Infrastructures of Large-Scale Geothermal Energy Projects in Kenya: Materialization, Generativity, and Socio-Economic Development Linkages

The linkages between infrastructures and socio-economic development have become increasingly complex and varied in transdisciplinary human science scholarship. In the Global South context in particular, these linkages entail unusual geographies of diffusion that defies many easy narratives. Using the case of geothermal energy projects in Kenya, this article explores the materialization and generativity of infrastructures in large-scale projects and their complex linkages to socio-economic development. In so doing, the paper shows how the delivery of 'core' infrastructure projects enable the provision of 'other' infrastructures – 'required' and 'generated' infrastructures, all of which entail different socio-economic development linkages for different interest groups at national and local community levels. In exploring these processes, we engage with multi-disciplinary scholarship on the materialization and generativity of infrastructures and their variegated and multifaceted linkages to socio-economic development. A methodological combination of expert and informal interviews, document analysis, and project-sites observations form the basis of our analysis.

Keywords: *Infrastructures, large-scale geothermal energy projects, materialization, generativity, socio-economic linkages, Global South, Kenya*

Introduction

Infrastructures are apparatuses such as dams, highways, geothermal plants, canals, airports, and harbors, in energy, transport communication and water sectors of an economy or society, which enable other things to happen (Star 1999). In his influential review essay, Larkin (2013) further describes infrastructures as "built networks that facilitate the flow of goods, people, or ideas and allow for their exchange over space" (p.328). For him, the "peculiar ontology" of infrastructure "lies in the facts that they are things and the relation between things" (Larkin 2013 p. 329). Following these lines of thinking leaves us with the understanding of infrastructures as a critical and necessary element for rapid socio-economic transformation. Yet, the existence of infrastructures or attempts to create them have generated critical debates on their potential causes of undesirable processes and outcomes such as human dispossessions, displacements, environmental degradation, and global warming (Beevers et al. 2012, Campbell et al. 2017, Divine et al. 2017). This paradox has increasingly become a subject of inquiry in interdisciplinary human science scholarship as many developing countries in the global south increasingly "turn to infrastructure" with increasing mix of actors (Glass et al. 2019, Addie et al. 2020).

Using the case of the development of large-scale geothermal energy projects in Kenya, this paper explores the materialization and generativity of infrastructures of large-scale renewable projects and their complex socio-economic linkages in the developing countries context. We argue that a more complete appraisal of the socio-economic impacts of large-scale renewable projects should prelude a process-tracing analysis of their materialization and generativity potentials. We demonstrate this argument in our study by showing how the materialization of large-scale geothermal energy infrastructures ('core' infrastructures) generates other infrastructures ('required' and 'generated' infrastructures), all of which, when considered as a whole, have multifaceted socio-economic implications, and impacts for interest groups at national and local levels. By so doing, this study responds to the growing calls to situate and understand infrastructure provisions in the realities faced by many countries in the Global South (Jaglin, 2015; Coutard & Rutherford, 2016). Empirical analysis of large-scale infrastructure projects in the Global South begs for wider thinking of the complexity and dynamism of infrastructure configurations, which challenges the predominant binary notion of their materialization and impacts (Lawhon et al., 2014; Silver 2014, Lawhon et al. 2018; Chamber 2019, Barry 2020).

The paper continues in the next section (section 2) by discussing the infrastructures, their materialization, generativity, intents, interests, and their socio-economic development nexus. Afterwards in section 3, it presents the methodology and the cases of the study projects. Based on these cases, it goes on in subsequent section (section 4) to analyze and discuss the materialization and generativity of geothermal infrastructure projects and their complex and differentiated socio-economic development interests and linkages at national and local community levels. The paper concludes in section 5 by summarizing its findings and presenting its implications for socio-economic impacts analysis and appraisal of large-scale infrastructure projects.

Literature Review

Materialization and Generativity Potentials of Infrastructures

The materialization of large-scale projects consists of a combination of infrastructure artefacts with generativity potentials to necessitate or enable the creation of other infrastructures in a networked configuration (Barry, 2020). Heterogenous Infrastructure Configurations (HIC) formulated by Lawhon et al. (2018) provides an analytical lens which serves as a starting point in understanding these networked configurations. The HIC analyses infrastructure artefacts "not as individual objects but as parts of geographically spread socio-material configurations: configurations which might involve many different kinds of technologies, relations, capacities and operations, entailing different risks and power relationships" (Lawhon et al, 2018 p. 722). In doing so, Lawhon et al. 2018, pushes thinking around infrastructures to better consider and incorporate the numerous other complexities embedded within infrastructure construction, including stakeholder interests, thereby allowing for a distinguishing or separating infrastructural artifacts from one another, based on their interests and rationale for materialization and generativity. In this sense, infrastructures of large-scale projects are therefore not independent apparatuses but are often geographically embedded and networked in wider socio-material configurations of relations and operations, possibly in network with other technical and social infrastructures, with socio-economic and political implications (Silver 2014, Chamber 2019, Thekdi & Chatterjee, 2019).

Before Lawhon et al. 2018, existing accounts attempted to frame the complex materialization and generativity potentials of infrastructures as hybrid and mixtures (Furlong, 2014; Larkin, 2008), continuous and incremental (Silver, 2014; Maringanti & Jonnalagadda, 2015), post-networked (Coutard & Rutherford, 2011; Monstadt and Schramm 2017), as well as people-centered and lived (Graham & McFarlane, 2014; Simone, 2004; Scott 1998). The hybridity of infrastructures materialization and generativity reflects in the diverse and that different ways in which infrastructure artefacts connects and embeds into existing formal geographies, sometimes causing the creation of other new infrastructures (De Boeck & Baloji, 2016; Kimari & Ernstson, 2020). Although similar literature focuses on the spread of networked infrastructure, Meehan (2014) suggests the consideration of 'informal' infrastructures which can emerge in large-scale projects, and which often serve as conduits outside of state control. These networked infrastructures often inspire new possibilities for social collective organizing, ownership and power relations as well as generating new platforms for engagements outside of the state, which may or may not be initially intended (Schouten & Mathenge, 2010; Ernstson et al., 2014; Silver 2014).

Infrastructures are also continuous and incremental in the sense that it involves constant socio-material production, maintenance, expansion and reconstruction (Silver, 2014; Coutard & Rutherford 2015, Maringanti & Jonnalagadda 2015), with diverse involvement of people as actors in shaping its constitution and determining its generativity in mutual constitution – leading some authors to argue for the wider notion of infrastructure that includes 'people as infrastructure' (Simone, 2004, Anand, 2011; Larkin, 2013; McFarlane and Silver, 2017). These processes involve a wide range of actors at public and private, local and international, formal and informal levels, consisting of project developers, investors, of local entrepreneurs, grassroots social movements, international NGOs, and individual community members, each with different interests, motives, incentives, and perceptions (Lindell, 2008; Pieterse, 2019, Cirola 2020). These increasing and diversified involvement of actors in infrastructure provision and the resulting generativity which they are increasing creating, have inspired works that seek to show how infrastructures have become layered by additional and partial infrastructures, with different other uses, coverages, logics, and ownerships (Anand, 2011; Chattopadhyay, 2012; Graham & McFarlane, 2014; Silver & Marvin, 2017).

Intents and Interests in Infrastructure Materialization and Generativity

The materialization and generativity of infrastructures in large-scale projects reflect and are conditioned by a combination of intents of diverse actors at international, national and community levels (Cirola 2020, Nweke-Eze & Kioko 2021). As infrastructure rush continues in the Global South and as development theory continue to emphasize the importance of industrialization particularly through infrastructure as the key to economic growth (Cooper, 1996; Luiz, 2010). Investments for these infrastructures are, however, scarce, leading to greater push to attract investments from new classes global funders (Terrefe, 2020; Van Noorloos & Kloosterboer, 2018). These realities have widened the scope and scale of interests and intents to include the geo-political and economic interests fund providers and financiers (Goodfellow, 2020; Klagge & Nweke-Eze, 2020).

At the same time, large-scale projects have domestic audience at national and community levels. National governments interests and intents in infrastructure provision are encapsulated in their intent to centralize power or to display the power of the state to foster national development and to delivery on national promises (Ballard & Rubin, 2017; Cirolia & Smit, 2017). Regardless of intent and interest, some of the infrastructure investments in the Global South have proven to be poorly coordinated leading to debt traps which result in dangerous continuities of macro-economic quagmires (Banerjee et al., 2008; Foster & Briceño-Garmendia 2010; Furlong, 2020). At the community level where infrastructure projects are constructed, interests and intents are mainly directed towards for meeting socio-economic requirements, while conserving the environment (Nweke-Eze & Kioko 2020). In some cases, community leaders have been shown to have vested interests in large-scale infrastructure projects, with the power to oppose and obstruct state provision of infrastructure and initiatives (Arrobbio et al., 2014, Klagge et al. 2020, Greiner et al 2021).

Infrastructures and their Complex Linkages to Socio-economic Development

Studies have shown that the degree of development linkages of infrastructures depend on specific geographies, timing, and politics (Edwards 2002, Straub 2011, Howe et al. 2015, Anand et al. 2018, Furlong 2020). The benefits from infrastructures can be significant and vary depending on specific local contexts (Turner 2018, Weinhold & Reis 2008). Constructing new infrastructures or improving existing ones can increase access to new markets by of helping rural farmer access urban markets, increase prices of their products and make more profits; as well as increase access to social and institutional infrastructures such as schools, hospitals (Jacoby 2000, Mu & van de Walle 2011, Aggarwal 2018). However, the positive impacts of new roads can be heavily outweighed by other socio-economic livelihood losses, bio-diversity disruptions, and environmental damages (Foley et al 2007, Mandle et al 2015, Beevers et al. 2012). For instance, in certain local contexts, new infrastructures can adversely affect access to water for domestic purposes or fishermen who depend on the water bodies for their socio-economic livelihoods (Appiah et al. 2017).

The extent of positive impacts of infrastructure on development in a particular country also depends on what Calderon et al. (2011), Estache & Garsous (2012), Garsous (2012) and Estache & Wren-Lewis (2011) refer to as the "the development stage" of a country. The more developed a country is, the higher its infrastructure stock and hence the lower the payoff from additional investment, unless it aims at addressing a major bottleneck or introducing a major technological improvement (Estache & Garsous 2012; Garsous 2012). On the other hand, the less developed a country is, the more significance is the impact of an additional infrastructure (Estache & Garsous 2012; Garsous 2012). These literatures, however, also note that some infrastructure projects, such as energy and transport infrastructures, do have positive impacts regardless the development stage of the country (Estache & Wren-Lewis 2009, Estache & Garsous 2012).

Studies have shown that the time-period over which the impact is assessed also matters. The significance of the positive impact of infrastructures from the 1950s to the 1980s were more prominent that after the 1980s (Estache & Fay 2010). Studies that observe infrastructure impacts over longer time-periods were more likely to observe more significant positive impacts (Albala-Bertrand & Mamatzakis 2004, Estache & Fay 2010) – this has been attributed to the long payback period of most infrastructures (Estache & Garsous 2012). The degree of impact an infrastructure may have on socio-economic development also depends on the type of infrastructure (Dethier, Hirn & Straub, 2008; Estache & Garsous, 2012). Most findings show that direct-impact infrastructures, such as energy and information and communication technology (ICT) infrastructures tend to have higher positive significance on development indices than other more indirect-impact infrastructures such as water and sanitation infrastructure, which often depend on other infrastructures (example, energy infrastructures) to function (Garsous, 2012).

Large-scale infrastructure projects often have far-reaching socio-economic impacts, often extending beyond the immediate spatiality of the project site, into nearby and further spaces, with varying temporal (short, medium, and long-term or even permanent) effects (Batey et al., 1993; Korytárováa & Hromádkaa, 2014). Studies such as Enns & Bersaglio (2019) and Brycesson et al. (2008), contend that infrastructures connect to socio-economic development in a selective and uneven manner – stating with empirical evidence that certain infrastructures have increased socio-economic development for some, while at the same time worsening socio-economic development and welfare for others.

Infrastructures are only useful to the degree they help to facilitate activities. Such facilitating activities of their provision, accessibility, reliability, scale, durability, and maintenance, allows us to differentiate the degree and extent of impacts of infrastructures in different geographical contexts (Amin, 2006; Hall et al, 2013; Talen, 2019). As Brycesson et al (2008) argues, infrastructures in themselves are blunt instruments which must co-exist with certain other enabling conditions and means to effectively translate or contribute to socio-economic development. The variegated impacts created by the differentiated quality of infrastructure facilitating activities has led to non-uniform outcomes of infrastructure provision (Lawhon et al. 2018).

Infrastructures and their Multifaceted Socio-economic Development Impacts

Large-scale infrastructures such as energy projects (electricity generation, transmission, and distribution systems), water projects (pumping, boreholes and sanitary systems), transportation projects (roads, railways, ports, pipelines), information and communication technology projects (broadband masts, telecommunication systems) have long been part and parcel of human socio-economic life. The development of these infrastructures is often connected to and/or justified in the mainstream development circles by grand narratives of development/underdevelopment, as conditions in which prosperity of nations are bound (Kanai and Schindler 2019). This infrastructure-development nexus has come to dominate national and international development policy agenda, subsequently leading to a surge of interest in infrastructural development, investments, and financing spear-headed by state and regional governments and supported by several old and new, international, and regional development institutions, multi-donor, and climate agencies (Boyer, 2019, Howe 2019, Klagge & Nweke-Eze 2020).

The ideology and perspective on infrastructure-development nexus have been subject to discourse, starting from Arrow and Kurz (1970) and Aschauer (1989). Since then, many other (inter- and multi-) disciplinary studies have begun to analyze, discuss and debate the subject matter. Generally, the findings of these studies are bifurcated. Many studies from national economic growth and development perspectives predominantly highlight the positive impacts of infrastructures based on macro-economic indices. These studies generally report that increase or improvement of infrastructures brings about positive impacts on several socio-economic and development indicators, including long-run economic growth, international trade enhancement, productivity and efficiency, economic development; poverty alleviation and the achievement of the Millennium Development Goals (MDGs) (Asher and Novosad 2020). Exemplary for this literature are studies on impacts of infrastructure are studies by Easterly & Rebelo (1993) and by the World Bank (1994) who conducted global, multi-country research in both the Global North and South; studies by Seethepalli et al. (2008), Straub (2008) and Straub & Terada-Hagiwara (2011) who focus on East Asia; and Calderon & Serven (2008) Calderon & Chong (2009) who conducted research in Sub-Saharan-Africa.

In contrast, however, studies researching from mainly local community development and bio-diversity perspectives report mainly negative impacts of infrastructure projects on biodiversity and environment (Trombulak & Frissell 2000, Laurance et al. 2006, Coffin 2007, Campbel et al 2017), its creation of socio-economic inequality and their disrupting effects on indigenous people's livelihoods (Kenley et al. 2014, Collier et al 2015, Barker et al. 2021). They report incidences of human-vehicle collision and accidents, animal-vehicle collision and accidents, noise pollution during construction of project or usage of infrastructure projects such as roads, restriction of movements, reproduction patterns and other disruptions of wildlife, increased spreading of invasive plants, landscape disasters such as landslides and erosions, and increased hunting, poaching, deforestation and other human-wildlife interferences.

Methodology and Case Studies

Methodology

The analyses and discussion of the study is based on expert interviews (2018-2020) with interview partners who work at different levels of government[1] (MoE[2], the National Treasury, County and national commissioners), and in energy-related and other state agencies (ERC, GDC, KenGen, KETRACO, KWS, NLC)[3]. It also features interview partners in development finance institutions (AFD, AfDB, EIB, KfW, TDB, USAID)[4], in private consulting firms (Tetra-Tech, GeoHydro Energy Consultants Limited) and in an energy research institute (GETRI)[5]. In addition, the study analyses are also based on analysis of project reports, several project sites visits and observations as well as informal interviews with project staff and local community members and in the projects host communities (2018-2020).

Case Studies: Large-scale Geothermal Energy Projects in Kenya

In this section, we discuss the three geothermal projects in Kenya that constitute our case study, namely: Olkaria, Menengai and Baringo-Silali (see figure 1). The Olkaria project is the oldest and most advanced of the projects. It already generates about 623MW of electricity (KenGen interview 2019). This is followed by the Menengai project, where power plant construction by independent power producers (IPPs) for the first generation of 105MW of electricity is currently planned. The Baringo-Silali project is still in project exploration and test drilling stages.

Olkaria geothermal project is located in a semi-peripheral area of Naivasha town, Nakuru county, partly in Hell’s Gate National Park (a touristic Wildlife Reserve) and in partly on the homeland of Maasai people[6]. Menengai

[1]National, local and, since 2013, county levels – following the devolution of government functions in Kenya.
[2]Ministry of Energy.
[3]Energy Regulatory Commission, Geothermal Development Company, Kenya Electricity Generating Company, Kenya Wildlife Service, National Land Commission.
[4]Agence Française de Développement, African Development Bank, European Investment Bank, Kreditanstalt für Wiederaufbau, Trade and Development Bank, United States Agency for International Development
[5] Geothermal Energy Research and Training Institute.
[6]KenGen (the project developer) resettled the Massai people previously living in these areas in order for the project to carry on (KWS, NLC & KenGen interviews 2019).

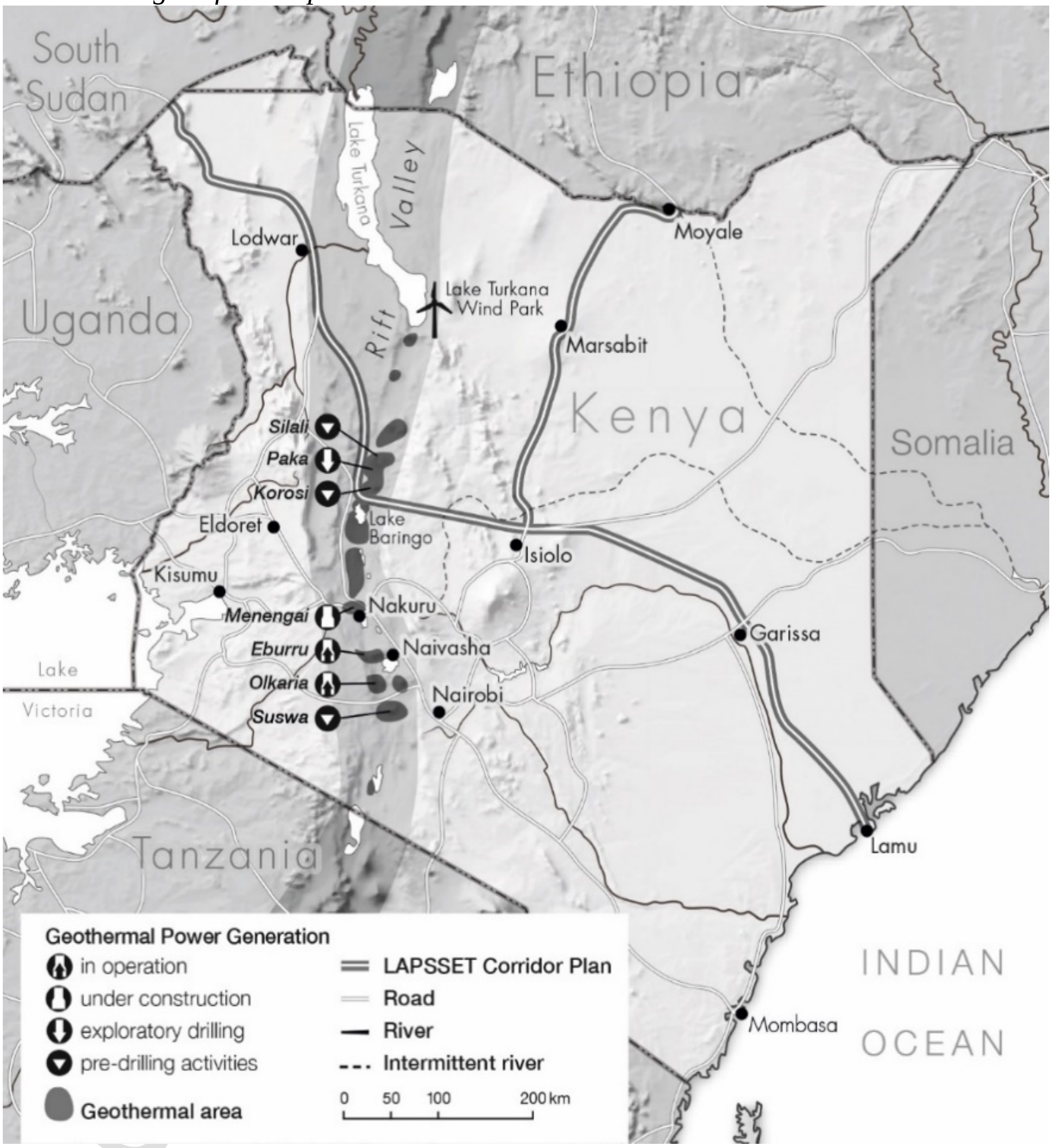
geothermal project is located in semi-peripheral area of Nakuru town also in Nakuru county, with most parts within the Menengai Crater in Bahati sub-county[7] and a smaller part encroaching in previously privately-owned land[8] (NLC interviews 2019). Nakuru county spans an area of 2,325.8 sq km with a population of 1,503,325 according to the 2009 census. Communities in both Naivasha and Nakuru town mainly engage in trading and farming. In contrast, the Baringo-Silali project (consisting of Paka, Korosi and Silali) is located in the peripheral, semi-arid Baringo county in Kenya, on communal land (NLC interview 2019). Baringo covers an area of 11,015.32 sq km with a population of 555,561 according to the Kenya Census data 2009.The dominant ethnic groups are the Pokots, Tugens, Endorois and Ilchamus. These communities mainly keep livestock, although the people living in the highlands practice farming.

The several components of Olkaria Geothermal project are majorly developed by KenGen[9] as well as by OrPower4 Inc[10] and Oserian Flowers Ltd[11]; while Menengai and Baringo geothermal energy projects are developed by GDC[12]. The three geothermal energy projects received technical and debt and grants financing support from development financial institutions such as AfDB, TDB, EIB, KfW, AFD, JICA[13], USAID and the World Bank, as well as by climate agencies such as SREP[14] and the GEF[15], at various stages of the projects' development (GDC, KenGen, National Treasury, DFI interviews 2019).

Although geothermal energy projects differ depending on their location, they generally go through similar stages and processes before their commissioning and operation. Preliminary surveys and exploration, test drilling and reservoir confirmation and feasibility studies, are first carried out to confirm the viability of the project development. This is then followed by actual site development, which then leads to start-up and commissioning of the project.

[7]Bahati sub-county is located close to an urban area where lands are predominantly privately owned (NLC interview 2019).
[8]The land was bought from their private landowners for the project to continue (NLC interviews 2019).
[9]a limited liability company with 70% Kenyan government shareholding
[10]private-owned company and an independent power producer licensed to develop the third component of the project (Olkaria III) (ERC interview 2019).
[11]A private company growing flowers for export, with its own geothermal power plant
[12]a government owned special purposed vehicle established in 2008 with the mandate to explore and develop geothermal field in the country
[13]Japan International Cooperation Agency
[14]Scale-up Renewable Energy Program
[15]Global Environment Facility

Figure 1. *Map showing geothermal fields and sites in Kenya, their locations, and their stages of development*



Source: Klagge & Nweke-Eze (2020).

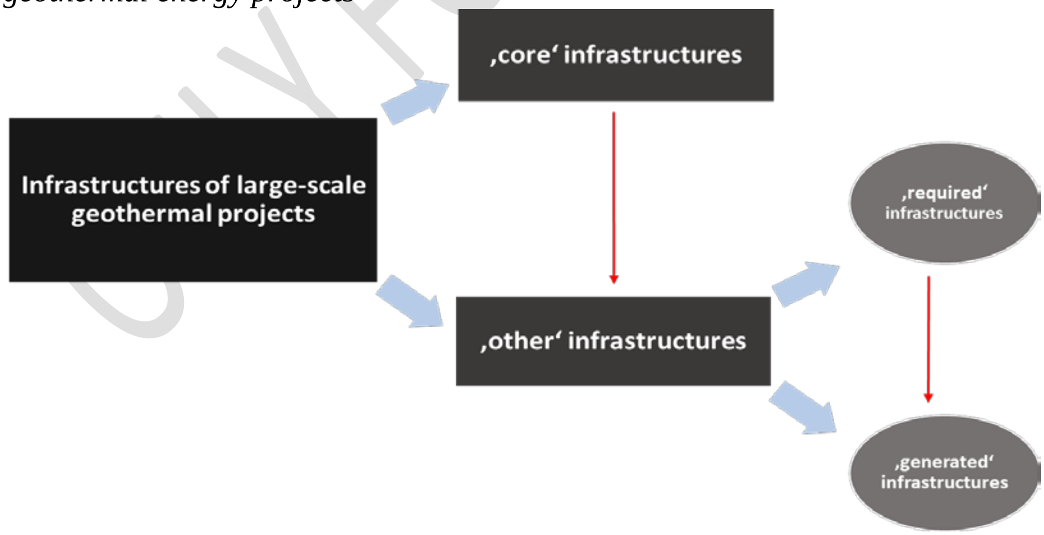
Results and Discussions

Infrastructures in Large-scale Geothermal Projects: Materialization and Generativity

This section shows how intended large-scale infrastructure projects become generative in their process of their materialization, allowing for the construction of other technical and social infrastructures in project-host communities. It reveals, using the case of large-scale geothermal projects in Kenya, how infrastructures of large-scale projects primarily materialize in two forms ‘core’ and ‘other’ infrastructures. It starts with core infrastructures, which are the actual intended infrastructures, made up of the geothermal plants and machineries. It then goes on to show how the construction of these core infrastructures both enables and necessitates the construction of other new or additional infrastructures – ‘required’ and ‘generated’ infrastructures. ‘Required’ infrastructures are additional technical infrastructures, which are provided to enable the construction of the core infrastructure projects. Such infrastructures usually consist of access roads and large water supply and storage systems. As the project proceeds, these ‘required’ infrastructures then further enable the provision of other ‘generated’ technical and social infrastructures – network roads, water abstraction points, schools, hospitals, housing, which are often provided in form of corporate social responsibility (CSR) and as resettlement plans for Development Induced Displaced Persons (DIDPs). These ‘generated’ infrastructures would not have been provided[16] if the ‘required’ infrastructures were not initially provided. In general, the required and the generated infrastructures do not only enable the construction of core infrastructures, but they also exist to ensure their continuous functionality.

These materialization and generativity processes (figure 2) reveal how infrastructures multiply, creating a catalyst network for social-economic (under-)development, especially in the peripheral and marginalized geographies where infrastructures are scarce. The following three sub-sections further discuss the materialization of these infrastructures in categories of their generativity potentials.

Figure 2. *Materialization and generativity of infrastructures in large-scale geothermal energy projects*



Source: Author’s own.

[16]Or would have at least been very difficult to provide, or take a long time to be provided

Geothermal Plants and Machineries as 'Core' Infrastructures

Generally, the geothermal power plants use steam obtained from geothermal reservoirs to generate electricity. Prior to commencement of the work for the power station, production and injection wells are drilled at the appropriate locations to bring this geothermal energy up to the surface (GDC 2010). A mixture of steam and water is then collected from the production well, which are then separated using the Steam separators. The steam is then used to operate turbines which runs the generators, hence, generating electricity. The condensed steam and the water collected from the production well are injected back into the reservoir through the Injection Well (GDC 2010).

Other than the above-described power plants, other facilities in the geothermal power project sites are called Steam field Above Ground System (SAGS) (GETRI interview, 2019). They consist of the steam pipelines, brine/condensate pipelines, separators, scrubbers, and the rock mufflers (GETRI interviews 2019). Geothermal steam & fluid from production wells is piped downhill from the separators as two-phase flow (GETRI interviews 2019). The pipelines are made of carbon of robust inches (GDC 2010, Fieldwork 2019). First, there are pipelines from each well pad to separator (GETRI interviews 2019). These are then followed by the Steam pipelines from the separator to the power station, the Brine pipeline from the separator to each injection well pad, and the Condensate pipeline from the cooling water piping to the injection well pad (GETRI interviews 2019). Necessary pipe loops are provided on those pipelines to absorb thermal expansion (GETRI interviews 2019).

The cyclone-type separators are used to separate steam from two-phase liquid coming from production wells (GETRI interviews 2019). Steam goes to power station while brine to injection wells (Project sites observations 2019). Scrubbers of corrugate type are provided just before the power station to eliminate further moisture (GETRI interviews 2019). Surplus steam is released to the atmosphere through vent valves (Project sites observations 2019). Rock mufflers are provided near the separator station to reduce the noise level of the released steam (GETRI interviews 2019).

Access Roads and Water Systems as 'required' Infrastructures

The construction and operation of these 'core' infrastructures necessitate the delivery of 'required' infrastructures, namely: access roads and water pumping and storage systems. The access roads, as the name implies, provide access to the project site, and connect the core project sites to stand-by water system and the equipment-offloading storage sites (Project sites observations 2019, 2020; GDC interviews 2019). These access roads are necessary for transporting heavy Well exploration and drilling equipment such as exploration and drilling gears and pumps, drilling rigs, hydraulic excavators with large diameters and thickness; the SAGS as well as other materials such as diesel fuel, cement and concrete and (in some cases) water with bulk mass; into the project field or site (Project sites observations 2019, 2020; GDC interviews 2019).

The access roads are provided either by improving the capacity of already existing roads through expansion, or by constructing entirely new ones, usually in marginalized peripheral areas where there were no prior existing roads leading to the project sites (GDC 2010, 2013, 2019). Access roads for the projects are fortified with several layers of gravels before surfacing in other to withstand the frequent movement of heavy vehicles, equipment and materials, over-time (GDC 2010, 2013, 2019, Project sites visits 2019, 2020).

Project construction cannot also occur on site without the delivery of water pumping and storage systems, which come in different scales depending on the size of the project. The pumped water is used for testing steam and for mixing materials during the construction phases of the project (Project sites observations, 2019). Other than for the development of the project, water also plays an integral role of steam generation in flash and binary geothermal power plants[17] (GDC and KenGen interviews 2019). During the operation of the geothermal power plant, water is used in both high- and low-pressured form to generate steam, which is used to drive the geothermal turbine for the generation of electricity. The pumped water is sourced from nearby water bodies, using diesel-fuel-power generators and through laid-pipes, into large water storage systems (Project sites observations, 2019; GDC 2010, 2013, 2019). Stored water from the storage tanks is then pumped or excavated through other pipes which connect the stored water systems to the project sites, when needed (Project sites observations, 2019; GDC 2010, 2013, 2019). Projects which are developed in areas that are far from water bodies, where construction of laid-pipe are non-feasible, often depend on large water-tank-vehicles which carry water over long distances using already existing or constructed access roads (Project sites observations, 2019; GDC interviews 2018).

Other Technical and Social Infrastructures as 'Generated' Infrastructures

'Generated' infrastructures are the infrastructures that follow and because of the provision of the 'required' infrastructures, in the development of large-scale geothermal projects. These 'generated' infrastructures are provided in several forms: as extension of already existing required infrastructures, as Corporate Social Responsibility projects or activities, as part of resettlement schemes for project affected person (PAPs), as well as temporary or sometimes permanent structures for project workers in host communities (GDC 2010, 2013, 2019, Fieldwork 2019, 2020). They are technical and social infrastructures including road networks, water abstraction points, schools, hospitals, housing, etc (GDC 2010, 2013, 2019, Fieldwork 2019, 2020).

[17]Most modern geothermal power plants are flash or binary. Binary geothermal power plants are said to the power plants of the future (KenGen interviews 2019).

Infrastructures of Large-scale Geothermal Projects: Socio-Economic Development Linkages and Interests

In this section, we use our case study of three different geothermal projects in Kenya to contextualize and illustrate the socio-economic development linkages of infrastructures in large-scale projects. As shown in section 3 (figure 1), the projects are different stages of their development, with Olkaria being the most advanced consisting of already existing plants (see Olkaria II in figure 3), generating over 600MW of electricity in the country. Menengai is in its plant development stage while the Baringo-Silali block is in its drilling and steam striking stages.

Infrastructures of Olkaria Geothermal Projects

The Olkaria geothermal plants, as 'core' infrastructure projects, were constructed primarily for the purpose of electricity provision at the national level. In some cases, however, the local project-host communities are connected to the electricity generated from the projects, not because of the proximity of projects to them, but according to the national electrification plan (MoE interviews 2019, 2020).

Figure 3. *Aerial view of Olkaria II geothermal plants and SAGS*

Source: ArGeo archives (2020).

The project development was preceded by the provision of access roads and water supply systems as initial required infrastructures. The 24 km Moi South Lake Road (MSLR)[18] had existed for a long time but had mostly remained in a bad condition. The planned development of geothermal projects and the existence of the Hell's Gate National Park and flower farms in the area, sparked the discussion for and eventually led to the tarmacking of the road

[18] Code named D-323

(Kuiper 2019, KenGen and MoE interviews 2019). The tarred road is sporadically maintained and repaired by flower farms, hotels and several other NGOs operating in the area, with some contributions from KenGen (Kuiper 2019; KenGen interviews 2019). The access road was used for transportation of construction equipment and materials used for the construction and maintenance of the different components of the Olkaria geothermal project as well as for the construction of transmission lines for the evacuation of generated electricity to the national grid (KenGen interviews 2019). The MSLR is the only paved class D road[19] in Naivasha district of Nakuru county so far, providing quicker access to the main Nairobi-Naivasha highway. This connectivity has enabled quicker transportation of farm produce from the project region, as well as increased access to better social infrastructures in nearby towns (Ogola 2013, Fieldwork 2020). The road, however, also increased air and noise pollution from vehicles and increased the number of illegal and informal settlements in the area.

Other than access roads, water pumping, and storage systems were also constructed from water sourced from Lake Naivasha. The water systems were used as a drilling fluid during construction and for Well-testing during construction stages of the project. The water systems are also maintained and utilized for pumping water for operating the Olkaria geothermal power systems (GIBB Africa 2009, Fieldwork 2019). The pumped-water was then further purified by KenGen and piped for use by the surrounding Massai communities at several community water-points, as part of CSR (Ogola 2013, Fieldwork 2020). Four Massai villages[20] were resettled due to concerns for noise pollution and the emission of Hydrogen Sulphide gas (H_2S) at dangerous levels during the construction of the Olkaria IV project (Fieldwork 2019). The resettlement action plan (RAP) provided for the resettlement of the four villages as one entity with the provision of resettlement infrastructures including roads, pipe-borne water[21], electricity, houses, schools, health centres, lands and land title deeds[22], all of which cover a space of 1700 acres (KenGen interviews 2019, Schade 2017, 13-14). There are however concerns over the efficiency and suitability of the resettlement scheme, as a result of massive records of dissatisfaction among many of the resettled community members (Schade 2017, Nweke-Eze & Adongo, forthcoming).

Infrastructures of Menengai Geothermal Projects

At the time of Menengai geothermal project development, the region surrounding the project site was already well serviced by a network of earth roads and all-weather roads, linking up the Nairobi-Kisumu Railway line and trans-Africa highway passing through the southern part of the area (GDC

[19] Class D roads are secondary roads according to the classification of roads in Kenya

[20] The four villages were: Cultural Centre, OloNongot, OloSinyat and OloMayana Ndogo.

[21] 5 water structures were constructed for the benefit of humans and livestock in the resettled communities as well as in Narasha, Maiella and Iseneto.

[22] The provision of land title deed was very significant in the resettlement process, as it was the first-time project affected persons (PAP) would become official landowners upon resettlement.

interviews 2019). The Menengai crater, which constitutes a major part of the project's site, had long been an attraction site for tourists and a site for excursion for school pupils and students. The already available access roads leading up to the project site were, however, widened to make it adequate for transporting heavy plant and equipment, personnel, and project supplies (GDC interviews 2019). New network roads connecting to these already existing access roads, were then constructed to further open access to the region for the host communities, for new business creation and expansion of existing ones.

In addition, the government-owned developer Geothermal Development Company (GDC) constructed a 20-million-liters water storage system for storing water sourced from Lake Naivasha. The stored water was used for cooling the power plants during drilling and for well-testing and is further maintained for use to operating the power plants when they are constructed (GDC 2013, Project sites observations, 2019). As the Menengai geothermal project is located in the Menengai crater, there were no displacements of the communities in villages of Bahati sub-county (GDC 2013, Project sites observations 2019,GDC interviews 2019). However, private farmers whose lands were acquired for road expansion and whose farmlands were affected by the passing of the power transmission lines were compensated in monetary terms (GDC & NLC interviews 2019, Fieldwork 2019).

Figure 4. *Menengai Geothermal Project Water Storage Systems*

Source: GDC archives (2020).

<u>Infrastructures of Baringo-Silali Geothermal Projects</u>

Unlike the Olkaria and Menengai geothermal projects located in Nakuru county – a semi-peripheral area with some existing infrastructures before the development of the projects, the Baringo-Silali geothermal project is in Baringo county – a peripheral and marginalized area of northern Kenya where infrastructures were scarce. For this reason, ample time was taken to build access roads, out of bare pathways; before it was able to move plant machineries and SAGS to the project site (GDC 2019, GDC interviews 2019). A 70km access roads were completed and more than 100km of existing roads were expanded and paved[23], creating a robust road network[24]. These roads are, however, not tarred (see figure 4), leading to air pollutions (dusts) as heavy and light vehicles drive in high speed along the roads (Project site visits 2018, 2019). The construction of roads was followed by the construction of water pumping systems together with 4.5-million-litre water tanks for storing water sourced from Lake Baringo in Paka, Korosi and Silali (Project site visits 2018, 2019). The water pumping and storage systems were constructed for sourcing water for drilling and cooling activities during geothermal site development and will be maintained and utilized for operating the geothermal power plants at a later stage (GDC interviews, 2019, (Project site visits 2018, 2019).

Figure 5. *Aerial View of 'required' Infrastructures in Baringo-Silali Geothermal Project Site*

Source: GDC archives (2020)

Water from the storage tanks was planned to be purified and piped for domestic use in the community[25] through 20 newly commissioned watering points and water treatment plants[26] [27], as part of CSR (Project site visits 2018, 2019, GDC 2019). These watering points were however not initially planned; they were constructed upon the request of the host communities during negotiations (GDC interview 2019, Community members interviews 2019). Before the construction of the watering points, portable water was, for the meantime, periodically provided using large water-tank-vehicles, which carry water over long distances using already existing or constructed access roads (GDC interview 2019, Community

[23]The paved B4 road running upward-north through Marigat ends in Chemolingot.

[24]Paka – Silale; Kadingding – Korossi; Korossi – Lomuge; Naudo – Akwichatis; Chepungus – Kadokoi.

[25]For both humans and animals

[26]Kadingding, Mesori, Nakuórojang, Moinonin, Cherisan (Pump station I), Tuwo, Chepungus, Reong'o, Chemoril, Natan, Naudo, Angromit, Ponpon, Orus, Katungura, Kwokwototo, Nasorot, Korossi (tank site), Adomejong, Akwichatis

[27]Some of the provided water points were still under construction at the commissioning, while some of the finished ones were not functioning at full capacity – lacking water at times.

members interviews 2019). GDC is also involved in further CSR activities in the project area (GDC 2019, Fieldwork 2019). It constructed an Early Childhood Development (ECD) classroom at Kibenos in the North Rift Valley and provided scholarships to needy students in the project area to attend universities, secondary and primary schools (GDC 2019, Fieldwork 2019). Since, there is no project displaced persons so far, there were no resettlement infrastructures in the development geothermal energy in the area (GDC 2019, Fieldwork 2019).

Figure 6. *Provided community water point in Baringo, as part of Corporate Social Responsibility*

Source: GDC archives (2020).

The table below summarizes the three categorizations of infrastructures in large-scale geothermal energy projects in Kenya; depicting their types, means of materialization and socio-economic development linkages.

Table 1. *Infrastructures of large-scale geothermal projects and their socio-economic development linkages*

Categorization of infrastructures in large-scale projects, based on their generativity	**Infrastructure types**	**Materialization**	**Socio-economic development linkages and interests**
‘core’ infrastructures	Power plants	Actual projects	Electricity provision, serving interests at the national level
	Steamfield Above Ground System (SAGS).		
‘required’ infrastructures	Access roads	Project development requirement	Access to project sites and to markets, serving interests at both national and community levels
	Water pumping	Project	Water for

	and storage systems	development requirement	construction and geothermal steam production, serving interests at both national levels
‘generated’ infrastructures	Network roads	Corporate Social Responsibilities (CSR) or community improvise	Market connections and mobility, serving interests at community levels
	Community water points		Water supply for domestic and agricultural use, serving interests at community levels
	School buildings	CSR, Resettlement schemes*	Education, serving interests at community levels
	Health centres		Health services, serving interests at community levels
	Housing	Resettlement schemes*	Modern shelter, serving interests at community levels

*The modern housing infrastructures provided as part of the resettlement schemes are however under question as to their impact and suitability to the communities (Schade 2017, Nweke-Eze & Adongo, upcoming).
Source: Author’s own

Differentiated Provisions of Infrastructures in Large-scale Geothermal Projects

The analysis in the previous sections reveals how the provision of infrastructures in their various forms differ in their nature, types, and quantity, depending on where they are provided, why they are provided, for whom they are provided, and who is providing them. Olkaria and Menengai geothermal projects are in semi-peripheral areas of Nakuru county where there were already some existing technical and social infrastructures (Fieldworks & interviews 2019, 2020). In these areas, we see that more ‘generated’ infrastructures and relatively less ‘required’ infrastructures were provided. In contrast, in the case of Baringo-Silali project, which is in the peripheral and marginalized Baringo county, considerably more ‘required’ infrastructures had to be provided, as they were either too little or non-existent, in addition to the provided ‘generated’ infrastructures (Fieldworks & interviews 2019, 2020). So far, the total number of extra infrastructures as well as the capital and maintenance costs for providing them, are more for the Baringo-Silali geothermal projects in Baringo county when compared to Olkaria and Menengai geothermal projects in Nakuru county (Fieldworks & interviews 2019, 2020).

The provision of different ‘required’ infrastructures unveil interesting stakeholder involvement conditions and dynamics based on their category of goods (that is, whether they are public or private goods). The reconstruction or tarmacking of already existing roads in semi-peripheral areas, which are public goods (that is, serving the interest of not only the project but also the interests of other members of the public), are often not solely delivered by the project developers and investors (GDC, KenGen, DFI interviews 2019). Other actors or stakeholders who also benefit from the infrastructure make contributions for their construction and maintenance, as the MSLR in the Olkaria geothermal projects illustrates (Fieldwork 2019, Kuiper 2019). In contrast, the new roads usually constructed in formerly marginalized peripheries (example, the access roads for the Baringo-Silali project) as well as the water pump and storage systems provided in all the projects are more of private goods (that is, specifically serving the purpose of the project at the time of their construction) (GDC interviews, GDC 2019). These kinds of private goods are therefore often solely provided by the project developers and investors.

Projects with more involvement of international development institutions and agencies as investors or financiers, so far, recorded a greater number of 'generated' infrastructures provision in form of corporate social responsibility and resettlement schemes for project affected persons (PAPs). There are currently more involvement of international development institutions and agencies in Olkaria and Menengai geothermal projects, and subsequently a greater number of 'generated' CSRs (Fieldwork 2019, 2020; GIBB Africa 2009, GDC 2010, 2013). However, this can be explained by the fact that Baringo-Silali project is just completing its exploratory stage. More CSR projects are expected to be provided in Baringo-Silali host communities in the future as the project proceeds into steam gathering and plant construction stages (GDC interviews 2020). Such development institutions and agencies, by so doing, seek to establish their reputation as players who abides by sustainability principles (EIB, AfDB, KfW interviews 2019).

Furthermore, the level of engagements and negotiations between the project developers and host communities depends on whether the 'required' infrastructures are provided as a new project or as a reconstruction of already existing ones. The reconstruction of the MSLR roads leading to the Olkaria projects or the expansion of the roads leading to the Menengai Caldera, had little or nothing to do with the host communities, expect in specific cases where land had to be bought from their private owners (like in the case of Menengai geothermal projects) or in cases where project affected persons (PAPs) had to be resettled (like in the case of Olkaria geothermal projects) (Fieldwork 2019, 2020; GIB Africa 2009, GDC 2010, 2013). In contrast, the construction of new access roads for Baringo-Silali project development entailed constant and meticulous negotiations between the project developers and the host communities (Fieldwork 2019, GDC interviews 2019, Greiner et al. 2021). In this case, non-adherence to negotiated terms either due to change of contractors or ignorance of workers in the project sites often present protests and risks of conflicts (Fieldwork 2019, Klagge et al. 2020).

Conclusion

The foregoing analyzed the infrastructures in large-scale geothermal energy projects in Kenya, depicting their different processes and forms of materialization, and their complex socio-economic development linkages. We see how the materialization of 'core' infrastructure projects become generative, enabling the provision of other 'required' and 'generated' infrastructures. We also see that while the 'core' infrastructures of the projects are determined by and serve electrification interests at national level, their associated 'required' and 'dependent' infrastructures, mainly serve socio-economic development interests of project-host communities at local levels. Furthermore, by comparing the degree and scale of the provision of these infrastructures, the study reveals that the provision of these infrastructures is differentiated based on the local socio-economic and spatial contexts of the project-host communities. These findings demonstrate the complexity of sustainable large-scale projects planning and implementation in the Global South. It further shows how impact evaluation studies of large-scale development projects will be more encompassing and complete, when we consider the socio-spatial and socio-economic generativity potentials of their infrastructures. Overall, large-scale infrastructure projects are fully appreciated when considered as an expression of larger paradigms of human and organizational efforts. The materialization and existent of these infrastructures often lead to the emergence of other technical and social infrastructures – which also assume lives of their own, serving different interests. It is the combination of these infrastructures and their connections and interaction that allows for a more encompassed appraisal of the socio-economic impacts of large-scale infrastructure projects, especially in the global south context.

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