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Published in:
Energy Policy

DOI (link to publication from Publisher):
10.1016/j.enpol.2018.02.011

Publication date:
2018

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Lema, R., Hanlin, R., Hansen, U. E., & Nzila, C. (2018). Renewable electrification and local capability formation: Linkages and interactive learning. *Energy Policy*, *117*, 326-339. https://doi.org/10.1016/j.enpol.2018.02.011

Energy Policy 117 (2018) 326–339

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Renewable electrification and local capability formation: Linkages and interactive learning[☆]

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ARTICLE INFO

Keywords:
Technology transfer
Sustainable industrialisation
Capabilities
Global value chains
Renewable energy
South–South

ABSTRACT

This paper discusses the prospects for developing production and innovation capabilities arising from renewable electrification efforts. This discussion falls at the intersection of several literatures within innovation studies and development studies. It requires a combination of ideas from across several academic fields of study. This paper focuses on value chain linkages and interactive learning. Because this is largely unexplored terrain, the paper seeks to provide conceptual framing based on insights from the literature and it discusses whether linkages within the global South offer specific advantages over North–South linkages. It then uses this conceptual framing to draw insights from the case of renewable electrification with wind and solar PV in Kenya. It ends by identifying key avenues for promoting interactive learning in this context.

1. Introduction

In recent years, the potential for more effective and appropriate linkages has resurfaced as a prominent topic as developing countries become increasingly interconnected by economic flows: importing capital goods (Hanlin and Kaplinsky, 2016), engaging in value chains (UNCTAD, 2015) and undertaking foreign direct investments (FDIs) (Arita, 2013). This has received renewed attention as a means of progress with respect to the sustainable development goals (SDGs), including those of ensuring access to affordable and sustainable energy to all (Goal 7) and promoting sustainable industrialisation and fostering innovation (Goal 9).

The overall objective of this paper is to inform policy-driven research that ultimately aims to create and deepen synergies between these two SDGs, thereby facilitating a process of 'low carbon development' (Lema et al., 2015; Urban and Nordensvärd, 2013). Within this terrain, the paper is concerned with the following. Generally, it is concerned with the creation of relevant ('developmental' or 'inclusive') pathways and associated economic activities involved in clean energy provision. Specifically, it is focused on the 'learning opportunities' that may provide in the context of renewable electrification. Learning is understood here as the accumulation of relevant capabilities; we are informed by the increasing body of literature that emphasises the importance of local production and innovation capabilities for effective low carbon development (Ockwell and Mallett, 2013; Urban and Nordensvärd, 2013; de Coninck and Sagar, 2015).

Given the importance ascribed to such capabilities in the literature, there is relatively little attention to 'where' and 'how' such capabilities arise in local economies, particularly the role of interactive learning as a means to building these production and innovation capabilities. In this paper, we therefore address the following closely related issues:

- First, we address the issue of local capability formation in the context of low carbon electrification technologies in developing countries. Large investments are made in renewable energy in developing countries, not least in sub-Saharan Africa and South Asia where access to energy is a top priority on the policy agenda. Clearly, the levels and types of pre-existing capabilities are of crucial importance for the success of these investments. However, we are not focused (primarily) on such existing capabilities, but instead on the opportunities for further capability formation arising in and from such investments.
- Second, given the gap in resources and capabilities between advanced and developing economies and because of global governance mechanisms in support of the SDGs, there is a *de facto* high degree of inbound flows of 'technology' related to these investments. We

[☆] This article is part of a Virtual Special Issue entitled 'South-South Technology Transfer and Cooperation for Low Carbon Energy Technologies'.

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https://doi.org/10.1016/j.enpol.2018.02.011
Received 10 August 2017; Received in revised form 22 December 2017; Accepted 6 February 2018

therefore focus on the learning opportunities that may potentially arise in and around the linkages that facilitate these flows.

- Third, we address the issue of linkages between emerging economies, such as China, India or South Africa, and poorer parts of the world. In the 1980s economists began to argue that 'South-South technology transfers offer undoubted advantages since the technologies exported are better adapted to the needs of the developing countries' (Sabolo, 1983, p. 606). Considering the many years in which South–South technology transfer and co-operation for climate-relevant technologies has been on the agenda, the literature provides surprisingly little empirical evidence on this. We argue that the relative lack of progress in shedding light on the third issue so far is the difficulty of framing it and connecting it to the first two issues.

This paper therefore starts, in Section 2, providing background for the discussion by outlining the challenges of creating access to electricity in low and middle-income countries and South–South flows of trade and investment in this respect. Section 3 provides an outline of the key conceptual building blocks from across the innovation studies and development studies fields. It draws on and seeks to bring together perspectives from the literatures on technology transfer, interactive learning, global value chains (GVCs) and appropriate technology. Section 4 seeks to recast international technology transfer as occurring in value chain relations with opportunities for interactive learning between users (importers) and producers (exporters) of electrification technology. Section 5 then seeks to go deeper by considering typical value chain structures in and around renewable electrification projects, using the case of wind and solar photovoltaic in Kenya as an example, drawing on new vocabulary for analysing capability formation in the context of renewable electrification. Section 6 concludes by highlighting the key insights of the paper, asking what the implications are for South–South discourse and emphasising different types of interactions for local capability formation and the importance of local shaping of technology as key areas of attention for those involved in researching or promoting low carbon development activities.

2. Renewable electrification

We start by providing a background to the drive to create access to electricity and the importance of South–South connections in green energy, particularly electrification. This provides an essential foundation for later analyses of whether and how investment in the field can be harnessed for local capability formation.

2.1. Access to energy

One of the most critical issues to development in low and middle-income countries is access to energy, not least in sub-Saharan Africa and South Asia. Electrification is one of the most critical issues here. In total, more than one billion people do not have access to electricity. Sub-Saharan Africa has an electrification rate of 32% and in rural areas it is just 17% according to the International Environmental Agency (see Table 1).

Table 1
Access to electricity.
Source: OECD/IEA (2015).

Region	Population without electricity millions	Electrification rate %	Urban electrification rate %	Rural electrification rate %
Developed countries	1	100%	100%	100%
Developing countries	1200	78%	92%	67%
Sub-Saharan Africa	634	32%	59%	17%
Developing Asia	526	86%	96%	78%
India	237	81%	96%	74%
Latin America	22	95%	98%	85%
Middle East	17	92%	98%	79%
World	1201	83%	95%	70%

Note: Electricity access in 2013 – Regional aggregates.

Table 2
Renewable energy in Africa: installed capacity and projections.
Source: AEEP Power Project Database/AEEP (2016).

	2010	2015	2020 Growth Scenario 1 (Linear)	2020 Growth Scenario 2 (25%)	2020 Growth Scenario 3 (50%)	2020 Growth Scenario 4 (75%)
Hydro	33.01	35.18	37.36	41.97	48.63	55.30
Wind	1.12	3.13	5.14	4.93	6.62	8.30
Solar	0.10	1.55	2.99	3.25	4.61	5.96
Other	0.95	1.50	2.05	2.49	2.94	2.98

Note: Other = Geothermal, biomass.

Fossil fuel and renewable energy sources will be used to bring electricity to poor countries and rural areas within them. Renewable energy sources are particularly high on policy agendas, however, due to the foreseen socio-economic development opportunities in terms of local employment and industrial development. As seen in Table 2, hydropower is the predominant renewable energy source in sub-Saharan Africa. While starting from a much lower base, wind and solar are growing much faster, with wind moving forward at a compounded annual growth rate of almost 23% while solar grew 73% between 2010 and 2015. In terms of added capacity, hydropower amounted to 2.17 GW compared to 2.01 GW of wind and 1.45 GW of solar photovoltaic (PV) in the same period.

Table 2 also shows projections for growth. Scenario 1 is linear growth whereas scenarios 2–4 are pessimistic (25%), middle ground (50%) and optimistic (75%) realisation rates of project pipelines. With all the scenarios, there are massive investments in renewable energy on the African continent currently and in the foreseeable future.

There are various ways in which these investments are organised to increase rural and renewable electrification. First, there are those focused on grid connection. These are typically large hydro and solar projects. For these to make a difference for rural communities they need to be combined with extension of grids into areas that currently do not have access. Second, there are mini grids where self-contained grids are established in rural villages, using micro hydro, solar and micro wind, or a mix of these. Finally, there are various off-grid solutions where electricity generation is tied to the household or factory – typically solar rooftop or other solar stand-alone solutions, sometimes combined with micro wind. These off-grid solutions range from small solar home systems that power a couple of lights and can charge a mobile phone to stand-alone systems that power factories or public institutions. Electrification in Africa will involve all of these pathways, but the question is about the balance between them and about how they are set up to maximise inclusiveness and economic development (NRECA International, 2017).

2.2. International trade and investments in renewable energy

Southern-based suppliers of component parts or whole systems in grid connected, mini grid and off-grid solutions are increasing annually in Africa. Inbound flows (from countries not only in the Global South, but also in the Global North) to Africa comprise trade, FDIs and foreign indirect investments, i.e. private capital investments or development finance. Data specifically on South–South trade and investment flows in renewable energy into the African continent is difficult to obtain. It is clear, however, that such flows are significant and growing in importance.

2.2.1. Trade flows

South–South trade in solar PV (cells and modules), wind turbines and hydropower is growing faster than global trade in the same sectors (UNEP, 2014). Africa is a relatively small importer (compared to Asia and Latin America), but in absolute terms, energy equipment imports are significant. African countries collectively imported wind turbines to the amount of US$342 million from other developing countries in the period 2009–2013. The largest importers were South Africa, Ethiopia and Egypt (UNEP). China exported PV cells and modules to African countries worth US$869 million in the period 2009–2013, with South Africa as the largest importer.

Looking a little deeper at Southern country exporters of PV cells and modules, we find that South Africa, the African country with the most solar generated electricity, had a significant rise in Chinese imports between 2005 and 2011 as compared to the top solar PV exporting countries in the Global North (see Fig. 1). The same is true of Kenya, which is well-known for its growth in off-grid small-scale solar home systems (see Fig. 2).

A similar picture can be found for wind turbine imports into Africa. Utilising trade data for wind turbines, we can see that for South Africa (also Africa's largest market for wind as per 2016 rankings) imports of Chinese turbines increased significantly in the period after 2010 as compared to those from the USA or Denmark (the other top producers of wind turbines in the world) (see Table 3). A similar story is true also in Kenya (although figures are only available until 2013 on UN Comtrade), while in Ethiopia, China has been the biggest importer of wind turbines by a significant margin since data started to be collected in 2005.

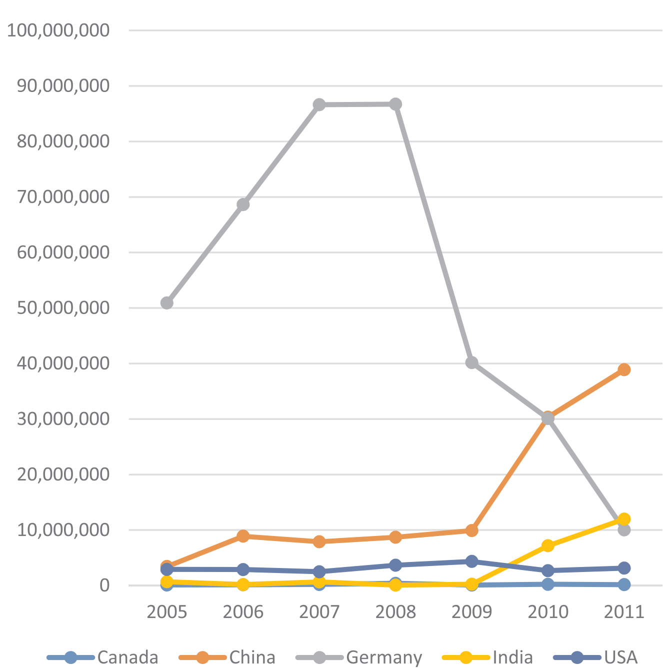

Fig. 1. Solar PV imports to South Africa by major exporting countries (2005–2011), USD. Source: UN Comtrade database utilising trade code: HS 854140.

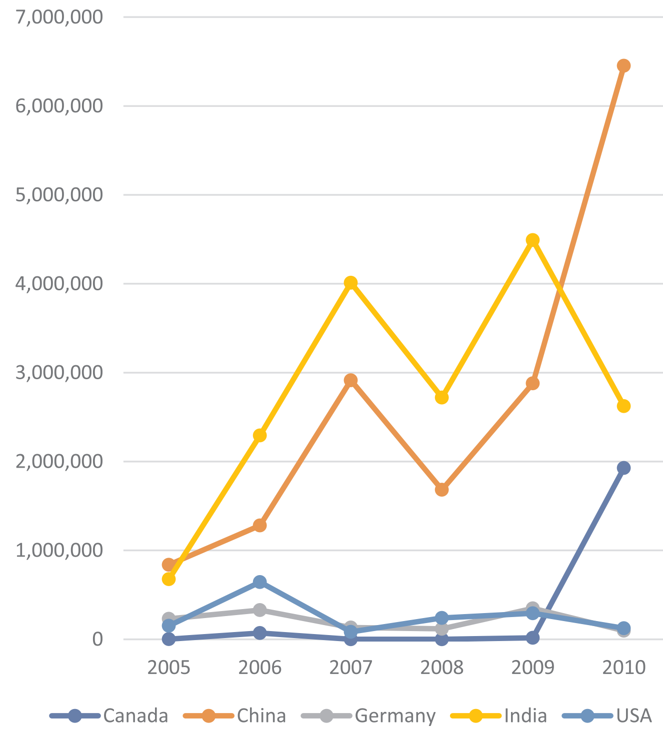

Fig. 2. Solar PV imports to Kenya by major exporting countries (2005–2010), USD. Source: UN Comtrade database utilising trade code: HS 854140.

Table 3
Imports of wind turbines into South Africa (2000–2016, total value US$). Source: UN Comtrade database utilising trade code: HS 850231.

	Total imports	to 2010	from 2010
China	497,024,320.00	689,567.00	496,334,753.00
Denmark	367,908,423.00	1,450,615.00	366,457,808.00
USA	39,323,759.00	703,236.00	38,620,523.00

2.2.2. Foreign direct investment and foreign indirect investment

In terms of FDI, Chinese power projects in sub-Saharan Africa cover the whole electricity mix except for nuclear. Fifty-six per cent of the projects of additional generation capacity completed, under construction or planned over the 2010–2020 period use renewable energy sources, essentially from hydro (49%), while other renewables (7%) reflect a relatively small share. However, it is difficult to track smaller projects, such as typical mini-grid projects (International Energy Agency, 2016, p. 12). In 2009, China announced that it would set up 100 clean energy projects across Africa, including some small-scale solar projects (Shen and Power, 2016). Such investments are much needed. Sub-Saharan Africa's electricity sector is projected to require capital investment of about US$835 billion by 2040 to enhance the generation, transmission and distribution (T&D) capacity, which is essential to supply the growing electricity demand and specified electrification targets (Castellano et al., 2015). Table 4 provides details of China's current power project portfolio in sub-Saharan Africa.

The literature on investments in the power sector in Africa undertaken by Chinese companies shows that investments have increased significantly over the past decade. The International Energy Agency (2016) shows that the Chinese have accounted for 30% of all capacity addition in the renewables sector in Africa with an investment of US$ 13 billion between 2010 and 2015, mostly from public funds. The Chinese contractors undertaking these investments are typically construction and energy infrastructure companies that develop the projects on a turnkey basis under so-called engineering, procurement and construction (EPC) contracts. In terms of capacity size, most of the Chinese-

Table 4
Chinese power projects in sub-Saharan Africa (2010–2020).
Source: International Energy Agency (2016).

	Generation capacity			T&D capacity		
	Completed projects	Under construction	Planned and financed	Completed projects	Under construction	Planned and financed
East Africa	14	9	5	10	10	1
West Africa	17	4	2	6	2	2
Central Africa	8	5	2	5	1	2
Southern Africa	15	7	8	4	5	1
Total	54	25	17	25	18	6
	96			49		

built power plant projects are large, utility-scale plants, in particular large hydropower plants: the average size of all projects completed, currently under construction or planned is 188 MW (International Energy Agency, 2016). A similar picture emerges with regard to solar power plants in Africa (Hansen et al., 2018).

3. Technology transfer and local capability formation

This section provides a brief outline of the theoretical underpinnings that constitute the foundation for later sections. We draw on complementary bodies of literature that tend to be treated in separation. This paper seeks to bring them together in the discussion of local capability formation in the context of renewable electrification. The aim of this section is, therefore, not to provide an in-depth review of the literature, but to briefly sketch the conceptual building blocks that are combined in different ways later for a critical capability-oriented perspective to technology transfer. We posit that such 'new combinations' advance the debate about the opportunities and challenges for 'sustainable industrialisation' associated with the provision of clean energy. We draw on the following literatures:

- *International technology transfer* (Bell, 2012; Ockwell and Mallett, 2013), defined as cross-border flows of technology from suppliers to users. Transferrable technology can take the form of 'hardware' (equipment and machinery) or 'software', i.e. knowledge, skills and capabilities. Bell (2012) decomposed the forms of technology into flows of (a) capital goods, services and designs, (b) operating skills and know-how, and (c) knowledge and experience for changing technology. There is, then, an increasing 'software' content in these flows. Whereas the transfer of capital good hardware (in this context, e.g. solar panel, wind turbines or biogas systems) may help to provide access to energy, it does not necessarily add much in terms of capability formation.
- *Below the radar innovation* (Clark and Chataway, 2009; Kaplinsky, 2011). Chataway et al. (2014, p. 33) emphasise the 'trajectory of innovation' as one key contributing factor behind the increase in the number of people living in absolute poverty in Africa because the trajectory has been characterised by solutions that are large in scale, capital intensive and, as such, better suited for richer countries. Hence, this literature emphasises that the selection of technologies that are appropriate in nature and scale leads to better outcomes in terms of social and economic development and vice versa. The global diffusion of innovative capabilities, not least to large emerging economies such as China, India and South Africa, may change existing unsatisfactory pathways.

It is in this context that the transition from production to innovation in BRIC countries is gaining added significance, as innovation arising out of these countries may prove more relevant in low-income settings compared to rich-country alternatives (Altenburg et al., 2008). South–South technology transfer is, therefore, increasingly seen as a particularly promising avenue for enhancing more appropriate innovation pathways in low and middle-income countries.

3.1. The importance of local capabilities and shaping of technology

There is increasing recognition that local capability formation is more than simply a linear push of technology from the exporting country to the importing country in a technology transfer relationship. This paper aligns with the literature that argues that emphasis needs to shift to the 'receiving end' so that the focus is on how technological capabilities are *acquired*. In this respect, the paper highlights multiple levels of agency that exists along complex technology linkages. Acquisition depends on the type and form of user–producer interaction, as well as the type of learning, that takes place (the importance of experiential learning through importing). The focus is on importing countries' ability to select and deploy the most relevant technologies in this respect, including the typical organisational arrangements associated with such technologies. This echoes literature allied to innovation and development studies, which suggests that technologies become 'contextualised', i.e. they are shaped by local organisational and institutional arrangements (c.f. MacKenzie and Wajcman, 1985; Sovacool, 2014)

As a result, there is a need to focus attention on the building of local innovation system structures that recognise the relevance of imported technology and promote the building of such systems. This requires policy linkage between ministries that moves beyond rhetoric and local content rules. Some have argued this is best achieved through the use of climate-relevant innovation system builders or CRIBS (Ockwell and Byrne, 2015) or what others have termed 'system operators' (Chaudhary et al., 2012; Lema et al., 2015, p. 180), which are key individuals or groups of individuals who successfully push for a functioning and conductive policy environment and innovation system.

Ockwell and Mallet (2013, p. 120) therefore talk about the need for policymakers and practitioners to start funding other forms of technology transfer and to 'move beyond hardware financing' as part of efforts to build a more functional innovation system relevant for low carbon development. They argue there is a need to focus on software technologies because without these successful low carbon technology transfer will not take place, nor will local capabilities be built to incrementally build on the hardware that is imported. This requires a decentralisation of energy and industrial policy discussions in order that local communities are engaged in these discussions.

This is not just a matter for policymakers. Fernández and Gavilanes (2017) emphasise the active role that importers (in all forms) need to play in investing in learning to absorb and shape technologies and capabilities. This includes the need for service providers to talk with local community governments to combine service level standards and social standards to enable the democratization of technology choices and enhance job generation.

3.2. South linkages and appropriate technology

As outlined above, a major set of debates considers the extent to which technology transfer—whether North–South or South–South—provides appropriate technology to those being provided with them. In the case of South–South technology transfer, we have seen the importation into sub-Saharan Africa of a significant level of embodied hardware; the amount from China has risen quite significantly in recent years. However, China's engagements in infrastructure projects in sub-Saharan Africa (not all specifically technology transfer projects) are known precisely for their large-scale characteristics (Kaplinsky and Morris, 2009; Mold, 2012); in agriculture, China has established technology demonstration centres where seemingly 'inappropriate technologies are piloted and pushed' (Xu et al., 2016, p. 88).

On the other hand, studies of Chinese imports to Africa in the capital goods sectors provide evidence to the contrary. Hanlin and Kaplinsky examined agricultural mechanisation in Tanzania, furniture in Kenya and apparel in Uganda and made a systematic comparison of northern and southern, particularly Chinese, sources of technology:

> Southern-origin equipment is distinctive by comparison with northern-origin capital goods. At observed capacity utilisation rates, southern-origin capital goods are economically efficient, accessible and profitable to users, and demonstrably appropriate to operating conditions in these economies (Hanlin and Kaplinsky, 2016: 361).

These authors examined the 'intrinsic properties' of southern capital goods for manufacturing and agricultural sectors. they found technology to be both cheaper and more appropriate along several dimensions (Table 5).

Corresponding studies have not been carried out in renewable energy technologies for electrification in sub-Saharan Africa. There is, therefore, a need for more attention on the degree to which Northern and Southern capital goods used in energy sectors, such as solar PV, hydropower, geothermal energy and wind energy, are inclusive or not, i.e. have characteristics such as those in the third column marked 'South' in Table 5.

4. Renewable electrification: linkages and interactive learning

Low carbon technology transfer is not just about the export–import of embodied technologies. It is also, and perhaps more importantly, about the software; the skills and capabilities from the outside that may become internalised and shaped to help more appropriate pathways of low carbon development. In other words, technology transfer is about local 'learning' and the facilitating or inhibiting role that trade and foreign investments play in this respect. We therefore now address low carbon technology transfer as an issue about learning in GVCs, utilising thinking from within the following literatures:

Table 5
Stylised differences between Northern and Southern capital goods used in sub-Saharan Africa.
Source: Simplified from Hanlin and Kaplinsky (2016).

	North	South
Acquisition cost	High cost	Low cost
Scale of operation	High output	Medium output
Efficiency	Efficient at rated and actual capacity	Efficient at rated and actual capacity
Labour intensity	Capital intensive	Labour intensive
Skill profile	Complicated to operate; skills for repair in short supply	Easy to operate and repair by in-house staff
Repair	Infrequent breakdowns; high cost of repair work	Frequent breakdowns; low cost of repair work
Access to spare parts	Expensive and hard to find	Cheap and easy to access
Fabrication	Locally fabricated spare not parts available	Locally fabricated spare parts available

- *Global value chains* (Gereffi, 2014; Humphrey and Schmitz, 2002; Kaplinsky and Morris, 2000). The value chain perspective complements the technology transfer literature in two main ways. First, it helps to move beyond a narrow focus on technology producers (exporters) and users (importers). This in turn helps to decompose the locus of learning between actors in the full range of steps in which renewable energy technology is being designed, produced, distributed, installed, used, maintained and decommissioned at the end of its lifecycle. Second, it is centrally concerned with the issue of 'power', which is often neglected in the transfer literature. Most studies in the GVC tradition focus on the role of powerful lead firms that can influence the conditions under which other actors in the chain operate. They have the power to specify designs, standards, and requirements backwards and forwards in the chain.
- *User–producer interaction and learning* (Lundvall, 1985). Whereas the GVC perspective is strong in, mapping out the sequence of activities in product and service provision and in understanding the constraints to 'upgrading' in various points in the chain, it offers little with respect to the actual mechanisms that contribute to such capability formation. Here, it is relevant to draw on the insights from the learning perspective that arose from user–producer studies. Interactive learning can be defined as the exchange of knowledge resources conducive to competence building and innovation.

4.1. Learning from importing

In the typical GVC setting, this literature is focused on 'lead firms' in the North and the global chains that connects them with local suppliers in the South. The key point is that chain governance (understood as the co-ordination undertaken by lead firms from advanced economies) influences the possibilities for extracting more economic value through learning in the South. The challenge is one of 'learning from exporting' so that local suppliers can upgrade by making better products, introducing better processes or assuming new tasks in the value chain (moving up the value chain).[1]

The underlying assertion in this paper is this literature on 'value chain learning' is an overlooked issue in the debate about technology transfer and particularly in discussions about low carbon sectors used for renewable electrification in the South. We posit that the key concepts and underlying logic behind GVC analysis is a useful, but so far neglected, approach. Bringing this out and highlighting the significance requires some explanation and framing of the typical value chains in the renewable electrification setting:

- First, technology transfer chains are *reverse value chains* in the sense that they are vehicles primarily for goods and services flowing from advanced economies to low and middle-income countries – not the other way around, which is the main focus of most GVC studies.
- Second, this means that the challenge is one of *learning from importing* in GVCs (rather than from learning by exporting).

4.2. User–producer interaction in tech transfer relationships

Lundvall (1985) describes the elements of 'user–producer interaction' as follows. *Producers* (a) monitor the users in terms of their processes and products and (b) become involved in the implementation of new products with feedback. They learn from this feedback. *Users* (a) monitor the new technological opportunities among producers and (b) draw upon producers when installing the new product. They learn from collaborative problem-solving. In the context of renewable electrification, the most important outcome is that users may learn by interacting

[1] For example, Schmitz and Knorringa (2000) identified ways in which it was possible to learn from lead firms and global buyers, while de Marchi et al. (2015) identified both intra-chain and extra-chain learning mechanisms.

with the producer and build capabilities.[2]

The outcome is likely to vary significantly depending on who are the users and who are the producers. If the technology in question is solar lanterns, there is a direct relationship from manufacture through distributors to end-users of those solar lanterns, which are likely to predominantly be rural households. In this paper, we are not concerned with consumer goods like a solar lantern, but specifically with grid-connected electricity generation technologies or mini grids. In these cases, users are professional organisations responsible for implementing and running the projects. For many consumer goods, the producer dominates the relationship between producer and user. The producer may pursue market research and give selective information on product characteristics through sales efforts such as advertising. Another reason for focusing upon *professional users* is that they have needs that can be defined by an external observer, while consumers more often act based on 'wants' that might be impossible for the external observer to observe.

4.3. Technology transfer and appropriate pathways

The nature of hardware, such as capital goods and their design, have intrinsic properties that are more or less inclusive (see Section 2). They also significantly influence the type and nature of operating skills and know-how and indeed the knowledge, skills and capabilities required to engage creatively with the technology. It is often emphasised that equipment is transferred without a corresponding transfer of skills and capabilities for replication, upscaling and local innovation. But there is little discussion of the relationship between the 'equipment' itself and the processes that enable localised upscaling.

There is considerable scope for professional users to choose different organisational models around given equipment. But the selection of core technology has important ramifications for the subsequent trajectories in terms of the developmental potential and inclusiveness of pathways. In rural and renewable electrification, there may be alternative options available depending on economic and geographical factors and the availability of natural resources for energy provision. There may be important ramifications from choosing between technologies (e.g. wind, solar, hydro) and within each domain are further technological choices (e.g. small wind versus large wind).

4.4. Trade-centred and investment-centred value chains

The prior subsections sought to frame technology transfer relationships in terms of GVCs and learning from importing. This section proceeds by discussing typical value chain structures in renewable energy and the implication of these structures for localisation and localised learning.

The value chain may be organised in a myriad of ways. In this paper, we start from a simple distinction between two types of chains:

- *Trade-centred value chains*: These refer to international flows of capital goods from exporters to importers. They are typically used for the transfer of relatively simple products with manageable transportation costs. For example, this type of chain may be used in the case of solar home systems where solar PV panels are produced in the EU or East Asia, and they imported by a wholesale dealer in sub-Saharan Africa before being installed in a village by a dedicated provider of rooftop solutions. Small wind turbines may also be transferred internationally in such trade-centred value chains.
- *Investment centred-value chains:* These refer to cross-border investments by internationally operating firms. They are typically used to transfer more complex and capital-intensive products or systems with technological characteristics that inhibit or increase the cost of trade. Large-scale solar power is one example of a renewable energy technology that tends to be organised in investment-centred value chains. Here, Chinese solar PV lead firms establish themselves in end-user markets through FDIs in large-scale solar farm projects. From the end-user market, they organise construction of the solar farm, using personnel and equipment from the home and host country while importing core components such as the panels. The diffusion of large-scale solar PV and wind for rural and renewable electrification is typically organised in investment-centred value chains.

Trade-centred and investment-centred value chains are ideal types and two ends in a continuum. There are many variations of both types as well as hybrid forms. This distinction is important nevertheless because it provides conceptual hooks to address how technology selection and purchase agreements structure value chain arrangements and how these arrangements have important ramifications in terms of opportunities to localise the production of goods and services and facilitate technological learning and innovation in host countries.

4.5. The 'local content' of renewable energy products and services

International technology transfer is contested territory because of the economic interests at stake. Benefits, such as green jobs and profits, are unequally divided depending on the way value chains are organised. In principle, the country undergoing the renewable electrification process would reap most development benefits by undertaking all steps in the chain domestically in terms of employment, learning, productivity gains and local industrial development.[3] But in practice all countries, even large countries, partake in an international division of labour to a certain degree. However, the risk is that renewable electrification becomes an 'enclave process' with little local content and with few linkages or spill-overs to the rest of the economy. The danger is that renewable electrification processes mimic patterns found in manufacturing, in export processing zones or in extractive industries where 'local content is limited, shallow and inefficient' (Hansen et al., 2016, p. 201). It is a question of choosing steps in the chain that are feasibly undertaken locally.

Renewable energy value chains combine:

- *Core technology manufacturing steps* related to the production of energy-generating equipment. These steps are typically organised by different types of producers.
- *Deployment steps* related to their installation and use. These steps are typically organised by different types of services companies that are the 'professional users' of renewable energy technology.

In the context of wind energy, Schmitz and Lema (2015) referred to these as the *manufacturing chain*, consisting of the production of turbines and their different parts and components; and the *deployment chain* that involves the distribution and the utilisation of the energy (see Fig. 3). There are big differences between these steps across wind, solar and hydropower.

However, these elements are present in the provision of all renewable energy technologies, whether organised as trade or investment

[2] The interaction takes different forms with different outcomes. Mutually beneficial interactive learning is not an automatic outcome. Lundvall's (1985) study of the dairy industry in Denmark in the 1980s showed that powerful producers limited innovation spaces of users by framing innovation challenges in their own interest and by pushing their own (overly) advanced solutions. Lead firm technology producers in the dairy sector thus pushed 'unsatisfactory innovations' within the dairy cooperative user organisations. This suggests that one needs to pay careful attention to the 'direction' of interactive learning and innovation.

[3] Trade economists argue that this comes at a price of a loss in overall welfare gains as it effectively involves barriers to (free) trade to localise all of these activities. For example, it could raise the prices of the products produced locally as opposed to simply importing them.

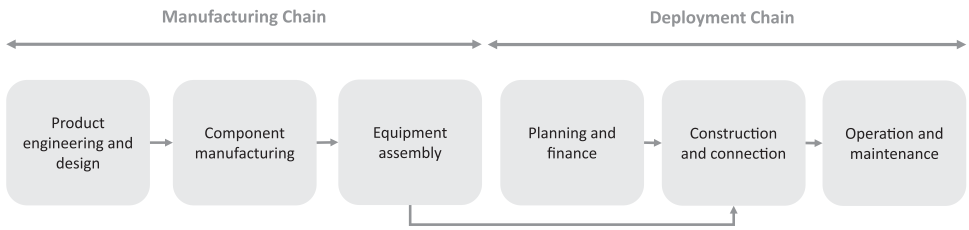

Fig. 3. Generic manufacturing and deployment chain. Drawing on and Schmitz and Lema (2015) and Lema et al. (2016).

intensive chains. But their distribution between countries is different. This is particularly so when it comes to manufacturing.

- In trade-centred global value chains, manufacturing core technology are often based in the exporting country. The technology provider and its networks of component suppliers undertake manufacturing production and assembly and hence there are few or no opportunities to contribute to, for example, component manufacturing in the country of end-use (the importing country). As such, the potential here is limited to the deployment chain activities only.
- In investment-centred value chains, on the other hand, component production and/final assembly of core technologies is typically 'localised' to a much greater extent in the country of end use. For example, material inputs such as cement is typically produced locally. Even solar PV technology transfer may be organised as investment centred chains, with the assembly of core technology undertaken locally (IRENA, 2016: Table 7). The steps involved in deployment are remarkably different because their location is typically tied to the site of installation in both cases.

However, trade- and investment-centred chains differ with respect to the organisational separation of supply and installation. In trade-centred chains, separate lead firms undertake the manufacturing and deployment elements, whereas in investment-centred chains, there is one lead firm that co-ordinates the entire range of steps.

The discussion of local content above sought to disentangle and describe different patterns with respect to the location of production and service provision activities and their organisational division of labour. However, the discussion of localisation also needs to consider the question of *ownership*. In principle, foreign-owned firms may undertake all the steps in the value chains described above with little involvement of local enterprises and/or local-staff. In fact, there is evidence of very strong dominance of multinational enterprises in renewable energy provision in low- and middle-income countries (McCrone et al., 2016)

5. Renewable electrification using solar PV and wind in Kenya

Technology transfer and the learning and development potentials involved in technology transfer projects depend not only mainly on the properties of the capital goods (hardware) involved. These potentials also depend significantly on the organisational (software) arrangements involved in the modes of diffusion. While probably the most important element for local capability formation, these software elements are also the least understood. As such, this is uncharted territory.

Table 6 draws mainly on Hansen et al. (2018) who analysed the sectoral innovation systems for solar PV and wind in Kenya, examining large-scale (grid connected) and small-scale (mini grid) segments for both technologies. The table draws on some specific Kenyan examples of non-representative cases; as such it is heuristic and not intended as a generalizable picture.

The following sub-sections discuss the potentials for learning and innovation in each step of the two chains with specific references to examples in Kenya. Kenya is a relevant country of study because it is regarded as one of the exemplar countries in sub-Saharan Africa for renewables use and has historically had a much more established local manufacturing base than many other sub-Saharan countries.

5.1. Manufacturing chain

When it comes to the core focus of this paper, i.e. local capability formation and industrial development in renewable energy industries in Africa, there is very little evidence of this taking place within the manufacturing chain. In Kenya, large-scale wind projects, such as the Lake Turkana Wind Project, are utilising European turbines that are designed, engineered, assembled and manufactured by European firms (although using manufacturing sites in China). Even where large-scale projects with and South-driven chains are in evidence (e.g. the new solar PV Garissa project), all important stages of the manufacturing chain are conducted in China (Bellini, 2017). Hence, in the case of large-scale renewable energy projects in Kenya, local companies typically are primarily involved in the site construction activities, including the building of roads, site offices and electricity transmission lines (Hansen, 2017). With small-scale projects, however, there is a more nuanced picture. Regarding wind turbines, Vanheule (2012) distinguished between three types of wind turbines: imported, locally produced and sold in Kenya. To this comes a fourth category, which

Table 6
Stylised differences between Northern and Southern renewable energy technology transfer linkages in sub-Saharan Africa: the example of solar PV and wind in Kenya.
Source: Based on information from Tigabu (2016) and Hansen et al. (2018).

<table>
<tr><th></th><th>North-driven</th><th>South-driven</th></tr>
<tr><td>Manufacturing
– Product design and engineering
– Equipment assembly
– Component manufacture</td><td>Manufactured in Europe and imported in trade-centred value chains (mini-grid) or investment-centred value chains (large-scale projects).</td><td>Manufactured in China and imported in investment- centred VCs (large-scale projects).</td></tr>
<tr><td></td><td colspan="2">The situation is changing with local production facilities of solar PV starting up and local wind turbine manufacturing capability having always been present (but not popular for electrification, although this might change due to a project to encourage development of small wind turbines in Kenya by Danish company Vestas.</td></tr>
<tr><td>Deployment
– Planning and financing
– Construction and connection
– Operations and maintenance</td><td>European contractors/subcontractors predominately manage all aspects of the deployment chain, but some use African financing, subcontractors in construction phase, and, increasingly, local actors involved in operations and maintenance. There is often more local input when the project is on a smaller scale.</td><td>Chinese finance, Chinese project managers and construction firms, and often Chinese engineers utilised, although with a phase-out period (sometimes very long).</td></tr>
</table>

Table 7
Types of wind turbines manufactured and imported in Kenya.
Source: Modified from Vanheule (2012) and Hansen et al. (2018).

	Local production		Imports	
	Micro	Small	Small	Large
Production	Local re-used materials and parts	Small-scale, local materials	Serial production	Built to order
Power	20–300 W	200 W to 10 kW	200 W to 10 kW	Up to 1.5 MW
Efficiency	Low	Medium	High	Very high
Cost	Very low–low	Medium	High	Very high
Quality	Low	Medium	High	Very high
Repair and maintenance	Can be repaired locally; spare parts available	Can be repaired locally; spare parts available	Local skills and spare parts may not be available	Local skills and spare parts are not available

involves wind turbines with capacities significantly above 10 kW and up to 850 kW used in the large-scale wind power plants constructed in Kenya (Table 7).

The value chain related to the first category of so-called 'informal manufacturing' is highly localised and characterised by relatively simple and short linkages between local producers of small-scale 'Jua Kali' wind turbines (20–300 W) and suppliers of various kinds of locally available input materials. These local (informal) producers typically consist of local welders, craftsmen, electricians and mechanics, who are involved in the design, manufacture and sale of these small-scale wind turbines themselves, mainly to supply rural households and farmers (see Fig. 4). The technologies are small and relatively simple systems that are developed based on their own designs mainly from the copy and imitation of imported goods, catalogues and from other local artisans (Vanheule, 2012).

The second category of so-called 'formal manufacturing' of wind turbines with a higher capacity (200 W to 10 kW) involves a smaller number of enterprises with a formal license to operate, which among others include the companies Craftskills, WindGen (now called PowerGen), WinAfrique, Access:Energy and Chloride Exide (AHK, 2013; Carbon Africa Limited, 2015) These companies produce wind turbines in local factories mainly based on open source designs and by using locally available spare parts and materials. Vanheule (2012) estimated that in 2012, such local producers had sold around 120–150 turbines in this category in Kenya. The wind turbines are sold under their own company brand names primarily to prosperous households, businesses and organisations. The wind turbine suppliers are involved in all aspects, from production to installation and maintenance.

As shown in Fig. 3, this typically involves local production and assembly of the wind turbines, including import of critical parts and after-sale service to customers. Some of the companies involved in importing wind turbines are considering importing Chinese systems to reduce the costs of their products, but the equipment for small-scale wind is typically provided by small specialised suppliers (Kamp and Vanheule, 2015). In this context, it should be noted that some of the global lead firms are beginning to take an interest in this segment. Danish wind turbine company Vestas has started a new project focusing on the development of a small-scale wind turbine for sale in Kenya, which is intended to include locally produced components (SustainableEnergy, 2017).

The third category of wind turbines in the Kenyan market involves the import of fully operational, pre-fabricated systems from renowned wind turbine suppliers abroad. Around 20 companies in Kenya are involved in import of importing such systems, which include companies such as EAWEL and Davis & Shirtliff, who mainly operate as wholesalers and distributors (Kamp and Vanheule, 2015). Finally, in the value chain related to large-scale wind power projects planned and constructed in Kenya, lead firms in co-operation with international construction and engineering companies play an essential role in all stages related to the import, installation and operation of the wind turbines used in the plants. In these projects, lead firms, such as Vestas, General Electric and Iberdrola, are typically involved as total system suppliers—in so-called engineering, procurement and construction (EPC) contracts—under which they are responsible for the detailed engineering design of the project, the procurement of all the equipment and materials necessary, and the construction and delivery of a fully operational (turnkey) plant to their clients.

In the area of small-scale solar PV, the majority of projects that were

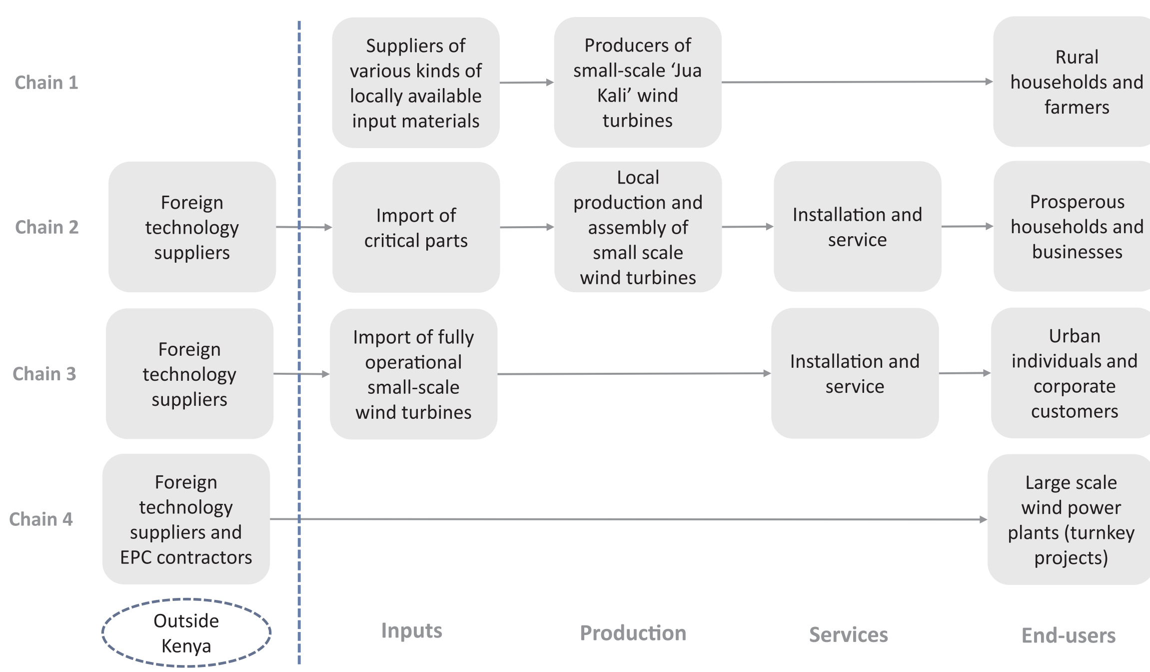

Fig. 4. Value chains for wind turbines in Kenya. *Source*: Hansen (2017).

undertaken over the last 10 years have predominately utilised equipment wholly manufactured in European countries or the USA. Now, cheaper Chinese PV modules are available and a local manufacturing facility in Kenya called Solinc (previously Ubbink). The plant at the Strathmore University (0.6 MW) uses key components from European and Chinese suppliers (including panels from JinkoSolar and inverters from Solaredge). It is interesting to note that local manufacturing facilities for solar PV have been established in other African countries too, including Senegal, South Africa and Mozambique. These local assembly plants involve South–South co-operation, for example through direct engagement by the Indian government in the establishment of the solar assembly plant in Mozambique (Nygaard et al., 2017), the direct role of Chinese lead firms in setting up solar assembly plants in South Africa (Baker and Sovacool, 2017) and linkages to Chinese equipment in the case of the assembly plant in Senegal (Nygaard and Hansen, 2016). That said, in Kenya, a Dutch company set up the solar PV manufacturing facility and a tag line on their website reads, 'Engineered in Europe, manufactured in Kenya' (Ubbink/Solinc, 2017). Other components required in solar PV systems are also manufactured in Kenya, notably lead acid batteries by, for example, Chloride Exide and Associated Battery Manufacturers Ltd.

The situation within the manufacturing value chain highlights a complex situation, particularly in small-scale projects where we do not have a clear-cut difference between North- and South-driven chains in terms of whether they are trade or investment chains. In both cases, the situation appears to be ripe for a significant level of 'learning through importing' unless, over time, local manufacturing capability is increased, thus enabling more locally focused firms of interactive learning.

In large-scale projects, there appears to be a clearer difference between Southern-oriented (or at least Chinese-dominated) chains and Northern ones in the degree of focus on investment-centred chain activities. In terms of functional upgrading, i.e. moving towards higher value-added activities with increased skills content, the establishment of local assembly and production could function as a starting point for the typical industrialisation trajectory identified in the GVC literature (Hobday, 1995). Local production of towers could conceivably materialise, such as under license agreements with foreign technology suppliers, as have been observed in South Africa, for example (Rennkamp and Boyd, 2015). Local construction companies could also acquire project-related engineering capabilities from lead firms through their involvement as sub-contractors in large-scale projects.

Over time, this may enable the local companies to independently venture into the development of projects based on the accumulated expertise from prior project involvement. However, as shown in Fig. 5. It should be remembered that local production typically involves the lowest value-added activity in the value chain. Further, the profitability for local companies to produce locally should be considered in light of the increasing competition from the import of Chinese and Indian components. As highlighted by Ockwell and Byrne (2016, p. 97), local manufacturing of solar components in Kenya 'has almost disappeared as a result of Chinese-made products coming into the Kenyan market', as 'Chinese firms were able to manufacture them with higher quality and lower prices than Kenyan firms'. Accordingly, the relatively limited degree of local production of key components and products in the renewable energy sectors in Kenya and across Africa may not be surprising.

5.2. Deployment chain

We would argue that it is in the deployment chain where we see the most opportunities for local capability building currently taking place in solar PV and wind in Kenya. This is not surprising given the infancy of the local manufacturing sector in Kenya in these two areas of renewable energy. Most of these opportunities are found in the downstream activities of the deployment chain, notably the construction and connection stage of the chain, and the distribution activities.

In large- and small-scale projects in Northern driven chains, there are opportunities for local companies and individuals to participate in the construction phases. In large-scale projects, such as Lake Turkana Wind Project, different elements of the construction phase are contracted out to local suppliers of everything from security and food to construction of turbine plinths. In small-scale projects, the Northern based companies involved often employ local engineers or workers to help with installation/construction or have an explicit link with the local community, organisation, household or factory to ensure local ownership of the project through active engagement with the project at all stages, including the construction and connection phase. For example, Solar Century, one of the oldest UK-based solar energy firms, has teamed up with Kenyan registered company Powergen on several projects including a 200 kWp solar and battery storage system and an 800 kWp Garden City shopping mall project (Powergen, 2017).

There is also evidence of the potential for capability building in the last stage of the deployment chain in relation to distribution, operations and maintenance. Indeed, in general, the further downwards in the value chain, the higher the prospects for employment and value added for local actors (see Table 8).

The downstream segments of the value chain include the entire range of activities, from the primary import, wholesale, retail, and local sales offices and distribution to the final clients and end-users (see Fig. 6). In Kenya, an extensive network of local companies is involved in the import, retail and distribution of components and products to the final customers (Hansen, 2017). For example, many local companies in Kenya are involved as primary importers of solar panels and auxiliary components, such as inverters, charge controllers and batteries, under agreements with foreign suppliers to distribute and sell their products.

Estimations suggest there are around 10–20 local companies involved in the import and further sale of solar panels and auxiliary components to projects and systems at various scales in Kenya (Muchunku, 2013). These companies, which include Centre for

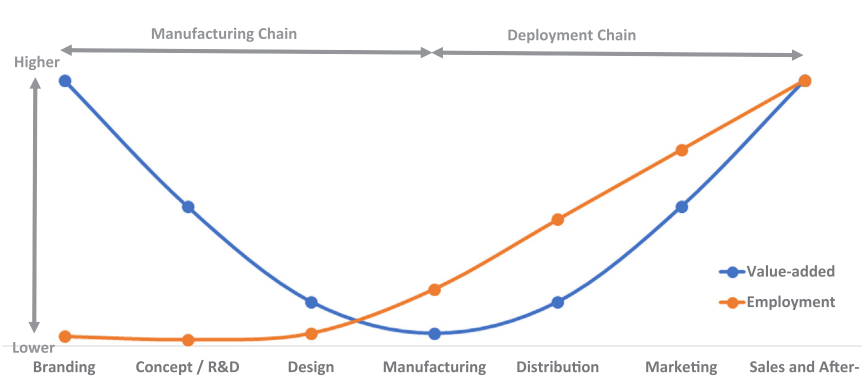

Fig. 5. Stylised representation of value-added and employment potential along the value chain: 'smiling curve' vs 'sloping curve'.

Table 8
Solar PV industry investment, jobs, value added and barriers to entry.
Source: ERG (2012).

	Value (USD)/W	Jobs/MW
Silicon	0.30–0.50	–
Ingot, wafer	0.10–0.30	2–4
Cell	0.25–0.80	–
Module	0.35–0.70	3–4
Balance of system	1.60–3.60	1000
Distribution, installation and service		

majority work in Kenya (see also Rolffs et al., 2015).

As noted above, many Northern driven chains involving small-scale projects have Kenyan companies and/or have a high level of connection to the locally based client. Many mini-grid solar PV projects in Kenya are handed over to the local community once built, and they become responsible for their operation and maintenance. For example, Kenya's electricity provider Kenya Power manages several hybrid solar PV or wind with diesel mini grids for the Kenyan Rural Energy Authority (REA). These were installed by a range of providers, including University of Southampton, and through GiZ/KfW, but they are now operated and maintained by the Kenyan power company or by the local communities themselves (Muriithi, 2016).

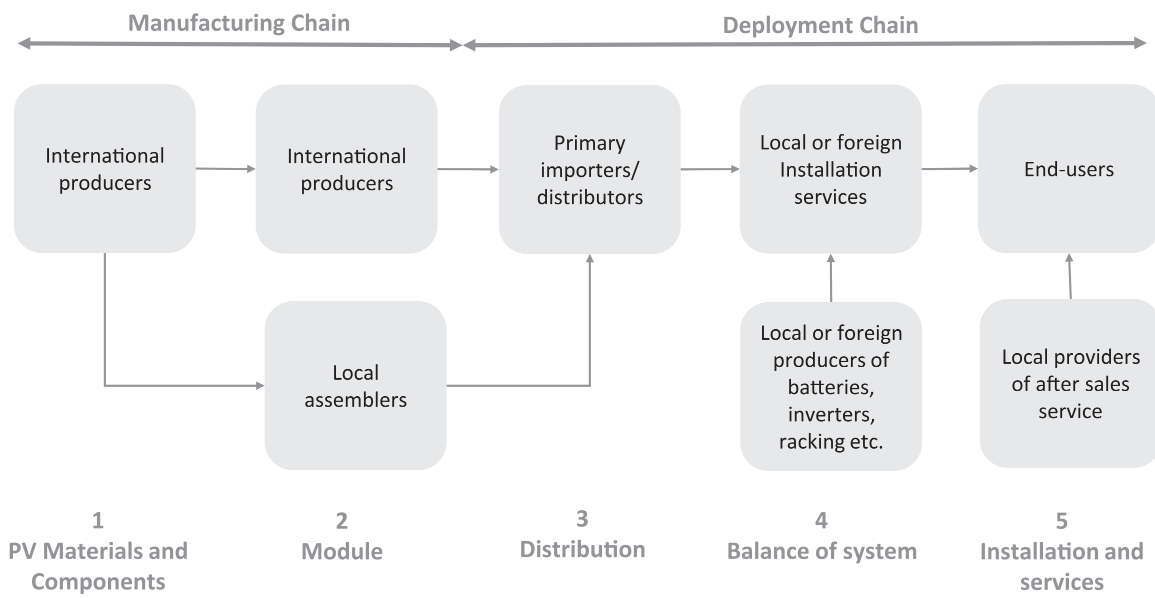

Fig. 6. Solar PV value chain in Kenya. *Source*: Based on information from Muchunku (2013) and Hansen (2017).

Alternative Technologies (CAT), Davis & Shirtliff, Solar Works and Harmonic Systems, are typically larger businesses that offer a range of products and related engineering and consultancy services. An illustrative example is the Kenyan-based company Solar Works, which imports solar panels and inverters from German companies, such as Energiebau Solarstromsysteme GmbH, Schott Solar and SMA Solar Systems. Similarly, Davis & Shirtliff imports solar panels from Yingli in China and batteries from Yuasa in Japan. In other cases, the importers operate as local subsidiaries of foreign technology suppliers, such as in the case of the companies Suntech Power Ltd. and Dreampower Ltd., which import solar modules from their parent companies in China and Italy. Hence, there are both vertically integrated forms of relationships between the primary importers of solar panels and foreign technology suppliers, and other types of relationships that are based on sales agreements and arms-length transactions.

In the downstream activities in the solar PV value chain in Kenya, there are hundreds of retail shops that supply (mainly imported) PV panels and other auxiliary components directly over-the-counter to consumers throughout Kenya in local shops, supermarkets and stockists. Generally, it appears that the further downstream in the solar PV value chain, the more local actors are involved in the form of local businesses, technicians and individual operators that are (sometimes loosely) connected to solar distributors or retailers. Most of these local entities are involved in the supply of small-scale solar (PICO) PV systems and solar home systems to customers in rural areas, which has developed into a particularly vibrant local industry (Nygaard et al., 2017). To illustrate the scale of this local industry, IRENA (2017) estimates that the two dominating local suppliers of small-scale solar home systems based in Kenya, M-KOPA and Azuri Technologies, currently employ around 3000 workers in East Africa, of which the majority work in Kenya (see also Rolffs et al., 2015).

Kenya Power is also retrofitting 22 existing diesel mini grids with renewable energy by themselves. The Kenyan REA has also installed over 670 solar PV systems for schools and healthcare centres in off-grid areas, many of which are also now maintained on a day-to-day basis by the schools or healthcare centres.

In large projects, such as Lake Turkana Wind Project, Kenyan engineers have been employed to maintain the turbines; despite initial expectations that only Danish engineers would be used in the initial stages of the project's operational phase. Furthermore, the Ngong hills 25.5 MW wind power plant uses European turbines (Vestas and Gamesa), but it is operated and maintained by Kengen. But in North-driven chains there may also be significant involvement of Asian firms. For example, in the Kipeto Energy Wind Park, the Chinese company China Machinery Engineering Corp was contracted as the EPC contractor, responsible for a large share of the activities in the deployment chain.

When it comes to the planning and financing stage of the deployment chain, there is less evidence of opportunities for local capability building. However, there have been local banks involved in financing green energy projects in Kenya. For example, Commercial Bank of Africa Ltd manages a credit line of 10 million Euros from African Development Bank for the financing of green energy projects in Kenya (CIO East Africa, 2015).[4] There is less evidence of such engagement in Southern-driven, or rather Chinese-driven, large-scale chains in existence in Kenya.

[4] Key to the success of such finance is knowledge and understanding of the sector being supported by the banking sector and vice versa. For the case of Pharmaceuticals, see Banda (2013).

The Garissa solar project, for example, is financed by Chinese money and will involve a Chinese engineering firm that will then operate the 55 MW plant through a 25-year power purchase agreement with the country's power supplier, Kenya Power (Construction Kenya, 2017). It involves Chinese technology supplier JinkoSolar and Chinese project developer Jiangxi Corporation for International Economic and Technical Cooperation Ltd.

The capability building found in this chain is less ‘hardware’ specific (as in the manufacturing chain above) and often more ‘software’ oriented, due to the nature of most of the activities being service oriented or involve operating skills and know-how, to use Bell's classification discussed earlier. In addition, user–producer relations are key in this chain in the more traditional sense of client (user) and contractor (producer) than in the manufacturing chains where professional users (project managers of large- and small-scale projects) dominate.

In summary, it seems that the insertion of local actors in the deployment activities related to renewable energy value chains involves significant opportunities for learning, capability development and employment creation. However, these activities may essentially be considered 'service jobs' related to imported technology and hence not worthwhile supporting from a political perspective, given the limited locally produced content and manufacturing jobs.

5.3. Capability building: linkages and local ownership

The analysis provided in Sections 5.1 and 5.2 highlights several important points. First, it shows that the neat categorisation of South-driven and North-driven projects is overly simplified. Thus, there are often Southern firms, particularly locally owned Kenyan firms, involved in North-driven projects. Second, this calls for detailed value chain analysis at the project level. Third, Table 8 and description above is merely a mapping of actors. Understanding the more detailed potential for interactive learning requires in-depth studies of (typically very complex) projects. These points highlight collectively the difficulty of examining the creation, use and transfer of software technology in renewable energy services and activities. Paradoxically, the area typically highlighted in the technology transfer field as key for low carbon development is the most difficult to examine and distil for relevant policy advice.

There are differentiated opportunities with respect to involvement of locally owned firms, but so far their participation in these value chains is often marginal. The capital and capability requirements of large-scale projects tend to supersede those that are available locally, except in some areas of the deployment chain. This is also the case even in emerging trajectories of small-scale and distributed renewable energy provision. For example, Hansen et al. (2018) examined ownership patterns of wind and solar power projects in Kenya (both small and large scale) and found there was very limited involvement of local firms in the organisation and development of projects in these sectors. In other words, most projects relied significantly on foreign sources of capital, technology, expertise and know-how, mainly from Europe. For example, the Kitonyoni solar PV mini grid in Kenya was developed by UK researchers and then brought to Kenya in a ready prepared container for immediate installation (with local community members) in the space of one week in 2012 (Energy for development, 2017). In a similar, more recent example, two communities in Kenya have received solar nano grids in a collaboration with other UK researchers under what is known as the SONG project (Clarke, 2017). The nano grids were again developed in the UK and transported in a container to Kenya and put up in the communities.

In a similar example, one mini-grid solar project in Uganda was based on technology transferred from Northern Europe (Mathiesen, 2015). This was state-of-the-art solar PV technology with highly advanced online control systems. These systems were monitored and operated by the technology supplier in its home country, not by user communities in Uganda. There was only little local involvement, with Ugandan participation only in maintenance tasks related to non-core elements, such as solar panel racks. More serious problems in core technology (panels or electrical systems) required in-person attention from supplier-firm staff. In this case, there was modest transfer of technology beyond hardware and little local engagement with technology, which could allow for capability-building in Uganda. For the Ugandan communities, the new system provided electrical power to households in the villages where the system was installed, but the underlying technology came as a ‘black box’. It was defined, installed and operated from the outside due to a gap between system requirements and local capabilities.

That said, in the Kitonyoni and SONG projects, there is local ownership, and it has been built in from the very start, even if the equipment itself is ‘parachuted in’. In the SONG project, for instance, the nano grids are run and managed by a local energy committee, and the local communities have been involved in decision-making around the design of the nano grid and what the energy produced will be used for (personal communication with SONG project manager, 2017).

The examples of Kitonyoni and SONG, but also the involvement of local Kenyan construction firms in the Lake Turkana and other deployment chain examples outlined above, suggest that the issue is not one of learning from exporting or learning from importing even, but rather one of learning from participating.

6. Concluding remarks

This paper has highlighted the need for researchers and, by extension also policymakers and practitioners, to take a stronger interest in the conditions for local capability formation that arise during interactions for low carbon energy projects. This is important, if we are to move debates in this area from predominately focusing on access to energy (Goal 7) or sustainable industrialisation (Goal 9) and consider how these two goals can be developed in tandem through the promotion of ‘low carbon development’. As shown in Section 3, there is a rapid increase in trade and investment in renewables for electrification in sub-Saharan Africa. The paper set out to provide conceptual framing and substantiation for a research agenda focusing on local capability formation in this context. This concluding section highlights the main points and identifies key issues for further research.

6.1. Renewable electrification and local capability formation

In bringing together otherwise separate literatures to frame this issue, we sought to provide a novel lens and associated vocabulary to address the opportunities and constraints for local capability formation. The key objective was to bring out novel perspectives that are otherwise underemphasised in the literature on technology transfer and local capabilities, namely those of value chain linkages and interactive learning within them.

Section 3 provided a brief account of the relevant but diverse literature and perspectives in this research to situate the discussion in relation to the state of the art and provide some basic conceptual building blocks for the analysis. Section 4 then focused on the core concepts of (value chain) linkages and interactive learning in the renewables setting in developing countries while Section 5 sought to illustrate key value chain structures in the Kenyan solar PV and wind industries. The paper is exploratory in nature, but gives rise to the following general propositions for further investigation:

- Projects for renewable electrification differ in balance between trade- and investment-centred value chains. Investment-centred value chains, even if they are part of more complex sets of technology transfer, tend to ‘bundle’ requisite tasks that are organised by the (foreign) investor. Trade-centred value chains, or the elements of transfers/projects that are traded, may allow for more local substitution of products and services, local participation and local shaping.

- Both types of chains can be subdivided into a manufacturing chain (centred on the 'core products') and a deployment chain (centred on the 'core services' and auxiliary products). Much literature on technology transfer collaboration and value chains tend to focus predominantly on the former. This can be explained, in part, by the fact that this type of (embodied) transfer is visible 'on the radar'. However, deployment chains deserve most attention for several reasons, even if the software elements involved are difficult to detect and often highly complex. Many of these functions are labour-intensive, tied to the point of end-use, and provide a main possible entry point for local value chain participation and learning.
- The degree of bundling may differ in both large (centralised) and small (decentralised) sets of technology transfers, i.e. renewable energy 'projects' (Hansen et al., 2018). But decentralised diffusion projects may typically involve higher degrees of unbundling. Such openness in the organisation of value chains is associated with lower entry barriers and more fruitful spaces for interactive learning.

We propose that these hypotheses deserve further investigation in future studies of renewable electrification pathways and their specific features.

6.2. Local capability formation: a role for South–South linkages?

The paper also sought to address the key question of whether and (if so) why South-South linkages make a difference for capability formation. Discussing this question in general terms is difficult due to the enormous complexity of the matter, with a huge variability across different sectors and settings. The paper has sought to find a path through these dimensions but falls short of any clear-cut response to this question. Framing the issue in terms of interactive learning between professional users (importers) and producers (exporters), understanding the typical chain structures and their different learning opportunities in and around localised activities, and laying out the specific loci of such learning helps. But it is also evident that these steps do not provide a clear-cut equation that can help determine the relevance of South–South linkages when it comes to local capability formation.

As discussed, there are indications that transferred hardware technologies from the South may be more inclusive than technology from advanced economies. But there is little to suggest that Southern transfer linkages as such provide better opportunities for localised learning. In fact, the opposite may often be true. Because of lower wages in the South, Southern producers may have a higher propensity to do not only core technology manufacturing and assembly, but also to undertake deployment-related services and associated less sophisticated manufacturing—thereby crowding out and displacing local actors from the most obvious stepping stones for learning. In other words, both producers *and* professional users in such projects may be from China and India, transferring mainly hardware and little in terms of software, and creating higher entry barriers for local learning. This is the likely scenario in many full-package deals (finance, manufacturing, construction and operation) offered by some Chinese firms, which again leaves the onus on promotion of local content and participation.

6.3. Promoting interactive learning in renewable electrification

The final area of discussion is with regards to the types of interactions and learning that are important, but often neglected. This paper has identified three types of interactive learning of special interest from a development perspective. These will be outlined briefly below. These forms of learning go beyond simply the uptake of new technology (hardware or software) but are about forms of interactive learning that will specifically create the opportunity for low carbon development; for the promotion of firms that make products that alleviate energy poverty and increase energy access while also building the industrial base of the country.

- *Interactive learning between contractors and local suppliers:* As noted above, there is a need to recognise the role of service providers and local firms in the value chain and the importance of their interactions with their clients, especially the main contractor of a wind or solar PV project; this main contractor is essentially a professional user (as opposed to an end-user; see Lundvall, 1985). Professional users have more defined needs in terms of what products and services they require and as such, a good level of interaction—which focuses on learning the needs and wants of the other—between suppliers and the main contractor will ensure a more efficient project and should reduce delays. This is important on both sides, not only for building up competences of local suppliers and their reputation in the market, but also reducing the 'lock-in' of dominant sourcing policies of lead firms in a project setting (Hanlin and Hanlin, 2012). Both are needed if strong backward and forward linkages are to be created within GVCs. These need to be encouraged by governments so as to create the development of dynamic capabilities in firms and through these a stronger more diversified economic base (Morris et al., 2012; Lundvall and Lema, 2014).
- *Local labour learning to 'use' the new installations—operating and maintaining:* The paper has highlighted the importance of recognising less codified knowledge and experiential learning that comes through 'doing, using and interacting' (Jensen et al., 2007). For more local content to be utilised, there is a need for local labour to understand how different parts of the technology within a solar PV or wind project work and are provided with the opportunity to take over the 'operations and maintenance' part of the project lifecycle. This requires not just a new mindset from lead firms in the projects, but also government support of the relevant training and education needed to ensure there are technicians and/or engineers available locally to conduct such work.
- *Public authorities learning to manage major projects:* We have already mentioned the importance of public authorities taking more of an active role in regulating and supporting the sector through promotion of training schemes etc. However, sometimes governments are the 'lead firms' in projects: commissioning, managing and/or running the projects once construction is completed. This requires a change in mindset for government departments as they need to start behaving like lead firms and act in a more commercially oriented manner than might otherwise be the case.

At the same time, this also provides opportunities for governments to actively promote local content and linkages building proactively through public procurement. Large, publicly managed infrastructure projects – such as—of which large-scale wind and solar PV farms—provide a targeted way in which governments can develop local skills and capabilities that can go on to work on, and even manage, other similar projects in the future. This is a mechanism that is not new but has been promoted in infrastructure projects in the USA, China and Singapore for some time (Wells and Hawkins, 2010). Unfortunately, issues of corruption have often been cited as hampering such efforts in African large-scale infrastructure projects (Appolloni and Nshombo, 2014). There has been an increasing interest taken in the role of public procurement as a way of stimulating the development of local industry in recent years, particularly in the health sector in Africa (Chataway et al., 2016). We would argue that, despite the issues of corruption, public procurement should not be neglected as an opportunity for local skills building (Edler and Georghiou, 2007; Rolfstam, 2009).

All three of these types of learning may not arise automatically, so one issue of critical importance is mechanisms for *a priori* planning of interactive learning and again reiterates the importance of systems builders and interactive learning to be encouraged at firm level. Ambitious local content policies may enable a more active role of local firms, and such policies should be combined with investments in public organisations for applied research and consultation that can be responsible for giving advice about establishing and operating renewable energy projects. Having the necessary resources to engage high-level international expertise on a permanent basis is crucial in this respect. A major task would be to accumulate experience from projects, to develop standards for projects, and to give advice on projects to maximise interactive learning channels and to transfer local knowledge and expertise from one project to the other.

Acknowledgment

This research is supported by the Danish Ministry of Foreign Affairs Grant DFC 14-09AAU. We are grateful to our collaborators in the Innovation and Renewable Electrification in Kenya (IREK) project and two anonymous reviewers for constructive feedback.

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