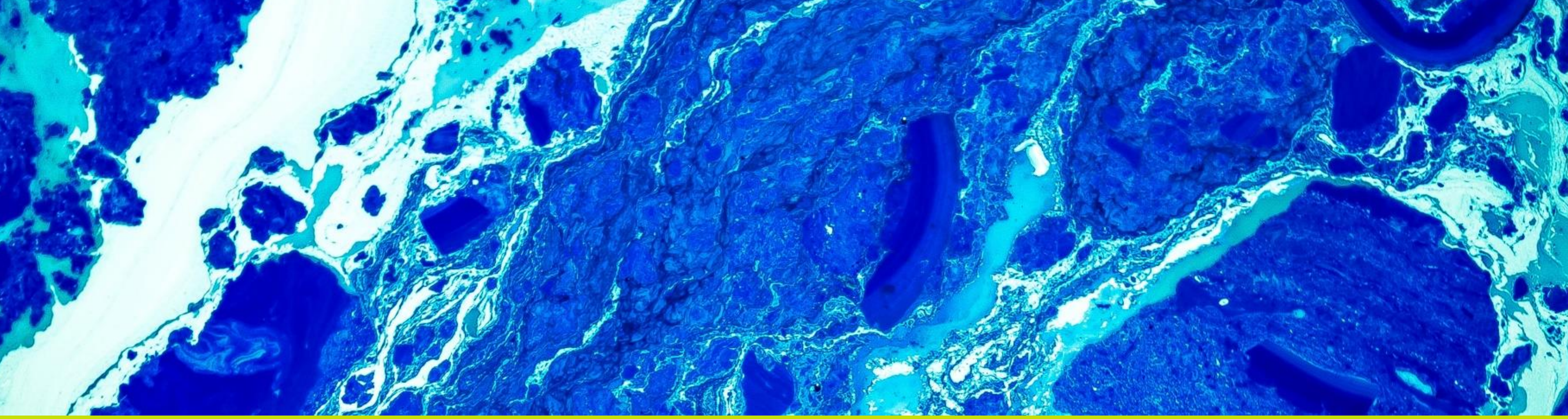


Renewable Energy Policy, Local Content Requirements and Technology Transfer: Evidence from South Africa

Benedict **Probst**, Antoine **Dechezleprêtre**

C-EENRG Working Papers, 2021-3

March 2021

UNIVERSITY OF CAMBRIDGE

CEENRG
Cambridge Centre for Environment, Energy and Natural Resource Governance

Please cite this paper as:

B. Probst, A. Dechezleprêtre, 2021, 'Renewable Energy Policy, Local Content Requirements and Technology Transfer: Evidence from South Africa'. C-EENRG Working Papers, 2021-3. pp.1-44. Cambridge Centre for Environment, Energy and Natural Resource Governance, University of Cambridge.

The Cambridge Centre for Environment, Energy and Natural Resource Governance (C-EENRG) was established in 2014 within the Department of Land Economy in order to conduct integrative research on the governance of environmental transitions, such as the climate-driven transition from a carbon-intensive inefficient energy matrix to a decarbonised and efficient one, or the water/population-driven transformation of food production systems. The role of law and governance in such transitions is of particular importance. C-EENRG approaches law as a technology to bring, guide and/or manage environment-driven societal transformations. Whereas other research groups within the University of Cambridge cover questions relating to the environment, energy and natural resources from a natural science, engineering, conservation and policy perspective, until 2014 there was no centre concentrating on the law and governance aspects of environmental transitions. C-EENRG was established to fill this gap in the policy research cycle, in line with University's strategic research initiatives on energy, conservation, global food security and public policy.

The **C-EENRG Working Papers** provide a platform to convey research aiming to support the effective governance of such environmental transitions. The series hosts research across disciplines, including law, economics, policy, and modelling, and welcomes research on a wide range of environmental topics across the food-energy-water-land nexus.

SCIENTIFIC COMMITTEE

GUIDELINES FOR AUTHORS

Submit your manuscript in *.odt, *.doc, *.docx, or *.rtf format, together with a *.pdf version. It should contain title, abstract, keywords, and contact details for the lead author. Email your file to the editor. The manuscript will be processed and sent to two reviewers. The editor will process the reviewers' feedback and request the scientific committee to adopt a final decision about the publication of the manuscript

DISCLAIMER

Benedict Probst
Cambridge Centre for Energy, Environment and Natural Resources Governance (C-EENRG),
Department of Land Economy, University of Cambridge, UK

Antoine Dechezleprêtre
London School of Economics and Political Science (LSE)
OECD

Contact:
Benedict Probst
Silver St., CB3 9EU, Darwin College, Cambridge, UK
Cambridge, UK
bsp26@cam.ac.uk

Renewable Energy Policy, Local Content Requirements and Technology Transfer: Evidence from South Africa

Benedict Probst, Antoine Dechezleprêtre

ABSTRACT

In less than a decade, South Africa has substantially changed the way it procures and generates electricity. Until 2011, its power system almost entirely relied on coal-fired power plants built and operated by the national utility Eskom. Since then, South Africa has introduced a renewable energy promotion scheme, awarding more than 6 GW (13% of total installed power capacity) to private developers, mainly in onshore wind and solar PV. The purpose of this paper is twofold: First, we analyse the impact of the renewable energy support scheme and local content requirements on technology transfer to South Africa in solar and wind energy to date. We argue that focusing on defining LCRs as project value rather than focusing on specific components, led to a localisation of down-stream value segments, such as services, rather than component manufacturing, particularly in the first two rounds. The analysis also demonstrates that limited technology transfer has taken place in component manufacturing, particularly due to the establishment of wholly-owned subsidiaries of international renewable energy manufacturers. Second, we develop a typology that allows identifying the most promising segments in renewable energy technologies to guide future localisation efforts by bringing together various existing approaches, such as economic complexity, into a coherent framework. We show that localising down-stream value segments rather than component manufacturing may be more desirable for South Africa and many late-mover countries anyway due high job creation potential and investment volumes, particularly for solar PV. In contrast, the key components of solar PV (cells and modules) and wind (nacelle, blades) exhibit high economic complexities and thereby limit the potential of late-comer countries to break into these markets.

Key words: South Africa, Local content requirements, renewable energy policy, technology transfer

1. Introduction

Accelerating the deployment of existing and novel low-carbon technologies on a global scale is critical to effectively mitigate climate change. International technology transfer has long been recognized as a critical topic in the climate change negotiations held under the auspices of the United Nations Framework Convention on Climate Change, as illustrated by the adoption of a Technology Transfer Framework in 2001, followed in 2010 by the creation of a Technology Mechanism (UNFCCC, 2019). Technology diffusion from the North to the South is particularly important, as 90% of the increase in global carbon emissions until 2050 is expected to occur in developing and emerging economies (OECD, 2012), while the vast majority of low-carbon technologies are still invented in industrialised countries and China (Dechezleprêtre *et al.*, 2011; Lam, Branstetter and Azevedo, 2017).

Although what matters from a global climate change mitigation perspective is only the widespread adoption of carbon-saving technologies such as wind turbines or solar panels at the lowest cost, the perspective of national governments, in particular in developing countries, is different: what matters is that the adoption of new low-carbon technologies comes with the transfer of the knowledge necessary to produce these technologies (IRENA, 2017a, 2017b). This ensures that developing countries do not remain dependent upon foreign technologies, that there are spillovers on local development and that domestic companies ultimately reap part of the significant market for green technologies. That localising clean technologies locally is possible is partly inspired by China's success in building a competitive domestic wind and solar PV manufacturing sector (Lewis, 2007; Binz and Anadon, 2018b), and large bodies of literature in technology innovation systems (Freeman, 1995), catching up (Lee, 2019) and related diversification (Hidalgo *et al.*, 2007), among others (Lewis, 2012; Qiu and Anadon, 2012; Nahm, 2017).

One of the most widespread and controversial mechanisms to ensure that low-carbon technologies are not simply adopted locally but that the capacity to produce them locally are also transferred, are local content requirements (LCRs) (UNCTAD, 2013). LCRs are a trade policy that sets a minimum threshold of intermediary goods used in a particular production process that need to be sourced locally (Kuntze and Moerenhout, 2012). China's progress in wind technology is partly credited to its stringent LCR in the early 2000s (Lewis, 2007). Since then a number of countries have enacted LCR, such as Saudi Arabia, Brazil and India (UNCTAD, 2013; Malek, 2019; Probst *et al.*, 2020). Yet, LCR are at odds with World Trade Organisations (WTO) rules and have led to the abolishment of LCR in countries such as India (Cimino, Hufbauer and Schott, 2014). Despite these challenges, LCR are set to become more important and a number of countries, such as Russia and Argentina, have recently introduced their own LCR policies (IEA, 2015, 2018). Legally, linking LCR to government procurement might be a way to circumvent WTO stipulations. For instance, India is planning to re-introduce LCR for solar projects developed public sectors actors (e.g., state-owned companies) for sizeable tenders of 12 GW solar PV to be developed until 2023 (Lal, 2019).

The existing literature on LCRs consists of to two main research strands. First, various studies use (ex-ante) analysis of possible impacts of LCRs using computable generable equilibrium models predicting the expected impact of LCRs using various wide range of assumptions and simplifications (Böhringer, Rutherford and Wiggle, 2012). Second, various studies analyse the legal and political aspects of LCRs, such as compliance with WTO rules (Kuntze and Moerenhout, 2013; Cimino, Hufbauer and Schott, 2014). Several studies specifically analyse South Africa, such as Matsuo and Schmidt (2019), Ettmayr and Lloyd (2017), Leigland and Eberhard (2018) and Baker and Sovacool (2017). These studies concur in their conclusion that the South African RE auction programme led to limited technology transfer for manufacturing to South Africa. Yet, Matsuo and Schmidt (2019) underscore that while RSA may not have localised manufacturing to the envisaged extent, it attracted a more varied set of downstream project developers, engineering- procurement-construction (EPC) contractors, as well as local financiers (due to PPAs being denominated in South African Rand) than comparable countries without LCRs, such as Mexico. Yet, Existing studies do not specifically highlight different technology transfer challenges (and the effects of LCR upon them) and also do not analyse the localisation and commercial potential of different value segments of wind and solar PV technologies.

In this article, we therefore attempt to fill this gap in the literature by analysing in a first step the role that renewable energy policy with LCRs played in facilitating technology transfer and the localisation of key solar PV and wind technology components in South Africa between 2011-2019, with a special focus on the different transfer channels. As there is existing research on down-stream activities (Matsuo and Schmidt, 2019), we delve into specific wind and solar components and how the LCR design has led to the localisation of which components. We specifically investigate how the LCR design, which was based on overall project value rather than on a component level (such as in India), affected the localisation of key components. We then develop a typology that allows for identifying promising value segments based on its localisation and commercial potential, building on various literatures (e.g., economic complexity) in order to guide LCR design.

Analysing the most common technology transfer channels identified in the economics literature (Keller, 2009), we find that the focus of the South African RES programme in defining LCR levels in terms of on project value rather than targeting specific components led to the localisation of downstream value segments in both technologies, as the project value-based LCR requirements led to the localisation of local services first, such as EPC, transportation, and other related services. In a second step, we show that localising down-stream value segments rather than component manufacturing may be more desirable for many late-mover countries, such as South Africa, due higher job creation potential. The key components of solar PV (cells and modules) and wind (nacelle, blades) exhibit high economic complexities and thereby limit the potential of late-comer countries to break into these markets.

The paper is structured as follows: In Section 2 we provide a theoretical background on transfer channels (2.2), local content requirements (2.3) and the composition of the value chain of onshore wind and solar PV energy technologies (2.4). In Section 3 we discuss the South African renewable power sector, with a specific focus on the auction scheme. Section 4 provides an overview of our data sources and methods. Section 5 proceeds to discuss the technology transfer that has taken place so far and outlines parts of the chain that for the future renewable energy leadership in South Africa. Section 6 concludes with policy recommendations.

2. Theoretical Background

The section provides a background on Technology Transfer Channels (2.1), Local Content Requirements (2.2) and reviews the literature on the value chain of renewable power industries, particularly solar PV and wind (2.3), which South Africa seeks to increasingly localise.

2.1. Technology Transfer Channels

The theoretical foundation of this paper rests on the economic literature on international technology transfer. Much of the initial discussion in this stream of literature sets out to explain the considerable income variations observed across the globe (Keller, 2004, 2009). Since Solow (1956), it has become widely accepted in the economic literature that technological change is crucial for productivity, which underpins economic growth (Hall and Jones, 1999; Easterly and Levine, 2001). However, relatively few countries are responsible for the majority of innovation activity, which underlines the importance of technology transfer. Keller (2004) points out that for the majority of countries, non-domestic sources of technology account for 90% and more of domestic productivity growth. The interest in technology transfer has further gathered momentum through the realisation that mitigating climate change requires concerted global action. However, analogous to global R&D expenses, only a few industrialised and emerging countries drive the development of low-carbon technologies (Dechezleprêtre *et al.*, 2011). For instance, Europe and the US alone account for around half of the global public and private R&D efforts in clean energy technology (McCrone *et al.*, 2018).

A useful heuristic to distinguish different types of technology is the distinction between codified vs. uncodified technologies (Maskus, 2004). Technologies can be codified, for instance through manuals, formulas, and patents, as well as uncodified through the acquisition of tacit knowledge of the staff, through, for instance, the adoption of the imported technology to local conditions and requirements through learning and experimentation. Another distinction that is commonly made is between embodied and disembodied technologies. Embodied knowledge, as in the form of a tangible product, can be more easily reverse engineered than disembodied knowledge, such as software, which as Maskus (2004, p.9) points out '*wears the technology on their face.*' However, disembodied knowledge, such as in the form of tacit knowledge, is more difficult to copy, but has been shown to be crucial in transferring technology (de la Tour, Glachant and Ménière, 2011). While these heuristics are useful, they often represent a false dichotomy, since many technologies display both codified and uncodified characteristics. Hence, technology transfer requires not only the transfer of technological artefacts, but also of human capacities and institutional quality to be able to understand, adapt, manufacture, deploy and maintain a certain technology. Therefore Maskus (2004; p.9) defines technology transfer as '*any process by which one party gains access to a second party's information and successfully learns and absorbs it into his production function.*'

The economic literature identifies four main channels of international technology transfer, which are used for technology transfer:

- **Trade in goods and services:** Technology can be embedded directly in goods and services, which are imported by the recipient country. The design characteristics can be reverse-engineered to get access to the underlying technology used to produce the good. In addition, technologies, such as industrial chemicals, hardened metals and software can directly be used in the production process (Maskus, 2004).
- **Foreign direct investment (FDI):** FDI refers to a party, located in one country, acquiring productive assets or establishing business operations in a foreign country. These can either be fully (subsidiary) or partly owned (joint-venture). FDI commonly exploits either higher quality or lower price advantages in the host countries. For instance, lower cost of assembling solar PV modules due to cheaper labour might motivate a company from an industrialised country to establish operations in China. The local labour force trained in the production process constitutes a technology transfer (Keller, 2009).
- **Licensing:** Licensing relates to the acquisition of production or distribution rights of a codified technology. It also includes the technical know-how to effectively exercise those rights (Lewis, 2007).
- **Movement of personnel:** This form of transfer can be either intra-firm, within one multinational, or inter-firm between different companies. This channel has been shown to be fundamental in the transfer of technology in the Chinese photovoltaic sector (de la Tour, Glachant and Ménière, 2011; Binz and Anadon, 2018a)

Firms that want to expand into a new market need to choose between different modes of entry, which has an important effect on technology transfer, since it determines the 'boundaries' of the firm and hence potential spillovers to local companies (Gandenberger et al., 2015). There is a fundamental difference, for instance, between transfers within the firm (e.g., from a mother company to a wholly-owned subsidiary) and joint ventures in terms of risk, investment and other factors important to the firm's operations. Williamson (1981) argues that particularly three factors, 1) asset specificity, 2) frequency of the transaction; and 3) uncertainty surrounding the transaction determine the cost, efficiency and choice of transfer channel. Renewable energy firms often have a very specific asset (e.g., the modular nature of wind turbines). Many markets outside the major industrialised economies, the frequency of transactions is low because of the small market size, and the uncertainty is often high due to policy insecurity. This indicates that transfers through creating wholly-owned subsidiaries in target countries – in contrast to licensing – might be a more frequent way of entry for these countries.

A pertinent question that arises is what effect LCR will have on the transfer of technology through each one of the above-mentioned channels. For instance, LCR might reduce the proportion of imported goods and increase FDI, since firms are legally obliged to increase production capacity in the local market. On the other hand, if LCR are too restrictive and the market size too small, international companies might cease to operate in the market. We now explore the literature around LCR in Section 2.2.

2.2. Local Content Requirements (LCR)

Governments are using different policies with the intention to increase the local benefits of trade and enhance technology transfer. LCR are a trade policy that sets a minimum threshold of intermediary goods used in a particularly production process that need to be sourced locally (Lewis, 2007). LCR are reviewed here, since they are particularly relevant to the South African context. While LCR largely conflict with WTO rules, they have risen in popularity in developed and developing countries (Kuntze and Moerenhout, 2013). As mentioned, while they conflict broadly with WTO stipulations, they might be legal if linked to government procurement (Kuntze and Moerenhout, 2013).

LCRs in the context of renewable energy (RE) commonly follow two approaches, either granting firms access to cheap finance (e.g., Brazil), and/or public tenders (e.g., South Africa). While governments are pursuing strategies to increase the share of RE in the energy mix, other objectives such as job creation, local industry growth and sustainable economic development feature prominently on the political agenda (Altenburg and Assmann, 2017). The cheapest option of increasing RE might not always yield the most substantial employment benefits for the host country, hence different priorities need to be ordered accordingly. However, as commonly noted in the literature, protecting industries might also harbour inefficiencies, precluding the development of a competitive edge (Melitz, 2005). Table 1 provides a comprehensive overview of common arguments for and against Local Content Requirements.

Arguments For and Against LCR

For	Against
Protecting infant industries from international competition until develop competitive advantage	Lower competition, allocative inefficiencies and international trade distortions. Local intermediary goods are commonly more expensive and/or inferior quality.
Learning spillovers (transfer of technology and technical capabilities)	Higher overall cost for downstream electricity producers
Increased political and public acceptability of more expensive renewable electricity sources	Higher cost of capital due to lacking track record of local firms
Higher local job creation and ownership	Limited job creation in medium to long-run
More manufactured exports	Increased policy uncertainty given future development of LCR

Table 1: Arguments in favour and against local content requirements (LCR) based on *Kuntze and Moerenhout (2013) and UNCTAD, (2013)*

For LCR the central challenge is to set them at an appropriate level, where the policy actually leads to localisation effects that would not have occurred without the policy while not leading to excessive increases in the cost of renewable power. If LCR lead to localisation effects that would have occurred anyway, then this just adds administrative cost to the policy. In contrast, if LCR are set too high, this might make the cost of power prohibitively expensive by increasing the difficulties of acquiring debt financing (leading to higher equity shares, which again increases the cost) and lead to substantial delays in the programme (Lewis and Wiser, 2007).

2.3. Solar PV and Wind Value Chain and Job Creation Potential

LCR are commonly defined in one of two ways: set to a specific level, which commonly refers to the proportion of cost that needs to be sourced locally, or target specific components, such as in India (Probst *et al*., 2020). Hence, it is important to analyse the composition of the value chains to understand how local content requirements apply across the two technologies – wind and solar PV – that we analyse.

The value chain in renewable power technologies can be separated broadly into manufacturing and services (Figure 1). Manufacturing can be separated into the central hardware and components related to the balance of plant (which are supportive components or systems in a power plant integral for the proper functioning). Services, in turn, can be distinguished into development, construction and Operations and Maintenance (O&M). There are a number of firms active in the different parts, ranging from component manufacturers (commonly called Original Equipment Manufacturers or OEMs), project developers, banks and insurance companies, Engineering, Procurement and Construction (EPC), transport companies and O&M firms. These, in turn, are also backed by a number of supporting actors, such as research laboratories, consultancies, and financial service providers.

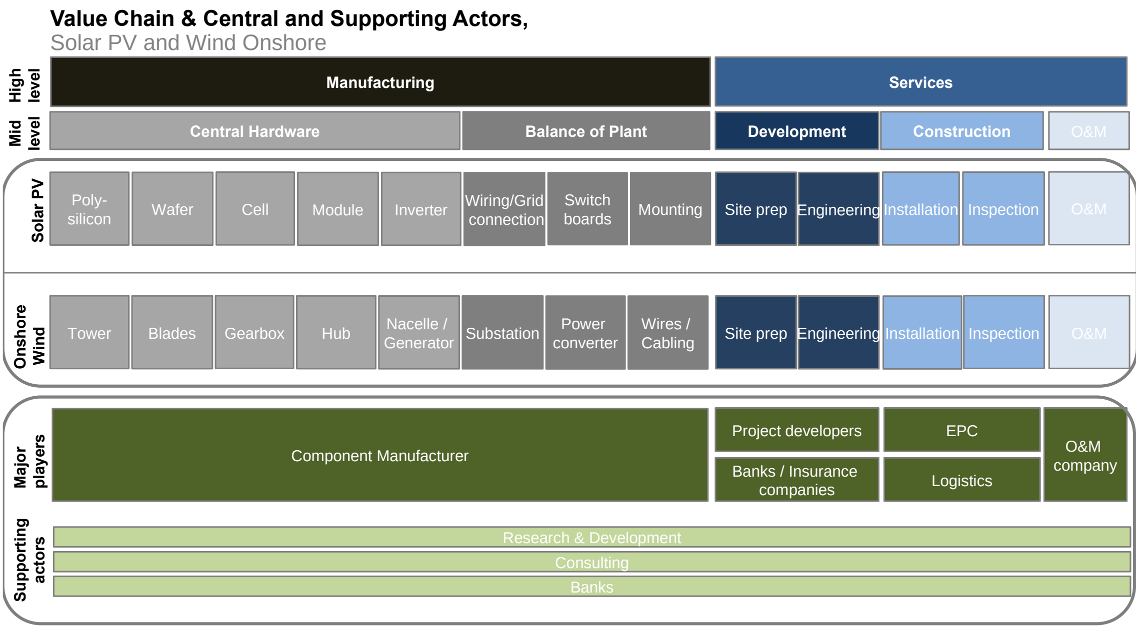


Figure 1: Value chain and central and supporting actors for solar PV and wind onshore technologies based on *EIB (2015) IRENA (2015) and IRENA (2017a, 2017b)*. The two central components of the value chain are manufacturing and services, which can be further sub-divided into central hardware and balance of plant (for manufacturing) and development, construction and Operations and Maintenance (O&M) (for services). The value chain is composed of major players (such as component manufacturers) and supporting actors (such as banks). Note: Does not include grid connection, which is commonly done by local utility / TSO.

Solar PV and wind technology supply chains exhibit complex supply structures. For instance, Surana et al. (2020) show that 13 wind technologies OEMs are supplied by hundreds of smaller suppliers that manufacture components for OEMs. These suppliers are often small and medium enterprises that supply the main wind OEMs located in Europe (e.g., Vestas), the United States (e.g., General Electric), Japan (e.g., Mitsubishi), China (e.g., Goldwind) and India (e.g., Suzlon). Using the product complexity index

(PCI), Surana et al. (2020) also show that for low-complexity components (e.g., towers and generators) it was much easier for new suppliers to break into these markets than for high complexity components (e.g., blades and gearboxes).

Figure 2 shows the cost components of utility-scale solar PV (fixed axis, crystalline silicon) and Figure 3 for onshore wind technology. These values are taken from the South African renewable programme (Ahlfeldt, 2017), but they are roughly comparable across countries (IRENA, 2017a, 2017b). The main cost component of the utility-scale solar PV in South Africa is the module, which constitutes around 43% of overall cost, followed by balance of plant expenses (29%) and services (28%).

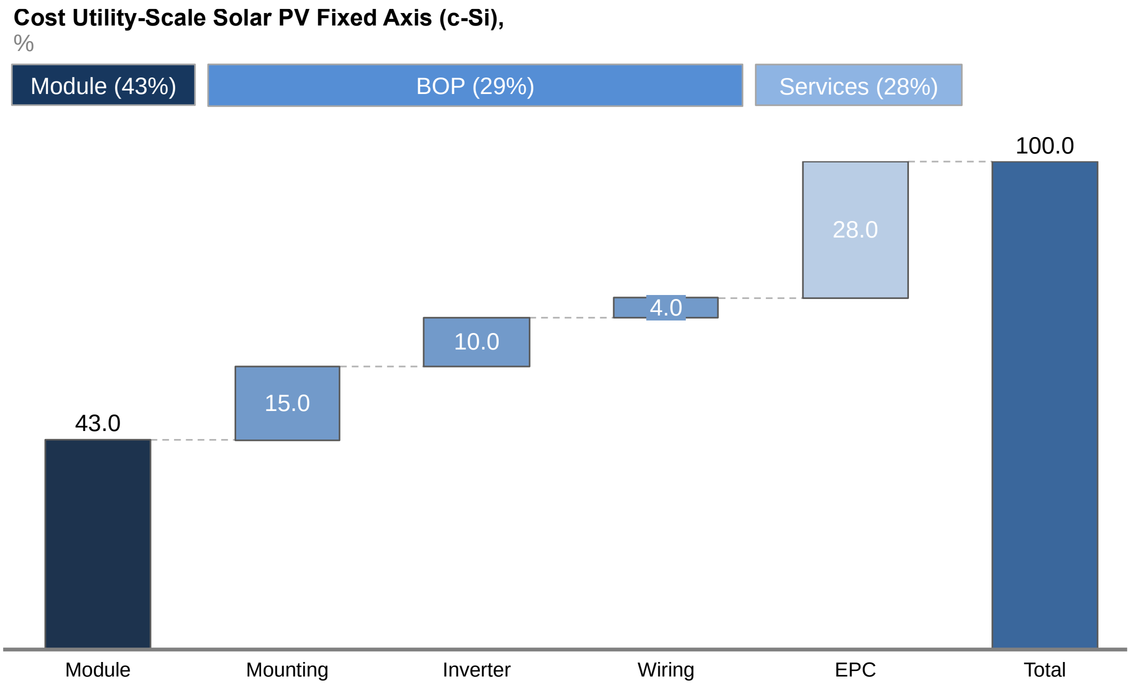


Figure 2: Proportion of investment volume for each of the three major components (Module, Balance of Plant (BOP) and Services) of an utility-scale solar PV fixed axis plant in second bidding round based on *Ahlfeldt (2017)*. Average values, might differ slightly between projects. Excludes development and financing cost.

For onshore wind, the main cost component for wind energy is the turbine (55%), which consists of the nacelle, tower and blades (and other components). Balance of Plant components, which account for auxiliary components and systems of the technology, account only for 12.5% of the cost. This is mainly electrical work. Services, in turn, play an important role in wind technology, with around 32.5% of the total cost accruing in this cost component. This includes foundation and transport and erection of the wind farm.

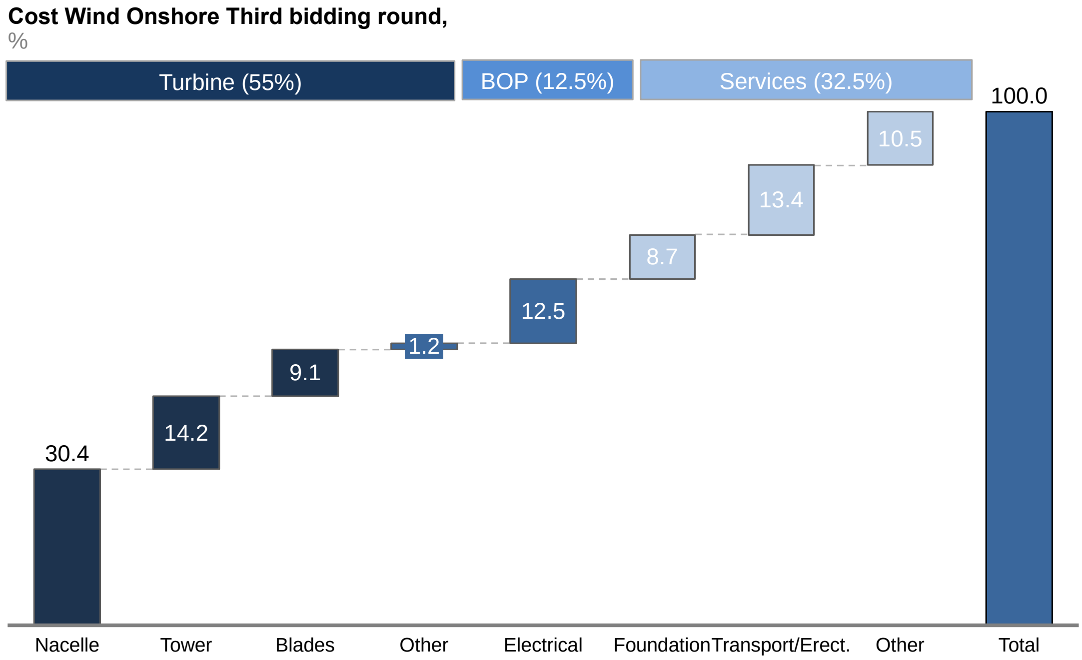


Figure 3: Proportion of investment volume for each of the three major components (Module, Balance of Plant (BOP) and Services) of a utility-scale onshore wind project in third bidding round based on *Ahlfeldt (2017)*. Average values might differ slightly between projects.

In terms of job creation potential, there are substantial differences between the technologies as indicated in Figure 4 (IRENA, 2017a, 2017b). For wind, more jobs are created in the manufacturing and procurement sector (59%), whereas for solar PV only 22% are created in that sector (Figure 4). Construction and development, in relative proportions, is also similar across both technologies. Yet, O&M is less important in relative terms for wind (24%) than for solar PV (56%).

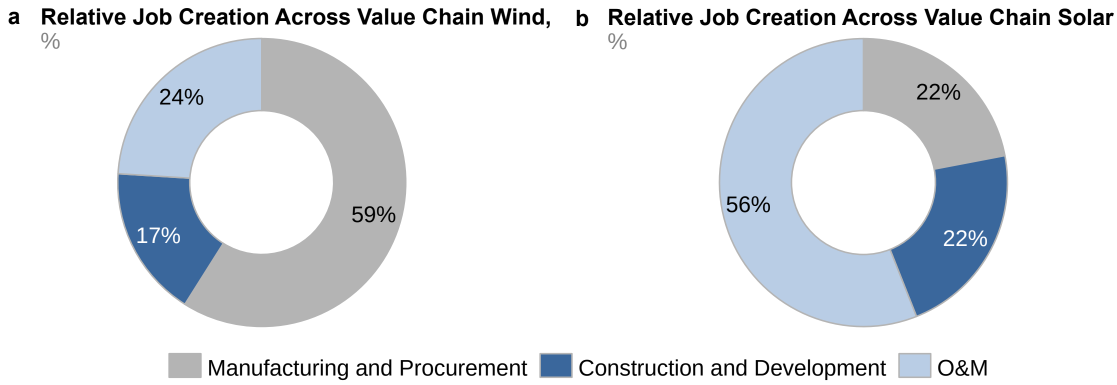


Figure 4: Relative and Absolute Job Creation in different parts of the value chain for a) solar and b) onshore wind technology based on *IRENA (2017a, 2017b)*

Two things are noticeable: First, for both technologies, services play an integral role both in investment volume and job creation potential. This is important to note as much of the debate on local content requirements is focused on component manufacturing. The role of services is slightly larger for onshore wind (and even larger for offshore wind). Second, job creation potential for solar PV is substantially higher and many more jobs are created in downstream sectors, which are commonly localised in the host countries (e.g., South Africa) and not in the country where the polysilicon, cells and modules and manufactured (e.g., China). In contrast, for onshore wind, most jobs are created in manufacturing and procurement, which are typically the most complex parts of the value chain. Wind turbines are mostly produced by highly specialised workers and firms located in industrialised countries.

3. Renewable Energy in South Africa

This section provides an overview of the developments in the renewable energy sector and LCR in South Africa.

3.1. Renewable Energy Auctions in South Africa

South Africa's energy production relies predominantly on cheap and locally abundant coal, accounting for 77% of primary energy use and more than 80% of its electricity (Baker, Newell and Phillips, 2014). The state-owned monopolistic utility Eskom provides electricity at one of the lowest rates in the world. This has led to the creation of energy-intensive industry clusters, such as mining companies, with little regard to energy efficiency (Winkler and Marquand, 2009). Between 1990-2014, South Africa featured higher CO2-emissions per capita than China, India and Brazil, albeit China is set to overtake South Africa (Korsbakken, Andrew and Peters, 2019).

The Department of Energy (DoE) is responsible for planning the future expansion of electricity generation, with the current period set out in the Integrated Resource Plan (IRP) 2012-2030. Former President Zuma's surprising pledge at COP15 in Copenhagen, as a Non-Annex I country, to reduce CO2-emissions by 34% by 2020 compared to a business as usual pathway serves as the target for the IRP. The latest draft of the IRP approved by parliament in 2019 envisages that 26.3 GW of new renewable power generation be added by 2030 (which includes delayed projects from Round 3.5 and 4, where Eskom refused to sign Power Purchase Agreements, which are long-term contracts to purchase electricity at given price). This represents a fundamental break from the past, as a growing share of electricity is being generated not by the state utility from coal but by private firms from renewable energy sources.[1]

As Figure 5 illustrates, the IRP (2019) envisages that by 2030 the coal-based generation capacity falls substantially from 39.1 GW to 33.8 GW, as many of Eskom's coal-fired power plants are nearing age-related decommissioning. New gas power plants will be added to the power system, which are a good complement for fluctuating renewable power sources given quick ramp-up times. In contrast to the previous version of the IRP, no new nuclear capacity will be built. The former plan to build additional 9.6 GW of nuclear has come under attack for high costs, low transparency and allegations of corruption (Campbell, 2018). Wind capacity is set to increase substantially from 2.0 GW to 17.7 GW and solar is set to increase from 1.5 GW to 8.7 GW. The IRP also includes a deal with the Democratic Republic of Congo to import electricity generated through the Inga hydropower plants. This is where the additional hydro capacity that can be observed from 2018-2030 (Figure 5a) comes from: no new capacity will be built locally in South Africa.

[1] There are, however, tenders envisaged for private firms to generate electricity from fossil fuels. See, for instance, the small IPP coal tender (IPP, 2017).

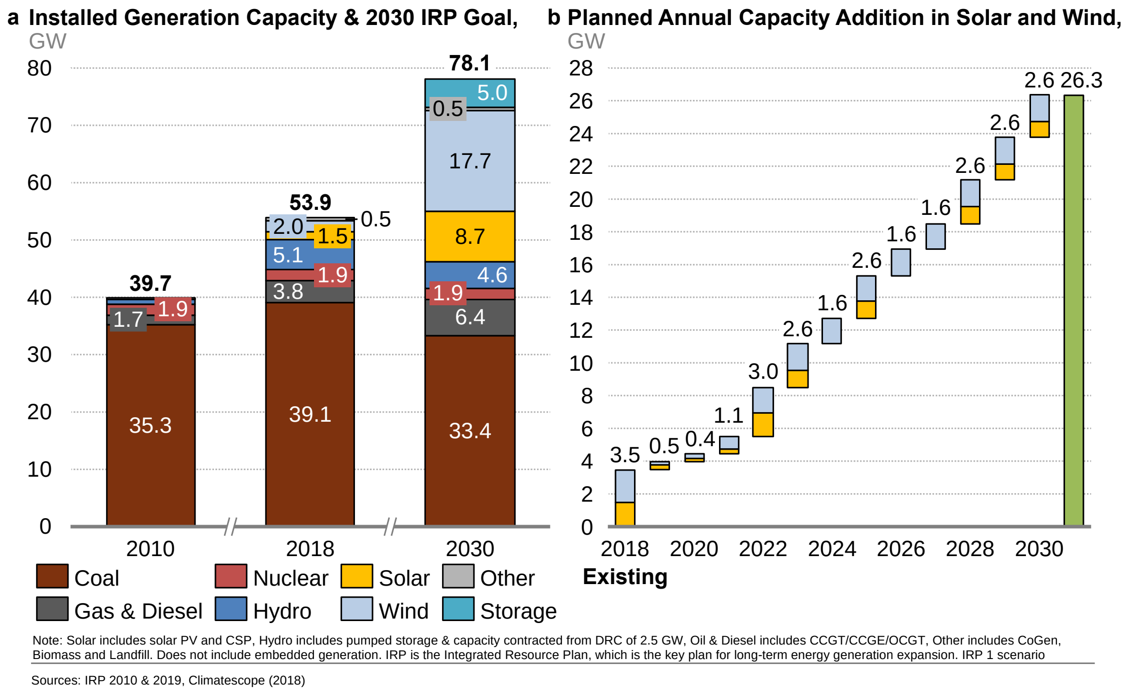


Figure 5: Current and planned installed generation capacity in South Africa.a) Current installed generation capacity and the goal of the Integrated Resource Plan (IRP) for b) 2030 and annual addition in renewable power generation envisaged in the IRP (2019). Existing values for 2018 include delayed and recently signed 27 projects in solar PV and wind. Solar includes solar PV and CSP, Hydro includes pumped storage & capacity contracted from DRC of 2.5 GW, Oil & Diesel includes CCGT/CCGE/OCGT, Other includes CoGen, Biomass and Landfill. Does not include embedded generation.

The IRP 2018 – which was never approved by parliament – had planned to introduce substantial capacity expansion for renewable power generation only from 2025 onwards. Yet, it became clear that the stop-and-go nature of the auction schemes, postponing the bulk of new renewable power generation expansion to the mid-2020s, would further lower investors' confidence and is unlikely to kick-start new developments in the industry. The IRP 2019 therefore creates stable build-out targets, with yearly additions ranging from 400 MW to 2.6 GW annually.

South Africa is endowed with excellent renewable resources, featuring high wind speeds and solar radiation (DoE, 2015). While there had been high-level political support for renewable energy for a considerable time, the power shortages in 2007-2008 added new momentum to the debate. This started to materialise beginning in 2009 with a fixed Feed-in Tariff (FIT) program, which did not add a single megawatt to the grid due to legal, institutional and technical shortcomings (Baker, Newell and Phillips, 2014). Hence, in 2011 a competitive tender system was introduced with greater political independence and the support of local and international experts.

Between 2011 and 2015, the IPP-office, operating at arm's length of the Department of Energy, awarded 92 projects to private power producers, with 63 RE power plants already being operational. These projects will ultimately have a capacity of more than 6 GW, representing roughly 13% of current installed capacities (DoE, 2019). By early 2019, 1.9 GW of solar (including CSP and solar PV) and 2.0 GW of onshore wind were online. During periods of high demand, renewable power is already filling important gaps and saving cost. During severe load shedding in 2014, Bischof-Niemz (2015) estimated that solar PV and wind saved ZAR 3.7 billion (around USD 270 million) by offsetting costly open-cycle gas turbines.

In only three years (2011-2014), the average tariff for solar PV has decreased by 83% from 3.65 R/kWh in 2011 to 0.62 R/kWh in 2015 (Figure 6a). Similarly, the cost of wind power has decreased by 59% from 1.51 R/kWh to 0.62 R/kWh over the same period of time. Both technologies are now 40% less expensive than the LCOE for baseload coal, which costs 1.05-1.16 R/kWh, and nuclear, which costs R/kWh 1.17-1.30. Comparing the auctions results to other countries in 2015 shows that South Africa achieved very low bid prices, even cheaper than India and Brazil (Figure 6b).

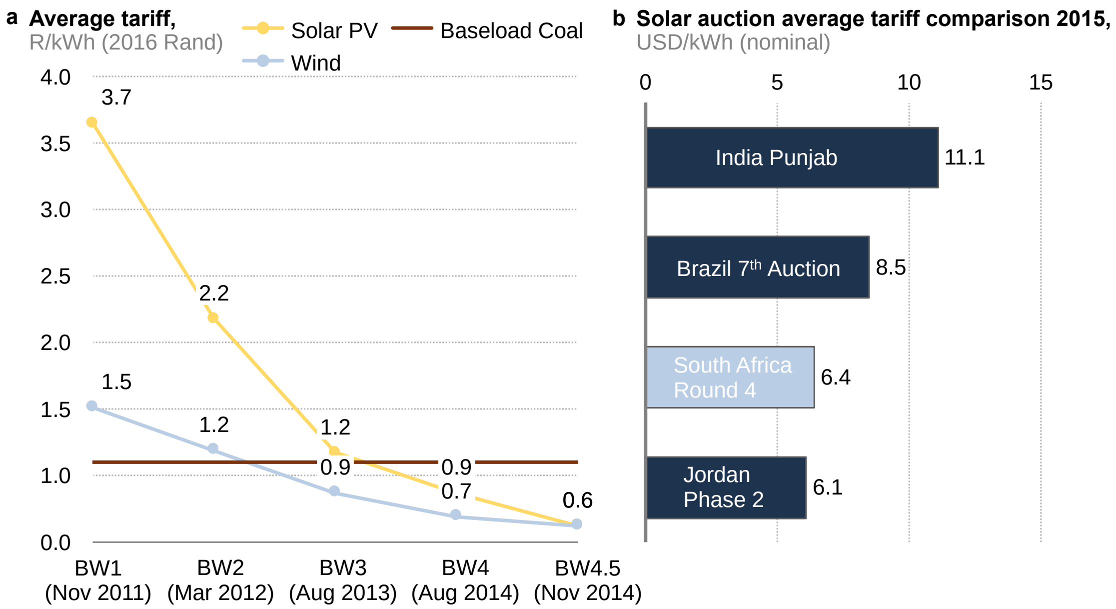


Figure 6: Average tariff bid across the four main auction rounds (a) and solar auction average tariff in 2015 from other countries in comparison to South Africa (b) based on *Bischof-Niemz and Fourie (2016)* and *Dobrotkova, Surana and Audinet (2018)*. Red bars include variation between coal baseload price from IPPs (1.03 R/kWh) and average Eskom fleet. Does not include Mid-merit Coal, which is substantially more expensive (~1.51 R/kWh). Exchange rate 1st of April, 2016; 1 USD = 14.1866 R. Round 3.5 excluded since CSP-only auction. All auction results from 2015. Bid Window 4.5 refers to expedited bid window.

3.2. Local Content Requirements in the South African Renewable Energy Auctions

The programme management selects bids of private renewable energy firms on two principle factors: price (70%) and economic development considerations (30%). The latter includes LCR, which account for 7.5% of total bid value. While this might not seem to be very high, not complying with minimum LCR leads to exclusion as selection process takes place in two steps: First, projects are screened whether they fulfil these minimum requirements. Second, the remaining projects are ranked in terms of price and economic development considerations. Subsequently, IPPs that won contracts enter into a power purchase agreement (PPA) with Eskom, which runs for 20 years.

Figure 7 shows the minimum, target and average bid for wind (Figure 7a) and solar (Figure 7b). Minimum local content has increased from 25% for wind and 35% for solar in bid window 1 to respectively 40% and 45% in bid window 3/4. As can be seen from Figure 7, solar PV managed to increase local content substantially across the rounds, reaching 62.3% in window 4. In contrast, onshore wind struggled to increase local content further than the 48.1% achieved in window 2, and local content actually feel in windows 3 and 4.

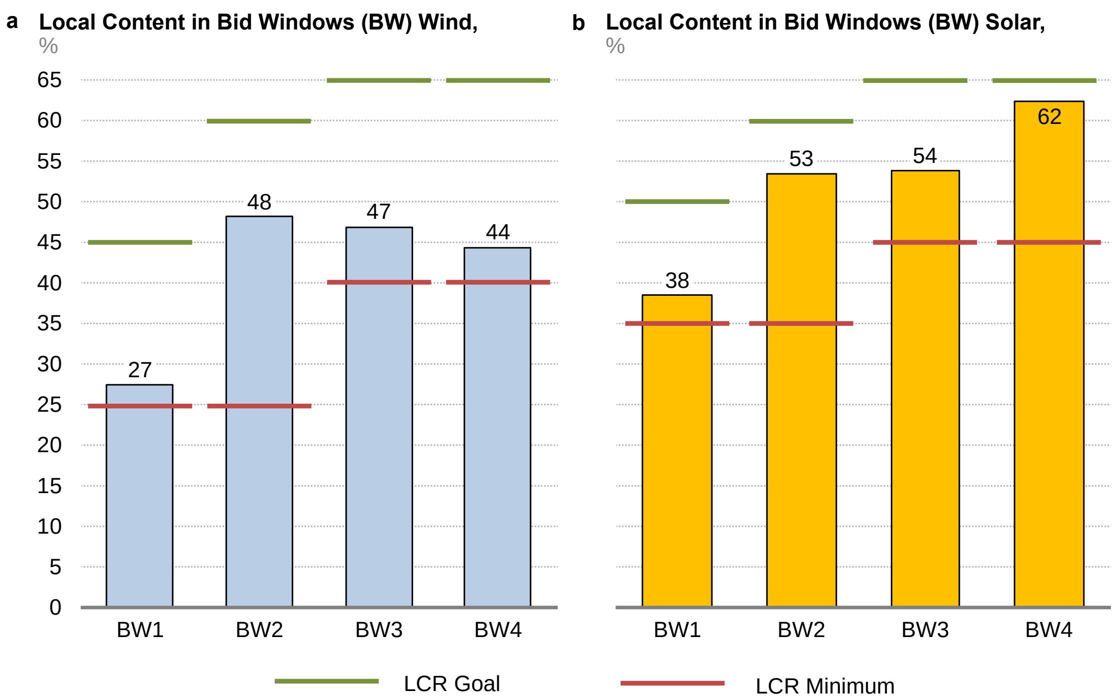


Figure 7: Local Content Requirements (LCR) minimum requirement, goal and actual achieved LCR results across different bid windows (BW for wind (a) and solar (b) based

on *Eberhard* et al. *(2016)*. Omitted bid window 3.5 (only CSP) and combined bid window 4 and 4.5 for simplicity sake.

4. Data and methods

This section provides an overview of our data and methods that we use in our empirical analysis. We set out to investigate two distinct questions. First, to what extent has the renewable energy auction scheme (coupled with LCRs) led to technology transfer in solar PV and wind energy technologies and local innovation? Second, what are the main components in these two technologies that provide the most substantial benefit in terms of localisation and commercial potential in the future? How we address these questions is answered below.

4.1. Data

In order to investigate whether the renewable energy auctions coupled with LCRs led to technology transfer we rely on the following data sources:

Quantitative data was compiled from several sources. Trade data was gathered from the United Nations COMTRADE (2016) database from 2001-2019. Commodities were identified using the Harmonized Commodity Description and Coding System, which provides international uniform codes for product identification (UNEP, 2014). We used commodity codes *854140*[2] for solar and *850231*[3] for wind. FDI data was collected from Climatescope (2018), which relies on Bloomberg New Energy Finance data, to evaluate countries on their investment environment for clean energy. This data contains disclosed asset finance for projects larger than 1.5 MW, which is suitable to our needs because we study utility-scale solar and wind energy investments with project sizes ranging between 5-140 MW. Yet, the data may underestimate project finance for residential solar and small-scale wind projects.

We directly use data from the South African patent office Companies and Intellectual Property Commission (CIPC, 2019). CIPC contains information on the first registration of patents in South Africa, which allows tracking patent flows across countries. Patent data was collected using IPC codes H10L and H20N for solar PV and F03D for wind energy patents. Our final hand-curated wind patent database contains 231 entries, whereas the solar PV patents contain 171 patents spanning 1982-2015. We

[2] The HS code specifies this as "Photosensitive semiconductor devices, including photovoltaic cells whether or not assembled in modules or made up into panels, Light emitting diodes" (EIS, 2019; p.1).
[3] Defined as "Electric generating sets; wind-powered, (excluding those with spark-ignition or compression-ignition internal combustion piston engines)" (COMTRADE, 2019a; p.1).

omit the 2017-2019 due to truncation issues common in patent data, as it takes 2-3 years for a patent to go from first filing to publication.

Qualitative data was collected via semi-structured interviews between 2016-2019. Interviewees represent a wide variety of perspectives on the subject, covering local ministries, academics, investors, solar PV and wind turbine manufacturers, and international organisations. Of the 17 interviews, one took place in London, two by phone, seven in South Africa and the rest via Skype. The interviews had an average length of 47 minutes. An anonymised interview list can be found in the Supplementary Information.

Transfer Channel	**Data**
Trade in goods and services	UN COMTRADE Database
Foreign Direct Investment	Climatescope and Bloomberg New Energy Finance
Licensing	Interview data
Movement of personnel	Interview data

Table 2: Technology transfer channels and relevant data. Source: author

In order to investigate the second question – the localisation and commercial potential of different parts of the value chain for wind and solar PV –, we rely on a number of data sources from IRENA (2017a, 2017b, 2018), IEA (2020), Hausman et al (2013) and Surana et al (2013).

4.2. Methods

For this article, we used a mixed methods approach, combining qualitative and quantitative evidence (Clark and Creswell (2006). We use the sequential explanatory design described in detail in Creswell (2003) in which we use qualitative interview data for enhance and complement findings from the quantitative analysis.

In order to investigate whether the renewable energy auctions coupled with LCRs led to technology transfer we rely on the following methods:

On the quantitative side, we analyse descriptive statistics of foreign direct investment and trade data. We also examine solar PV (codes: H10L and H20N) and wind (code: F03D) energy patent filings in South Africa from domestic and international inventors to see whether local innovation has changed substantially since the start of the programme. We compile this data from the South African patent office. Our final dataset contains 171 solar PV patents and 231 wind energy patents. Trade and FDI have been shown to be associated with patent filings originating from the source country, as both of these channels might convey some codified knowledge that can be protected by intellectual property rights (Smith, 2001)

We complement the quantitative data with interviews. We interviewed 17 major players in the South African energy space (interview list in the SI), including investors, academics, major solar PV and wind manufacturers, employees from the relevant ministries, and international organisations. We complement these interviews, with quantitative evidence on trade, FDI, and other relevant channels.

As discussed in Section 2.1, there are a number of different transfer channels through which both codified and non-codified technologies are transferred. Hence, merely relying on tracking trade statistics and other quantifiable measures of technology transfer is likely to overlook certain parts of technology transfer that cannot be readily quantified, such as tacit knowledge transferred through increased labour mobility[4].

On the qualitative side, we thus employ a semi-structured interview-method, with part of the questions previously determined while others developed within the natural flux of the interviews. This structure allows ensuring a common ground between interviews, whilst allowing for a certain degree of flexibility in case of interesting digressions from the interview script. It also allows us to analyse questions surrounding the licensing of technologies from Western companies to South African firms, as we do not have data available on this question. It also provides insights into the movement of personnel across borders.

To investigate which parts of the value chain seems most promising in terms of localisation and commercial potential in the future, we progress in several steps. To gauge localisation attractiveness, we calculate the likely investment volumes in South Africa considering expected deployment under the IRP (2019) targets and learning rate data from IRENA (2018). As not only investments are an important consideration for policy makers, we also estimate job creation potential based on the investment volumes, using estimates from IRENA (2017a, 2017b). To estimate commercial attractiveness of both wind and solar technologies, we use investment projection from the IEA to compute the expected global market until 2030. We use expected global market estimates from IEA (2020) *Stated Policy Scenario*, which relies on currently stated government policies to project future renewables build-out. We rely on this rather conservative scenario, which represents the lower bound of future buildout, not to overestimate the market potential. As Surana et al (2020) show for wind power technologies, higher technology complexity leads to less supply chain diversification, indicating that technological complexity is a key market barrier. We rely on the Atlas of Economic Complexity, developed by Hausmann et al (2013), as well as Surana et al (2013), to gauge the technological complexity of components. All inputs to the index are normalised to between 0-1 (see Figure 8 and the appendix for more details). We compute the mean localisation attractiveness by averaging I_k and J_k, but multiply G_k and $M_{p,p'}^{P}$ to compute the commercial attractiveness score, because for the commercial score the market barriers are a crucial limiting factor for firms to enter a global market (i.e., simply put, this means

[4] While this can be measured in principle, accurate data on this is commonly not available.

that even a large global market is worth zero for late comer firms if the market barriers are extremely high).

Prioritisation of renewable power value segment			
Localisation attractiveness		Commercial attractiveness	
Domestic investment	Domestic job creation potential	Global market	Market barriers
Investment based on capital and operating expenditure estimates as well as learning rates from IRENA (2018)	Based on estimates from a meta-study reviewing the jobs created per MW installed (IRENA, 2017a, 2017b)	Current (2020) and expected (2030) overall global market of the respective technologies from IEA (2020)	Market barriers based on product complexity index (Hausman et al., 2013)
$I_k = \sum_{t=2018}^{2030} (C_{tk} * I_{tk})$ where *C* is the newly expected installed capacity p.a. in the IRP (2019) and *I* investment per MW. *t* indexes the time and k the technology (solar PV, wind)	$J_k = \sum_{t=2018}^{2030} (C_{tk} * J_{tk})$ where *C* is the expected newly installed capacity in the IRP (2019) and *I* investment per MW. *t* indexes the time and k the technology (solar PV, wind)	$G_k = \sum_{t=2018}^{2030} (G_{tk} * I_{tk})$ where *G* is the expected newly installed capacity p.a. globally and *I* investment per MW. *t* indexes the time and k the technology (solar PV, wind)	$\tilde{M}^{P}_{p,p'} = \sum_{c} \frac{M_{cp} M_{cp'}}{k_{c,} k_{p,0}}$ which is computed by estimating the average diversity of countries that make a certain product and the mean ubiquity of the other products these countries make

Figure 8: Approach to evaluate the localisation and commercial attractiveness of renewable power value segments. Source: Author

5. Results

In this section we describe the results from our qualitative and quantitative analysis. We first discuss the technology transfer that took place in South Africa from 2011-2019 (5.1). We analyse the four main channels from least common to most common and whether the transfer channels have led to local innovation (5.1.5), examining patents filed in South Africa and compile qualitative evidence on other technology transfer (R&D investments & upgrades). Lastly, we analyse the future of the South African renewable industry (5.1.7) by assessing the localisation and commercial potential of different parts of the wind and solar PV value chain.

5.1. Technology transfer to South Africa, 2011-2019

5.1.1. Licensing

Lewis (2007) showed that licensing played a major role in the acquisition of Chinese and Indian wind manufacturers of foreign technology. For instance, Indian wind energy manufacturer Suzlon entered into various licensing agreements with German companies, such as Südwind (Lewis, 2007), which received royalties for each turbine that Suzlon sold over a predetermined period. Yet, in the context of the South African renewable energy programme, interviewees underscored that licensing has not been a major entry channel to South Africa. An interviewee from a large European wind manufacturer stated that this has little to do with the risk of being copied by South African firms; this risk is far more prevalent in Asia. It rather has to do with bad experiences in other Africans countries, such as Namibia, where deadlines could not be met and the quality was subpar. In addition, there were no domestic counterparts – apart from one or two exceptions – to which the technology could have been licensed, particularly in wind.

5.1.2. Labour mobility

Several studies show that labour mobility has been a key transfer channel of foreign technological and managerial skills to China (Binz and Anadon, 2018). For instance, De La Tour *et al.* (2011) report that 61% of China's largest solar PV firms have worked or studied abroad, such as the CEO of Suntech or Yingli. As there is only one South African original equipment manufacturer (OEMs) that supply integral parts of the two technologies, this transfer channel has not (yet) reached the same importance as in China. Yet, the effect of movement of personnel is pronounced in downstream activities, such as project development, where most South African firms are active. For instance, 50% of the major project developer Group Five's management board received at least one degree from a University abroad, such as its CEO Thabo Kgogo, who received a PhD from Imperial College, UK (G5, 2019). Similarly, for other major developers, such as Mulilo and Murray & Roberts, more than half of its management board report experience abroad.

5.1.3. Foreign Direct Investment

Foreign firms can enter a market by directly building or purchasing productive assets, such as manufacturing plants. These can be partly (joint-venture) or fully owned (so-called wholly owned subsidiary). Empirical studies show that FDI is commonly associated with transfer of technological, managerial, and other important knowledge (Branstetter, 2006; Keller, 2009). Yet, evidence appears to be stronger for joint ventures than for wholly owned subsidiaries, which appear to allow for lower knowledge spillovers (Keller, 2009). Figure 9 shows the uptick in FDI in 2012 for the first four rounds of the auction programme, which levels off in 2016 and 2017 due to the delays in the programme. FDI flowed primarily into down-stream activities (e.g., towers, foundations for wind and services for solar) in the first two rounds, but with increasing LCR levels led to investment in assembly plants for solar PV and tower manufacturing for wind (see Table 3).

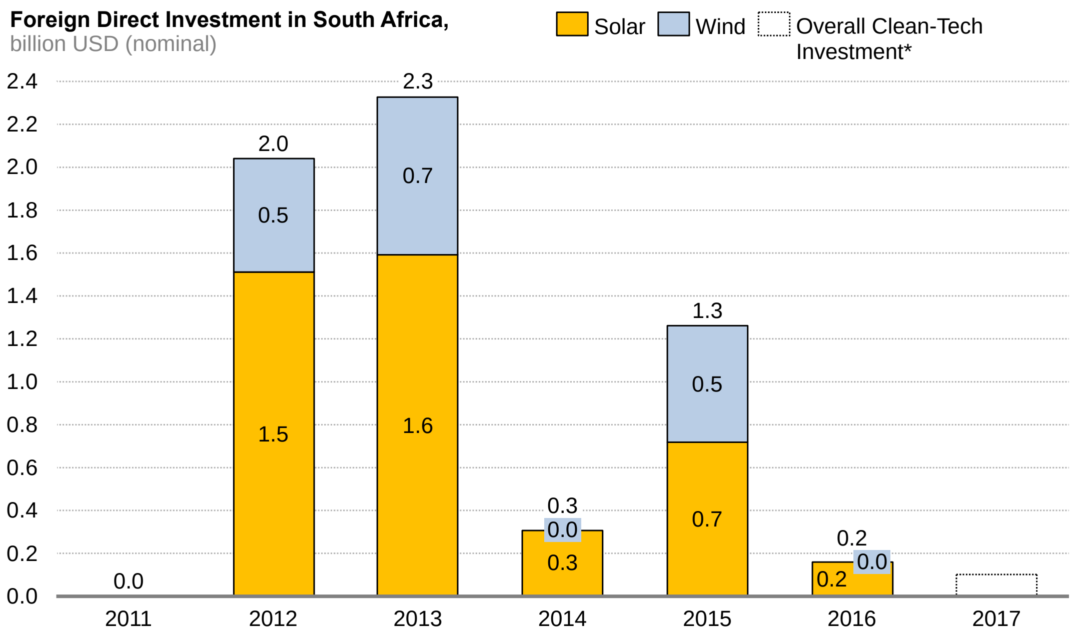


Figure 9: Investment per in USD billion per year in South Africa in RE compiled from Climatescope (2018) and McCrone et al. (2018). FDI figures for 2017 are unclear. Overall, USD 102 million was invested in clean-technologies in South Africa as reported by McCrone et al. (2018) but unclear whether FDI or from local sources.

Detailed BNEF data on FDI financial transactions shows that several major solar PV manufacturers have opened plants in South Africa (Table 3). Three companies from China – Jinko Solar, Powerway, and ZNShine – established plants in 2014 in South Africa, and continue to be operational. Solaire Direct – a French company that had been active in South Africa previous to the programme – even extended its operation. South Africa similarly attracted major PV inverter manufacturers, which all became operational in 2014. These include German company SMA, Swiss ABB and Luxembourg-Dutch AEG.

The delay (2016-2019) in the renewables programme led to the close of the SMA PV-inverter in 2016, only two years after it opened its doors in Cape Town, Western Cape. Yet, despite these delays, Chinese Seraphim and Spanish ILB Helios have recently announced a joint venture, backed by the South African Industrial Development Cooperation (IDC), a state-owned development finance institution to support industrialisation. The new solar PV module manufacturing facility was built in East London, Eastern Cape and will be capable of producing 300 MW worth of solar PV panels each year.

The FDI in the South African wind sector has been lower. The Spanish metal manufacturer Gestamp opened a wind tower facility in South Africa in 2014. At the same time, the South African steelmaker DCD also ventured into tower manufacturing, supported by major European wind OEMs, such as Vestas. However, due to delays in the programme, DCD needed to file for bankruptcy in 2019.

Firm	**Type**	**Status / Year**	**Home Country**	**Location**
International solar PV manufacturers				
Seraphim & ILB Helios	PV module assembly/ manufacturing	Operational (2018)	China & Spain	East London, Eastern Cape
Jinko Solar	PV module assembly/ manufacturing	Operational (2014)	China	Cape Town, Western Cape
Powerway	PV module assembly/ manufacturing	Operational (2014)	China	Port Elizabeth, Eastern Cape
ZNShine	PV module assembly/ manufacturing	Operational (2014)	China	Cape Town, Western Cape
Solaire Direct	PV module assembly/ manufacturing	Operational (2014)	France	Cape Town, Western Cape
SMA	PV inverter	Operational (2014) – Closed (2016)	Germany	Cape Town, Western Cape
ABB	PV inverter	Operational (2014)	Switzerland	Johannesburg, Gauteng
AEG	PV inverter	Operational (2014)	Luxemburg / Netherlands	Cape Town, South Africa
International wind energy manufacturers				
Gestamp	Tower Manufacturer	Operational (2014)	Spanish	Cape Town, South Africa
DCD (with support from Vestas and Nordex)	Tower Manufacturer	Operational (2014) – Closed (2019)	South Africa	Port Elizabeth, Eastern Cape

Table 3: International solar PV and wind manufacturers active in South Africa since the introduction of the RE auctions. Source: author, based on Bloomberg New Energy Finance (BNEF, 2019) investment data.

5.1.4. Trade in manufactured equipment

All interviewees underscored that the main entry channel for the equipment manufacturers active in South Africa were imports to its wholly owned subsidiaries. The uptick in imports is clearly visible in the trade statistics (Figure 10). The delay noticeable in the data between the first bid window in November 2011 and the substantial uptick in imports in 2014 stems from the nature of the auction process. For the first bid round, in November 2011 bids were received, preferred bidders were announced in December 2011, financial close (signing of contracts) took place between June and November 2012 and the actual commercial operation date was between June and December 2014. Hence, it typically took around 9-12 months from the bids to financial close, and 24-30 months to the opening of the plants (Eberhard and Naude, 2017).

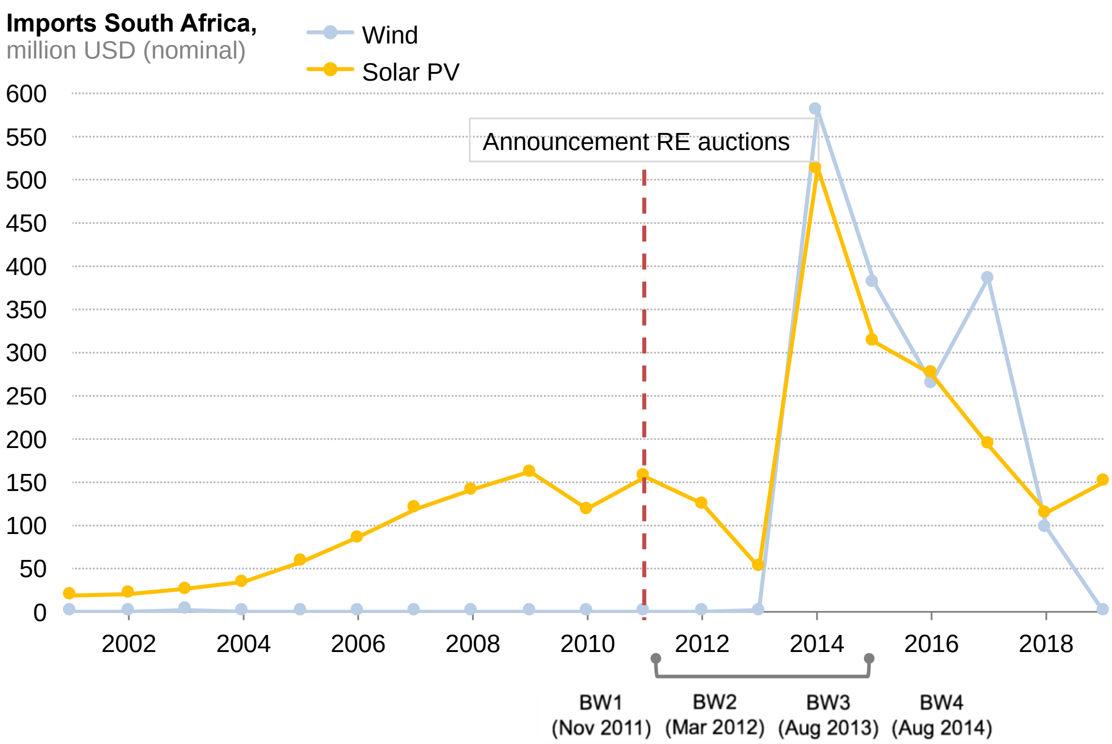


Figure 10: South African solar PV and wind energy imports in USD million p.a. (nominal) from 2001-2019 based on *COMTRADE (2019)*. Note: Trade statistics for 2019 up to September 2019.

5.1.5. South African patenting

Trade and FDI have been shown to be associated with patent filings originating from the source country, as both of these channels might convey some codified knowledge that can be protected by intellectual property rights (Smith, 2001). Given that trade and FDI are the main entry modes of major international RE equipment manufacturers into South Africa, we now analyse patenting activity in wind and solar technology at the South African intellectual property office.

As can be seen from Figure 11 patent filings at the South African patent office CIPC started to rise with the announcement of the feed-in tariff in 2007/2008. Particularly international inventors – mainly from the US, major European countries, and China – likely intended to protect their inventions in the newly developing South African market. This led to a substantial increase between 2007-2010, and further grew from 2010/11 onwards, as the renewable energy auction scheme was introduced. South African invention remained relatively unaffected by the scheme, ranging between 0-3 patent filings annually in the technologies.

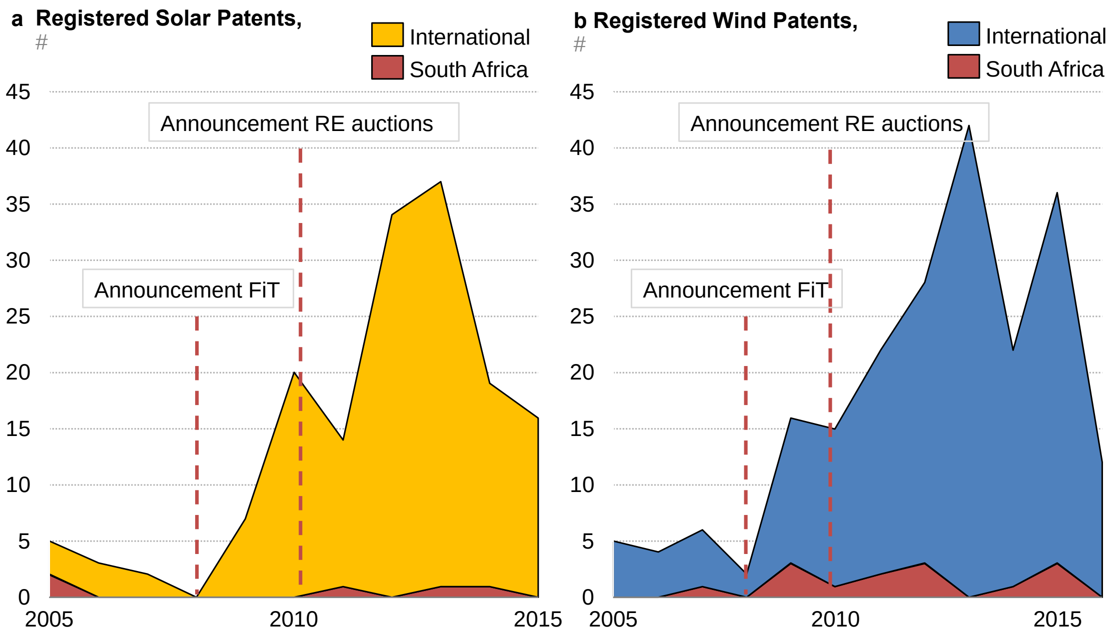


Figure 11: Registered solar and wind patents from 2005-2015 in South Africa. Based on South African patent office. 2015-2019 omitted due to delays in patenting.

The apparent lack of an effect of the renewable energy programme on locally-invented patents in South Africa might not be that surprising, as locally induced innovation might require a longer time period to materialise than the short lags observed in industrialised countries (Calel and Dechezlepretre, 2012) and in other emerging economies, such as China and India (Lewis and Wiser, 2007). While past research has indicated that inventors respond quickly to changes in market conditions (Calel and Dechezleprêtre, 2016), the programme might primarily have induced domestic public and private R&D efforts, which have not (yet) led to patentable innovation.

Yet, interviewees indicated that private R&D efforts remain limited, particularly because no local original equipment manufacturer is active in either technology and R&D activities are rather concentrated at universities. Yet, as a response to the programme, skills development centres, such as the South African Renewable Energy Technology Centre (SARETEC), has been introduced in South Africa. SARETEC is the first national training centre, located at the Cape Peninsula University of Technology (CPUT), which provides industry-related training in wind, solar PV and energy efficiency. For instance, it offers a certified wind turbine technician courses (SARETEC, 2019).

Overall, it becomes evident from Figure 9, 10 and 11 that foreign patent registrations occurred first, followed by FDI and then by the imports of manufactured goods. Foreign patent registrations started increasing from the first announcement of the renewable support scheme onwards. This increase can likely be explained by foreign patentees expecting an increase in the overall market volume of wind and solar technologies in South Africa, thereby making their patents more valuable in the South African market. The increase in patenting was followed by a hike in FDI, which came in the year after the RES auction scheme was announced in 2011. One year later imports starting to flow into South Africa. The patent-FDI-import link suggests that patent registration are the easiest and first step for foreign firms, whereas FDI in downstream sector is then followed by the import of more complex components, such as blades for wind and cells for solar PV.

5.1.6. The role of LCRs on technology transfer channels in wind and solar PV

We next turn to the question how LCRs affected the relevant transfer channels. Interviewees stressed that during the first round of the auction scheme – with LCRs of 25% for wind and 35% for solar – LCRs were not binding. This non-binding nature of the LCRs means that even without LCRs a similar proportion of the value would have been localised. For instance, roads construction for wind and solar projects, or classical transport work, would have been done by South African firms anyway, as several world-leading infrastructure firms operate in South Africa.

Yet, returning to the investment proportions per component introduced in Figure 2 and 3, requirements of 40% and 45% for wind and solar PV, respectively, could not have been reached without a greater localisation of key parts of the technologies, such as wind turbine towers and solar PV inverters. It is likely that these components would have otherwise been imported, thereby LCRs diverted technology flows from trade towards FDI, as several firms set up local assembly and manufacturing plants (Table 3). Yet, LCRs did not have a noticeable effect on licensing or movement of personnel.

The main transfer channels, our main findings, and the effect of LCRs on these channels is summarised in Table 4.

Transfer Channel	Main Finding	Effect of LCRs
Trade in goods and services	▪ Next to FDI, trade in goods was the most important entry channel of international renewable energy manufacturers	Reduction in the trade of goods towards greater local procurement in rounds 3-4
Foreign Direct Investment	▪ FDI is an important entry channel, as manufacturers created wholly owned subsidiaries locally ▪ Manufacturer Jinko Solar and inverter company SMA build local manufacturing facilities; Gestamp and DCD build wind tower manufacturing plants	Increase in FDI in round 3-4 (at expense of imports) to meet high LCRs in wind and solar
Licensing	▪ In contrast to China and India (Lewis, 2007), licensing has not played a major role in technology transfer due to negative experiences in other SSA countries as several manufacturers indicated in interviews	No or limited effect due to no specific requirements in LCRs
Movement in personnel	Movement of personnel is an important channel, but likely not as important as in other emerging countries, such as China (de la Tour, Glachant and Ménière, 2011; Binz and Anadon, 2018b).	Effect unclear, but likely no significant increase as increase in domestic workers due to LCRs required in manufacturing was low-skilled

Table 4: Main findings on relevant channels and effect of LCRs on these channels. Data from empirical analysis and interviews.

5.1.7. Future potential in localising onshore wind and solar PV in South Africa

If the IRP (2019) is put into action as expected, then South Africa will add roughly 26.3 GW of solar and wind power between 2018-2030. This includes the 27 projects that only recently have reached financial close. Around 17.7 GW will come from wind and 8.7 GW from solar power. With this sizeable market, South Africa can expect – if implemented stringently and transparently – to attract substantial foreign direct investment and technology transfer. Figure 12 shows the projected investment volumes we calculated in South Africa (shown for each year where auction takes place, apart from 2018 where the financial close was reached later). More details on learning rates and projected technology cost can be found in SI.

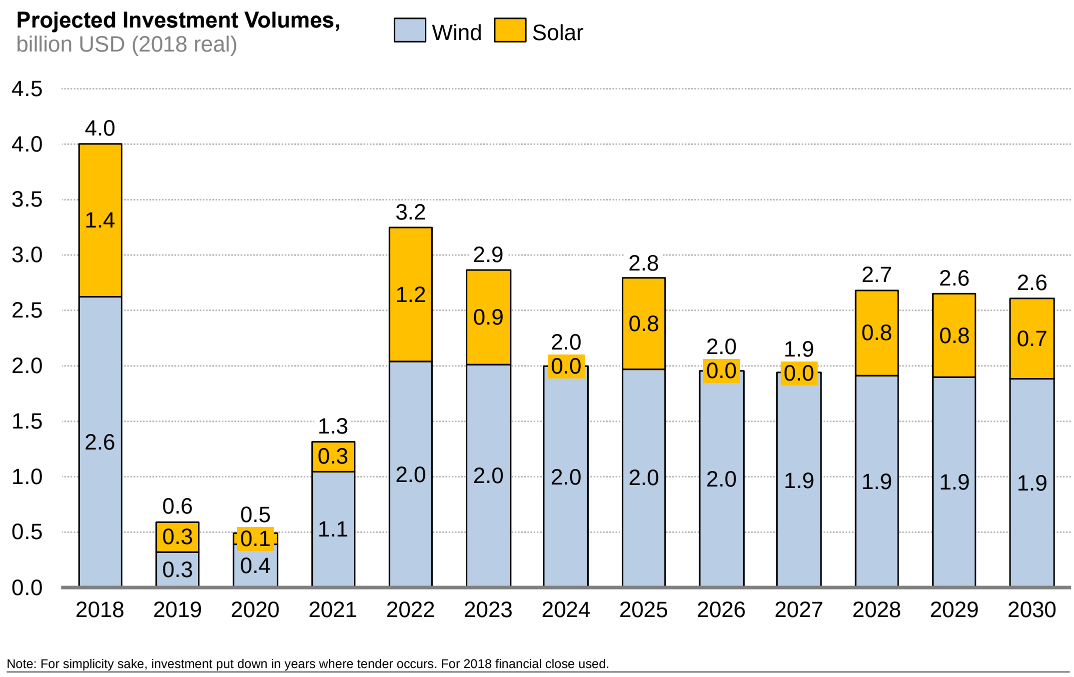


Figure 12: Projected investment volumes based on the IRP (2019) and projected solar PV and onshore wind price developments based on projections from IRENA (2018). For simplicity sake, we assume that investment takes place in the year where the tender occurs (except for 2018, where the power purchase agreements (PPAs) for 27 delayed solar PV, CSP and wind project was finally reached after a two-year delay).

Given the substantially higher capacity, and slightly higher expected investment cost for onshore wind per MW, we expect that the programme can attract 21.9 billion USD (real, in 2018 values) (Figure 13). Around one-third of these investments would likely flow into solar PV (7.1 billion USD) and two-thirds in onshore wind (21.9 billion). It is noteworthy that services (which we define as all works that do not pertain to central components or balance of plant) for both technologies account for around one third of the entire investment volumes. Values are slightly higher for wind, where services comprise 33% of costs, compared to 26% for wind. For the initial years of the projects (~5 years), O&M services are often provided by the equipment manufacturers (e.g., Vestas, Juwi). Later on, operation and maintenance companies take over, which includes South African companies, such as BioTherm Energy and Momentous Energy (DTI, 2013).

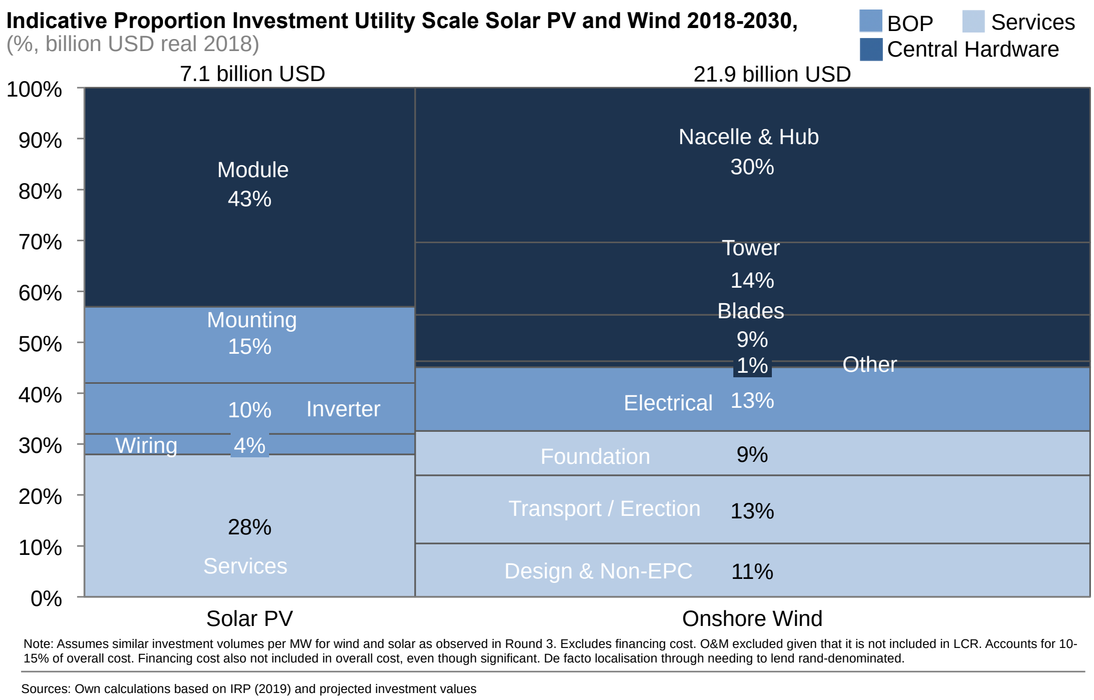


Figure 13: Indicative proportion of investment for utility-scale solar PV and wind from 2018-2030 in three main components (central hardware, balance of plant (BOP), and services) based on own calculations, IRP (2019), Ahlfeldt (2017) and IRENA (2018). O&M is excluded as no detailed numbers exist. Learning rates for solar PV and wind components reported in SI.

We rank the components shown in Figure 13 on two central factors: (1) localisation potential and (2) commercial potential and divide the components in low propriety, medium priority and high priority components from a policymaker's point of view (see Figure 8 in the methods section for detailed approach). The size of the bubbles indicates investment volumes per component, which underscore potential economies of scale. In order to rank the localisation attractiveness, we use a) job creation potential and b) investment volumes. However, as all major renewable firms eventually turn towards international markets, we gauge the international market opportunities for each component. We rank the commercial attractiveness in terms of a) market barriers, b) expected future global market. The underlying data is described in Section 4.1 and 4.2.

Our analysis shows that for solar PV services should be the first to be localized, because of substantial job creation opportunities, but also because it is less likely that firms from abroad can easily take over the market, particularly for certain services such as construction, site preparation and O&M. However, in the decision what to localise next, South Africa faces an inherent trade-off between: First, localising parts that have high localisation attractiveness due to high investment volumes (and moderate job creation), but are very unlikely to break into international markets (solar PV cells + modules). Or, second, to localise those where there is a higher potential for exporting these / competing internationally, such as building up an industry that focuses on mounting, but local effects might be not as high (due to low job creation potential).

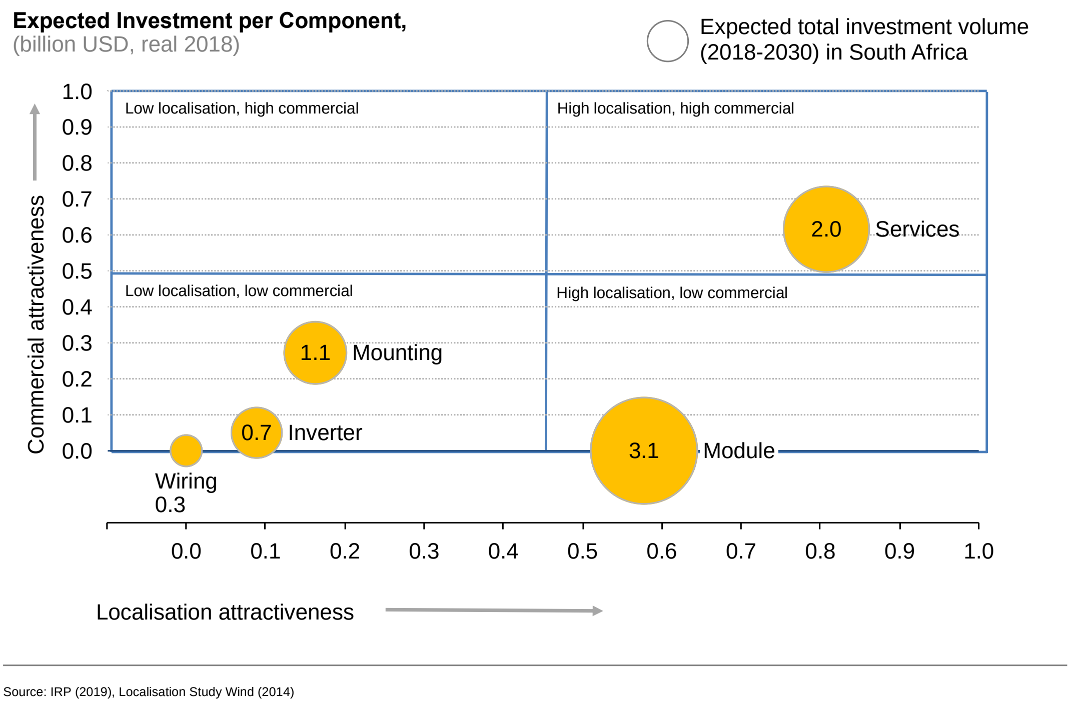
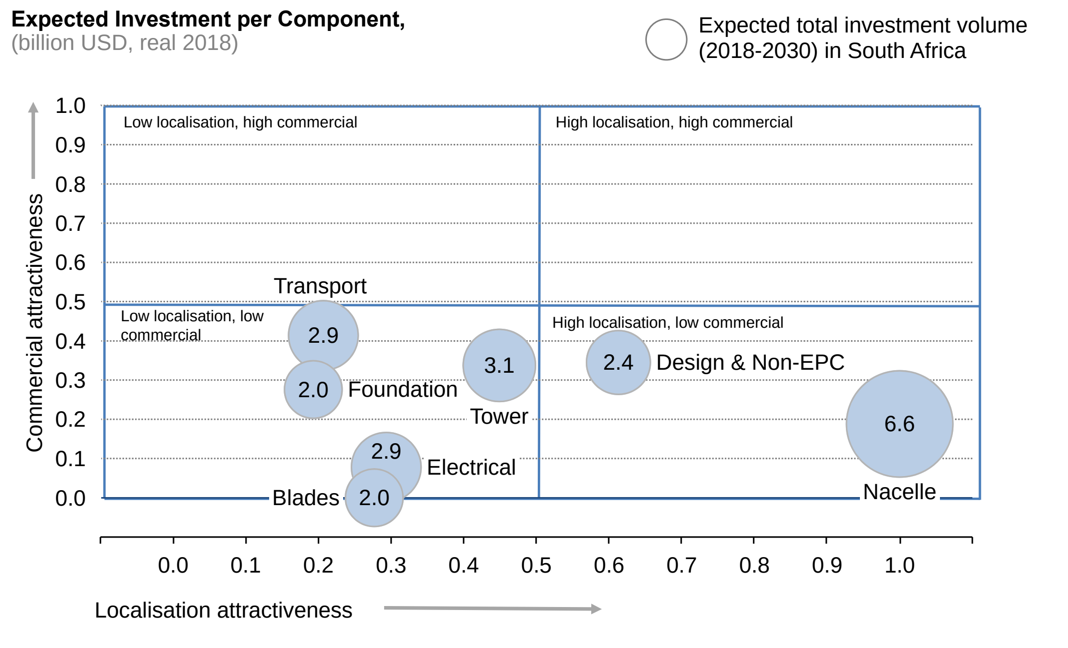


Figure 14: The localisation and commercial attractiveness of each solar PV component. Bubble size is the total expected investment volume in South Africa between 2018-2030 based on IRP (2019).

For wind technologies the question on what to focus localisation efforts is not as straightforward as for solar PV. The trade-off stems from the fact that manufacturing harbours a much greater job creation potential (e.g., blades) than in solar PV technologies, but these jobs normally require highly trained labour, which in short supply in South Africa. Design & non-EPC offer some potential for local jobs, but localisation attractiveness in terms of domestic job creation and investment potential is much lower than for solar PV. While transport, foundation and tower all have a certain localisation attractiveness, it is unlikely that South Africa breaks into global export markets for these technologies, as these markets are very local due to high transportation cost. However, South Africa could export these components to neighbouring countries in the region that do not have the same manufacturing capacities.



Source: IRP (2019), Localisation Study Wind (2014)

Figure 15: The localisation and commercial attractiveness of each onshore wind component. Bubble size is the total expected investment volume in South Africa between 2018-2030 based on IRP (2019).

Yet, of course, there are several reasons why one could expect South Africa to fall short on its promise to put the IRP (2019) into action. First, the IRP rests on a solid South African growth rate over the next ten years. Over the last years, South Africa has fallen short on its growth aspirations, translating into lower-than-expected power demand, which has been exacerbated by the Covid-19 pandemic. Hence, if South African growth does not pick up over the next years, the demand for additional power will be limited. Second, Eskom has refused to sign power purchase agreement (PPAs) with independent power producers in the past on the basis that these are not financially viable. These led to the renewable power programme grinding to a halt for two years, substantially dampening investors' confidence. If something similar were to happen again, this could lead to renewable power auctions being undersubscribed in South Africa, in turn leading to lower growth rates.

Hence, the above-mentioned figures on the future of the South African market should be seen as an upper bound. While it is possible that South Africa surpasses these expectations – for instance, due to robust economic growth and further substantial reductions in the cost of renewables – it seems more likely that South Africa will remain below these targets.

6. Conclusion

The utility-scale renewable power auctions in South Africa are leading to a gradual break from the coal-dominated past. Since 2011, 92 renewable power projects have been awarded in competitive auctions, mainly in onshore wind and solar PV. These jointly account for 11% of installed capacity. They also signal a shift in the power system once dominated by a single utility towards more competition between independent power producers.

In this paper, we first analysed whether the LCR programme to date has led to substantial technology transfer in the two main technologies solar PV and onshore wind. In a second step we analysed which components harbour the greatest localisation and commercial attractiveness for South Africa in the future.

Localisation in the first two rounds of the renewable energy support programme – which mainly focused on basic infrastructure services – would likely have occurred anyway as local firms in these sectors already existed in South Africa. Yet, round 3 and 4 led to the localisation of parts of the value chain that would likely not have been localised without LCRs. These include tower manufacturing for wind technologies and inverter and module assembly for solar PV. LCRs therefore led to the diversion of trade flows into FDI, as firms were unable to fully import components and had to assembly part locally. Yet, further increasing the minimum local content beyond the 40% for wind and 45% for solar will be a substantial challenge by interviewed manufacturers. For instance, wind blade manufacturing requires highly specialised machinery and labour. The delay of the programme triggered by Eskom's refusal to sign power purchase agreements with independent power producers for two years, and limited prospects of renewable power generation expansion until 2025, have already led to the closure of several manufacturing plants, including DCD Wind Towers and a solar inverter plant owned by SMA (Moyo, 2016; Thipa, 2019).

Of the four main channels of technology transfer (movement of personnel, imports, FDI and licensing), imports and FDI have played the most important role to date in South Africa. International component manufacturers have created local wholly owned subsidiaries through which the technology is transferred. This mode of transfer is associated with lower local spillovers than, for instance, licensing (which entails sharing detailed knowledge about the production, development, construction and O&M of a specific technology) but with higher spillovers than importing, in particular through training of the local workforce. LCRs have likely increased the importance of FDI compare to trade, as a greater percentage of projects needed to be manufactured locally. In comparison with China (de la Tour, Glachant and Ménière, 2011), international movement of skilled workers, in particular by recruiting South African engineers working abroad, has not been as an important channel (compared to China) of technology transfer in the wind and solar industry.

Despite delays in the last rounds of the programme, the future of the South African renewable power harbours a potential. The latest South African Integrated Resource Plan, the central policy document that sketches the future evolution of the power system, foresees 26.3 GW of additional renewable power capacity by 2030, which will make South Africa a sizeable market for wind and solar PV investment. We estimate that 29.0 billion USD will flow into South Africa until 2030, with one third of the investment volume going into solar and two thirds into wind.

In the short-run, our analysis demonstrates that many services (in contrast to manufacturing) harbour a substantial part of overall investment value and job creation potential as it comprises around one third of overall project investment volumes. Prominent South African project development companies, such as Mulilo, have already demonstrated their ability to develop large-scale projects.

However, in the decision what to localize next, South Africa faces an inherent trade-off between: First, localizing parts that have high localization attractiveness due to high investment volumes (and moderate job creation), but are very unlikely to break into international markets (solar PV cells + modules and the nacelle in onshore wind). Or, second, to localise those where there is a higher potential for exporting these and competing internationally, such as building up an industry that focuses on solar PV mounting or wind tower manufacturing, but local effects might be not as high (due to lower job creation potential).

Our analysis contributes to the literature in several ways. First, our analysis shows that LCRs can lead to fast and tangible localisation effects that would likely not have happened without the programme (e.g., localisation of wind tower manufacturing in less than two years). This is true even in smaller markets, such as South Africa. Previous analyses have focused primarily on China (Lewis, 2007) and Brazil (Gandenberger *et al.*, 2015), which have substantially bigger domestic markets. For instance, the Brazilian wind market is around ten times the size of South Africa (Gandenberger *et al.*, 2015), increasing the incentivises for manufacturers to localise their production as a result of a LCRs. Second, the choice of the transfer channel likely has an effect on technological spillovers. Interview data indicates that the predominant entry mode for international manufacturers was to establish wholly owned subsidiaries, which are associated with lower technology transfer than licensing. For instance, Lewis (2007) demonstrates that licensing arrangements have been crucial to China's and India's acquisition of foreign wind energy technologies. Our analysis demonstrates that while some production has been localised, the spillovers to domestic in South African innovation has been limited, as shown in the patent data we presented. Third, while most of the literature on LCRs criticised it on legal grounds (Kuntze and Moerenhout, 2013), we show that focusing LCRs on ancillary services (instead of manufacturing) might be a more fruitful approach, as it harbours a greater localisation and commercial potential.

Several limitations of our research should be underscored. Our claims – while supported by evidence from interviews and descriptive statistics – should not be seen as causal. The data for South Africa is limited, and bid data is not made available by the relevant authorities of the renewable energy programme. The patent data we rely on – as a proxy of innovation – also has its limitation, as discussed in Section 4.1. While we complement our patent data, with interview data, we do not have detailed data on private and public R&D as response to the renewables programme in South Africa. In addition, our projected investment volumes rely on the IRP 2019. While it could well be that the IRP will be put into practice with the envisaged generation capacities, political and technological changes might require a substantial revision in the future.

Future research could analyse more specifically to what extent different bids in South Africa with varying levels of LCRs led to different price outcomes. If this data becomes available, it would be highly interesting to compare the results to our chapter on the Indian solar auctions, to see to what extent we observe similar effects. Future research could also focus on how late-comer countries with smaller domestic markets than other emerging economies, can break into the market for clean technologies. Should we expect utility-scale markets to lead to localisation effects or are other niche markets needed for experimentation and subsequent scale-up?

South Africa also holds a number of important lessons for other developing and emerging economies. First, it demonstrates that even in coal-abundant countries the cost of renewable power can quickly fall below that of baseload coal generation if the auction scheme – as in South Africa – is well planned, monitored and executed. In South Africa, renewable power is currently 40% cheaper than coal-based electricity, even if storage and integration cost might narrow this gap. Second, it shows that even without liberalising the power sector, it is possible to introduce more competition through independent power producers and competitive auctions. Third, South Africa demonstrates that creating a long-term policy plan that investors can rely on is critical to attract international investments. Investors need a sufficient market size (either locally, or through exports) to be able to justify investments in local manufacturing capabilities. Fourth, large-scale renewable power auctions may not be the best environment for renewable energy start-ups, which try to enter higher parts of the value chain, such as wind blades. Getting a certificate for technologies with no or limited track record is a key challenge for new, untested technologies to get financing. Hence, programmes that allow for greater experimentation (possibly at the expense of higher prices) may catalyse new industrial growth through small-scale IPPs, where LCRs are not a barrier since large equipment manufacturers may not be interested in these small-scale projects. Similarly, for solar PV, embedded generation may provide an interesting sector that can lead to more job creation per MW and allow South African firms to enter the market more easily. Lastly, it is critical to create the right framework conditions for the localisation of new industries. This is not just about providing a stable and sizeable market. It also requires access to skilled labour, export markets, and predictable macro-economic conditions.

REFERENCES

Ahlfeldt, C. (2017) Localization Case Study on South Africa 's Utility-Scale Wind and Solar PV Sectors.

Altenburg, T. and Assmann, C. (2017) Green Industrial Policy. Concept, Policies, Country Experiences. Geneva, Bonn: UN Environment; German Development Institute / Deutsches Institut für Entwicklungspolitk (DIE). doi: 10.1093/oxrep/gru025.

Baker, L., Newell, P. and Phillips, J. (2014) 'The Political Economy of Energy Transitions: The Case of South Africa', New Political Economy. Taylor & Francis, 19(6), pp. 791–818. doi: 10.1080/13563467.2013.849674.

Baker, L. and Sovacool, B. K. (2017) 'The political economy of technological capabilities and global production networks in South Africa's wind and solar photovoltaic (PV) industries', Political Geography. Elsevier Ltd, 60, pp. 1–12. doi: 10.1016/j.polgeo.2017.03.003.

Binz, C. and Anadon, L. D. (2018a) 'Unrelated diversification in latecomer contexts— The emergence of the Chinese solar photovoltaics industry', Environmental Innovation and Societal Transitions, (September), pp. 14–34. Available at: http://www.circle.lu.se/publications.

Binz, C. and Anadon, L. D. (2018b) 'Unrelated diversification in latecomer contexts: Emergence of the Chinese solar photovoltaics industry', Environmental Innovation and Societal Transitions, 28(January 2017), pp. 14–34. doi: 10.1016/j.eist.2018.03.005.

Bischof-Niemz, T. and Fourie, R. (2016) Cost of new power generators in South Africa Comparative analysis based on recent IPP announcements. Pretoria.

Böhringer, N. J. R., Rutherford, T. F. and Wiggle, R. (2012) 'Green Jobs and Renewable Electricity Policies: Employment Impacts of Ontario's Feed-in Tariff', The B.E. Journal of Economic Analysis & Policy, 12(1). doi: 10.1515/1935-1682.3217.

Branstetter, L. (2006) 'Is foreign direct investment a channel of knowledge spillovers? Evidence from Japan's FDI in the United States', Journal of International Economics, 68(2), pp. 325–344. doi: 10.1016/j.jinteco.2005.06.006.

Calel, R. and Dechezlepretre, A. (2012) 'Environmental Policy and Directed Technological Change : Evidence from the European carbon market', Grantham Research Institute on Climate Change and the Environment, Working Paper, 98(1), pp. 173–191. doi: 10.1162/REST_a_00470.

Calel, R. and Dechezleprêtre, A. (2016) 'Environmental Policy and Directed Technological Change: Evidence from the European Carbon Market', Review of Economics and Statistics, 98(1), pp. 173–191. doi: 10.1162/REST_a_00470.

Campbell, R. (2018) 'South Africa's nuclear industry raises objections to new IRP'. Available at: https://m.engineeringnews.co.za/article/south-africas-nuclear-industry-raises-objections-to-new-irp-2018-08-31/rep_id:4433.

Cimino, C., Hufbauer, G. C. and Schott, J. J. (2014) 'A Proposed Code to Discipline Local Content Requirements', Peterson Institute for International Economics.

CIPC (2019) South African Patent Office CIPC. Available at:

http://www.cipc.co.za/index.php/find-enterprise-ip-informatr/patent-searches/.

Clark, V. L. P. and Creswell, J. W. (2006) Designing and Conducting Mixed Methods Research.

Climatescope (2018) Climatescope – About.

COMTRADE (2019a) Comtrade HS Code Wind. Available at: https://comtrade.un.org/db/mr/rfCommoditiesList.aspx?px=H4&cc=8502.

COMTRADE (2019b) General Database. Available at: https://comtrade.un.org.

Creswell, J. W. . (2003) Research design: Qualitative, quantitative, and mixed methods approaches. 2nd edn. Thousand Oaks, CA: Sage.

Dechezleprêtre, A. et al. (2011) 'Invention and transfer of climate change-mitigation technologies: A global analysis', Review of Environmental Economics and Policy, 5(1), pp. 109–130. doi: 10.1093/reep/req023.

Dobrotkova, Z., Surana, K. and Audinet, P. (2018) 'The price of solar energy : Comparing competitive auctions for utility-scale solar PV in developing countries ☆', Energy Policy. Elsevier Ltd, 118(January), pp. 133–148. doi: 10.1016/j.enpol.2018.03.036.

DoE (2015) State of Renewable Energy in South Africa. Pretoria.

DoE (2018) Integrated Resource Plan 2018. Available at: http://www.energy.gov.za/IRP/irp-update-draft-report2018/IRP-Update-2018-Draft-for-Comments.pdf.

DoE (2019) IPP Project Database.

DTI (2013) 'The localisation potential of photovoltaics (PV) and a strategy to support large scale roll-out in South Africa', (March), p. 171.

Easterly, W. and Levine, R. (2001) 'What have we learned from a decade of empirical research on growth? It's Not Factor Accumulation: Stylized Facts and Growth Models', World Bank Economic Review, 15(2), pp. 177–219.

Eberhard, A. et al. (2017) 'Independent Power Projects in Sub-Saharan Africa: Investment trends and policy lessons', Energy Policy, 108, pp. 390–424. doi: 10.1016/j.enpol.2017.05.023.

Eberhard, A. and Naude, R. (2017) 'The South African Renewable Energy IPP Procurement Programme: Review, lessons learned & proposals to reduce transaction costs'. Available at: https://www.gsb.uct.ac.za/files/EberhardNaude_REIPPPPReview_2017_1_1.pdf.

EIB and IRENA (2015) Evaluating Renewable Energy Manufacturing Potential in the Mediterranean Partner Countries.

EIS (2019) HS Codes 854140. Available at: http://www.exportimportstatistics.com/HS-Codes/Photosensitive-semi-conductor-devices-Hs-Codes-854140.aspx.

Ettmayr, C. and Lloyd, H. (2017) 'Local content requirements and the impact on the South African renewable energy sector: A survey-based analysis', South African Journal of Economic and Management Sciences, 20(1), pp. 1–11. doi: 10.4102/sajems.v20i1.1538.

Freeman, C. (1995) 'The ' National System of Innovation ' in historical perspective', (March 1993), pp. 5–24.

G5 (2019) Board of Directors.

Gandenberger, C. et al. (2015) The international transfer of wind power technology to

Brazil and China Working. Karlsruhe.

Hall, R. E. and Jones, C. I. (1999) 'Why Do Some Countries Produce So Much More Output Per Worker Than Others?', The Quarterly Journal of Economics.

Hidalgo, C. A. et al. (2007) 'The Product Space Conditions the Development of Nations', Science, 317(5837), pp. 482–487. doi: 10.1126/science.1144581.

IEA (2015) Decree No. 449 on the Mechanism for the Promotion of Renewable Energy on the Wholesale Electricity and Market. Available at: https://www.iea.org/policiesandmeasures/pams/russia/name-44254-en.php?s=dHlwZT1yZSZzdGF0dXM9T2s,&return=PG5hdiBpZD0iYnJlYWRjcnVtYiI-PGEgaHJlZj0iLyI-SG9tZTwvYT4gJnJhcXVvOyA8YSBocmVmPSIvcG9saWNpZXNhbmRtZWFzdXJlcy8iPlBvbGljaWVzIGFuZCBNZWFzdXJlczwvYT4gJnJhcXV.

IEA (2018) Law 27.191 Program to Promote the Use of Renewable Energy in Electricity Generation. Available at: https://www.iea.org/policiesandmeasures/pams/argentina/name-158841-en.php?s=dHlwZT1yZSZzdGF0dXM9T2s,&return=PG5hdiBpZD0iYnJlYWRjcnVtYiI-PGEgaHJlZj0iLyI-SG9tZTwvYT4gJnJhcXVvOyA8YSBocmVmPSIvcG9saWNpZXNhbmRtZWFzdXJlcy8iPlBvbGljaWVzIGFuZCBNZWFzdXJlczwvYT4gJnJ.

IRENA (2017a) Renewable energy benefits: Leveraging local capacity for onshore wind. Abu Dhabi.

IRENA (2017b) Renewable Energy Benefits Leveraging Local Capacity for Solar PV. Abu Dhabi. Available at: www.irena.org.

Keller, W. (2004) 'International Technology Diffusion', Journal of Economic Literature, 42(3), pp. 752–782. doi: 10.1257/0022051042177685.

Keller, W. (2009) 'International Trade, Foreign Direct Investment, And Technology Spillovers', NBER Working Paper.

Korsbakken, J., Andrew, R. and Peters, G. (2019) China's CO2 emissions grew slower than expected in 2018. Available at: https://www.carbonbrief.org/guest-post-chinas-co2-emissions-grew-slower-than-expected-in-2018.

Kuntze, J. and Moerenhout, T. (2013) Local Content Requirements And The Renewable Local Content Requirements and the Renewable Energy Industry - A Good Match? Geneva, Switzerland.

de la Tour, A., Glachant, M. and Ménière, Y. (2011) 'Innovation and international technology transfer: The case of the Chinese photovoltaic industry', Energy Policy, 39(2), pp. 761–770. doi: 10.1016/j.enpol.2010.10.050.

Lal, P. V. (2019) India prioritizes domestic products in plan for 12 GW of new solar. Available at: https://www.pv-magazine.com/2019/02/07/india-prioritizes-domestic-products-in-plan-for-12-gw-of-new-solar/.

Lam, L. T., Branstetter, L. and Azevedo, I. M. L. (2017) 'China's wind industry: Leading in deployment, lagging in innovation', Energy Policy. Elsevier Ltd, 106(August 2016), pp. 588–599. doi: 10.1016/j.enpol.2017.03.023.

Lee, K. (2019) The Art of Economic Catch-Up. Cambridge University Press. doi: 10.1017/9781108588232.

Leigland, J. and Eberhard, A. (2018) 'Localisation barriers to trade: The case of South Africa's renewable energy independent power program', Development Southern Africa. Taylor & Francis, 35(4), pp. 569–588. doi: 10.1080/0376835X.2018.1487829.

Lewis, J. I. (2007) 'Technology acquisition and innovation in the developing world: Wind turbine development in China and India', Studies in Comparative International Development, 42(3–4), pp. 208–232. doi: 10.1007/s12116-007-9012-6.

Lewis, J. I. (2012) Green Innovation in China. New York Chichester, West Sussex: Columbia University Press. doi: 10.7312/lewi15330.

Lewis, J. I. and Wiser, R. H. (2007) 'Fostering a renewable energy technology industry : An international comparison of wind industry policy support mechanisms', 35, pp. 1844–1857. doi: 10.1016/j.enpol.2006.06.005.

Malek, M. (2019) 'Saudi Arabia leads Middle East's rush to renewables, but policies lag behind ambition', S&P Global Platts. Available at: https://blogs.platts.com/2019/04/18/saudi-arabia-renewables-policies/.

Maskus, K. E. (2004) 'Encouraging International Technology Transfer', Sustainable Development, 7(7), p. 47. Available at: http://books.google.com/books?id=6QhNGgAACAAJ.

Matsuo, T. and Schmidt, T. S. (2019) 'Managing tradeoffs in green industrial policies : The role of policy design', World Development. Elsevier Ltd, 122, pp. 1–40. doi: 10.1016/j.worlddev.2019.05.005.

McCrone, A. et al. (2018) Global trends in renewable energy investment 2018. Frankfurt am Main. Available at: http://fs-unep-centre.org/sites/default/files/publications/gtr2018v2.pdf.

Melitz, M. J. (2005) 'When and how should infant industries be protected?', Journal of International Economics, 66(1), pp. 177–196. doi: 10.1016/j.jinteco.2004.07.001.

Moyo, A. (2016) 'German solar giant pulls plug on SA', IT Web. Available at: https://www.itweb.co.za/content/z5yONPvEnkx7XWrb.

Nahm, J. (2017) 'Exploiting the Implementation Gap: Policy Divergence and Industrial Upgrading in China' s Wind and Solar Sectors', (May). doi: 10.1017/S030574101700090X.

OECD (2012) 'Green Growth and Developing Countries: A Summary for Policy Makers', OECD, (June 2012), pp. 1–28. doi: 10.1787/9789264111318-en.

Probst, B. et al. (2020) 'The short-term costs and benefits of local content requirements : Evidence from the Indian solar auctions', pp. 1–7.

Qiu, Y. and Anadon, L. D. (2012) 'The price of wind power in China during its expansion : Technology adoption , learning-by-doing , economies of scale , and manufacturing localization', Energy Economics. Elsevier B.V., 34(3), pp. 772–785. doi: 10.1016/j.eneco.2011.06.008.

SARETEC (2019) Formal Wind Turbine Technician.

Smith, P. J. (2001) 'How do foreign patent rights affect U.S. exports, affiliate sales, and licenses?', Journal of International Economics, 55(2), pp. 411–439. doi: 10.1016/S0022-1996(01)00086-1.

Solow, R. M. (1956) 'A Contribution to the Theory of Economic Growth', The Quarterly Journal of Economics, 70(1), p. 65. doi: 10.2307/1884513.

Surana, K. et al. (2020) 'Effects of technology complexity on the emergence and evolution of wind industry manufacturing locations along global value chains', Nature Energy. Springer US. doi: 10.1038/s41560-020-00685-6.

Thipa, L. (2019) 'Uncertainty over renewable energy results in job losses at wind turbine company', SABC. Available at: http://www.sabcnews.com/sabcnews/uncertainty-over-renewable-energy-results-in-job-losses-at-wind-turbine-company/.

UNCTAD (2013) 'Local Content Requirements and The Green Economy'.

UNEP (2014) South-South Trade in Renewable Energy a Trade Flow Analysis of Selected Environmental Goods.

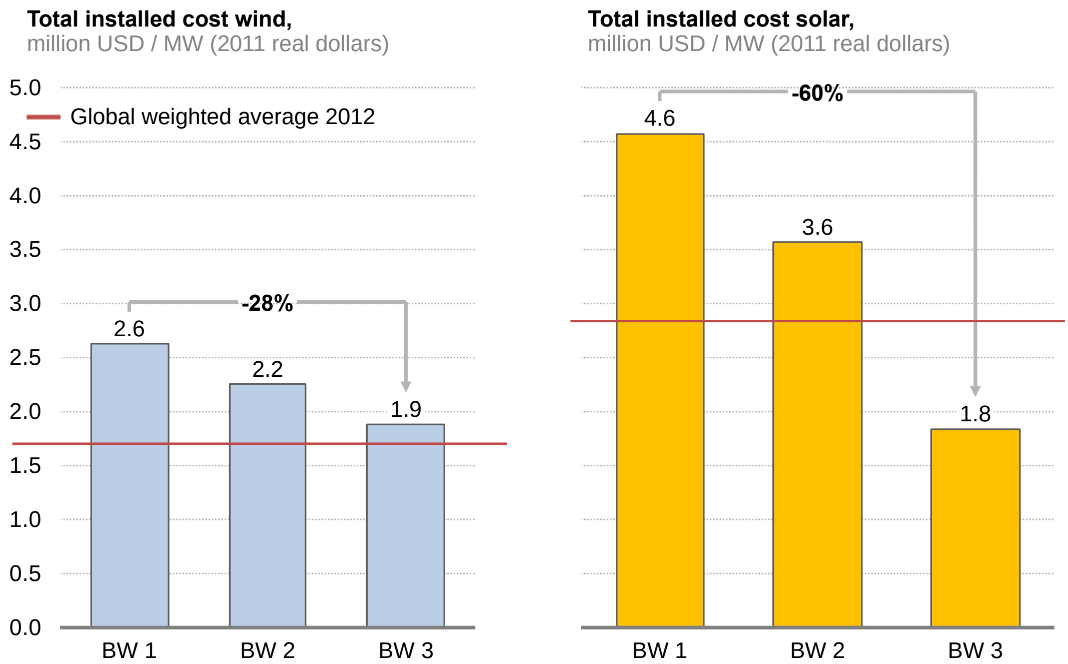
UNFCCC (2019) UNFCCC. Available at: https://unfccc.int/ttclear/tec/tech-transfer-framework.html.

Williamson (1981) 'The Economics of Organization : The Transaction Cost Approach Author (s): Oliver E . Williamson Source : American Journal of Sociology , Vol . 87 , No . 3 (Nov ., 1981), pp . 548-577 Published by : The University of Chicago Press Stable URL : http://w', American Journal of Sociology, 87(3), pp. 548–577.

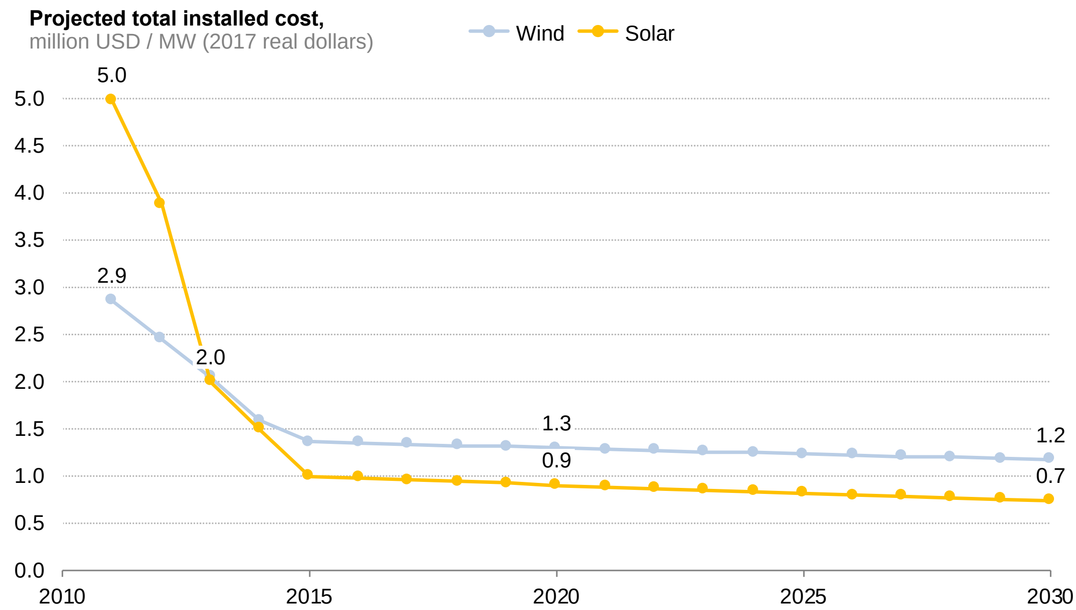
Winkler, H. and Marquand, A. (2009) 'Changing development paths: From an energy-intensive to low-carbon economy in South Africa', Climate and Development, 1(1), pp. 47–65. doi: 10.3763/cdev.2009.0003.

SUPPLEMENTARY INFORMATION

In order to calculate future investment volumes, we use the actual total investment cost per MW from the first three auction rounds and combine these with the international cost trajectories compiled by IRENA (2018) and cost declines observed in bid price for the fourth bidding round. We combine these with cost projections from IRENA (2018) to 2030 to calculate the future cost of these technology in South Africa (Figure 1 & 2).

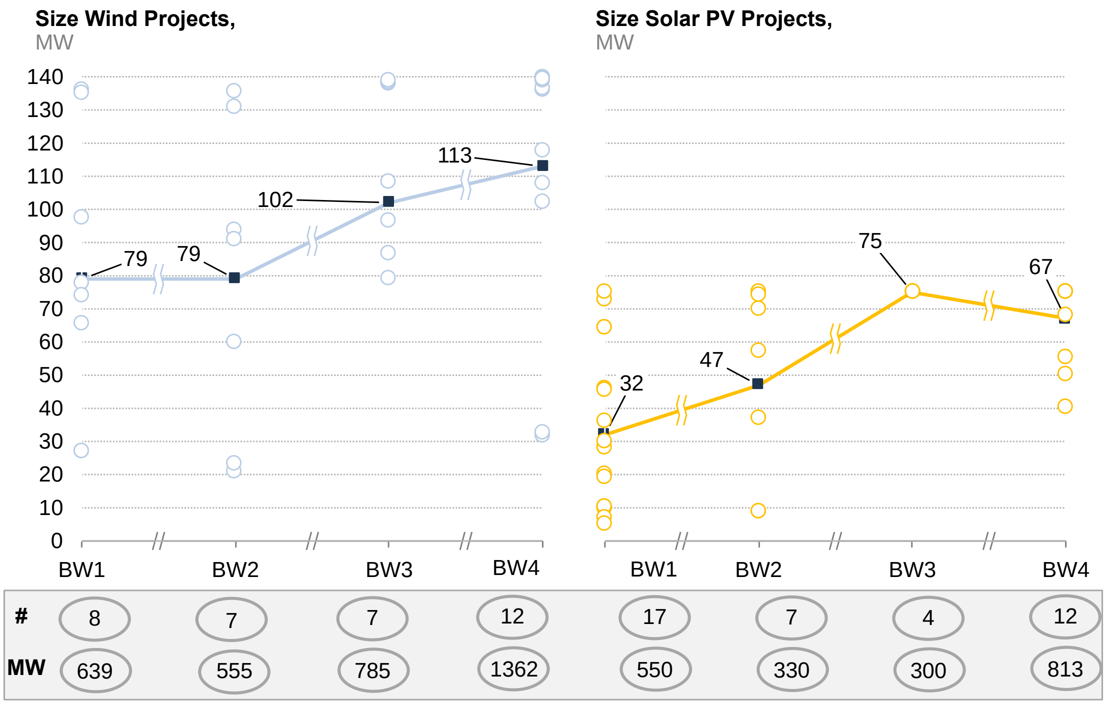


SI Figure 16: Total installed cost across the bidding rounds for wind and solar PV (2011 real dollars) based on *Eberhard, Kolker and Leighland (2014)*

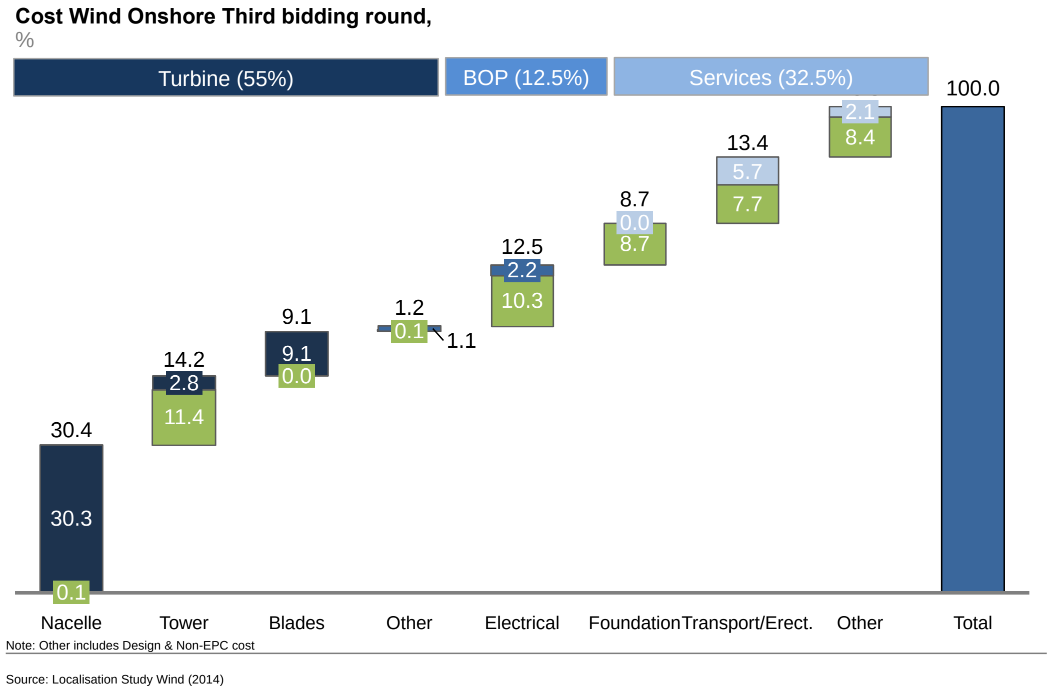


SI Figure 17: Projected total installed cost per year in 2017 real dollars for solar and wind to 2030. Figures from 2010-2015 are actual values. Rest prediction based on Irena (2018) expected evolution of prices to 2030.

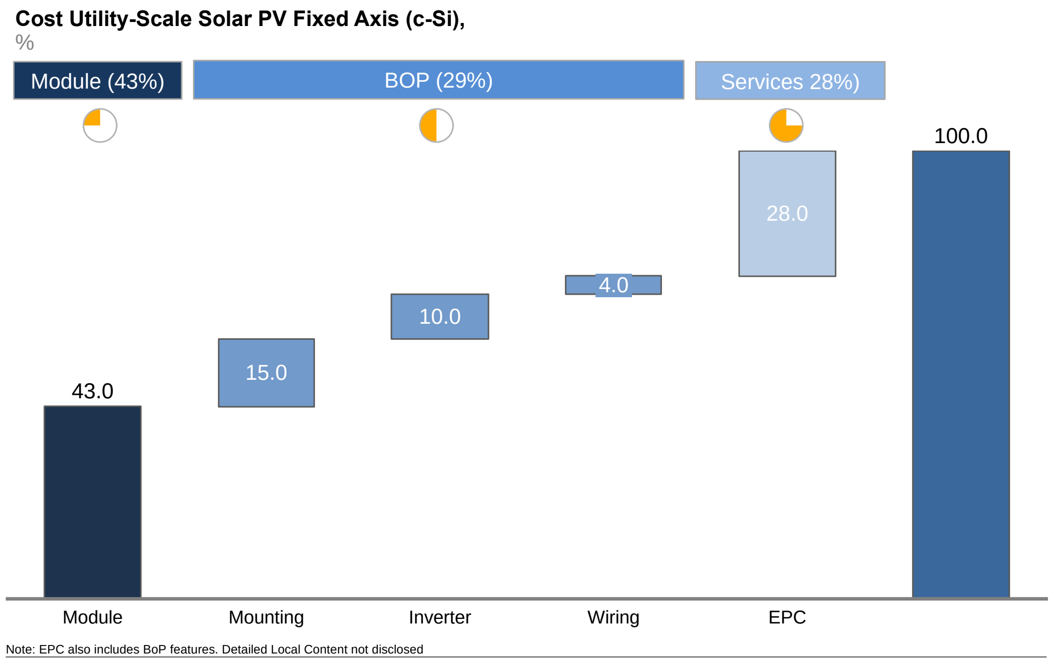
Figure 3, 4 and 5 provide additional information on the size of the solar and wind projects across the bidding rounds and specific values on the local content observed in the first three rounds.



SI Figure 18: Size of wind and solar PV projects across the different rounds



SI Figure 19: Proportion of cost per component for wind onshore in third bidding round



SI Figure 20: Average cost distribution per component for utility-scale solar PV fixed-axis in South Africa (bid round 2). Orange Harvey balls indicate proportion of localisation of each component type (no detailed numbers available).