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The Use of the Technological Innovation Systems Framework to Identify the Critical Factors for a Successful Sustainability Transition to Rooftop Solar in Low-Income Communities within South Africa

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Additional information is available at the end of the chapter

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Abstract

South Africa has a large unemployment rate with many households almost completely dependent on social grants for survival. Under such circumstances the potential of rooftop solar in developing vibrant and local energy micro-economies, which can generate and trade in electricity, is highly attractive. In this chapter, it is shown that such systems are uneconomic if considered from the perspective of a private investor. However a different conclusion emerges with respect to public funding. Even without considering the additional benefits of improved health and learning opportunities, lower levels of crime and lower levels of non-payment, rooftop solar becomes an attractive investment for the state, especially in areas of high solar irradiation. The 'electrification grant' could be delivered in several ways including the use of a subsidised feed-in-tariff. An initial analysis using the framework of technological innovation systems shows that much of the required structure for a rooftop solar system is already in place. However the state will need to boost efforts to train technicians to install and maintain the infrastructure, accelerate its initiatives to support local manufacture of photovoltaic modules, and strengthen the capability of the science and technology system to support the processes of technology diffusion and adoption.

Keywords: sustainability transition, technological innovation system, rooftop solar, photovoltaic, low-income community, South Africa

1. Introduction

Photovoltaics (PV) has evolved to be a significant source of electrical energy; by the end of 2014, cumulative PV capacity had reached 237 gigawatts (GW), equivalent to about 1.3% of the global electricity demand (see **Figure 1**). New capacity has been growing at an average of 40% per year since 2000 and it is predicted that by 2050 solar PV will be the largest source of electrical power, accounting for 16% of global demand [1].

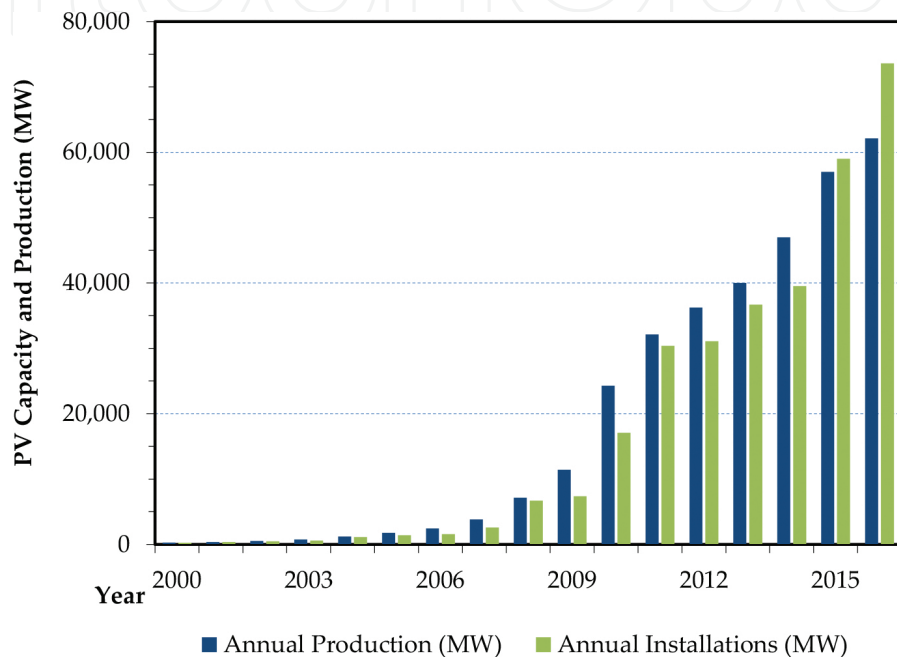


Figure 1. Annual PV production and installations. Source: updated with permission from REN21 [2], Masson and Brunisholz [3].

Surprisingly, this growth has been non-homogeneous with only five countries (China, Germany, Japan, United States and Italy) accounting for 62% of the total installed capacity. Although developing countries (excluding China) are becoming more visible as investors in PV capacity, driven largely by the increasing cost-competitiveness of the technology [2], their collective markets remain small compared to the developed countries.

The transformation of all countries to more sustainable energy systems, including both generation and demand, has become an active research area and forms part of a much broader set of studies on sustainability transitions, where the latter considers the means of promoting and governing a transition to sustainability. Although the studies do partly consider the technical challenges and possible technological solutions, the core of the research is focussed predominantly on how to change relationships, business models and behaviours, and hence achieve a fundamental transformation towards more sustainable modes of production and consumption [4]. The approach of technological innovation systems (TISs) has been proposed as one of several theoretical frameworks which can be used as a basis for such studies [5, 6].

In this chapter, the TIS framework has been applied to both understand and develop recommendations for how to change the relationships and conditions which presently shape the market for rooftop solar in South Africa. The framework is particularly applicable to analysing systems which display strong path dependencies and lock-ins, as is so evident generally for national energy systems. The chapter has four main sections. In the first section, the existing market structure and technological basics for PV are described. This is followed by a section on the principles of rooftop solar and particularly the application of the technology within low-income communities in South Africa, including a detailed techno-economic assessment. In the third section, the theory of technological innovation systems is introduced and then applied to the situation in South Africa. In the final section, the conclusions and recommendations of the study are presented.

2. The photovoltaics value chain and market structure

2.1. Manufacturing technology and cost

Although other materials are used, silicon wafer technology accounts for 93% of the total PV production [7]. The value chain begins mostly with the material polysilicon (also known as multi-crystalline silicon) which is cast into ingots, sliced into wafers, inlaid with a conductive grid to produce the silicon cells, then assembled into modules and finally installed onto rooftops (or other applications) in the form of complete PV systems. Other raw materials include monocrystalline silicon and thin films based on various combinations: cadmium, tellurium, selenium, gallium and arsenic.

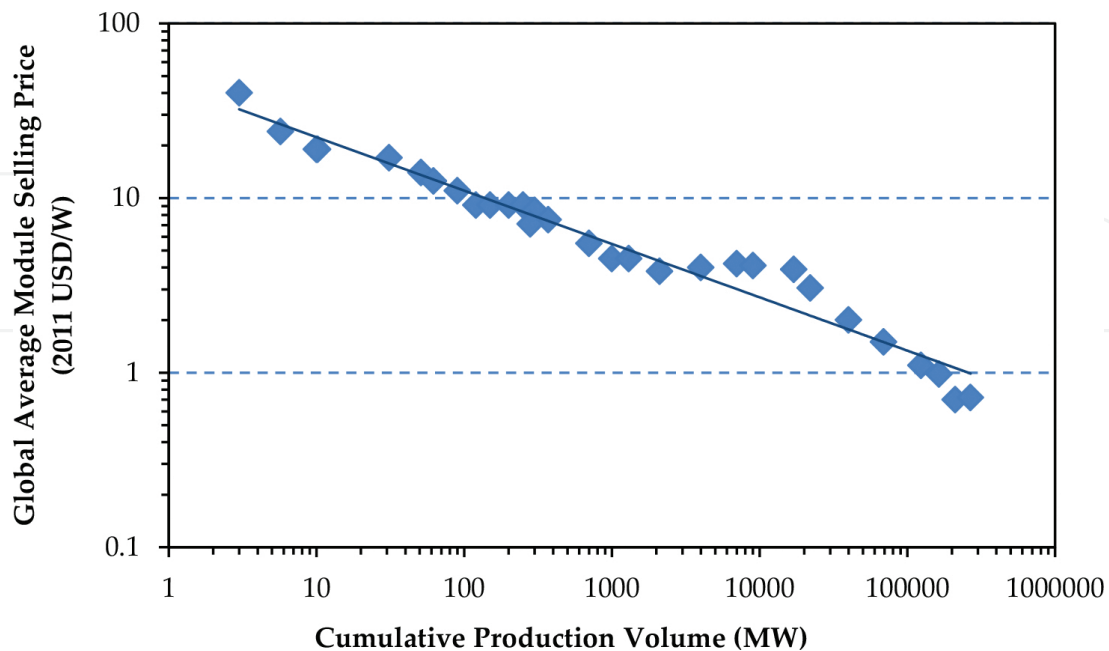


Figure 2. PV module selling price decreases as cumulative volumes increase.

The earlier stages of the manufacturing value chain are capital intensive, and the later stages labour intensive, with cost components (or value addition) being spread relatively evenly. The overall cost of PV has declined as manufacturing volumes have grown, as shown in **Figure 2**. The average module selling price is now about R10.1/W_p or \$0.72/W_p¹, a decline of 15 times since 1992 when the price was R154/W_p or \$11/W_p. Using the equations of the learning curve [8], it is calculated that in the last 35 years, the average module price decreased by 35% for each doubling of cumulative production volume.

Much of the cost savings have been achieved as a result of the decreased usage of materials, which has been reduced significantly from about 16 g/W_p to less than 6 g/W_p due to increased efficiencies (17–22%) and thinner wafers [7]. In terms of energy payback (amount of time to produce the total energy required for manufacture), payback is reached in less than 1 year for southern Europe and countries with similar solar irradiation. The carbon dioxide avoidance factor of PV is reported to be 0.715 kg CO₂/kWh [7].

The cost of PV modules is only partly located in the modules themselves. Other components include the inverter, the wiring (electrical connectors) and the mounting frames. Relative costs by component are shown in **Figure 3**.

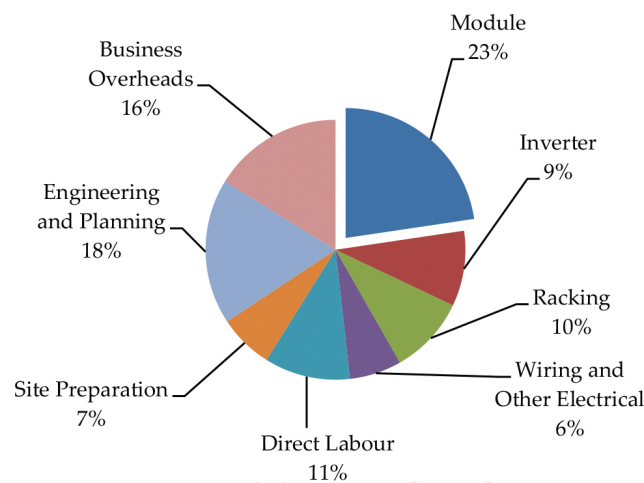


Figure 3. Breakdown of costs for PV systems. Source: Chung et al. [9] and IRENA Secretariat [10].

2.2. Job creation in the photovoltaics value chain

About 70% of the global manufacture of photovoltaic modules takes place in China, followed by the rest of Asia Pacific and Central Asia [7]. Of the 2.8 million global jobs in PV, 1.65 million are located in China, 377,000 in Japan and 194,000 in the United States [2]. The estimated number of jobs per segment of the value chain is shown in **Figure 4**; total jobs are 30 jobs per MW_p.

¹ Throughout this paper, two conventions have been used. All monetary values are quoted in US dollars, adjusted to 2011 values, and South African Rands, adjusted to 2015 values, with the approximate conversion rate being R14/\$. In addressing issues of power, these are quoted in watts (W) or kilowatts (kW) or megawatts (MW), with the suffix p referring to peak power (at a capacity factor of 100%) and the suffix c referring to actual output.

Currently, most of the local jobs are in the installation, operations and maintenance of the modules, with manufacture of the cells and modules taking place in other countries [12]. Although the REI4P includes criteria for value addition, these requirements have not been terribly successful in developing the value chain. Previous studies have suggested that sustainable jobs will most likely be created in countries with long-term policies and a holistic approach that addresses barriers all along the value chain [13].

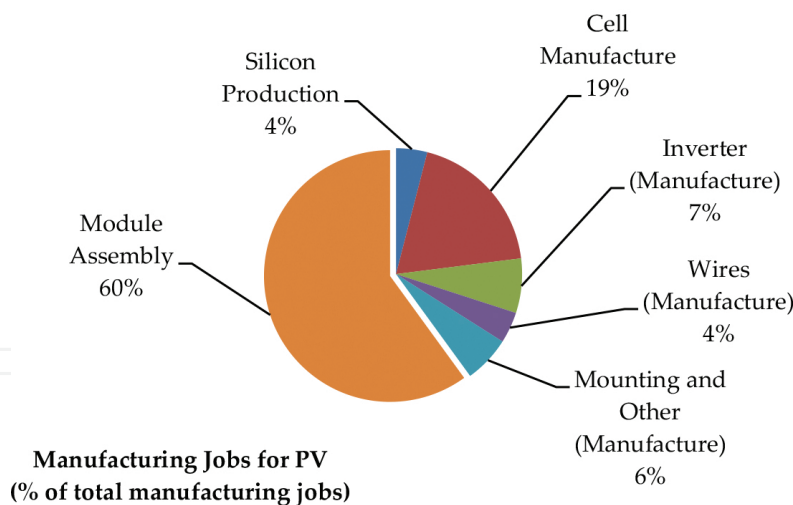
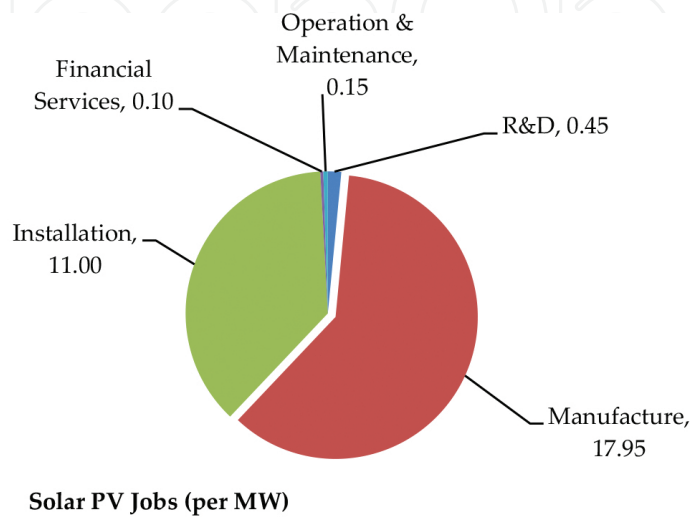


Figure 4. Solar jobs per MW_p in photovoltaics. Source: Walwyn [11].

2.3. Rooftop solar

Rooftop solar is already an appreciable component of power-generation systems in only a handful of countries, with the leading country being Australia, where the penetration of solar PV in residential consumption has reached 15% of the total electricity demand [14]. The use of PV as a means of both producing and consuming power has led to the definition of the term

prosumer, which refers to the growing practice of rooftop systems supporting the energy needs of homeowners and also selling energy to the national grid.

Further growth of the residential market is constrained by the economics or payback periods associated with private purchase and ownership of such systems. For instance, although the cost of rooftop solar in Germany has fallen considerably from 5000 Euro/kW_p in 2006 to 1270 Euro/kW_p in 2015, consisting of 48% for the module and 52% for the balance of systems, the feed-in-tariff for PV has fallen to about 0.125 Euro/kWh [7], which is lower than the break-even production cost of about 0.148 Euro/kWh (the details of this costing are shown in Section 3.2). In other words, the tariff is generally too low to support investment in rooftop systems unless the bulk of the electricity generated is consumed within the household (i.e. consumption takes place during the hours of sunlight and the use of storage is avoided almost completely).

However, this analysis is not applicable to the case of low-income communities with high rates of unemployment and poverty, and significantly dependent on social grants as a means of survival. In such contexts, PV-derived energy offers the potential for the development of new economic activity. A regional innovation system built on rooftop solar could be an ideal application of an inclusive innovation leading to a high-impact sustainability transition and the long-term economic upliftment of these communities. This proposition is discussed in more detail in Section 3.2.

3. Photovoltaics in South Africa

3.1. Independent power producers

PV in South Africa has grown rapidly over the last 5 years and has now reached a total value of 1.2 MW_p of installed capacity with another 1.1 MW_p in progress, comprising at least 45 separate 'single-site' installations with an average capacity of 51 MW_p. This rapid expansion has been supported almost exclusively by the Renewable Energy Independent Power Producers Programme (REI4P). In the first four-bidding windows of the programme, it has successfully procured 6,300 MW of power from 92 independent power producers, involving an investment of \$13.8 billion, including \$3.8 billion in foreign investment [15]. The target for the programme is 17,800 MW of renewable power by 2030, with a mix between wind, PV, concentrated solar power, biogas, hydro and biomass. Wind and PV are presently the major technologies, accounting for 53 and 36%, respectively [15].

There has been some criticism of the programme, including that it has failed to deliver a new industrial base and new areas of technological capability [8, 16]. Instead, the local content provisions have only managed to encourage elaborate transfer-pricing practices which effectively bypass the requirement, and some short-term investment in local assemble [16]. It is not surprising that the REI4P should encounter criticism from various stakeholders. The public-policy environment is complex given the high rate of unemployment, the present low economic growth conditions, the severe legacy of an institutionalised inequality left by apartheid and the persistent poverty. Although social grants have been effective in dealing

with the most severe forms of inequality and poverty, the country's political and economic spaces remain highly unequal and as a consequence the public-policy space is strongly contested.

This contest is evident in the energy sector, with the REI4P having to balance the needs for low-energy cost (and hence competitive tender processes) against social development, job creation in energy against job protection in mining and social development in outlying areas against social wages within urban areas. One important consideration is that the present energy policy is largely silent on the question of distributed generation. Although the REI4P has been successful in diversifying energy production, the independent power producers are still located as single sites. The programme and its overarching policy framework, the Integrated Resource Plan [17], has little provision for the incorporation of rooftop solar or other distributed technologies. The conditions for rooftop solar are now discussed in more detail.

3.2. Rooftop solar

Residential PV, or rooftop solar, is still in its infancy within South Africa. The existing regulatory process covers installations only above 100 kW, and there is presently a regulatory void in respect of smaller systems, referred to as small-scale-embedded generation. The country's energy regulator, the National Energy Regulator of South Africa (NERSA), is preparing the regulations governing net metering, or the process and rates by which rooftop solar systems or other forms of energy generation would be able to feed electricity into the national grid. A draft discussion paper was released in early 2016 for comment and is supposedly being finalised by the Department of Energy [18].

In the absence of the regulations, two municipalities (Cape Town and Nelson Mandela Bay Metropolitan Municipality) have already proceeded with schemes to allow larger scale producers to sell power back to the municipality. In the case of Cape Town, the allowable tariffs are unacceptably low (R0.57 per kWh relative to a purchase price in excess of R1.10 per kWh). The Nelson Mandela Bay Metropolitan Municipality, on the other hand, has agreed to purchase excess power from rooftop systems at the same value as the selling price from the municipality to the consumer. In other words, the consumer pays for the net usage only.

One reason often cited for the slow reform of energy regulations in South Africa for small-scale producers is that local authorities subsidise low-income consumers through a tiered-pricing system which allows the sale of energy to these consumers at lower prices. A shift to rooftop solar, particularly by the high-end consumers (>3000 kWh per month), may remove this flexibility and restrict the ability of municipalities to balance their revenue requirements with broader policy goals of economic development in low-income communities. In particular, the widespread adoption of rooftop solar and other means of local power generation could undermine revenue collection, and hamper other programmes on infrastructure development and redistribution [19].

However, this assertion does not survive closer evaluation. A separate study of municipal revenues for Cape Town has shown that the impact of rooftop solar will be minimal, especially if municipalities act proactively to reallocate their cost structured between distribution and

supply [11]. As shown in **Figure 5**, although the high-end consumers pay on average 30% more per unit of energy than the low-end consumers, the former only account for 5% of the total revenue. More than 93% of users consume less than 500 kWh/month and provide 75% of the city's total revenue from electricity sales. In other words, the immediate impact on municipal revenues from the loss of electricity sales to high-end residential users, who are the most likely to invest privately in rooftop solar, will be negligible.

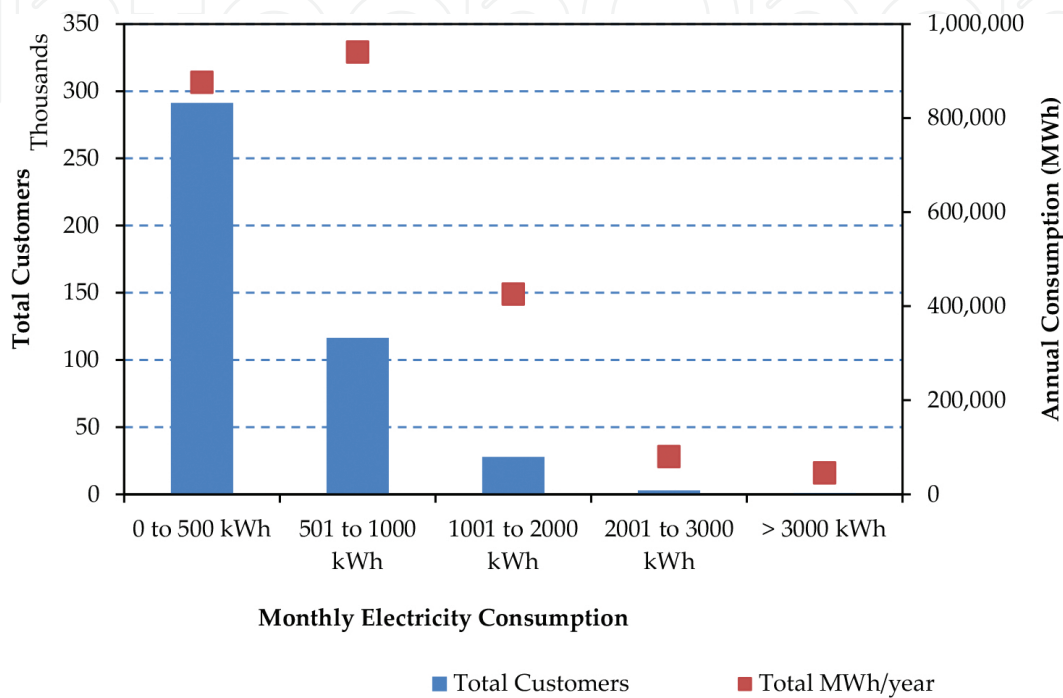


Figure 5. Profile of electricity consumers (Cape Town). Source: Walwyn [11].

At this point in the chapter, we are now ready to take an entirely new approach to the adoption of the technology. Rather than considering rooftop solar as a threat to revenues and redistributive programmes, it should be considered as precisely the opposite, namely as an effective means of achieving economic development within low-income communities. There are two critical factors in this discussion, namely the standalone rate of return or payback period for a newly installed grid-connected rooftop solar system without storage, and the overall level of support for low-income communities through the social grant system. Both aspects are now covered in more detail.

3.2.1. Techno-economic evaluation

In this chapter, the rate of return or payback period for rooftop solar has been estimated using a standard technique for obtaining a fully absorbed cost or single-year cost [20]. The technique requires the input of various parameters including capacity utilisation, the inverter efficiency, panel size, roof area and installed cost (see **Table 1**). The sizing of the system is based on the average rooftop size for a small house (detached or semi-detached, typically with a total rooftop area of about 45 m²) and the average electrical energy demand for low-income

households (about 500 kWh/month, as shown in **Figure 5**). It is also assumed that the project lifecycle is 20 years, capital is depreciated over 10 years, and that the only direct or indirect costs other than capital charges are a small amount of maintenance necessary to maintain high-capacity utilisation (4% of the installed capital cost per year). All labour costs are excluded since it is considered that the rooftop systems will be managed by the homeowners who will not charge for their labour.

Factor	Units	Value
Capacity utilisation	% of kW _p	25%
Inverter efficiency	% of input power	95%
Panel output	kW _p	0.25
Roof area	m ²	23
Installed system cost	R/kW _p	27,307
Selling price (to municipality)	R/kWh	1.40

Table 1. Input parameters.

The results show that the single year, fully absorbed cost is about R2.04 per kWh, this value being almost insensitive to the installed panel area, equivalent in effect to the number of panels. In other words, the break-even price is about R2.04/kWh or \$0.15/kWh and the feed-in-tariff for rooftop solar should be at least this value for the system to generate a return on investment under standard assumptions. In the event that the excess power is sold at the present purchase price for power within a municipal area of South Africa (about R1.40), the project's internal rate of return will be 4%, which is below the cost of capital, and the net present value (NPV) of the estimated discounted cash flows will be negative (−R20,000 or −\$1440), as shown in **Table 2**.

Number of panels		12
Rating	kW _p	3.0
Panel output	kWh/year	6,242
Capital cost	R	81,922
Fully absorbed single-year cost	R/kWh	2.04
Internal rate of return		0%
Net present value	2015 R	−20,000
	2011 \$	−1440

Table 2. Economic model output values.

The techno-economics are sensitive to both module price and capacity utilisation, as shown in **Figure 6**. The latter is already high for most sites within South Africa, and the model has assumed a value of 25% and an inverter efficiency of 95%. However, the module prices have been declining over a long period, as discussed in Section 2.1. Further decreases are expected, which will make rooftop solar more competitive as a source of electrical energy.

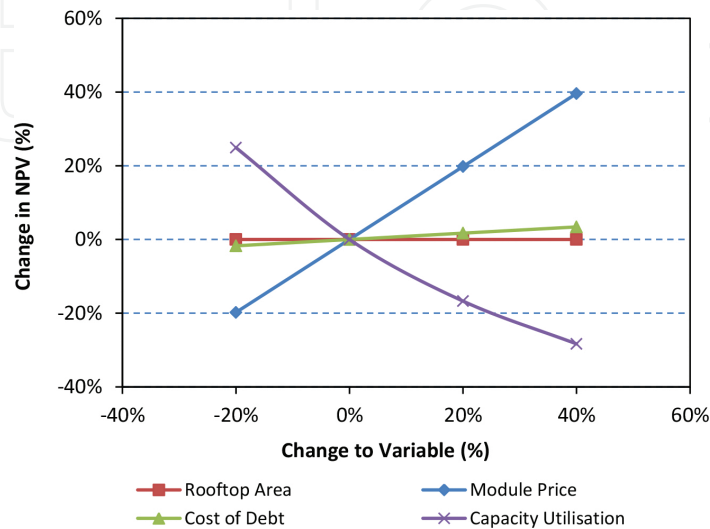


Figure 6. Sensitivity analysis for rooftop solar.

It is clear from this analysis that for the high-end consumers in South Africa rooftop solar is not presently competitive versus grid-delivered electrical energy, notwithstanding the recent price increases and the tiered system of electricity charges. However, this analysis must be nuanced when applied to low-income communities which are already recipients of extensive social grants, the latter aimed at addressing the high levels of unemployment and poverty in the country. In the following section, the extent of unemployment and the social-wage approach, which has been implemented by the Government post 1994, is discussed in more detail.

3.2.2. Social grants through household electricity

Social grants have been the most important means by which the government in South Africa has attempted to deal with unemployment and poverty. Although gross domestic product (GDP) and total employment have grown since 1994 (see **Figure 7** and **Table 3**) (expanded), unemployment rates have remained almost constant at about 35% of the total population. Government revenue has increased as shown in **Figure 7**, and a proportion of the increased revenue has been used to fund increases in the social wage, which now reach about 17 million citizens at an average wage of R6,870 per year (values in 2015 Rands) or \$335/year, where these values have been adjusted to allow for the costs of distribution from Treasury to the recipients (10% of the total disbursements). The total cost of social grants in 2015/16 was R129 billion, and this figure is projected to grow further to R169 billion in 2018/19 [21] (see **Figure 8**).

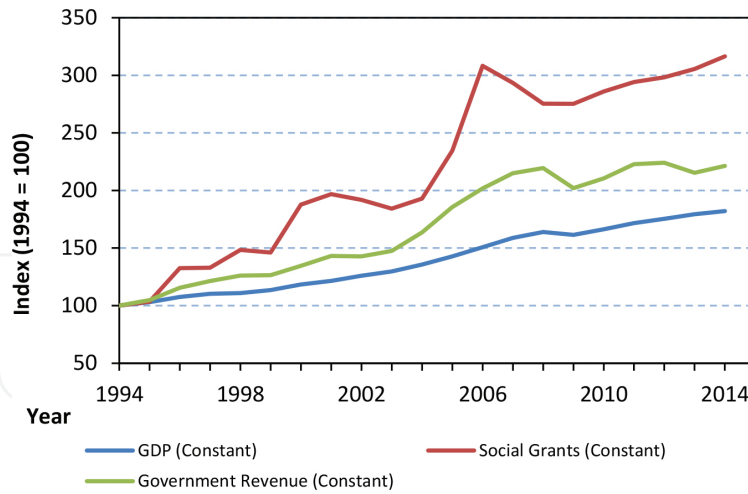


Figure 7. Relative values of GDP, total employment and government revenue. Source: Statistics South Africa [22].

	1994	2014	2015	% Change
<i>Strict</i>				
Employed	8896	15,055	15,830	69%
Unemployed	2489	5067	5400	104%
Unemployment rate	21.9%	25.2%		15.2%
<i>Expanded</i>				
Unemployed	4707	8157		73%
Labour force	13,603	23,212		71%
Unemployment rate	34.6%	35.1%		1.6%

Source: Statistics South Africa [23].

Table 3. Employment in South Africa, 1994–2015.

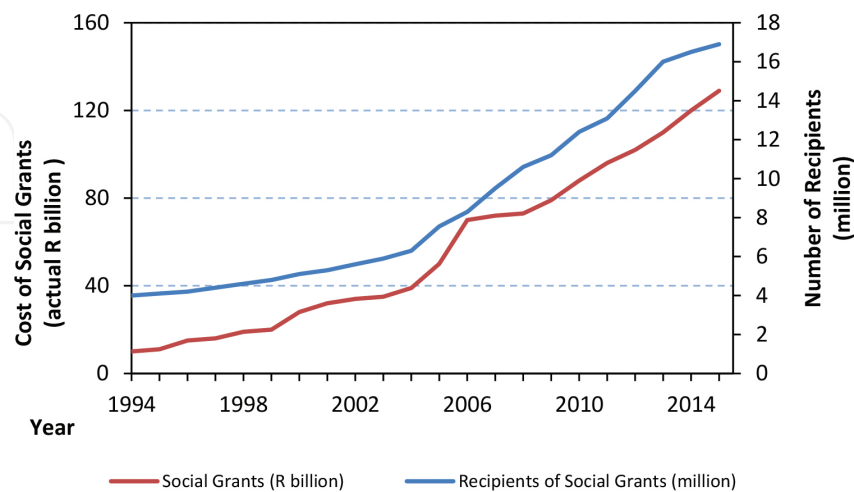


Figure 8. Value of social grants (actual R billion) and numbers of recipients (million). Source: updated with permission from National Treasury [24].

Assuming that there is at least one person per household on a social grant, and that the municipality already subsidises low-income household electricity purchases by about R360 per household per year [11], the net subsidy from central and local government is calculated at about R7230 per household per year. This calculation ignores a number of other factors which also contribute to the public cost including the high level of default on electricity payments within such communities, the opportunity cost as a consequence of inadequate lighting and heating in homes, the cost of crime and the public health burden.

In summary, it is apparent that rooftop solar is not presently viable for the private investor in South Africa. The break-even price is R2.04 per kWh, which is 50% higher than the average retail price at which electricity is available directly from the national grid for domestic consumers. However, there is a strong argument for the public sector to become more actively involved in the electrification of homes within low-income areas using rooftop solar. The state is already subsidising such homes at an average value of about R7,230 per year. If we assume that this subsidy is instead delivered in the form of a higher purchase price from all power delivered to the grid, or a net saving on energy purchases, the techno-economics of rooftop solar in low-income communities become more favourable with a neutral (as opposed to a negative) return on investment. Further discussion of this important result follows in Section 5.

4. Technological innovation systems

4.1. Theory and parameters

Discrete sub-sectors of a national system of innovation, such as the energy, machinery and transport, can be conceptualised as technological innovation systems. Such systems consist of actors, networks and institutions (rules and standards of the system), as well as material artefacts and knowledge, broadly classified as sociotechnical systems. Sociotechnical transitions, and by definition sustainability transitions, can be studied using a combination of the theory of TIS [25] and a three-phase model for technology development [26]. Such a framework is now applied in this chapter.

Sustainability transitions are long-term, multidimensional and fundamental transformation processes through which established sociotechnical systems shift to more sustainable modes of production and consumption. The objective in an analysis such as this study on South Africa is to identify which critical parameters need to be addressed in order to expedite a sustainability transition. In terms of TIS theory, there are seven key functions that need to be fulfilled in the maturation of emerging innovation systems [5], namely knowledge development and diffusion, resource mobilisation, market formation, influence on the direction of search, legitimisation, entrepreneurial experimentation and development of positive externalities. For the purposes of this study, three indicators have been selected for each function as a means of defining the extent to which the necessary conditions for transition have been realised. The functions and their related indicators are shown in **Table 4**.

Item	Indicator	Level	Comment
Development of formal knowledge			
Volume of knowledge creation and development	Publications from South African universities; growth of research centres	Medium	Research on PV, rooftop solar and smart-grid technologies has increased in recent years but still in its infancy (about 50 publications on PV or smart grids per year relative to 650 in Germany).
Mode of knowledge creation and development	PhD studies and other	Medium	Limited relative to potential demand.
Process of knowledge creation and development	Linkages between universities/business	Poor	With the exception of Art Solar, the local market is dominated by international companies with limited links to local universities.
Resource mobilisation			
Developing human capital and specialised labour force	Graduates in PV	Medium to Poor	Growing output of university graduates with relevant qualifications but very limited numbers of technicians for installation and integration.
Mobilisation of financial resources	Funding for investment in production, innovation and R&D	Medium	Cost of capital generally higher in South Africa; R&D financial resources are available but not specific to the sector.
Existence of complementary assets	Formation and growth of centres for providing intellectual property services	High	South Africa has a strong intellectual property regimen including the patent office and the National Intellectual Property Management Office.
Market formation			
Market size and its growth	Market size; growth rate	High	PV market is growing strongly driven by the REI4P and the shortfall in energy generation within the national grid; high potential to expand to all areas including low-income communities in Northern Cape.
Incentives and inducement mechanisms for market growth	Scale of incentives	Medium	Present although not specific to PV; specific demand-side measures (supply contracts) and generalised supply-side incentives (R&D, human capital).
Customer groups and their purchasing behaviour	Differentiation of market	Low	Some interest from remote communities and households, but generally very limited awareness.
Influence on the direction of search			
Visions and expectations about the growth potential	Media interest	High	Strong media interest in renewables and carbon emissions.
Policy development and priority setting	Clear government policy	Medium	Government policy is clear for the development of independent power producers but uncertain for rooftop solar (IRP 2010–2030 and REI4P include detailed tender documents, quotas, price caps, requirements for local content, cap on foreign exchange exposure).
Current and complementary businesses	Development of new business areas within existing companies	Low	Local firms have been slow to diversify into renewable technologies with the exception of multinational and financial services firms.
Legitimation			
Developing necessary institutions and required regulations	Institutes for standardisation and	Low	Lack of clarity on the inclusion of rooftop solar systems within the national grid, including all

Item	Indicator	Level	Comment
	regulations for grid inclusion		aspects of integration, smart grids, metering and feed-in-tariffs.
Formation of advocacy coalitions and interest groups and their lobby power	Secretariat and lobby groups; releasing overall policies and strategies for promotion and development	Medium to High	Formation of the South African Photovoltaic Industry Association and Green Cape in order to support the development of local industry and lobby for policy support.
Promotional and extension activities	Newsletters and other	Poor	Infrequent newsletters and media coverage.
Entrepreneurial experimentation			
Mode of entrepreneurship	Entry of new 'diversified companies' from other sectors for exploiting the 'niche market'	Poor	This area of assessment is very unclear; although the market is apparent, there has been little innovation in terms of how firms can enter and prosper in the market given the existing regulatory context.
Experiences in using technology and its applications	Launch of new products	Medium	Some firms have developed unique products which incorporate PV such as lighting and home-cooking applications.
Knowledge diffusion and development of positive externalities			
Formation of division of labour and specialised value chain	Formation of networks and technology incubators	Poor	This area of the system is still weak; the value chain is largely undeveloped except for single-site installations and the provisions of the existing programme for local content are being avoided.
Information and knowledge flows and spillover	Formation and growth of the firms	Poor	Although the science and technology system in South Africa is strong by international standards relative to its peer group, knowledge spillovers have been minimal and local public research institutions have had limited impact.

Source: own data, [12, 16, 27, 28].

Table 4. Variables and levels of attainment.

It is noted that TIS is not the only analytical framework which can be used to study sustainability transitions. In a separate study of the renewable energy sector in South Africa, the frameworks of technological capabilities and global production networks have been applied in order to understand the embeddedness of PV as a technology within the national and international political economy [16]. The research highlighted the importance of finance and investment, the nature of global supply chains and the abuse of the more progressive elements of South Africa's renewable energy programme by international companies. In particular, Baker [16] concluded that a tension exists between the country's dependency on international companies and its desire to establish local manufacturing, and considered that the resolution of this tension is critical to the success of the programme. Similarly, an earlier study also argued that technology transfer on its own would not enable South Africa to reach its low carbon targets [27]. Noting that technological development was critical to achieving the targets, and that technology transfer in support of product sales did little to build internal or local capa-

bilities, Rennkamp and Boyd [27] concluded that stronger policies were required to boost domestic technological capabilities.

Although both studies are relevant to our discussion, TIS has been used as the preferred framework since the focus of this work has been to understand the potential and constraints of rooftop solar in low-income communities. To a large extent, the roll-out of large-scale PV in this market will depend on the development of an innovation system which is quite distinct from the single-site architecture which has prevailed so far. In particular, the deployment as discussed in this chapter will require micro-economies of suppliers and service providers who will be able to install, integrate and maintain small-scale systems across a large number of sites. In this sense, TIS is a more appropriate analytical framework since it specifically covers the important aspects of entrepreneurial experimentation, knowledge diffusion and legitimation. The application of the framework to this micro-economy within the broader sector of PV is now discussed.

4.2. Evaluation of photovoltaics and rooftop solar systems in South Africa

Based on the results of this study, the PV and rooftop solar TIS within South Africa is at various stages of development, as shown in **Table 4**. Although there are strong demand factors including the net shortfall in generation capacity, several other factors remain weak including the availability of skilled human resources, the absence of a regulatory policy for feed-in systems within local authorities, limited progress in the establishment of local manufacture including PV modules and inverters, and a slow development of the necessary entrepreneurial skills within firms.

All of these factors will need to be addressed in the opening of the proposed micro-economy for rooftop solar within low-income communities. The issue of skilled human resources is an ongoing constraint to the economy and has been identified in several sectors, not only energy [29]. Furthermore, the weakness of entrepreneurial activity within the country has also been highlighted in several surveys and remains an issue for government policy [30].

However, the most important issue at present is the regulatory framework for rooftop solar and how the systems could be managed within the local authorities' distribution networks, including metering and feed-in-tariffs. As already mentioned, the national regulator is currently in a process of public consultation on this issue, but the decision has already passed its deadline and there seems little progress by the regulator. This tardiness reflects a general inability with respect to decision-making within government and has been ascribed to deeper political struggles over what is supported by the state and who benefits [28]. As a consequence, the government does not appear to move forward on important issues involving substantial realignment of public benefit, innovation and state support.

Although the government may seem intent on resolving the unemployment crisis, based on its policy documents such as the National Development Plan [31], at this stage it is failing to support the development of distributed energy generation due to a perceived disruption of the coal-mining sector and the stranglehold of Eskom, the latter being a parastatal that controls the national grid and most of the country's generation capacity. The transition from coal to PV

will require more than the transfer of technology and support for a new cohort of homeowner entrepreneurs; it will require government to tackle the concerns of its partners in the trade unions and the parastatals over the diversification of the energy system. Such conflicts are not unusual in transitions and generally are only resolved under the pressure of widespread mobilisation or popular demand.

5. Discussion

The energy sector is evolving in several ways which have profound implications for policy makers. Firstly, energy generation is becoming increasingly distributed with energy sources being located closer to consumers [2]. Secondly, energy systems are becoming more complex with multiple sources, suppliers and distributors. Both aspects are particularly relevant to rooftop solar and stimulation of the latter requires careful consideration of the possible impacts including issues such as employment and grid stability. In South Africa, the technology has the potential to deal with three important public-policy objectives, namely equity, employment and economic growth. The development of vibrant local economies in rooftop solar systems could create much-needed jobs in low-income communities, improve access to electricity, provide new income sources to the unemployed and grow local economies.

However, this potential is being overlooked in favour of the continuation of a centralised power-generation system which is both exclusive and inefficient. It is argued that rooftop solar is uneconomic relative to the single-site systems, and that fluctuating outputs from PV systems require a duplication of generation sources. It has been shown in Section 3.2.2 that direct government support for rooftop solar in low-income communities can be justified on the basis of the high level of social grants which are already being delivered to these households. By switching from a system in which government provides cash grants to one in which it purchases power or power savings from poor households, it will simultaneously be meeting other important developmental priorities including those of increasing employment and economic growth. As noted in Section 2.2, 11 jobs per MW_p are created in the installation and maintenance of PV panels alone. These are generally less-skilled jobs which will not require long periods of retraining and investment in human resource development.

These arguments can be illustrated by considering a pilot scheme involving the installation of $3 kW_p$ rooftop solar systems across a single community of 1000 homes. The total installed cost for the systems will be about R80 million (about R80,000 per home), giving a total system capacity of $3 MW_p$ delivering 6,250 MWh per year into the homes with the surplus being direct to the national grid. The equivalent value of this energy to each home will be R8,740 per household per year, should the panels be connected directly to the national grid and the feed-in-tariff be set at the average selling price, as is presently the case in the Nelson Mandela Bay Metropolitan Municipality. The single-year cost to government for the installation has already been discussed and amounts to R12,730 per household year (R2.04 per kWh).

It has already been noted that the total value of government grants and subsidies amounts to approximately R7,230 per year for a single low-income household. If we now assume that the

system of social grants is replaced by the installation of a rooftop solar system, the net additional cost to government will be R5,500 per household per year, for which it gains at least 33 jobs per 1000 households and the benefits of improved electrification. It makes sense that at least a portion of the initial capital investment is paid by the homeowner and that this loan should be handled in the same way as the present system for housing subsidies. If we assume that this proportion is at least as large as the extent to which the value of the electricity to each household exceeds the present value of social grants, then the net additional cost to government is R3,300 per household per year, or about R100,000 per job. The latter figure is reasonable for employment creation with values being reported by the existing government-sponsored scheme for employment creation (the Jobs Fund) being in the region of R50,000–150,000, depending on the sector and the quality of the job.

The details of this analysis provide a compelling argument. Replacing a system of social grants with a subsidised means of individual households becoming energy prosumers (consumers and producers) will have benefits at a number of levels. Firstly, it will improve access to and the affordability of electricity, which is recognised as a fundamental means of accessing other public goods, secondly, it will create local economic and employment growth at a competitive value, and thirdly, it will decrease levels of poverty in low-income communities without resorting to the use of a social grant. Finally, it will simultaneously address the need for the transition of South Africa's energy sector from non-renewable to renewable resources, as has been outlined in the Integrated Resource Plan [17].

6. Recommendations and conclusions

This study has shown that rooftop solar has real potential to deliver a viable and beneficial sustainability transition within South Africa. In particular, the development of a comprehensive technological innovation system will support the economic upliftment of low-income communities in addition to addressing the commitments by South Africa to the goals of the Paris Convention, creating employment and new economic activity.

However, the government has moved slowly to date in facilitating the development of rooftop solar. This transition will require it to take fundamental policy decisions relating to energy systems and economics; it will require the lead departments to coordinate and integrate the activities of multiple stakeholders; it will need the supporting departments to ensure that the appropriate regulations, infrastructure and resources are in place to support a country's energy vision.

There is little evidence that such decisions have been taken or even considered. The immediate priority for government if it wishes to develop a rooftop solar market in low-income areas as a sustainable alternative to social grants, the latter rapidly becoming unaffordable, is to finalise the regulations for feed-in-tariffs and the integration of rooftop systems with the national grid. In the medium term, it will also need to boost efforts to train technicians to install and maintain the infrastructure, accelerate its initiatives to support local manufacture of photovoltaic

modules and smart metres, and strengthen the capability of the science and technology system to support the processes of technology diffusion and adoption within the sector.

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