1. Introduction

The rapid global deployment of solar photovoltaic (PV) technologies since the early 2000s has attracted sustained and critical attention. Solar PV technology has become an increasingly established, widespread and flexible form of electricity generation. Solar PV technology costs have fallen dramatically since 2010, and in many circumstances, the electricity from solar PV has become cost competitive with fossil fuel-based generation (UNEP/BNEF, 2016: 19; REN21, 2016: 65). Solar PV is now diffused within a range of configurations, from pico-Watt applications in lighting and charging equipment, solar home systems, mini-grids serving collections of buildings, to utility-scale projects feeding into national power grids (Razykov et al., 2011; Andersson and Jacobsson, 2000). Whilst innovations in areas such as materials science, electronics, grid connection and battery-power storage promise further improvements, solar PV technology is already deployed across diverse climatic conditions and physical geographies. Institutionally, a variety of policy, market and investment instruments for solar PV are diffusing internationally, ranging from feed-in tariffs and competitive bidding programmes that guarantee a price for power producers selling to the grid, to service-payment business models for off-grid applications.

In the research language of socio-technical or energy transitions, solar PV can reasonably be seen to be gradually acquiring the characteristics of a 'socio-technical regime.' Such regimes are found where a co-evolving set of inextricably linked social and technological developments have built sufficient momentum for a particular technology to become accepted as an established part of the energy provision system (Rip and Kemp, 1998; Geels, 2011). As solar PV becomes integral to the project of providing secure, affordable and sustainable energy for development, this momentum is spreading across sub-Saharan Africa (Byrne et al., 2018; Ockwell and Byrne, 2016; Brew-Hammond, 2010) and indeed elsewhere in the world. Taken together, these attributes suggest that solar PV consists internationally of what are regarded as the core ingredients of a socio-technical regime: a body of codified knowledge, well-known technologies, institutionalised norms, political and economic support, development infrastructure, emerging industry, skilled workforce, and financially viable user-application domains (Geels, 2011; Smith et al., 2005).

While longstanding regimes of centralised electricity generation, transmission and distribution, particularly those which depend on coal, hydroelectricity, nuclear or gas will take decades to reconfigure, solar PV has nevertheless exceeded specific 'niche' applications and is entering a phase

of regime-like formation in terms of knowledge, capabilities, finance and skills. This rapid evolution and geographical expansion of solar PV provides an analytically useful case for sustainability transitions. The literature on the development of socio-technical systems argues that as momentum builds, and transition proceeds from niche to regime, so the need for exceptional conditions conducive to the special needs of the immature technology diminishes. As niche configurations become more robust and institutionalised, they can compete more effectively with incumbent regimes (Smith and Raven, 2012). Following earlier socio-technical transitions thinking, the inhibiting features of specific and localised geographies and histories become less pronounced as a regime builds momentum, the protective affordances of particular spaces matter less and less, and it becomes more feasible to "roll out" the technology across diverse social and geographical settings (ibid).

Yet, as transition studies has turned to questions of the ways that geographies shape the nature and dynamics of socio-technical change, those theoretical propositions are coming under question (Truffer and Coenen, 2012; Bridge et al., 2013). Whilst recent studies argue for a more nuanced account of how geography and power relations matter in the formation of niches (Hansen and Coenen, 2015; Murphy, 2015), the significance of geography in regime dynamics has received far less attention. In this article, we address this lacuna by analysing the rise of solar PV in two southern African countries, Mozambique and South Africa. This focus enables us to examine and contribute to theory on the dynamics of how niche technologies come to be established with regime-like features, across diverse conditions, with implications for how we might understand the geographies of socio-technical transitions. While solar PV has gained ground in both countries, it has done so in different ways, at different scales and with varying consequences. Our analysis suggests that rather than transcending the historical and geographical constraints that shape the initial development of socio-technical niches, more established regimes continue to be shaped by such conditions.

In the following section, we briefly revisit recent geographical contributions to socio-technical transitions (STT) theory. Our review indicates that rather than trying to determine when solar PV moves from niche to regime, analysis can more fruitfully adopt a perspective that sees socio-technical configurations, whether ostensibly niche or regime, as being taken up within energy landscapes (Bridge et al., 2013; Nadaï and van der Horst, 2010). In short, the recent literature suggests a re-framing of the problem identified above. This theoretical discussion leads us into an empirical examination of solar PV in South Africa and Mozambique, with reference to how codified and transferrable lessons on how to adopt solar PV, which circulate internationally, are being

mobilized, enacted and reshaped locally in each case. After discussing our findings, we conclude by offering some insights into the geography of socio-technical transitions.

2. Towards Transition Geographies?

The term 'socio-technical transitions' refers to 'deep structural changes' in systems, such as energy, food and transport, which involve long-term and complex reconfigurations of technology, policy, infrastructure, scientific knowledge, and social and cultural practises to sustainable ends (Geels, 2011: 24). The field of socio-technical (or sustainability) transitions draws from a wide-ranging literature, with its conceptual heritage in evolutionary economics (Dosi, 1982), sociology of technology (Hughes, 1993) and, more recently, political science and theories of governance (Meadowcroft, 2011). Contemporary work exists under various permutations, including the widely read literature on the multilevel perspective (or MLP) (Rip and Kemp, 1998; Geels and Schot, 2007), strategic niche management (Markard et al., 2012) and transitions management (Scrase and Smith, 2009). Simply put, while the MLP as a framework focusses on analysing how incumbent regimes lose stability and become open to change, the latter two are more concerned with managing and guiding transitions to more sustainable ends.

Broadly speaking, these approaches view the transition of socio-technical systems as taking place through interactions between niches, regimes and landscapes. These three analytical levels can be summarised as follows: the 'regime' refers to an institutionally robust and stable configuration of technology, shaped by cognitive routines and discourses shared and shaped by engineers, policymakers, scientists, users and vested interests, where the rules are settled and known (Geels and Schot, 2007: 400). The regime is stabilized by 'lock-in' mechanisms, such as sunk investments, core competencies and institutional commitments, but it can experience incremental improvements 'along path-dependent trajectories' (Geels et al., 2017: 1242). The 'niche,' meanwhile, refers to a protected space at the micro level, where 'radical innovations' and learning, such as new technologies, markets, ideas, practices and policies, can emerge (Geels, 2011: 27). These differ markedly from the dominant regime, but they can potentially gain a foothold in particular geographical areas or market niches. Finally, the 'landscape' refers to exogenous developments, such as slow-changing trends or shocks, including political elections, economic crises, climate change or wars, which can destabilize the system and create opportunities for niche innovations to break through (ibid).

The STT literature has been increasingly criticised for its longstanding focus on high-income countries and for its tendency towards techno-managerialism, which fails to account for the differentiated nature of state power, infrastructure provision, regulatory frameworks and national capacities for innovation, as well as postcolonial legacies and hegemonic dominance of the West (Swilling et al., 2016, Ramos-Mejía et al., 2018). In response, recent years have seen a turn towards consideration of politics and power relations within transitions (Ahlborg, 2017; Baker et al., 2015, Büscher, 2009; Power et al., 2016) along with analyses of the possibilities for transition in low and middle-income countries with large gaps in energy access (Castán Broto et al., 2018; Ockwell et al., 2018).

In a related turn, alternative approaches to STT have been further enriched by questions of geography, loosely summarised as the spatial ordering and relational dynamics of socio-material elements over time (Murphy, 2015). This perspective seeks to account for the role of context, space and power, and poses questions on how specific features of localities, territories and relationships across different spatial scales combine to shape the distribution of innovative activities and their effects in sustainability transitions (Raven et al., 2012; Murphy, 2015).

As this body of research has grown, proponents of transition studies have engaged with these spatial-political critiques (Geels, 2014). Yet, as Hansen and Coenen (2015: 104) observed, "the greater majority of the studies have focused primarily on the geography of niche developments and formative phases in technological innovation systems, whereas far less attention has been paid to regime dynamics or more mature technological innovation systems." Based on our analysis, we would add that the geography of socio-technical landscapes is another lacuna in the transitions literature. In contrast, recent work in human geography depicts 'energy landscapes' as material expressions of energy resources, infrastructures and the institutional and social practices associated with them (Nadaï and van der Horst, 2010; Castán Broto, 2017; Power et al., 2016). The term landscape in this context thus differs from the way it is used in the literature on socio-technical transitions and the MLP to describe overarching, exogenous structures and events that can influence the development of socio-technical systems.

The bias towards the geographical attention to niches within transitions studies risks presuming that specific conditions only need to be in place to the point where technologies are ready to be let loose, transferred, and diffused. This view is not only implied in many studies, but is also central to policy formation to support the uptake of clean technologies internationally (Ockwell and Byrne, 2016). Since the initiation of the United Nations Framework Convention on Climate Change (UNFCCC), for

example, the transfer of technologies for reducing GHG emissions and, more recently, adapting to climate change has been a central mechanism for achieving international cooperation and delivering on agreed targets (Bulkeley and Newell, 2015).

Evidence suggests, however, that the uptake of such technologies and their successful embedding is far from uniform and has often come about via "messy, negotiated interactions between competing ideologies," rather than through linear forms of technology transfer (Byrne et al., 2018: 6). Indeed, there is a widespread sense that in its earlier stages, technology transfer for development met with diverse fortunes, with the uptake of appropriate or alternative technologies patchy at best and abandoned at worst (Abram et al., 2019). Moreover, ownership of technology and expertise, particularly at the utility-scale, often remains in the hands of powerful transnational firms (Baker and Sovacool, 2017; Newell and Phillips, 2016). Such insights complicate the underlying assumption in STT that the context and conditions of innovation matter less as one leaves the niche stages of development, raising the question of how such geographies continue to matter in the ongoing institutional work required for building socio-technical regimes. Below, we explore in detail the ways the geographies of niche innovation and regime formation have been conceived thus far.

2.1 The geographical production of niche opportunities

The idea that new technologies require a wide variety of active support to develop effectively is a central tenet in socio-technical transitions research, and in the fields of innovation studies, evolutionary economics and science and technology studies (STS) on which this research draws. Analysts argue that a protective space is needed where capabilities for exploiting the technology can be built up. In evolutionary terms, this is seen as the creation of situations where the development of technological capabilities can be shielded from selection pressures typical in incumbent regimes. These pressures include market competition, regulatory frameworks, workforce skills profiles, user routines, and supporting infrastructures (Smith and Raven, 2012). Activities must be mobilised by advocates of the technological alternative to counter these selection pressures.

The uneven spatial distribution of protection and targeted policy support suggests that geographical processes are at work in cultivating niche spaces. Such cultivation involves the active production of conditions for innovation (Smith et al., 2014). Yet, whilst there is recognition that the conditions for developing niches are unevenly distributed, the active production of those conditions has yet to be fully interrogated. At best, localities are seen to offer up different 'contexts' that can be exploited for

the advantages they confer to niche development as compared to regimes. Taking their cue from actor-network theory (Callon and Law, 1989), and the possibility to enrol favourable contexts into PV development, Smith et al. (2014) found, for example, that solar PV advocates in the UK became increasingly adept at exploiting shifting contexts nationally and internationally, along with project opportunities locally, to position PV as an object of interest to architects and developers. In this case, they did so by mobilising ideas for building-integrated solar PV and taking advantage of what was then a lucrative feed-in tariff. This shifted the interpretative frame for PV performance and widened support from an architectural constituency. Whilst Smith et al. (2014) used discursive analysis to examine such niche spatial work, Coenen et al. (2012) incorporated material questions through their arguments about spatial proximity, such as skills, spill-overs, infrastructures and testing facilities. Drawing on economic geography and firm-level perspectives, Coenen et al. (2012) explain how the proximity of a configuration's socio-technical elements limit niche innovation developments to some spaces and restrict their spread to others. Additional research has pointed to the important cultural and historical processes and milieu that shape the development of niches, for example through the ways that communities respond to renewable energy (RE) interventions in relation to land use and resource management practices (Murphy and Smith, 2013; Haf and Parkhill, 2017). Taken together, these perspectives suggest that the conditions through which niche innovations become established are shaped by shifting geographical conditions over time.

2.2 Engaging with the geographies of socio-technical regimes

Opening niche spaces to geographical scrutiny has helped to reveal the various forms of work involved in stabilising socio-technical configurations. As noted above, the literature has tended to assume that once such configurations gain momentum, they can readily diffuse across space and time. Here, we want to suggest that the active work, which is itself geographically produced continues into the development and reproduction of proto-regimes, such as solar PV, as well as the protection of incumbent energy regimes such as coal-fired electricity.

Both niches and regimes are constituted by attempts to assemble and hold together elements across multiple scales, connecting diverse locations and carrying the circulation of socio-technical elements as varied as skilled workers, investment, artefacts, property rights and so forth. For example, efforts to protect a fossil fuels regime would appear to include high levels of subsidies supporting fossil fuels as compared to renewables (cf. Schmidt et al., 2017), the protection of path dependencies in the labour market, and vested interests and lobbying by political and industrial actors, including revolving

doors between terms in political office and positions on boards and trade associations. That said however, some authors have suggested the perceived stability, and permanence of fossil fuel-based regimes may now be exaggerated (Haarstad and Wanvik, 2017). Accordingly, it is important to examine the apparent differences between the active work required for opening niche protective spaces and that of maintaining regimes. These differences are likely to involve questions of relative power and agency, institutionalisation and embodiment through infrastructures, practices of legitimacy and the momentum of path dependency, but which nevertheless all have specific geographies.

If this is the case, the analytical task is then not one of trying to identify where and how protective space falls away and regime institutionalisation arises. Rather, as geographers have suggested, energy generation and use does not merely consume space but produces space in different ways, (re)producing energy landscapes (Nadaï and van der Horst, 2010; Castán Broto, 2017). Combining this perspective with ideas in STT, these energy landscapes offer the conditions in which socio-technical systems of energy can emerge, become established, and eventually, undone. Drawing on recent work on energy landscapes, and landscape studies more widely (e.g. Wylie, 2010), enables scholars to critically engage with the spatial arrangements of energy systems accumulated over time in particular places. Such an approach can enrich the a-geographical treatment of socio-technical landscape in transitions studies, enabling a more dynamic understanding of multiple ways of developing solar PV.

Accordingly, rather than discerning whether or how solar PV has shifted from a niche innovation to a regime, the question becomes one of understanding how it becomes established in relation to other technical configurations in an evolving energy landscape. Addressing the ways that solar PV is configured within energy landscapes also foregrounds history, cultural and institutional practices in studies of energy transition and innovation (Castán Broto, 2017). Such an analytical move also recasts spatial proximity, context and selection pressures not merely as the background upon which certain technologies emerge, but as core constituents of STTs, which are actively and continuously produced.

This approach points to the geographical features that shape decisions as to whether even the most transferrable and competitive technologies get taken up (or not) in dynamic energy systems. While this poses a challenge for transition theory, we suggest that without attending to diverse geographies, and the ways that they shape technology deployment on the ground, stories of technological innovation and transfer will remain more an academic exercise than a practical reality.

Before developing this perspective in relation to the emergence of solar PV in our case study countries, we provide background on the energy systems in Mozambique and South Africa.

3. Background and methodology

3.1 Understanding energy systems in Mozambique and South Africa

Our review above suggests there is scope for considering how and with what consequences the development and diffusion of innovations is geographically constituted, even when they have gained regime-like maturity. In this section, we explore in more detail the work afforded to solar PV through our two case studies, drawing on the geographies of transition.

A focus on Mozambique and South Africa enables us to examine different configurations of solar PV, and how they overlap and interrelate. The two countries have distinct histories, socioeconomic makeup, political systems and degrees of industrialization. Yet, they also share a nearly 500 km border, along with interconnected histories of colonial domination, state-led development and shifts to market-based liberalisation (Pitcher, 2002), which shape current practices of resource extraction and energy use (Power et al., 2016). The development of energy systems in each country has differed, but they also share interdependencies that reflect unequal power relations. Underlining these relations, Mozambique continues to export the majority of the hydroelectricity generated from its Cahora Bassa dam to South Africa's Eskom utility, following pre-independence agreements signed between Portugal and South Africa in the late 1960s (Isaacman and Isaacman, 2013).

Both states have governing parties that emerged as national liberation movements. Mozambique gained independence from Portugal in 1975, while in South Africa legal apartheid ended and multiparty democracy began in 1994. In Mozambique, the abrupt end of Portuguese colonialism left a vacuum of expertise as the country descended into civil war between the Frelimo-led state and the rebel group Renamo for the next 16 years (1977-1992). Frelimo's adoption of state socialism in the late 1970s evolved into a centralisation of economic and political control to enable the government to lead the task of modernizing the nation (Hanlon, 1984). This tendency has persisted amid Frelimo's shift to a market-driven economy, while the end of the war marked the start of an era of relative prosperity and growth at the national level. By the 1990s, under agreements with the IMF as a condition for lending, Mozambique abandoned its state-led, import-substitution-based approach for a market-led growth model (Pitcher, 2002). Rising foreign investment and international aid

inflows supported the state budget and, since the early 2000s, an interest in megaprojects based on extractive resources (ibid; Kirshner and Power, 2015).

Historically, South Africa's energy system, and wider economy, have been characterised by the minerals-energy complex (MEC) (Fine and Rustomjee, 1996). The MEC refers to the links between the country's centralised production of coal-fired electric power and vested interests in mining and minerals beneficiation developed during the apartheid era (1948-1994). South Africa's long-term dependence on abundant low-cost coal, mined by hyper-exploited black labour for the bulk of its electricity production, has resulted in an energy-intensive economy, though structural shifts in the economy have meant that this sector is now in decline. Electricity in South Africa has been provided by the state-owned monopoly utility Eskom, which owns and operates the grid. Eskom is responsible for 94% of the nation's electricity generation and 60% of distribution, while municipalities are responsible for 40%. Grid connection rates increased from roughly one third of the population (currently 56.72 million) to some 87% since the fall of apartheid. Yet, many low-income households are connected but cannot afford to use this connection, and 3.2 million households, particularly those in informal settlements, lack electricity and other basic services (SEA, 2015). During the transition to democracy, access to affordable electricity became 'a basic need and basic right' with social and political resonance (Mayr, et al., 2015), central to the governing African National Congress's (ANC) efforts to redress longstanding social and economic exclusion.

Mozambique faces persistent energy access challenges alongside its aim of reducing carbon emissions. Although estimates vary, only 26% of Mozambique's 28.8 million people have access to electricity (EDM 2017), while less than 5% can access clean fuels (Global Tracking Framework, 2017), one of sub-Saharan Africa's lowest energy access rates. The Mozambican government is increasingly looking to decentralised systems for rural provision, given the high unit costs of grid extension to dispersed populations (Interview, FUNAE director, August 7, 2014). Mozambique has also recently become a major exporter of hydropower, coal and natural gas, aiming to become a southern African energy hub (EDM, 2018). By comparison, centralised electricity generation and transmission hold sway in South Africa, although recent experiences of load-shedding, along with a financial and political crisis within Eskom, have called this model into question (Baker and Burton, 2018).

Within these complex and multi-layered energy systems, energy providers and users are configuring solar PV in different ways. Along with environmental and security concerns, abundant solar irradiation and persistent energy access challenges in both countries have sparked interest in solar

power. In South Africa, an upper middle-income country with a regionally dominant economy, most solar PV development has been utility-scale and grid-connected, largely generated by independent power producers (IPPs), built and operated by private engineering companies, and financed by South African banks, development finance institutions and foreign and domestic investors (Baker, 2015). However, as we discuss below, a smaller rooftop solar PV industry is also emerging, despite the lack of a facilitating regulatory framework. Since the rise of solar PV in the past decade, several private-sector industry associations have formed to lobby for the PV industry's interests nationally, notably the South Africa Photovoltaic Industry Association. In contrast, state policy for solar PV in Mozambique focuses on off-grid rural electrification projects, managed by the state agency *Fundo de Energia* (FUNAE). Thus far, there has been limited private sector involvement, with FUNAE funded through the state budget and international donors.

Apart from these material configurations, the political and socioeconomic significance of solar PV also varies. In South Africa, many view grid-connected solar as a means to boost generation, challenge Eskom's monopoly control, meet national climate mitigation pledges, and harness the development opportunities of the green economy while attracting investors. In Mozambique, PV is largely envisioned as extending off-grid energy access, regarded by state planners and donors as an alternative to costly grid extension or dispersed diesel generators. Both configurations draw on well-established international formats for solar PV. Yet, as we suggest below, their features also stem from the particularities of each country's socio-political context.

We suggest that rather than thinking of solar PV as a niche technology to which protection might be afforded, it is fruitful to engage with the active and multi-scalar processes through which it becomes viable in each country. This approach illustrates the ways that mobilizing a 'regime-in-the-making' unfolds. We now turn to the ways that developing this proto-regime takes shape, potentially enabling wider low-carbon transitions and reverberating well beyond their national contexts.

3.2 Methodology

Methodologically, the study is supported by field observations, semi-structured interviews with key actors and unstructured conversations with public officials and residents. The research in Mozambique consisted of two phases of multi-sited fieldwork in 2013 and 2014. In the first phase, we conducted 75 semi-structured interviews with officials with Mozambique's national electricity provider (EDM), the state agency responsible for rural energy (FUNAE), several government

ministries, the Centre for Investment Promotion, which channels foreign investment projects, and representatives of key donor organizations. The interviews focused on institutional histories, energy development priorities, on-grid and off-grid planning and coordination, donor engagements and locational characteristics.

The second phase involved extended site visits to six off-grid energy service projects in Manica and Zambézia provinces and a solar equipment assembly plant outside the capital city, Maputo. The visits explored the configuration of energy resources, technologies, infrastructures and demand in different parts of the country. Additionally, we carried out 14 interviews with residents and community leaders near project sites to understand their experiences of energy access and uptake of solar technologies. Return visits in 2015 and 2017 enabled follow-up interviews with representatives of key energy sector institutions and donors in Maputo. We also draw on a review of FUNAE's electronic archival records, desk-based studies, and earlier involvement in research projects to understand the wider energy and political histories at play in the country.

The research in South Africa draws on 62 semi-structured interviews undertaken between 2013 and 2015 with members of government departments, the national utility (Eskom), project developers, banks, lawyers, union members, civil society and community liaison officers. The research also included extended site visits to multiple solar PV projects and attendance of public conferences run by energy sector and finance representatives. We also surveyed documentary evidence, including policy papers, legal documents, minutes of public meetings, news reports and speeches by government officials and energy stakeholders.

4. Making Space for Solar PV in Southern Africa

4.1 Going off-grid in Mozambique

Mozambique faces a paradox of entrenched energy poverty amid plentiful energy resources. The historical legacy of colonialism and extractive mercantilist capitalism has led to the development of energy resources and infrastructures geared towards export markets, including South Africa's. The giant Cahora Bassa hydroelectric dam in the central province of Tete exemplifies these dynamics. Completed in 1974 in the last year of Portuguese rule, colonial authorities initially envisioned the dam as a wider regional development initiative that involved irrigating land in Tete province, part of a program to settle Mozambique with Portuguese farmers (Isaacman and Isaacman, 2013).

Construction began in 1969, with the project financed by foreign investors and the guaranteed sale of electricity to South Africa at below-market prices, in exchange for its strategic support in the colonial war (ibid). As a result, electric power flows into South Africa on high-voltage lines connecting to a substation outside Pretoria, with a proportion re-imported into southern Mozambique on lines owned by Eskom (Cipriano et al., 2015; EDM, 2018). More recently, FDI flows have shifted to the exploitation of hydrocarbon resources. With offshore gas discoveries in the far north, Mozambique is expected to become a global gas exporter, while growing coal operations have made it sub-Saharan Africa's second largest coal producer (IEA, 2014).

Until independence, electricity access was confined to formally planned sections of the capital, Lourenço Marques (the colonial name for Maputo) and several provincial centres, with generation from dispersed municipal diesel generators, a coal-fired power station and small hydropower plants (Baptista, 2017; Cuamba et al., 2013). Mozambique's state-owned electricity company, *Electricidade de Moçambique, E.P.* (or EDM), was founded two years after independence in 1977; its operations were severely curtailed during the civil war. From 1995, EDM began to expand the national grid inherited from colonial rule, with support from donors, regional partners and foreign investment (Baptista, 2017). For the next two decades, the grid expanded substantially, connecting all provincial centres and district seats by 2014, but still bypassing extensive rural areas (See Figure 1). The country's low population density and largely low-income population makes it difficult and costly to connect everyone to the grid (Interview, EDM representative, 2 November 2017).

[Figure 1: about here]

In this context, two strategies for supporting energy system transitions are emerging. First, a strategy of *grid expansion* in which EDM is extending transmission and distribution infrastructure to meet rising demand, mainly in urban and peri-urban areas. Second is a strategy of *decentralised generation*, operating off the centralised grid, and shaped by a recognition of the limits of grid extension, particularly in rural areas and by donor priorities for promoting clean sources of energy. This second strategy is often associated with low carbon innovation. Wider discussions of global climate change, the need to provision new parts of the grid, and recent state efforts to combat energy poverty underpin these approaches. Solar PV is being enrolled into these programmes in different ways, and they serve increasingly as the means to mobilize solar PV, in turn shaping its social and material configuration, practices associated with its use and its global development as a technology beyond a specialised niche.

At the heart of how solar PV is being mobilised in Mozambique is FUNAE, the state agency responsible for expanding energy access in rural areas. Mozambique's central government set up FUNAE in 1997 with Danish assistance, and it initially supplied diesel generators and kerosene in rural communities lacking energy services. By the early 2000s, its focus had shifted to promoting, supplying and financing renewables, as manufactured solar panels dropped in price and become more widely available. While FUNAE has developed some micro-hydro and pilot wind projects, its main focus is on solar PV. Between 2000 and 2011, FUNAE installed over 1.2MW of PV capacity with the support of European and Asian donors. FUNAE (2012) calculated that some 1.5 million Mozambicans benefited from installed solar PV systems by 2012, representing about 0.8Wp per person. The World Bank (2015) has estimated the installed capacity of solar power nationally at 2.2MW. While the amount of electricity supplied is small, its ability to improve rural health and education is considered significant (ibid). Solar PV installations have focused on these rural services, with former Energy Minister Salvador Namburete claiming that by 2014, micro-scale solar PV projects were used to electrify 700 schools, 600 health centres and 800 other public buildings in rural areas, at a total cost of US$51 million (MacauHub, 2015).

Solar PV has become an important technology in the development of new forms of off-grid rural electrification. Here, we might regard distance from the existing electricity grid network as constitutive of the ways that PV is embedded in specific contexts: solar PV emerges as a technology in the parts of the country that grid electricity cannot reach. Moreover, recent work in energy geographies suggests the ways that such configurations of the solar PV are actively produced (cf. Frantál et al., 2014). Access to grid electricity in Mozambique is a product of the development of extractive resources, transit corridors, ports and urban centres during colonial rule (Newitt, 1995). The prioritisation of some places and forms of electricity deemed worthy of supply also serves to shape what constitutes 'off-grid.' By agreement with EDM, FUNAE works in areas projected to be over 10 km from the grid network within five years. Solar PV is thus configured in the Mozambican context through the active production of a geography of those areas that are not-yet-promised grid electricity.

In these ways, off-grid solar in Mozambique competes not with an incumbent regime institutionalised through nationally-vested interests or centralised infrastructure networks, but with disaggregated configurations through which fuel for domestic energy needs is provided by kerosene and charcoal, and where diesel engines generate power in the domestic, commercial and public realms. In this context, FUNAE initially installed solar PV—via contractors following global ISO standards—outside the domestic arena to provide a public source of power for lighting and

refrigeration in schools, clinics, and rural government offices. Through building an association between solar PV and rural development, particularly in relation to delivering lighting for education and refrigeration for health services, solar PV came to be configured as a key mechanism of development within the donor community and the state. It also has produced new forms of demand, along with rapidly changing expectations of energy access in rural areas, which a patchwork of existing local energy systems based on kerosene, diesel or biomass struggled to meet in a cost-effective or secure manner. The growth of the public use of solar PV proved to be a testing ground for its further development as a means through which to provide domestic energy services.

In the past decade, FUNAE has developed projects focused on households, small businesses and villages, which include both mini-grids and solar home systems (SHS) installed in homes and shops. Here, FUNAE is actively involved in the production of solar PV within the rural economy, procuring systems of less than 100w, which households and commercial enterprises can buy through long-term loans underwritten by FUNAE. In a sense, solar PV has no direct competitors, for there are limited forms of energy service that provide the power required for lighting, mobile phone charging and entertainment. Yet solar PV is also configured in relation to other household and commercial dynamics outside the energy system, particularly amid limited resources and capital for investment. Given its capacity constraints, the use of PV has often not replaced charcoal and fuelwood, which many people use for cooking and heating even where solar power is available (Interview, FUNAE Manica office, August 16, 2014). The emergence of solar PV as a means through which development, at the scale of the rural economy and the household, can be achieved serves to enable its translation into particular sites and configurations on the ground.

As the demand for solar PV has been fostered through these means, FUNAE has also become engaged with ensuring its supply. In this *nurturing* role for PV, FUNAE has used various mechanisms. This has involved initiating and managing the construction of Mozambique's first solar module assembly plant, supported by a US$13 million concessional loan from India's Exim Bank. The FUNAE plant, which opened in 2013 in Beluluane, just outside Maputo, aims to produce 5MW of capacity annually, reducing imports and equipment costs, which are primarily intended to be used directly by FUNAE in its projects (Interview with FUNAE manager of Beluluane plant, 4 August 2014). It has also sought to set up favourable contracts in order to diversify the nature and range of solar PV available. In 2014, FUNAE awarded a contract to the German firm Fosera to install pico-solar systems in schools and homes in Manica province. The firm has established a subsidiary in Maputo assembling pico-solar units (from parts manufactured in Thailand), including solar lanterns and solar phone chargers. More recently, FUNAE has managed the development of PV mini-grids in Niassa province, in the far

north, a project financed by the South Korean government. As solar PV has increased in scope and visibility, it has come to be regarded as something of a status symbol in rural settings, such that there is a growing market demand for installation beyond the boundaries of the FUNAE programmes.

The processes of enacting solar PV in Mozambique encompass multiple actors, ranging from Danish and Belgian finance and technical assistance, Indian concessional loans, do-it-yourself shopkeepers in rural villages and technology developed in Germany, manufactured in Thailand and assembled in government-supported plants in the capital region. These actors foster configurations not derived from the 'hard' kinds of regulation that have led to the development of auctions or feed-in tariffs and incentives for innovation found elsewhere, including South Africa, but rather are 'soft', less direct and multiple in their origins and arrangement. This distributed, networked geography of solar PV configuration serves to translate the technology in relation with the changing landscape of the electricity grid, on the one hand, and growing demands for multiple forms of energy service on the other. While solar PV as a decentralised system can ostensibly be installed in any rural area sufficiently distant from the existing grid, in practice this process of installation has been uneven. Such projects, for instance, are rarely sited in the most remote areas of a district, according to interviewees. Moreover, there is a lack of integration with other dispersed systems, such as villages with micro-hydro generation (Interview, GIZ Mozambique, 28 August 2014).

In parallel, the policy support for expanding the national grid across Mozambique is further shaping the available space for solar. Since initiating a grid extension programme two decades ago, EDM has increased grid access from less than 5% in 1995 to 26% in 2015, narrowing the gap in electricity access (EDM, 2017). The geography of grid expansion as a largely urban project, privileging urban areas inserted into commercial networks, has in turn shaped the spaces within which solar PV is emerging as rural. Yet within such sites, solar PV is enacted in particular ways. The energy services that configurations of solar PV afford shape where and for whom it is translated. Unlike in South Africa and Kenya, for instance, energy planners in Mozambique do not widely consider solar PV a grid-connected technology. Amid electricity supply shortfalls, the Mozambican government has shown a growing appetite for using newly exploited hydrocarbon resources for domestic generation and export. Further, the persistence of 'non-modern' forms of energy (traditional biomass) compete with PV electricity—and grid expansion—as many Mozambicans prefer meals cooked over a charcoal stove or fire rather than foods prepared using an electric cooker.

Configured as a technology of rural development and mobilized through actors within development projects, finance and economies, solar PV has become a source of power that can deliver basic

needs, from lighting for education to refrigeration for vaccines, the workings of government offices, and increasingly the mobile phone economy. Yet such forms of energy service have not substantially altered energy demand in rural Mozambique, with systems ill-equipped to power electric cooking or appliances of various kinds. Often developed as one-off installations, recurring problems of maintenance, operating costs, disposal and theft further limit the ways that solar PV is embedded in the rural economy. This suggests that despite the multi-scalar opportunities afforded as solar PV is mobilized internationally, the narrating and assembly of solar as a development technology, creating solar aspirations, and nurturing the supply chain in a way that reduces costs and increases the security of supply, the actual translation of solar PV from a regime into particular places remains an ongoing project.

4.2 Making Solar Connections in South Africa

South Africa's electricity sector has been shaped by the social, political and economic legacy of apartheid, which prioritised the needs of industry and the white minority (Ziramba, 2009), operating through the minerals-energy complex (Fine and Rustomjee, 1996). Recent years, however, have witnessed several changes in the MEC's core features. These include, first, a decline in the contribution that mining and heavy industry make to the national and international economy: until 25 years ago South Africa accounted for 40% of the world's mining industry, but by 2015 accounted for only four per cent (Seccombe, 2015). Second, Eskom's historical dependence on South Africa's abundant sources of formerly low-cost coal is changing amid national commitments to reduce emissions and shifts in the national and international coal market. Despite these recent developments, 44 energy intensive companies currently account for 40% of South Africa's electricity consumption[1] while its electricity sector generates approximately 45% of its carbon emissions.

As might be expected given apartheid's unequal legacy, access to grid electricity (see Figure 2) remains highly uneven, compounded by a chronic lack of housing, and informal settlements where access is often very limited or achieved through illegal connections. As discussed above, the national electrification programme introduced amid post-apartheid state building led to a dramatic rise in domestic connection rates, assisted by surplus capacity and low electricity prices (Bekker et al., 2008). Yet, many cannot afford to use the electricity, and millions of low-income households are multiple fuel users, often prioritising paraffin, wood and coal over electricity (Tait, 2016). Moreover,

[1] http://eiug.org.za/

by the early 2000s, progress in national electrification slowed for various reasons, including the cost of infrastructure needed to connect sparsely-populated rural areas (Bekker et al., 2008). Achieving grid connection has come not only to symbolize development, but also figures importantly in the project of post-apartheid social integration. Off-grid energy systems have signified a poor substitute for access to grid-enabled services and a means only suitable in remote districts to support productive agriculture.

[Figure 2: about here]

If the culture of South Africa's energy system was historically based on a paradigm of "big coal, big nuclear, big networks" (Eberhard, 2013), the introduction of solar PV marks a shift. The emergence of utility-scale solar PV was sparked by the country's Renewable Energy Independent Power Producers' Procurement Programme (RE IPPPP) and its Integrated Resource Plan, both launched in 2011. More recently, and especially since 2014, affluent consumers and firms have set up grid-connected rooftop PV amid electricity supply shortfalls (Korsten, 2015). The process for RE IPPPP began in the late 2000s, when officials within the national energy regulator (NERSA), supported by German and Danish technical assistance, began to push for a renewable energy Feed-in Tariff (REFIT) (Baker et al., 2015). While there was opposition to REFIT from within the Department of Energy, the regulator, Eskom and energy-intensive users, by the late 2000s it had attracted attention from international RE developers and technology suppliers. Attempts to establish REFIT paralleled ongoing crises in the electricity system, resulting in national power shortages. They were joined by growing domestic and international pressure to address climate change and adopt new emissions targets, a global oversupply of PV technology, and mobile capital seeking new spaces for investment in RE, as the financial downturn weakened interest in the US and Europe. The support of foreign investors and development finance institutions, together with attempts to introduce independently produced power, gave impetus to those promoting a privately-owned RE generation industry. This momentum led the Department of Energy, backed by National Treasury, to replace REFIT with RE IPPPP, a competitive bidding process by which independent power producers (IPPs) could generate renewable electricity for the grid (Baker et al 2015).

A key challenge to this configuration of solar PV, as with onshore wind, concentrated solar power (CSP) and other renewables, concerns the grid's financial and technical capacity to incorporate intermittent sources, along with political opposition from Eskom and related political factions. Notably, there were delays to the RE IPPPP programme due to Eskom's refusal in 2016 to sign 27 power purchase agreements. The utility did not provide a formal reason as to why it refused to sign

the PPAs, though it claimed it would make a loss on having to purchase power from IPPs (SAREC 2017) and that the country's energy supply had stabilised since the latest round of load-shedding in 2014-2015, making additional capacity unnecessary. The projects were eventually signed off in April 2018, following President Ramaphosa's inauguration. While round five of RE IPPPP was intended to open in 2016, it is still on hold. Eskom's resistance can be seen as a political as well as a technical act, given that solar PV generated by IPPs would challenge its control and that of associated political factions (Baker and Burton, 2018). Further, the downgrading of Eskom's investment credit rating (together with South Africa's) in recent months and management scandals and allegations of corruption linked to the utility—part of broader national political turmoil—has served to discourage investors and financiers from the country's renewable energy sector, particularly in light of the opportunities offered by other emerging markets.

Solar PV's configuration as a technology capable of contributing to RE generation at utility scale arose not as an inevitable feature of PV as a modular technology, but from its mobilisation from within South Africa's wider energy system. With the launch of RE IPPPP nearly a decade ago, PV was positioned as a technology that could rapidly contribute to South Africa's electricity supply and emissions reductions targets. In contrast to its largely off-grid configuration in Mozambique, since RE IPPPP, solar is envisioned primarily as a large-scale and grid connected. Currently, 112 RE projects—some 40% of which are solar PV, constituting over 6,400 MW of capacity—were approved under RE IPPPP. Of these, nearly 3,800 MW of capacity is so far operational (IPP Office, 2018; Cotterill, 2019).

By March 2018, RE IPPPP had attracted R201.8 billion (US$14.2 billion) in private capital for debt finance and equity investment, of which 24% is foreign investment (IPP Office, 2018: 2). The regulation that facilitated RE IPPPP was thus able to open space within the otherwise utility-dominated electricity sector for PV. This mobilisation has echoes in the transitions literature, where regulation and protection serve to reduce the barriers to entry for new technologies until they can compete in the open market (see Smith and Raven, 2012). Yet, in South Africa, it was also the nature of the global market that shaped the configuration that solar could become. Fierce competition and oversupply in the manufacturing chain, in which China is the world's largest producer of PV cells and modules, has triggered falling costs of solar panels. This drop was reflected in dramatic tariff reductions during the early bidding rounds of RE IPPPP, such that in some instances, solar PV is now cost competitive with coal (Cotterill, 2019). While the wind industry was the greatest advocate for the feed-in tariff a decade ago, solar PV has caught up, reflecting global trends.

The emergence and adoption of solar PV in South Africa has been shaped by project finance structures and definitions of investment risk. While the country's five main banks provided debt finance, equity has been extended by a combination of RE developers, national development finance institutions, and national and international equity investment houses based in South Africa, such as Old Mutual Investment Group South Africa and Globeleq. Despite the requirements under RE IPPPP that domestic and black economic empowerment companies[2], along with host communities, are structured into project shareholding, interviewees expressed concerns that the programme privileges large international companies. Such companies, including global majors such as Abengoa, Acciona and Scatec Solar, hold sufficient capital to withstand delays in implementation while winning increasingly competitive bids with low prices.

While in many low-income countries with limited grid capacity, solar PV has emerged as an off-grid configuration, in South Africa it remains tilted towards grid-connected modes of deployment. It features in an energy landscape in which the national grid holds substantial economic, political and socio-technical influence. Accordingly, solar PV cannot be readily understood as a protected niche innovation separate from a regime. Rather, it must be viewed as the integration of a new configuration of actors, institutions, materials and technologies within the large-scale centralised system of generation, transmission and distribution. Nevertheless, there are technical and financial challenges around Eskom's integration of the technology—and other renewables—into the grid.

Utility-scale solar PV also contributes to the reproduction of social inequalities in energy provision in South Africa. This is not least because solar PV feeds into an electricity system with ever-increasing tariffs, prioritising those who can afford higher energy prices. Beyond RE IPPPP, however, alternative forms of PV are emerging. As the costs of solar PV equipment fall, South Africa's electricity rates rise, and Eskom's crisis deepens, the installation of grid tied rooftop solar PV by upper-income households and businesses is becoming an attractive option. Yet, these developments have occurred largely without formal regulation or monitoring. The growth of rooftop solar PV has also met with resistance from Eskom and those municipalities that hold responsibility for electricity distribution, as they will lose critical revenue raised from affluent consumers, which in turn cross-subsidises electricity services for the poor and other essential municipal services (Baker and Phillips, 2018). Such a reality belies assumptions that the socioeconomic benefits of renewable energy will automatically be felt locally. Although alternative initiatives are often poorly documented, one exception is 'I-shack' in

[2] Black economic empowerment refers to legislation introduced post-apartheid to address socio-economic marginalisation along racial lines.

Enkanini outside Stellenbosch, in the Western Cape, involving the insulation of houses with recycled materials and SHS for cooking, media and lighting (Hees, 2016).

5. Discussion

Empirically, our discussion has highlighted the interactions between multiple configurations of energy, and the ways in which country-specific dynamics, actors and political groupings mediate the emergence and development of solar PV in particular locales. Our findings suggest there is an active, multi-scalar process through which solar PV becomes viable. We emphasize the importance of attending to geographical and historical contexts, rather than pursuing a monolithic or universal approach to solar PV development.

The uptake of solar PV, while varying considerably among our case study countries, is also uneven within countries (cf. Ockwell et al., 2018). We found, for instance, that solar projects supported by the state and donors were often lacking in remote parts of rural districts in Mozambique, while such projects seldom have connections that extend beyond 20 km. In South Africa, grid-connected solar has been largely driven by private developers and investors, while state actors have played a pivotal role in shaping priorities and configurations on the ground, extending far beyond a protected niche. Eskom's actions and broader resistance linked to vested coal and nuclear interests have, however, stalled solar projects and other low carbon initiatives.

We have suggested that the material components of energy systems shape the spaces available for solar PV. These include transmission lines, substations and household connections, along with circulation of financial capital. Mozambique's generation capacity at Cahora Bassa dam, for instance, has long interlinked with transnational networks set up to supply Eskom while neglecting domestic energy needs. Additionally, policy approaches for extending energy provision in Mozambique have assumed a separation of urban and rural areas. The state has emphasized grid extension in urban spaces and for large-scale consumers while mobilizing solar PV in off-grid spaces where the grid is unexpected to reach. Current models of institutional coordination between EDM and FUNAE have circumscribed solar initiatives to rural areas (Castán Broto et al., 2018) despite everyday realities that belie this rural-urban division.

While grid coverage substantially exceeds that of Mozambique, in South Africa unreliable supply and disconnection continue to affect lower-income communities, reflecting wider injustices in the provision of energy. Compounding this, there is little transparency over the terms of private

investment, project ownership structures, regulatory frameworks, and the extent to which host communities surrounding utility-scale projects might enjoy longer-term benefits, such as training, jobs and affordable energy, despite the rhetoric of a country embarking on an inclusive green transition (Swilling et al, 2016).

Analytically, drawing on STS and the geographies of transitions, we have considered the ways in which innovations that emerged within protected niches may overlap and coexist alongside incumbent regimes. We have proposed that niches and regimes do not exist as a duality, opening up the possibilities of hybrid forms of contextually-generated innovation (cf. Bouzarovski and Haarstad, 2018; Mavhunga, 2014). Instead of replacing incumbent energy systems wholesale, relatively new and maturing technologies (such as PV) interact with existing social, political and infrastructural networks along with ad-hoc and localized forms of provision. These interactions shape wider transition possibilities (Smith et al., 2014) while demonstrating that sustainability transitions are "neither linear nor purely technical" (Abram et al., 2019: 4). Destabilizing framings of niche-regime as somehow separate enables us to better analyse the particularities of how solar PV materializes in specific contexts, and the active production of conditions for its development (Smith and Raven, 2012), rather than uncritically assuming its implementation or replication in any context.

Correspondingly, taking inspiration from energy geographies, the notion of energy landscapes has been useful for bringing out the connections between solar PV configurations and socio-material arrangements both within and external to energy systems. From this perspective, energy landscapes are flexible, fluid and connected to political relations and everyday practice, rather than passive and predetermined settings within which change occurs (cf. Wylie, 2010). We have suggested that further critical engagement and theorization from a multiplicity of sites, including those with large gaps in energy access, can enrich sustainability transitions thinking, along with policy approaches and learning for renewable energy planning.

6. Conclusion

Through this analysis, we have suggested that even as niche technologies reach maturity and transcend the contexts from which they have emerged, they remain constituted through multiple sets of relations that are continually remade, such that the geographies, histories and politics of transitions are an ongoing project. A presumption within transition studies suggests that once mature, technologies can free themselves from the constraints of specific conditions. Geographies

are consequently seen as bringing less to bear on the trajectory of how particular socio-technical systems evolve. Owing to a set of historical routes that focused on the technological attributes of transitions, the assumption has been that as a standardised and competitive technology emerges from its niche, it acquires sufficient capacity and momentum to mould specific conditions to its requirements. At this point, all the key elements for a working socio-technical regime are circulating globally, carried by a growing constituency and institutional platform (Geels and Raven, 2006), in which routinized transfer processes make rollout to new locations easier. Elements can be imported and assembled relatively easily via industrial processes, business models, financial investments and policy transfer, whatever the locality.

In contrast, we have argued that emerging and incumbent energy regimes at the local and national level must contain within them the agency and active work not only to reproduce themselves, but in so doing generate geographical conditions adapted to the perpetuation of their regime, autonomously of other configurations. Moreover, as with niche protective spaces (Smith and Raven, 2012), the work needed to build momentum behind a regime can be easier in some locations than others. Indeed, the reproduction of regimes and the cultivation of niche spaces closely interact within energy transitions. Yet despite these connections, we currently have a limited understanding of the role that geography plays in the production of such interactions and the distribution of their consequences.

Our analysis suggests one way of better understanding this geography: the multi-scalar processes of contending socio-technical configurations, some of which might appear to be maturing into regimes internationally, and yet which, like even incumbent energy socio-technical configurations, are perpetually reproduced, but in different ways. Considering the dynamic features of energy landscapes in positioning socio-technical configurations, it becomes apparent that a step-change is required in the geographical development of a configuration once a degree of maturity has been reached and diffusion picks up. A set of activities that is more characteristically political and economic needs to overlay the refined 'how to' knowledge production embodied in regimes internationally, such as those depicted for solar PV in the Introduction. In our analysis, this means recognising how and why geography continues to matter as the solar PV regime expands, since it is the localised histories and multi-scale interdependencies of incumbent energy landscapes that shape or inhibit the rollout of regime-like, maturing technologies like PV.

In the South African example, this means solar PV businesses, investors, advocates, policymakers and citizens need to address and challenge the opposition to its implementation by vested interests, as

well as ensuring that its implementation addresses ongoing socioeconomic injustices, along with renewable generation. It also means attending to the cultural aspects of energy landscapes, in which access to grid electricity is a right and forms part of post-apartheid emancipation, while off-grid is deemed for many low-income energy users as socioeconomically (and symbolically) inferior. In Mozambique, it is the power of a centralised ruling party enjoying the opportunities from newfound wealth in fossil fuels, inserting the country into globalized circuits of commodities, while shaping the available space for renewables. It also means examining the interplay of solar PV for certain uses, combined with continued reliance on biomass consumption. Sometimes this is out of necessity for subsistence, but as we saw for cooking, it can be for cultural reasons.

The rise of a socio-technical regime for PV internationally is helping more actors learn how to do PV better, installing it appropriately in geographically varied locations, developing businesses and connecting components that circulate at different scales. But more of the political, economic and cultural bedrock of energy landscapes has also to be worked at, and this is much more uneven and less susceptible to codification and transmission through a regime internationally.

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Figure 1: Mozambican electricity grid network, managed by *Electricidade de Moçambique* (EDM)
Source: www.geni.org (Global Energy Network Institute)

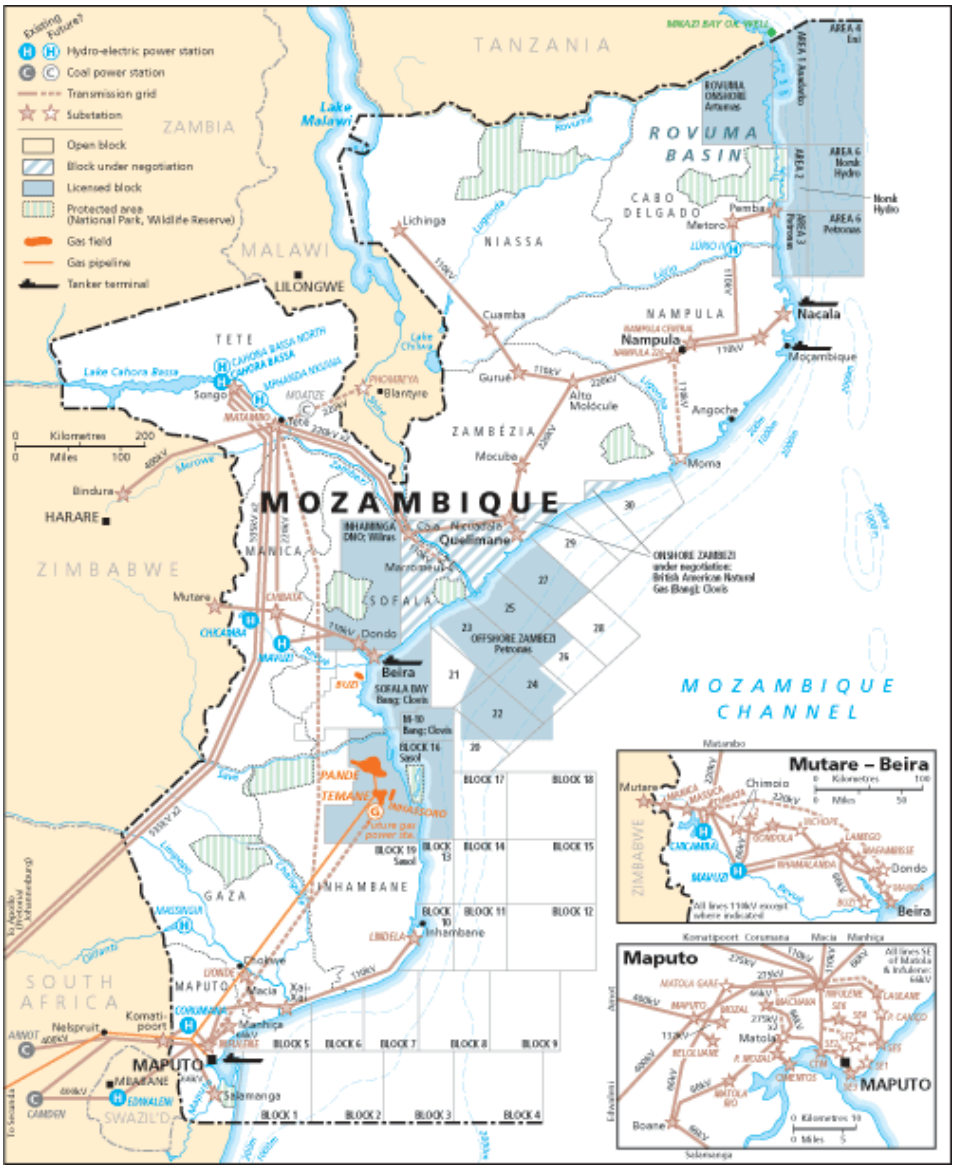

Figure 2: South African electricity grid network, managed by Eskom
Source: www.geni.org (Global Energy Network Institute)