to determine boundaries for inclusion or exclusion. The assertion of political authority and the influence of clientelism and patronage networks among state actors play a crucial role, especially in electoral processes (Ockwell & Byrne, 2016; Trotter & Maconachie, 2018). Bridge (2018) highlights land access policies that differentiate areas suitable for energy development, thus asserting power and authority. The criteria to determine such "suitability" reveals which power interests—military, industrial, environmental—prevail over the provision of equitable and sustainable energy access provision.

Countries in the region exert very different levels of control over the establishment of new territories. Independent power producers and distributors have seen regulatory changes in the designated areas as suitable for grid extension or off-grid solutions (Moner-Girona et al., 2019). Zonal territorial forms emerge as politically and administratively new territories, resulting from the allocation of energy production and supply licenses through energy sector liberalisation (de Bercegol & Monstadt, 2018; Koepke et al., 2021; Munro & Bartlett, 2019). Consequently, the size of the territory allocated to private energy producers can be affected by this process. For example, with its updated energy plan (2024–202), Rwanda decreased the area for off-grid solutions, leading many micro-grid companies to relocate to other regional markets (Agutu, 2020).

A pivotal territorial control mechanism emerges from the convergence of electrification, the internet, and mobile technologies. Networked technology and telecommunications enable transnational ownership and central control of electricity use in grid spaces, micro-grids, and SHS. These technologies create a socio-technical apparatus involving transactions (remittances, acquisition, and prepayment), monitoring, enforcement, and capitalisation of user data (Baker, 2023). In Uganda, Rwanda, Kenya, and Tanzania, the integration of solar PV systems with mobile banking has turned consumer data into a valuable product, allowing PV entrepreneurs to convert loans into securities for sale to multinationals (Baker, 2023; Gill-Wiehl et al., 2022). Despite expanding territories, some companies still struggle to remain viable. PAYGO SHS and pico-solar systems face low financial returns and high costs—customers' inability and unwillingness to pay pose significant challenges. For instance, Mobisol, a well-funded foreign PAYGO company, went bankrupt in Tanzania in 2019 (Cross & Neumark, 2021). Similar issues are documented in Kenya and Rwanda despite regulatory and financial support for private energy providers and low-income users (Bisaga, 2022; Ferrall et al., 2021; Mugisha et al., 2021; Ulsrud & Saini, 2022).

For analyses of energy territoriality in the region, it is essential to examine how colonial legacies and external interventions shape power dynamics. Unlike high-income countries, the post-colonial state's sovereignty over national energy territories in the EAC has never been unequivocal. Since national independence, governments have relied on foreign interventions for policy and funding mechanisms. This financial dependence persists but has evolved with the adoption of the Sustainable Development Goals (SDGs) and increased funding for renewable energy in climate mitigation efforts (Bhamidipati et al., 2019). These capital flows take the form of foreign investments, loans, and grants that promote specific policy paradigms, such as the Feed-in Tariff (FIT) and Clean Development Mechanism (CDM) (Bhamidipati et al., 2019; Brunet et al., 2021; Ndiritu & Engola, 2020). The neoliberal agenda of Western donors and the World Bank has pushed regional governments to liberalise the electricity sector to attract foreign investments (Newell & Phillips, 2016). As a result, the governments of Kenya, Rwanda and Uganda created an "enabling environment" to attract "green" investments, including tax exemptions, risk mitigation, and profit repatriation for large-scale renewable energy developers (Bhamidipati et al., 2019; Rodríguez-Manotas et al., 2018). International actors continue to advocate for private sector participation, provide funding and lobbying, and offer investment security and guarantees to private sector investors (Brunet et al., 2021). This has led to non-state actors controlling many donor-funded and private sector-owned project territories. Moreover, the involvement of local-external actors in energy project implementation, mainly outside of the state's influence, has created cross-scale political arenas where spatial control over the energy system can play a decisive role, enhancing a layer of complexity to the energy territoriality in the EAC (Ahlborg, 2018).

Some territories face competition, decline, or are dismantling due to poorly functioning services, outdated infrastructure, or imbalanced supply and demand, leading to shifts in energy sources and overlapping territories. Regional dynamics suggest that citizens

and policymakers often view off-grid solutions as temporary or secondary (Boamah, 2020; Gill-Wiehl et al., 2022). Conversely, competition and overlap among institutional layers indicate that grid expansion may not necessarily enhance state control. Koepke et al. (2021) and Trotter & Maconachie (2018) highlight that this governance transition redefines the government's role from interventionist to facilitator or passive observer, with variations between countries. Additionally, overseas governments may connect communities and places without necessarily securing agreements from domestic governments (Maclean & Brass, 2015).

There is also a trend towards regional energy territories through institutions like the EAC Secretariat on Energy and the EAC Regional Power Master Plan, funded by transnational actors. Despite high solar potential, renewable energy integration remains low (Sergi et al., 2018). Electricity production and grid upgrades still rely on fossil fuels. In Kenya, grid upgrades support the Standard Gauge Railway, enhancing regional trade and mobility and contributing to developing potential regional economic territory (Klagge & Nweke-Eze, 2020; Lesutis, 2021).

Applying the concept of territoriality to the EAC illuminates interactions among fragmented energy regimes and their distinct territories. A further exploration at the intersection of ST and EG may reveal how these territories overlap and evolve through cross-scale politics and technological and institutional influences. The region is possibly unique in how the centralised model of grid expansion does not necessarily increase state control and authority. Another regional characteristic is the co-existence of multiple territories in the same location, with users actively participating in multiple territories to ensure service access.

3.4. Spatial differentiation as a condition for and outcome of energy transitions

Spatial differentiation describes the production of geographical differences among energy systems' locations, landscapes, and territorialities (Bridge et al., 2013). While geographical variation is also inherent, the production of uneven development in energy transitions is the focus. Bridge et al. (2013) identify three dimensions of differentiation in energy transitions: 1) local and regional variations in the adoption of renewable energy; 2) the impacts of economic growth and development patterns; and 3) spatial distinctions in financial flows linked to low carbon energy services. While the first two aspects have substantial evidence, the third is underexplored in an EAC context (Baker, 2023). Nevertheless, indications from some studies suggest that financial flows perpetuate rural-urban inequality and the extraction of wealth from rural communities, benefiting national and international private-sector companies (Baker, 2023; Brunet et al., 2021).

In the GeoST literature, the spatial difference is primarily discussed in terms of location-specific conditions that influence the diffusion of innovation, where renewable energy is understood as a niche innovation competing with incumbent fossil fuel-based systems. This attention to niche development complements EG studies. For instance, Hansen & Coenen, (2015) establish the factors influencing the success of niche innovations in the energy sector. These factors include localised institutions, urban and regional policies, local natural resources endowments, local technological and industrialisation specialisation, and consumers and local market formation. Furthermore, ST studies highlight multi-scalar contexts. They also explain how proponents of renewable energy systems build cross-scale networks and draw on global resources and knowledge. These networks facilitate the development of local experiments in various places, aiming to overcome resistance from incumbents in one locality (Hojckova et al., 2020).

These complementary understandings of spatial differentiation are relevant to the region. The important role of context is displayed in intra-regional differences in the uptake of renewables. Frontrunners in renewable innovations (such as Kenya and Rwanda) maintain a privileged position over latecomers (like Burundi and South Sudan). The countries differ in policy and regulatory environments, political stability, the presence of a vibrant private sector, and natural resource endowment (Byrne et al., 2018; Chisika & Yeom, 2021; Klagge & Nweke-Eze, 2020). These factors help to explain the differentiated speed in energy sector change. The region's splintered energy regime highlights additional factors that produce differentiation, such as colonial legacies in governance (Klagge & Nweke-Eze, 2020; van der Straeten, 2021), the access gap, land use, and livelihoods. These factors may also hold significance elsewhere and warrant attention due to their impact on uneven development, and will now be discussed.

In the EAC, historical reliance on external expertise and funding has limited the capacity of governments to meet local demand and develop context-specific solutions (Ahlborg, 2018; Bhamidipati et al., 2019). Due to insufficient electricity for the entire population, governments prioritise certain areas. Utilities favour affluent neighbourhoods and commercial or industrial zones, leading to spatial differentiation (Koepke et al., 2021). National politics, trans-local relations, and funding practices further shape territorial divisions into on-grid and off-grid areas, reinforcing core-periphery dynamics (Brunet et al., 2021; Ferrall et al., 2021). In remote or disadvantaged areas, off-grid solutions are preferred to provide access. However, challenges such as lack of land rights, collateral, and housing types complicate customer access (Dominguez et al., 2021).

The access gap is a key aspect of spatial differentiation, structured along the urban-rural divide, class, and gender relations. Barriers to extending energy services are well-documented in energy and development literature from the region (Ahlborg & Hammar, 2014; Amuakwa-Mensah & Surry, 2022). In 2018, urban access rates were estimated at 81%, while rural access to electricity was under 35%[4] (World Health Organisation, 2023).

Class divisions are evident in "under-the-grid" urban neighbourhoods and unconnected rural villages near transmission lines. Poverty also limits the adoption of solar lanterns, certified energy-intensive SHS, and related practices (Boamah, 2020; Grimm et al., 2017). In daily life, energy supply and use are gendered activities, with prominent division of work, control of money or

[4] Government and international agencies frequently report statistics on customers with access to electricity infrastructure, including grid connection meters and SHS, rather than those who actually use electricity. In the case of off-grid solar systems, statistics usually focus on access to infrastructures provided by licensed providers (Ulsrud & Saini, 2022).

resources/assets, and decisions around energy technologies (Dijk & Clancy, 2010; Pueyo et al., 2020). In addition, gender differences are visible in spatial and temporal patterns of perception, as well as uneven access to the benefits of modern energy systems (Fingleton-Smith, 2018). Both private and public spaces are energised by gender-based norms (Muza & Thomas, 2022; Winther et al., 2018). Ahlborg (2017, 2018) conceptualises how class and gender intersecting relations shape EAC energy transitions on the ground, reproducing uneven local economic development. At the national and international levels, the incumbent energy sector is a predominantly masculine territory worldwide, with the lack of gender diversity in leadership and technical roles widely recognised as a barrier to rapid and inclusive energy transitions (Lieu et al., 2020; Ulsrud et al., 2018; Winther et al., 2018).

In the EAC, there is hope that infrastructure expansion will address spatially uneven economic development between urban and rural areas. However, a central question in the EAC and globally concerns the effects of energy transitions on land access and use (Bhamidipati & Hansen, 2021; Brunet et al., 2021). In the rural electrification literature, the issue of land acquisition and compensation for landowners is highlighted as a barrier (Ahlborg & Hammar, 2014). More recently, debates have arisen over land acquisition at the expense of indigenous rights and the displacement of rural populations (Bhamidipati & Hansen, 2021). As expansion continues and land scarcity increases, the current positive perception of infrastructural development may shift toward resistance and conflict, especially since regional evidence suggests energy projects rarely bring the expected economic transformation (Colombo et al., 2018; Lenz et al., 2017; Mulder & Tembe, 2008).

In summary, the extension of the spatial differentiation concept demonstrates that energy transitions in the EAC contrast with perspectives in GeoST and EG by highlighting the role of colonial legacies, land use, and the access gap. The politics of prioritisation of certain areas for grid expansion underscores the core/periphery dichotomies and highlights the uneven development of energy transitions in the EAC. The uneven development is also linked to regional differentiation in the uptake of renewable energy systems, reflecting the importance of the local contexts in shaping transitions. The regional literature highlights the role of gendered power relations in spatial differentiation, a dimension that is missing in previous applications of the framework.

3.5. *Scale: Within and beyond political jurisdiction levels*

The concept of scale crosscuts other spatial categories and helps constitute them (Bridge et al., 2013). GeoST scholars argue that the evolution of sociotechnical systems such as energy is associated with various scales and actors (Truffer et al., 2015). Scale takes on a wide range of meanings in geography, but it is mainly discussed as the ontological scale of things and relations in this context. This can be understood in the quantitative dimensions of objects or phenomena, such as the spatial extent, or temporal duration of infrastructures, organisations, actor networks, jurisdictions, or various processes (Bridge et al., 2013).

Scales are not given; they are produced to organise and govern various energy systems, a process known as scaling (Baptista, 2018; Bridge et al., 2013). Most of the time, there is an agreement that designates the national level as the platform for formulating and executing energy policies (Baptista, 2018; Bridge et al., 2013; McEwan, 2017). Referring to energy policymaking in the UK, Bridge et al. (2013) observed that this emphasis on the national scale in energy transition leads to the exclusion of certain actors. Energy policymaking is frequently a space reserved for a nexus of oligopolies, government utilities, and national government policymakers. This situation is also evident in multiple EAC countries and more broadly across Africa. Seen through the concept of scaling, the question is to what extent new governance structures emerge as regions, cities, and communities initiate or carry forward energy transitions (Coutard & Rutherford, 2010; Hoicka et al., 2021; van Dijk et al., 2022). These actors challenge the state and transnational oligopolies' territories and the role of rural areas as peripheral extraction sites in energy production and accumulation. However, lower levels of governance are rarely autonomous, and there is regulation from and dependence on national and international levels for financial and policy support and compliance. Energy transitions are thus increasingly multi-scalar (Dahlmann & Lindeque, 2017; van Dijk et al., 2022).

Scaling processes vary across contexts due to different technological, social, political, cultural, and economic conditions. In the EAC, the heterogeneity of service regimes, parallel pathways, and the presence of non-state actors illuminate questions of territorial competition or complementarity. Off-grid actors often bypass the state, relying on international networks for materials, knowledge, and finance, with major decisions made outside local contexts (Ahlborg & Sjöstedt, 2015; Eder et al., 2015). The combination of market and community governance, supported by local governments, can improve distributed energy systems and promote sustainable local economic development (Park, 2021). Meanwhile, strong support exists for reinforcing national grid systems by integrating renewable and fossil energy sources. National decisions shape operations, regulate non-state actors, and ensure their investment benefits (Rodríguez-Manotas et al., 2018). This scaling reveals a necessity for a balanced approach to influence off-grid and on-grid systems for a sustainable energy landscape.

Governance dominance at the national level, rooted in the colonial period, persists today through the adaptation of externally tested energy policies such as Feed-in Tariffs (FiTs) and the Renewable Energy Auctions Programme (Bhamidipati et al., 2019; Ockwell & Byrne, 2016). This entails coalitions and negotiations among transnational, ministerial, and regulatory actors whose influence has increased. Despite regional variations, some scholars predict the emergence of transnational oligopolies that benefit from financial risk mitigation and revenue repatriation, even with minimal domestic private sector involvement (Bhamidipati et al., 2019; Klagge & Nweke-Eze, 2020; Rodríguez-Manotas et al., 2018).

The reach of jurisdictions significantly influences territorial coexistence and challenges. In Tanzania, regulatory changes under former President Magufuli affected small power producers and distributors, shifting priorities to large-scale gas-fired plants. This destabilised a previously thriving sector, hindering the expansion of solar mini-grids (Klagge & Nweke-Eze, 2020). In contrast, former Kenyan President Kibaki's focus on electrifying Northeastern Kenya and funding solar PV in schools led to the growth of solar mini-grids, replacing diesel generators in public infrastructure (Ockwell & Byrne, 2016). This initiative, supported by government and

international partners like the World Bank, provided subsidies to developers and end users (Mugisha et al., 2021; Ulsrud & Saini, 2022). However, high replacement and maintenance costs, coupled with insufficient additional subsidies, threaten the initiative's long-term sustainability.

In summary, attention to scale highlights the pivotal role of the governance model and where it allocates decision-making power along with the scale of jurisdiction. As a cross-cutting dimension, we find that it works particularly well in combination with territoriality. The centralisation of power at the national level, rather than the devolution of decisions to local government, produces a situation where national-level decisions either facilitate or impede the expansion of small-scale energy systems in the EAC. Nevertheless, the presence of international donor organisations and emerging transnational solar PV companies illustrates cross-scale flows of finance and technologies in parallel to a strong national dominance. This suggests scales of jurisdiction may tilt even more towards trans-national levels as international finance flows into "green" energy projects. What this means in terms of governance arrangements that respond to the cross-scale dimensions of energy systems anchors into the discussion on polycentric arrangements (Goldthau, 2014) that comprise multiple organisational levels and stakeholder groups, yet the territories emerging are possibly jumping scales (bypassing both national and regional levels) beyond what scholars have expected.(

3.6. Spatial embeddedness and path-dependency

In the context of low carbon transitions, spatial embeddedness and path dependency are conceptualised as place-based obstacles (Bridge et al., 2013). Path-dependency, a key aspect of spatial embeddedness, includes economic, cultural, political, and institutional factors that reinforce conventional energy systems (Meyer, 2021). Systems evolve by following established paths and past local or international decisions (Baptista, 2018). In broader socio-technical transitions (ST), path-dependency and lock-in are central, well-researched concepts, often discussed with a focus on institutional embedding and alignment. Beyond formal institutions like laws and policies, geographical embedding and path dependency are evident in territory-based sunk costs of infrastructure and cultural factors in informal institutions such as norms and social practices (Baptista, 2018; Murphy, 2001).

The factors influencing path dependencies of energy regimes depend on the geographic context and can be endogenous or exogenous (Meyer, 2021). Endogenous factors arise when local energy system actors, such as firms, supply chains, customers, and regulators, resist the emergence and expansion of energy innovations. Exogenous factors occur when incumbent regimes lack local capabilities and resources, leading them to import or outsource from regional or international actors (Dong & Mori, 2017; Koepke et al., 2021).

The splintered energy regimes in the EAC feature specific challenges related to spatial embeddedness and path dependency. While influential advocates of energy transitions support replacing fossil fuels, several factors complicate a transition to renewable energy as integrated into large-scale grids. Firstly, the grid's geographic and technical configuration is often incompatible with the intermittency of solar and wind energy, affecting baseload capacity (Aly et al., 2019; Kazimierczuk, 2019). Secondly, the considerable distance from new plants to the main grid increases interconnection costs in large countries like Tanzania and Kenya. At the same time, unfavourable topography and dispersed settlements pose challenges in Rwanda and Kenya (Bisaga, 2022; Ulsrud & Saini, 2022). Thirdly, state/land governance issues, community land conflicts, and land use competition hinder the construction of large-scale renewable energy plants such as solar PV, wind, and biofuel (Amigun et al., 2011; Kazimierczuk, 2019). Fourthly, policymakers are generally sceptical about the technical feasibility of replacing fossil fuel-based electricity due to renewables' intermittency and high development costs (Aly et al., 2019; Manu et al., 2022). This also hinders the transition from fossil fuel-based emergency power plants to renewables (Dye, 2020; Meyer, 2021). Finally, hydroelectricity continues to dominate the grid electricity mix (Rodríguez-Manotas et al., 2018) despite its vulnerability to climate change and variable rainfalls (Falchetta et al., 2020). These issues, along with political, institutional, and financial factors (Koepke et al., 2021; Munro & Bartlett, 2019), cause stagnation in the grid electricity regime.

The fragmented large-scale regime can also present an opportunity for a transition to renewable small-scale energy systems. Some Western donors advocate for decentralised solutions and are restructuring institutional and regulatory frameworks to allow private sector participation in energy generation (Galan, 2022). However, several barriers complicate this transition, including relational dependencies between regional and international actors. Firstly, these dependencies persist due to funding and investments from traditional and new bilateral and multilateral donors that reinforce the incremental change of centralised electricity systems, rather than the development of small-scale solutions (Aly et al., 2019; Kazimierczuk, 2019; Sergi et al., 2018). Secondly, political leaders remain devoted to grid expansion to foster socio-economic transformation through industrialisation. This commitment stems from fulfilling electoral promises and maintaining political patronage (Dye, 2021; Ockwell & Byrne, 2016; Trotter & Maconachie, 2018). Political support for small-scale off-grid, mini-grid systems, and SHS in rural areas is limited and the development of newly discovered resources is favoured over renewable energies (Aly et al., 2019; Dye, 2021). Some leaders perceive large-scale energy systems as symbols of national independence against colonial powers (Dye, 2021; van der Straeten, 2021). Thirdly, state subsidies to grid utilities complicate the expansion of SHS and mini-grid operators who cannot compete with or operate with a profit due to low electricity prices (Newell & Phillips, 2016; Pedersen & Nygaard, 2018).

From the user's perspective, affordability is a primary barrier to shifting from one energy service to another, complicated by sociocultural factors. The traditional energy regime (biomass and charcoal) is well-embedded in rural life and reinforced by female unemployment, adherence to gender norms, and low education levels (Alananga & Igangula, 2022; Bisaga & Parikh, 2018; Bridge, 2018b; Choumert-Nkolo et al., 2019; Fingleton-Smith, 2018). In summary, spatial embeddedness and path-dependency patterns demonstrate the complexity of transitioning to renewable energy systems in a splintered regime. The centralised grid needs both upgrading and expansion, resulting in substantial technical and financial barriers to leapfrog to a smart, integrated and renewable energy based grid. Relational dependency on external funding, political commitment, institutional barriers, and sociocultural factors

constrain the adoption of renewables in small-scale energy systems. Power centralisation and incumbent interest at the national level, and low social and financial capacity at the local level foster path-dependency on traditional energy systems. Yet, the growth of the solar PV market in some countries in the region, and the integration of small-scale hydropower into Rwanda's grid, show that both transnational and domestic niche actors are quick to act if favourable policies and funding are in place.

4. A future research agenda for East African community energy geographies

The six concepts of Bridge et al. (2013) are intended to function as entry points to a spatial analysis of energy transitions and to provide basic conceptual language. Based on a literature review of spatially focused research on the EAC region, we aim to provide a basis for a future, cumulative body of work that explores energy geographies from the region. From the exercise, we can contribute some observations and suggestions to further conceptual cross-regional development and highlight some (of many) avenues for future research.

Firstly, the concept of location offers a way to map ongoing change statistically, spatially, and qualitatively. In a splintered regime, quantitative mapping needs to be complemented with deeper qualitative analysis to validate interpretations, as a location can be a node in multiple actor networks and overlapping territories and service regimes. The region-specific level of complexity thus calls for mixed-method analyses. Further regional analysis of fixed locations depends on data availability over energy resources (potential and exploited), classification of energy production plants (for fuels and electricity), the localisation of fuel supply chains, and transmission and distribution grids for electricity. As these are mapped in time, the evolution of infrastructure can be captured, and the density of fixed locations emerges as a pattern. Geographical information systems (GIS) are increasingly used for this aim, and some work exists for the region (Mbaka, 2022; Moner-Girona et al., 2019), but much remains to be done.

Even more interesting, the concept of relative location and proximity alerts us to changing urban-rural relations and the importance of cross-scalar dynamics. The countryside is becoming the privileged site for the current expansion of energy technologies, and the target for old and new actors and their discourses. The region's historical position as dependent on donor funding is increasingly complicated by the parallel development of fossil fuel-based and renewable energy pathways that cause repositioning within, and entrance of new actors into, existing actor networks involved in their development. There are many questions to explore regarding how these changes affect preconditions for intra-regional and domestic energy sector actors to thrive and the consequences in terms of service offerings to customers.

Secondly, the review of the landscape concept indicates that the concept is rarely used as an analytical lens in energy studies from the region, meaning there is significant scope for new contributions. Here, we highlight a few topics that could contribute to insights into the broader literature. Further analyses of the politics around land access, livelihoods, and service access seem important. The region-specific literature highlights a pathway where new services do not replace existing ones but create multi-layered and heterogenous service offers and unequal access, with the concepts of bricolage and fuel stacking reminding us that a decentralised solution may be preferred or the only option even when the national grid is present. In contrast to the European context, where roads, electric power lines and railways cut through the landscape, EAC landscapes can be reshaped with new mega-projects but may also maintain great diversity and a patchwork of small-scale, decentralised and large-scale infrastructures.

Yet, the temporality or permanence of future pathways of energy transitions will depend, among other things, on the acceptance of their landscape values. The cross-fertilisation between EG and ST suggests that the shape of "modernity" and the "industrial landscape" is thus open for reinterpretation, along with types of conflicts and political alliances. The region contrasts with already industrialised countries in that there is little public resistance to electricity infrastructure, which is desired as a promise of modernity and development (Winther & Wilhite, 2015). Our review indicates that this situation may change. By linking the idea of landscape transformation to the MLP understanding of "landscape pressures"—but prefereably calling these macro-level pressures—we are alerted to the cross-scale politics of a cumulative change across multiplying locations, leading to spatial reorganisation and effects on landscapes and livelihoods at more aggregated scales. As landscape transformation intensifies, there is an increasing need to understand the unequal effects on livelihoods and associated social responses concerning public opinion, which has hitherto favoured grid expansion. This can help us to understand a situation in which the project of modernity is rejected in favour of decentralised (yet possibly trans-national rather than locally owned) modes of electricity provision, in contrast to a situation in which it can balance land conflicts, distribution of benefits and costs to maintain public support.

Thirdly, the lens of territoriality seems highly relevant for further analysis of energy transitions in the region (Cormack & Kurewa, 2018). While the analyses are few so far, the region offers broader conceptual insights regarding future, more heterogeneous energy sector structures, given the prominent role of actors other than the state and the overlapping and competing territories, including unregulated and illegal ones. Studies (Baker 2023; Brunet et al. 2021) also indicate a new type of transnational actor-network that draws local-level customers into a transnational financialisation logic far from the idea of electricity access as a public good. It is not an easy task to map emerging territories and power exercise, especially given that practices of control and regulation can differ significantly from formal institutions and written documents. There is also secrecy and a lack of transparency around land deals, decisions, and money flows. Still, different policies, regulations, and technologies can be analysed to determine how they play a role in maintaining, expanding, and squeezing territories and actors.

Fourthly, to study spatial differentiation as both a condition for and outcome of ongoing energy transitions in the EAC points to the need for characterising and contrasting the diverse energy territories within each country. What the concept does as a lens, is to place the access gap front and centre of analyses, and ask how changing proximities and energy territories build on, reproduce or challenge existing patterns of inclusion and exclusion. Case studies can explore how power relations and categories of social difference shape and get reshaped through energy transitions. In addition, by mapping a location's place in production-supply chains and linking this to

livelihood impacts (combining statistics, satellite imagery, field studies, and environmental impact assessments), one may assess if a change in proximity contributes to closing the urban-rural gap as well as the class or gender divide.

Fifthly, scale is a cross-cutting dimension: we don't see it as a stand-alone issue, but rather as being at work both as an ontological concept and as part of epistemology in the framing of research. It forefronts the multi- and cross-scalar characteristics, relations, and processes involved in changing locations, landscapes, and territories/territorialities when used ontologically. Therefore, the multi-scalar and multi-sector nature of the impact on places, people, and nature need to be part of a research agenda for the region. The issue of scale also highlights the need to develop polycentric governance arrangements that can respond to local-level needs and provide context sensitive solutions. It appears as no small issue to put in place the coordination and learning that is necessary (Goldthau, 2014).

Sixthly (and similarly to scale), spatial embedding and path-dependency also crosscut the understanding of location, landscapes, and territories. The application of the concept to the EAC demonstrates the need for an analysis of spatial embedding and path-dependencies at multiple analytical scales. This analysis involves understanding how new infrastructures and practices become embedded in specific locations and landscapes and in daily life. In addition, it examines how existing and emerging territories are institutionalised or destabilised by the actions of national and international actor constellations and political and economic influence. By studying these patterns and contrasting experiences between countries in the region, we may learn about processes of embedding and lock- in a splintered regime, and how these differ and converge with what goes on in the global arena and other world regions.

In conclusion, a collective energy geography aids in understanding potential changes in the current fragmented regime during ongoing transitions. Overall, these changes might lead towards heterogeneous but better-aligned systems. The application of the Bridge et al. (2013) framework has provided valuable insights into the role of geographical diversity and place-specific characteristics of the current expansion of energy infrastructures. A weakness of the current framework is that concepts are overlapping and some are cross-cutting. Further work may select among them to delimit the analysis and thus enable deeper engagement. Further work should also consider building on the wider ST literature from the region, beyond energy, where geographical perspectives provide conceptual insights.

Contributing to the dialogue between the ST and EG fields, the region provides rich examples and comparisons between contexts with different starting points and levels of complexity. The heterogeneity present across all studied dimensions and the parallel emergence of territories in the region indicates a plurality of pathways and future energy sector structures that are theorised but not yet visible to the same degree in homogenous regimes in high-income countries. Further work needs to delve deeper and assess how these alternative energy transition pathways impact rural-urban relations and the access gap characterising the EAC. Research in this area can hopefully contribute theoretically to a broader understanding of energy pathways.

Declaration of generative AI and AI-assisted technologies in the writing process

During the revision of this work, the first author used Microsft Copilot to improve the language and readability of the text. After using this tool, the first, other authors and the language professional reviewed and edited the content as needed and take(s) full responsibility for the publication's content.

CRediT authorship contribution statement

Sylvère Hategekimana: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Helene Ahlborg:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization. **Innocent Ndahiriwe:** Writing – review & editing, Supervision.

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.

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Appendix 1. Complementary notes on the methodology

Table A.1
Search strings and results.

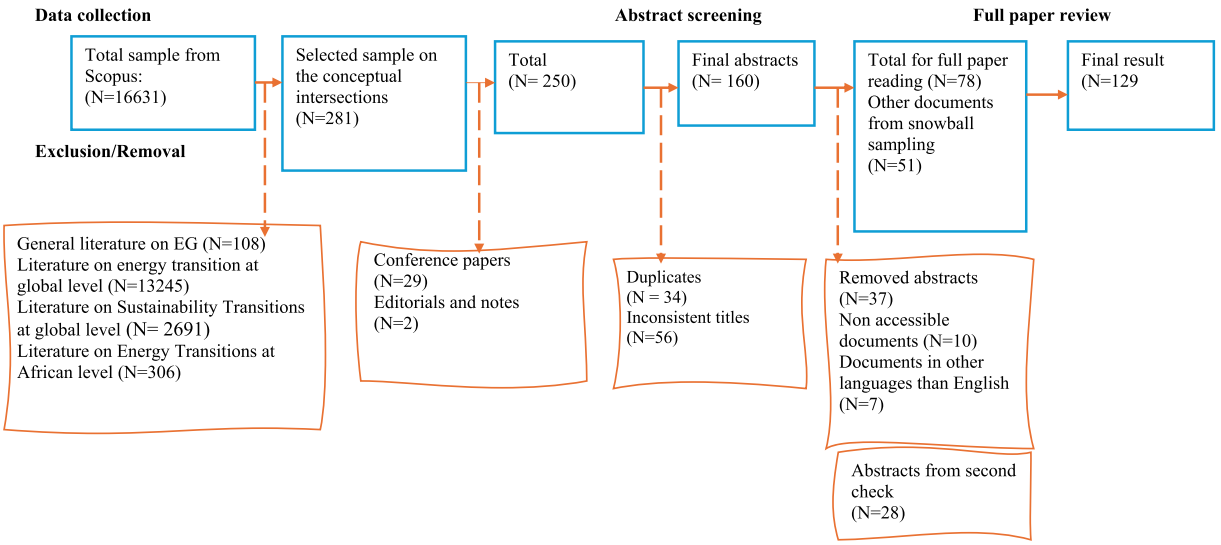
Search	Research area and interfaces	Search string	Number of hits
Search 1	The literature on energy geography	TITLE-ABS-KEY ("energy geography")	108
Search 2	Energy transitions at the global level	TITLE-ABS-KEY ("energy transitions")	13,245
Search 3	Sustainability transitions at the global level	TITLE-ABS-KEY ("sustainability transitions")	2691
Search 4	Literature on the energy transition at the African level	TITLE-ABS-KEY ("energy transitions " AND africa)	306
Region-specific searches			
Search 5	Literature discussing the energy sector in the East Africa	TITLE-ABS-KEY ("Renewable energy" OR "Sustainable Energy" AND "East Africa")	**109**
Search 6	Literature on energy transition in East Africa	TITLE-ABS-KEY ("energy transition" AND "East Africa" OR burundi OR tanzania OR kenya OR rwanda OR uganda OR "South Sudan")	**63**
Search 7	Literature on sustainability transitions in East Africa	TITLE-ABS-KEY ("sustainability transition" AND "East Africa" OR burundi OR tanzania OR kenya OR rwanda OR uganda OR "South Sudan")	**23**
Search 8	The geographically focused literature on energy sector in the East Africa	TITLE-ABS-KEY (bioenergy OR electricity OR "renewable energy " AND "energy geograph*" OR spatiality OR scale OR landscape OR "spatial differentiation" OR location OR "Path dependency" OR space OR spatiality OR territoriality AND "East Africa")	**36**
Search 9	Interface between energy geography and sustainability transitions at the global level	TITLE-ABS-KEY ("energy geography" AND transitions)	**45**
Search 10	Core interface of energy geography in East Africa	TITLE-ABS-KEY ("energy geograph*" AND "East Africa" OR uganda OR rwanda OR burundi OR kenya OR tanzania OR "South Sudan")	**5**
Total number of documents retrieved			**16,631**

Table A.2
Scope and settings for documents screening.

Criterion	Inclusion	Exclusion	stage of inclusion/ exclusion
Time frame (years of publication	NA	NA	Search
Language	English	Non-English abstracts and full documents	Full papers and abstracts screening
Type of sources	Peer reviewed articles and book chapters	Conference papers Field work notes Editorials	Titles screening
Place	EAC countries	Not limited to EAC countries only, publications with good conceptualization will be considered	Titles and abstracts screening
Settings	Energy sectors, renewable energy, sustainable energy, electricity, clean cooking technology, energy geography	Titles and keywords that do not cover transitions, energy systems in other fields than energy systems, electrification, and energy geography	Titles screening

Table A.3
Application of criteria for inclusion and exclusion.

Criterion	Inclusion	Exclusion	Stage
Conceptual relevance	Conceptualization of six energy geography anchoring concepts and its application in any geographic area. Conceptualization of energy or sustainability transition by linking it with any field of geography (evolutionary economic geography, human geography, and urban geography)	Documents that are empirically covering energy geography in empirical way in other countries than East Africa and without proper theorization	Abstracts and full papers screening
Empirical relevance	Provision of substantial evidence that complements the six anchoring energy geography concepts for example factors that enable, and practices being enabled by access modern energy systems and clean cooking fuels	Documents that provide modelling prediction results and mapping of energy resources, or are about a different topic altogether	Abstracts and full papers screening
Geographical relevance	Provision of analyses on energy geography in EA and renewable energy development in EA or individual member countries of EAC	Documents that present results that cover regions outside the EAC regions	Abstracts and full papers screening



Appendix 2. Flow chart for the review protocol (boxes at the top show the total sample while those below show the removal).

Data availability

Data will be made available on request.

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