Contribution of refurbishment of solar panels to energy security in South Africa

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SUMMARY

South Africa is currently facing an energy crisis which is affecting businesses and household. As more users install solar panels, some are left behind because the cost of solar panels is beyond their reach. Additionally, as PV installations grow, a challenge of waste management awaits us. This study proposes the refurbishment of used solar panels which can then be re-used, more so by disadvantaged groups in alternative energy access. The study explores the existing refurbishment landscape at an international level, since that is where the practice is happening bringing out its viability, even for small businesses. While it is expected that waste from solar panels will come after their given 25+ years, earlier PV waste generation resulting from early loss/failures is a possibility, providing opportunity for refurbishment. The associated costs and benefits are detailed. The study also explores the refurbishment value chain, identifying business opportunities. It further explores the South African refurbishment landscape, which is not well developed in terms of supporting legislation and standards. Finally, the study outlines international best practices that have enabled refurbishment. It is recommended that South Africa adopts refurbishment, but first the government needs to define legislation around PV waste management and the refurbishment. The practice will not only create jobs but also allow more people to own alternative energy supply sources.

KEYWORDS

Solar panels, refurbishment, South Africa, value chain.

1 INTRODUCTION

South Africa is burdened with frequent electricity cuts which have been recurring since 2008 with varying severity and frequency. Most recently, electricity supply is cut for up to 10 hours a day. Projections by the South African Reserve bank show that in 2023, the country will experience more than 200 days of load shedding [30]0. The electricity cuts have resulted in businesses making significant losses, laying off workers or closing down all together. Studies show losses of R900 million per day of stage 6 load shedding which resulted in a 5% points loss in GDP in 2022 [17]. Households and schools have also had disruptions in their daily routine, resulting in among others, disruptions to learning, food waste and safety concerns. South Africans have therefore sought alternative energy sources which include solar PV systems.

The adoption of solar PV systems as a renewable energy source has seen exponential growth globally. South Africa started seeing an increase in PV installations after Bid Window 1 in the REIPPPP which started in 2011. Lately, the unreliability of electricity supply, reducing costs, increasing innovation and government incentives have encouraged private businesses and households to also install solar panels. The challenge in this is that the average monthly household income for South Africans is about R24 813 [30], yet an average 5kWp home solar PV kit costs R145 600 [17]. For businesses, only about 19% have been able to afford alternative electricity supply. 54% of them prefer to install solar panels, but the average cost of a PV systems can go up to R29 120 per kWp, which is significant for small businesses and the poorer consumers. Low-income households, businesses and rural communities therefore continue to lag behind in accessing alternative energy sources.

The exponential growth of solar PV installations is expected to generate waste at an exponential rate both globally and locally. Panels have a long lifetime (25+ years), and assumptions are normally made that waste generation begins after the 25+ years. Estimations therefore place quantities of waste at 1.7 million tons by 2030 [13]. However, studies have shown that solar panels get damaged during transportation, and experience early life failures (1-4 years), mid-life failures (4-15 years) and late-life failures from 15 years [16]. These damages and failures can necessitate removal/replacement. Better technology can also be a driving factor for replacement as PV technology continues to evolve. All these can contribute to PV waste which can be environmentally toxic if it ends up in landfills. End of life management of PV waste currently more on focusses on recycling. There are very few PV recycling facilities in South Africa and the existing ones struggle with recycling the solar cell.

To address the aforementioned challenges, this study proposes the local refurbishment of solar panels, which entails repairs and replication of panels. South Africans sell used solar panels, albeit on a small scale, with many panels being sold without undergoing the necessary performance and safety checks. Panel re-use is growing globally with about 15 PV re-use private companies reported to be operational in 2021, reaching an estimated annual market of 500-600 MWp [21]. The benefits of panel re-use for South Africa include access to PVs for low-income households and businesses, waste management and creation of employment opportunities.

This paper will provide an overview of the current state of solar panels refurbishment in globally and in SA, identify opportunities in the re-use value chain, assess viability of re-use towards energy security and its social economic value to South Africans. The study will also highlight international best practices.

2 LITERATURE REVIEW

It is assumed that significant waste will be generated from 2030 and 2050 [2], [13]) when panels have been used for more than 25 years. Furthermore, discussions focusing on recycling of panels that reach their end of life are scarce. Commercial practices and research studies are however emerging to show that some discarded panels can be repaired and refurbished for re-use. Companies offering refurbishment services are shown in Table 1: Current global refurbishment facilities, including South Africa's Reclite (who have partnered with Rinovasol from the Netherlands) and eWaste Africa in South Africa [24]. The PV re-use market is estimated to be about 1 GWp/year 0 with demand for the used modules mostly coming from African countries [21].

Table 1: Current global refurbishment facilities

Country	Company
Germany	Solar-Pur GmbH, pvXchange, SMA Solar Technology, Hoermann Novo factory
Netherlands	Rinovasol Group
South Korea, Japan, and the United States of America	We Recycle Solar
America	Fabtech Solar Solutions, First Solar, SunPower
Netherlands	The Rinovasol Group
Sweden	SolarEdge
Italy	BayWa r.e., Alectris
Online market in Europe	Second sol

Circularity of the PV supply chain, including refurbishment and re-certification was explored by Tsanakas et al [14]. Standardization on reliability testing and re-certification were identified as challenges in the sector as they affect what can be claimed as a warranty period for re-used solar panels. Development of protocols for reliability testing and re-certification are however in progress by the EU's CIRCUSOL [6]. Radavičius et al [31] proposed strategies to promote circularity, including factoring second-life paths from manufacturing level, where panels can be designed to promote their second life through re-use, refurbishment and remanufacturing. However, refurbishment should be supported by re-testing, labelling and re-certification. Provision of a second life for solar panels can start with those on which faults occur on one component of the panel, for example broken glass that leaves the other parts of the panel intact. The re-use of panels is also unregulated with countries not having sufficient direct standards to govern it. Europe is leading in defining standards, but more needs to be done. Additionally, waste legislation, which has mainly targeted electronic waste, needs to be specified for solar panels. Guidelines for the re-use of solar panels were explored by Heide et al 0 covering technical, economic, environmental and legislative requirements. Refurbishment is also recognized as a viable option by global bodies such as IRENA [13], the IEA [16] and the UN [4].
Challenges in re-use of solar panels include collection, transportation, and storage costs, as well as damages during dismantling that can render panels unusable [4]. To know which panels qualify for refurbishment, a proposal has been set of panels that

retain 70% of their original power 0. Legislation, awareness and loosening international barriers for used solar panels are therefore recommended. Repairs are also currently being done by a few companies, some of which are small-sized [14]. The work can be labour intensive and requires specialized skills. It is also challenging to determine the life or duration of use for refurbished solar panels. Testing can be done to determine panel safety and performance, but standards and policies for re-certification are not fully developed and requires more focus. Finally, determination of panels that qualify for re-use is important to avoid dumping of PV waste in the name of re-use.

Minimal studies on refurbishment have been done for South Africa, prompting this study. Commercial refurbishment shows viability of the concept, an aspect that can benefit the local economy and create employment opportunities.

3 THE REFURBISHMENT PROCESS

When panels no longer satisfy their expected requirements, they may not necessarily have reached their end of life and can be re-used. The general re-use process (covering refurbishment and replication) involves sorting, cleaning, fault repairs or replication, testing, and certification as shown in Figure 1: Solar panel refurbishment process (Source: author analysis).

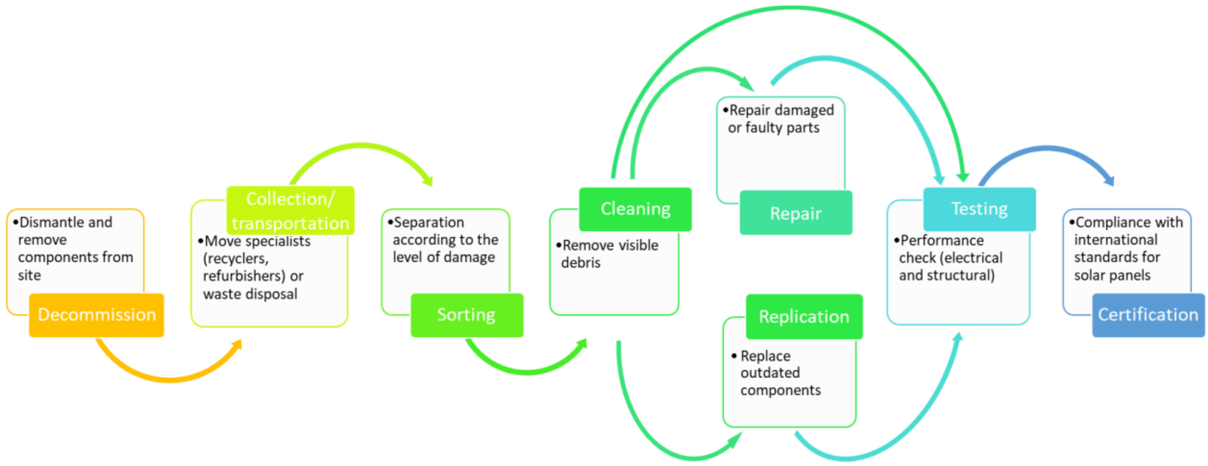

Figure 1: Solar panel refurbishment process (Source: author analysis)

These activities also point to business opportunities for South Africa. Depending on the level of damage, solar panels can either be repaired, replicated or go straight to testing if there is no damage. Replication is mostly done to solar panels that are outdated and their original parts are no longer available. Repairs have largely focused on crystalline solar panels and can be done when damages are on the materials, after weather-related events, animal destruction and lightning and overvoltage [28]. Failures that can be repaired on solar panels are limited to faulty junction boxes, backsheets, frames, bypass diodes and solar connectors. Damages that require replication include broken glass, cells and delamination. Testing services are currently offered by CSIR, Renewsys and Stellenbosch University. It is estimated that repaired modules can maintain 70%–95% of their initial power output [5]. Re-certification is the last and crucial step before the panels are reused again to ensure that solar panels meet national and international standards. Certification in South Africa is currently done by

TÜV Rheinland who rely on their overseas facilities and SGS, but re-certification of solar panels is still under development.

Currently, refurbishment is more suited for crystalline solar panels due to their structure and similarity over the years. The structure of a crystalline panels allows for repairs to be carried out on its parts and has been similar over years. When a panel is outdated or is beyond repair (broken glass, cells and back), replication can be done to give it a second life.

4 JUSTIFICATION FOR REFURBISHMENT

Since solar panels have a lifetime of more than 25 years, it is a common assumption that they will be used for the entire period. International Renewable Energy Agency (IRENA) and the International Energy Agency's Photovoltaic Power Systems Programme (IEA-PVPS) predicted that by 2050, 78 million tonnes of PV waste will be generated globally [13]. However, potential exists for solar panels to be uninstalled before their stipulated lifetime. Panels are becoming cheaper and more efficient, furthermore, many fail before the end of their lifetime [9]. Recycling capability of South Africa is also still developing hence alternative waste handling is necessary.

4.1 Failure of solar panels before lifetime

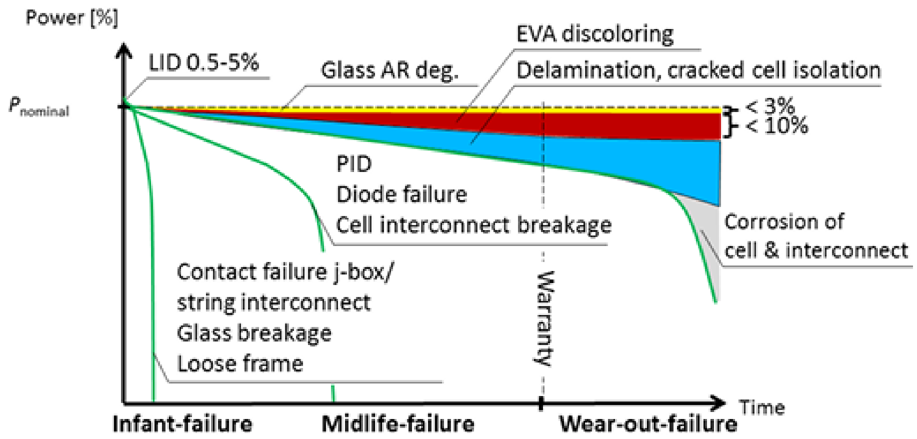

Figure 2: Failure modes for solar panels [16]

Analysis of failure modes for solar panels shows that failures are common and can affect the power output of a solar plant necessitating removal. Failed panels can be a problem more so for utility companies that have certain power delivery requirements. Three stages of failure can have been defined for solar panels as shown in Figure 2 where infant or early life failure happen about four years after installation, mid-life failures occur between 4 to 15 years and wear out failures occur from 15 years after installation. Infant failures include loose frames, glass breakage, failures from transportation, and defective j-box and cables [16]. Such failures result in dramatic reduction of power affecting overall plant performance.

Repairs can be carried out on module frames, backsheets, solar connectors, junction boxes and broken bypass diodes [28], including potential-induced degradation (PID) [14]. It is estimated that 90% of damaged modules are potentially repairable, claims that have been made by Rinovasol company [24]. The similarity in solar panels over time helps in replication especially for crystalline solar panels, with the process estimated to take about 2-3 weeks at $1.68 to $3.92/Wp for Second sol. Replication can be performed for various sized panels, but some companies see it as being cost-effective for panels manufactured within the last 10 years.

In South Africa, solar PV installations in the utility sector begun in 2012 for Bid Window 1 projects and as at March 2023, 2 293 MW had been procured up to Bid Window 5 [10]. At the time, the dominant PV technology used locally was polycrystalline followed by thin film PVs [26] and efficiencies were about 20.4% for polycrystalline and 16.7% for thin film (CdTe) [19]. Since then, efficiencies have increased to 24.4% and 22.3% polycrystalline and thin film respectively. The cost of the solar panels has also reduced to by about 63% between 2012 and 2021 [20], which can mean that replacement of failed older panels will yield better value. A general estimate is that about 60% of solar panels can be repaired or refurbished [6].

4.2 Refurbishment cost-benefit analysis

Existing refurbishment companies charge about at $1.68 to $3.92/Wp [28]. On the other hand, recycling costs are estimated to be between $15 and $45 per panel [18], while the costs of decommissioning are estimated to be about $50/kW. Avoiding the refurbishment or recycling costs means that panels can end up in landfills potentially being hazardous to the environment (groundwater and land) when materials such as lead, cadmium, and antimony leak from the panels.

The benefits of refurbishment of solar panels incudes potential affordability of solar panels to low-income communities and businesses, particularly. SMME's who contribute to 59% of economy wide employment in South Africa [29]. Refurbished solar panels can cost 50% less than new solar panels; JustSolar PV manufacturing company estimates sets its cost of a refurbished panel to be about 0.10/W in 2021 compared to $0.25 to $0.27/W for a new panel [15]. As solar panels take up the largest percentage of total PV plant costs, reducing their price is a win. Financial losses in businesses due to load shedding are estimated to be R900 million per day of stage 6 load shedding, yet only 19% of businesses can afford alternative energy solutions [17]. Small businesses also play a significant role in employment yet about 66% of businesses laid off retrenched their staff and about 5% completely shut down due to load shedding. Affordable alternative energy products can help to alleviate these challenges.

An additional benefit of PV refurbishment is that it can be done by small businesses, as has been the case with companies such as Second Sol and Reclite operating internationally and locally respectively, creating further opportunities for local SMME. The refurbishing businesses can also be operated with lower stock quantities, as compared to recycling facilities which require higher levels of stock for them to be profitable [25]. Emission levels from refurbishment processes are also lower.

The benefits of recycling include generation of raw materials that can be put back to the manufacturing sector of solar PVs [27]. For South Africa, localization of its PV manufacturing landscape is still developing with PV assembly being what has been successfully localised [26]. This means that the materials recovered will benefit international manufacturers. There are also claims that the value of recovered materials is not worth the process unless the PV wate volumes are high [25]. Local recycling companies are also few and are not able to recycle the solar cell, which is also the main carrier of toxic materials.

5 CURRENT STATE OF SOLAR PANEL REFURBISHEMNT IN SOUTH AFRICA

5.1 Scale of refurbishment in South Africa; drivers and challenges

Sub-Saharan Africa is experiencing a large increase in the amount of installed solar PV systems with some already becoming waste through transit and installation damages, mishandling and extreme weather events. Others are already becoming obsolete due to the pace of technology development. It is estimated that South Africa has 17 million solar panels installed, and most of these will require end-of-life (EOL) management before 2040 [12]. It is estimated that 1 million tons of solar PV waste will be generated through early loss and 750 000 tons by 2050 (see Figure 3).

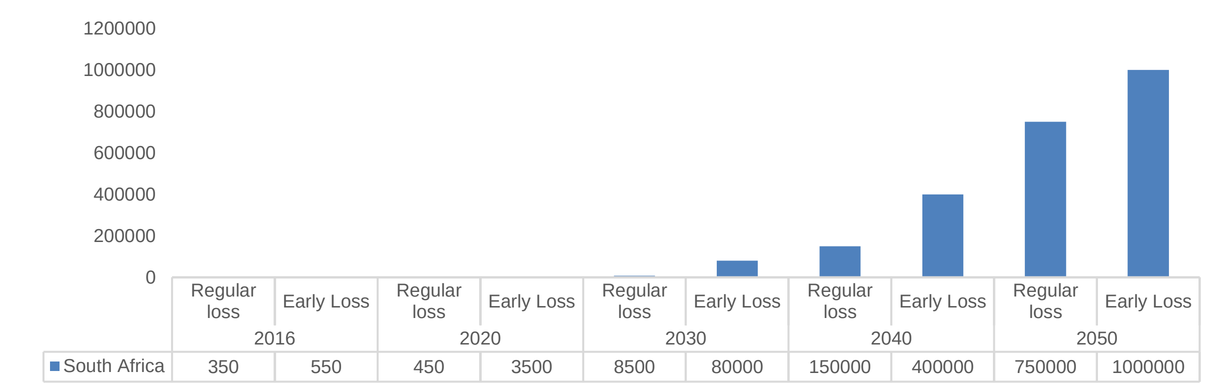

Figure 3: Estimated cumulative waste volumes of end-of-life PV panels in South Africa, Source: adapted from [13]

5.2 Regulations on PV waste in South Africa

The 2014 amendment to the National Environmental Management: Waste Act (No. 59 of 2008) states that e-waste, including all discarded or damaged solar panels was to be banned from landfill sites from August 2021. As a pro-active response to the growing national concern around waste and its impact on society and the environment, South Africa published the Section 18 Regulations to the National Environmental Management: Waste Act on 5 November 2020, which refers to the Extended Producer Responsibility (EPR) aspect of the National Environmental Management Waste Act (NEMWA). Under the Extended Producer Responsibility (EPR) Regulations, which came into effect in May 2021, solar panel producers must take responsibility to ensure that much of their products are returned (and recycled by an accredited and licensed facility after being sold and used [7]. The EPR regulations set out mandatory collection, recovery and recycling targets for off grid solar lighting, lighting solar panels and solar lighting energy storage (Government Gazette No, 43881), over a five-year period [11] as shown in Table 2.

The main stream of waste solar panels comes primarily from damaged panels, however, the amount of solar panel waste coming from aged and obsolete panels is likely to rise significantly in 5 years. In the short term (5-year horizon), the volumes will be insufficient to make full local recycling facility feasible, therefore the PV cells would need to be exported to countries where they are currently recycled. However local dismantling of PV systems is being done. Currently, only one local company, Reclite, provides solar panel refurbishment services, after which it has given the panels to local communities as part of the corporate social investment programme. Local research show that there are no local re-certification facilities for used solar panels exists. There is a need to invest in more refurbishment facilities and also for ongoing R&D for new technologies that would keep the value of the materials in the country, once economies of scale can be reached.

Table 2: Targets for identified waste streams, extracted from [11]

	TARGETS (%)														
PRODUCT	COLLECTION (%)					RECOVERY (%)					RECYCLING (%)				
	Y1	Y2	Y3	Y4	Y5	Y1	Y2	Y3	Y4	Y5	Y1	Y2	Y3	Y4	Y5
Fixtures/Modules/Associated electrical components	5	10	15	20	30	90	92	94	96	96	95	95	95	95	95
Lighting solar panels	5	10	15	15	18	70	70	70	70	70	90	90	90	90	90
Solar lighting energy storage	5	10	15	15	18	80	80	80	80	80	80	80	80	85	85

6 REFURBISHMENT VALUE CHAIN ANALYSIS IN SOUTH AFRICA

The refurbishment value chain in Figure 4 shows the activities that can benefit investors while contributing to the reduction in the country's unemployment levels.

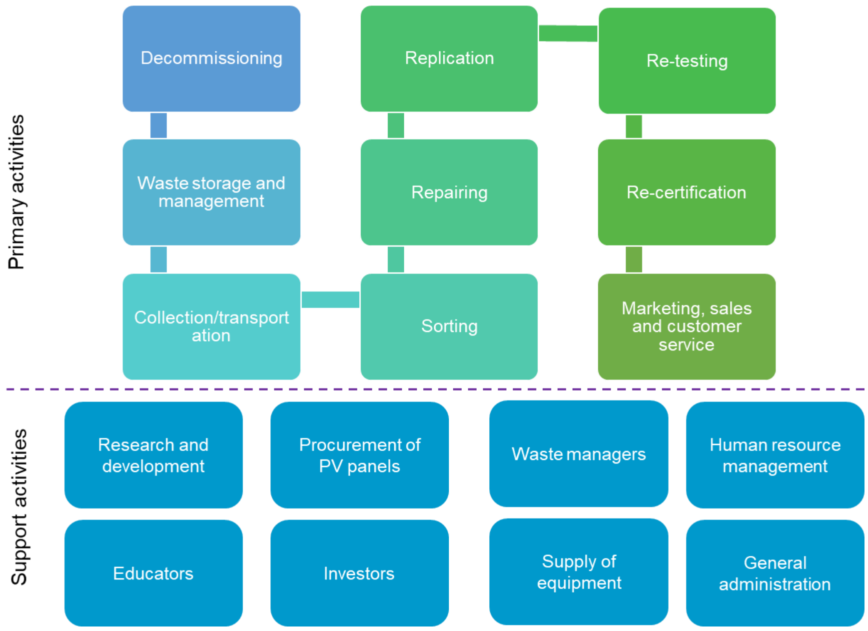

Figure 4: The solar panel refurbishment value chain

The primary activities cover the work functions to the refurbishment process and include PV plant decommissioning, storage and management of the PV waste, collection and transportation to the refurbishment facility. At the facility, sorting is first done to separate panels according to their levels of damage. Panels that are intact go to cleaning, re-testing, re-certification and sale. Damaged panels are repaired, while old are replicated. Re-testing and re-certification are then done, and panels are sold. Besides replication of solar panels, the primary activities are already ongoing in South Africa. More skilling and new skills development for replication can help to increase the service providers and workforce. Testing services are already being offered but re-certification is a challenge as the country currently relies on international service providers.

Supporting activities include research and development to determine the best refurbishment approach. Procurement of solar panels can be done locally and internationally where border policies allow. For South Africa, skilling is particularly important to develop the workforce. Investment and partnerships can also help to increase the number of local businesses. Supply of repair and replication equipment is also an opportunity. Skills and capabilities of secondary activities are established locally. However, more input is required in research and development, to determine refurbishment technologies that can best work for South Africa.

7 INTERNATIONAL BEST PRACTICES

One of the critical enablers for the development of an end-of-life management industry which includes the re-use of solar panels is government policies. In the USA, the state of Washington's Photovoltaic module stewardship and takeback program requires manufacturers to develop a plan for reuse of solar PV modules at their cost. A rate of more than 85% of the weight of collected PV modules must be re-used or recycled [32]. Movement of PV waste across international borders has also been done by PV Cycle company in Belgium which by 2019 had received 28 tons of wate from Panama and Senegal [22]. Such movement allows for sourcing of used solar panels. Decommissioned solar panels from adverse weather events have also created a significant source of supply for refurbishment businesses. Governments have also allowed for the operation of PV re-use companies which carry out repairs/refurbishment and replication of solar panels. At least 15 companies, which include small businesses are in operation globally. These companies carry out refurbishment through repairs and replications of old solar panels. They also create employment for skilled and low-skilled workers and have enabled PV ownership by lower-income earners, small business owners and contribute towards the reduction of PV waste. The cost of refurbished panels on the international market are also seen to be about 50% lower than new panels, increasing the numbers of those who are able to afford solar PV panels 0.

Lastly, collaboration has allowed for benefits from institutions that are already well versed with re-use of solar panels. For example, PV cycle, a non-profit created by the PV industry and strong in expertise in PV waste management, has collaborated with countries such as Japan, Germany, the USA, among others to provide their expertise in PV re-use and recycling [23]. International partnerships between stakeholders in the solar PV industry and research institutions created EU's CIRCUSOL which promotes circularity of solar panels.

8 DISCUSSION AND CONCLUSION

Energy security, inequality and electronic waste continue to be challenges for South Africa. Ongoing and projected load shedding in the country affects businesses and households negatively; rendering businesses inoperable, reducing employment, and disrupting activities of households. To mitigate these negative impacts, households and business have invested in alternative electricity supply options, and these include the installation of solar panels whose growth has been exponential. The affordability of these panels increases inequality as they are costly, with a minority of population being able to afford them. Additionally, solar panels get damaged from their early to late life, while others are decommissioned in adverse weather or replaced due to advanced technologies and reducing costs. These all contribute to potential future solar PV waste streams and this study proposed that these panels can be refurbished and re-used.

This study confirmed that refurbishment is not just possible, but it is already being done by 15 companies internationally and one in South Africa. Some of these companies are small businesses, with a market size estimated to be about 1 GWp/year. Reclite is a local company that refurbishes solar panels, in partnership with a Dutch company, Rinovasol. This also demonstrates the possibility of partnering with experienced players which can assist local businesses technically and financially. On the international side, refurbished solar panels benefit locals including communities, but most are exported to African countries where the demand is higher. This shows that a market for used solar panels already exists, and South Africa can explore these opportunities before the market is concentrated in certain regions. A look at the refurbishment process reveals activities which can be business opportunities for South Africa such as cleaning, repairing, replication, testing and re-certification. Some of these activities are already being carried out in South Africa, or whose skills can easily be learned (replication and re-certification). These, together with supporting activities, can capitalised on by investors and the unemployed (skilled and low-skilled). Moreover, refurbished solar panels cost about 50% less than a new solar panel, making then affordable to low-income businesses and households, and increasing energy access and security. One of the benefits of the refurbishment process is that it is not complex and can be started faster than recycling, implying that refurbishment opportunities can be harnessed early.

Challenges however exist in refurbishment. Legislation on PV waste in South Africa focusses on recycling, hence the refurbishment sector is currently unregulated. The same is the case globally, which can contribute to Africa being sold sub-standard refurbished panels. Definitions of a panel that can be refurbished are therefore required. Standardization of reliability testing and re-certification of used solar panels is still under development and by extension, warranty periods for used panels.

This study therefore recommends that legislation for the refurbishment of solar PV panels be developed in South Africa as this is a critical enabler. Legislation should also be developed to specifically address decommissioning and handling of PV waste locally and across borders. Moreover, specifications should also be made on which panels qualify for refurbishment and which ones do not to provide more value. Awareness should also be made on the re-use of panels. Testing and re-certification of used panels are important, yet the country has few facilities that provide testing and none that carry out re-certification. The development of the refurbishment market will benefit low-income households and businesses, who are currently unable to afford the high cost of solar PV systems while reducing solar panel waste. It will further enable taking up of business opportunities, including by SMME's hence contributing to economic growth and job creation.

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