Enkanini informal settlement, Western Cape, South Africa
Photo credit: MrNovel / Shutterstock

Solar Solutions: Bridging the Energy Gap for Off-Grid Settlements

The off-grid urban population

Access to electricity is fundamental to sustainable development and necessary for basic household activities.[1] The lack of electricity can hamper productivity, limit opportunities for income generation and inhibit the ability to improve living conditions. Nearly 1.1 billion people worldwide are still living without electricity and another one billion are connected to unreliable and unstable electricity grids.[2,3] While significant progress has been made in recent years to increase grid electrification in countries like India and Nigeria, projections suggest that by 2030 nearly 780 million people could still be off-grid.[2] New and sustainable approaches to providing electricity that transcend the established norms are required, especially if we are to achieve the Sustainable Development Goal of universal access to affordable, reliable and modern energy services by 2030.

Rural areas have the greatest need for off-grid energy solutions, however the issue of electricity access facing urban residents should also be recognized. About 48 per cent of developing countries' populations now reside in cities, and the proportion may rise to 63 per cent by 2050.[4] Nearly a quarter of the urban population lives in various forms of informal settlements and the proportion is much larger in the rapidly growing cities of Africa, Asia and Latin America. The mounting demands for infrastructure and basic services—suitable housing, clean water and sanitation, and affordable and reliable energy forms such as electricity—tend to exceed the capacities of cities to meet the needs of all their inhabitants.

Provision of basic services for urban informal settlements is a significant challenge that varies according to how the municipal government defines eligibility for the supply of formal urban services. In the case of electricity access, challenges include land rights, recognition by authorities of legal occupancy, stakeholders' reluctance to engage, price of services, return on investment made by the electricity provider, and distance to existing grid and other necessary infrastructure.[5]

Lack of formal possession of the property on which a shack or house stands can exclude an application to the local or national electricity utility for a formal connection.[6] Electricity providers worry about profitability when servicing these communities: the first concern is the high rate of default on financial commitment and the second concern is the low rate of electricity consumption. Both issues relate to the low and undependable incomes of these communities' occupants.[5,6]

Fire hazard is a major threat in informal settlements due to the high population densities, the close proximity of the structures and dwellings, and the common use of kerosene or paraffin lamps, candles and other open flame energy sources.[7,8] Those fire hazards, and associated indoor air pollution, should help persuade a variety of stakeholders to install electricity.[9-11] However, once a few connections are installed, illegal and overloaded electricity connections often abound and pose significant safety risks for informal settlements, in the familiar form as fire hazards but also as electrocution. Surveys from South Africa show that in some informal settlements, over 30 per cent of the population use an illegal connection as their main electricity source.[5]

Even when a grid connection has been established, power supply can be unreliable. In some developing countries, households with long established grid connections may adapt to regular blackouts by scheduling water pumping and battery recharging for periods when the power supply is most reliable.[12] Even developed countries experience power outages, sometimes completely when severe storms hit but also as rolling blackouts, also called rotational load shedding or feeder rotation, when other extreme events, such as heat waves, strain the supply.[13] Too often, households in developing and developed countries invest in small diesel generators for back up. These generators pollute, with greenhouse gas emissions, noxious exhaust and annoying noise.[12,13]

Earth at night, 2016

Photo credit: NASA Earth Observatory/NOAA NGDC

The solar photovoltaic evolution

For decades, multilaterals, governments and non-governmental organizations have promoted decentralized solar photovoltaic systems in inaccessible rural areas, particularly to power public services, such as school and clinic lighting, information exchange and communications, community pumping and vaccine refrigeration.[14,15] Now, they can be considered as an alternative solution to grid electricity anywhere in developing countries where governments and the private sector cannot meet expectations for the expansion and maintenance of a grid network, including informal urban settlements.[14]

Recent years have seen an increased popularity of small distributed solar energy systems in low-income communities in Africa and Asia, where at least 95 per cent of the off-grid population reside.[16-18] These systems range from a stand-alone lantern with a built-in solar panel, a battery and a light emitting diode (LED) bulb, to a small, or pico-scale, solar unit equipped with a panel, at least one LED bulb, and a battery with USB charging outlets for a mobile phone or even a low-power appliance.[3] Prices range from US$10 for a solar lantern to US$50 for a pico-solar system.

These relatively affordable solar lighting products offer a better return on investment, particularly considering their long lifespans in contrast to the recurring cost of kerosene or paraffin for lanterns, dry-cell batteries for torches, or candles.[3,19] More powerful solar home systems include similar features and can support several lights and relatively larger household DC appliances such as a radio, fan, television or even a refrigerator.

Many of the off-grid population in sub-Saharan Africa spend about 10-30 per cent of their household income on their kerosene supply and in sub-Saharan Africa and Asia kerosene lighting costs the poor nearly US$15.7 billion per year.[20,21] The replacement of kerosene lanterns by solar lanterns translates into significant cost savings for households over the lifetime of the solar lantern as well as a significant reduction of the use of open flames in lanterns and candles, reducing exposure to indoor air pollution and the risk of fire hazards in informal settlements.[11,21-23] These pico-solar and solar home systems have become attractive to a greater range of the off-grid population than ever before.

The continuing price reductions of the various photovoltaic components and rapid advances in technologies are notable. The cost of crystalline silicon solar cells dropped 85 per cent between 2008 and 2016 due to increased manufacturing efficiency and economies of scale.[21]

Advances in LED technology resulted in improved efficiency—more light emitted per electrical input. Highly polluting lead acid batteries are becoming obsolete, replaced by higher performance lithium ion batteries that provide higher energy storage capacity, longer service life, and faster and more efficient recharging.[24] While the batteries are the most expensive component of a solar home system, the price of lithium-ion batteries dropped nearly 65 per cent within five years, and is expected to fall further due to their widespread use in laptop computers and other devices.[21]

Kerosene wick lamps made from recycled cans

Courtesy of Evan Mills

Off-grid solar

The off-grid population

Middle East and North Africa
Urban: 1 million
Rural: 12 million

South Asia
Urban: 12 million
Rural: 327 million

Sub-Saharan Africa
Urban: 113 million
Rural: 504 million

East Asia and the Pacific
Urban: 5 million
Rural: 50 million

Latin America and the Caribbean
Urban: 5 million
Rural: 14 million

By 2030 nearly **780 million** people globally- could remain off-grid

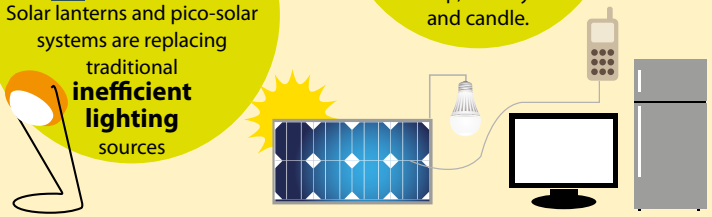
Solar photovoltaics

These solar photovoltaics range from a **solar lantern**, a small solar system or **pico-solar** supporting at least one light bulb, to a **solar home system** with a larger battery capacity that can power multiple LED lightings and household DC appliances.

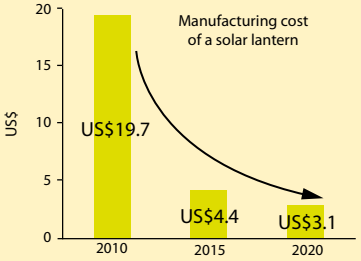
Solar photovoltaics are becoming mainstream among off-grid populations in rural and urban areas particularly in Africa and South Asia

Each year the off-grid population in Africa and South Asia spend an estimated **US$14.4 billion** and **US$ 6.6 billion**, respectively, on kerosene and lamp, battery torch and candle.

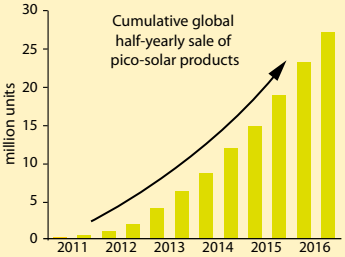
Solar lanterns and pico-solar systems are replacing traditional **inefficient lighting** sources



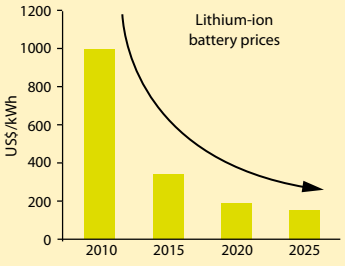
Prices are dropping



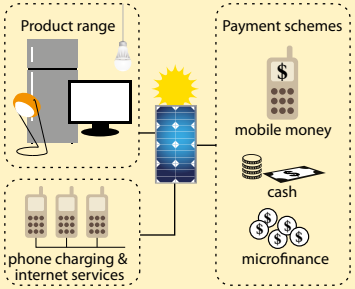
Sales are rising



Battery costs are falling



Diverse business models



Challenges and opportunities

The **well-designed policies** and clear vision on renewable energy combined with advancing **technology** and **market innovation** could encourage today's off-grid communities to remain on the clean energy and **sustainability pathway**

E-wastes generated by solar products are projected to increase exponentially in coming decades. This will require environmentally sound management of spent products, but at the same time, present business opportunities for **recycling markets**

Off-grid solar systems could provide **hundreds of thousands of jobs** throughout the value chain

UN Environment estimates that the transition to efficient off-grid lighting is likely to create **30 times more jobs** than the fuel-based lighting does

Innovative marketing of off-grid solar energy

A key factor that allows solar-powered electricity to enter the market in informal settlements is innovation in business models.[16,25,26] Although the retail prices of pico-solar and solar home systems may be manageable for some, those in the lowest-income portion of the off-grid population cannot afford the initial equipment purchase. Many small-scale and start-up companies are offering financial schemes to help consumers overcome the barrier of upfront costs, with the aim of eventual profitability through capture of the market's high volume.[16,17,19]

Several of these schemes arrange for people to pay the same small amounts they were paying for kerosene. In a pay-as-you-go scheme, customers pay a small instalment on a solar power system and make regular payments on a daily, weekly or monthly basis. If payment is not made, the system is automatically deactivated. After completing payments, customers own the product. This scheme is often used in connection with existing mobile-phone money services, which are well-established businesses in regions such as some parts of sub-Saharan Africa.[17,27]

In India, nearly a third of its urban population live in informal settlements.[28] A survey of Delhi's informal settlements estimated an average monthly income of only US$105 (INR 6 676) per dweller and 90 per cent of which is spent.[29] Most companies provide financing schemes to serve the most marginalized families who are rural migrants to informal settlements in India's rapidly growing cities.

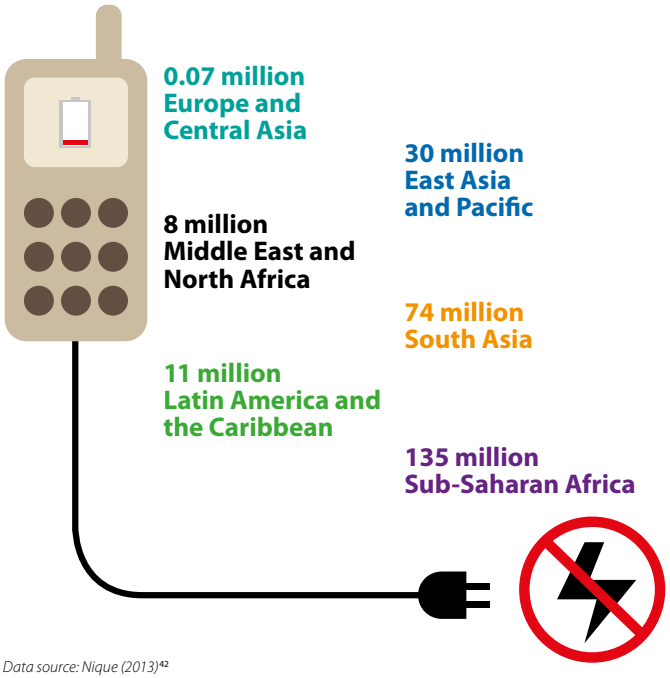
Without a formal address and less than a decade in their location, the families cannot access traditional financing services. Some companies employ local men and women who go door-to-door in the informal settlements offering products with affordable payment terms.[30] Customers can purchase a solar lantern on a 5-8 week payment plan. Some companies have evolved further to develop business relationships with microfinance institutions to expand financing options for lowest income consumers.[31]

In South Africa, even after the post-apartheid electrification and housing program, close to a quarter of the population live in informal settlements without electricity.[32] A sustainability

Video: Why solar power is spreading so fast in Africa

Video Link: https://www.youtube.com/watch?v=tkvbZ0ADmz0
Photo credit: Gabriela Gemio Beltrán
© The Economist

Estimated number of mobile phone subscribers living off-grid



Data source: Nique (2013)[42]

project led by the University of Stellenbosch aimed to improve the living conditions of the 4 500 inhabitants of Enkanini, an off-grid informal settlement in Western Cape Province.[33-35] Using energy-efficient technologies, the interventions included reorienting dwellings to optimize their passive solar potential, improving the building insulation and harvesting water.

The project ran an off-grid solar power business that served the settlement with an expectation to scale it up as a franchise model for other off-grid settlements. Solar home systems—a solar panel, two indoor LED lights, one TV, an outdoor spotlight and phone charging facilities—are offered to residents on a fee-for-service basis. Customers pay an installation fee of US$14 (ZAR 200) and monthly lease payments of US$11 (ZAR 150).[33]

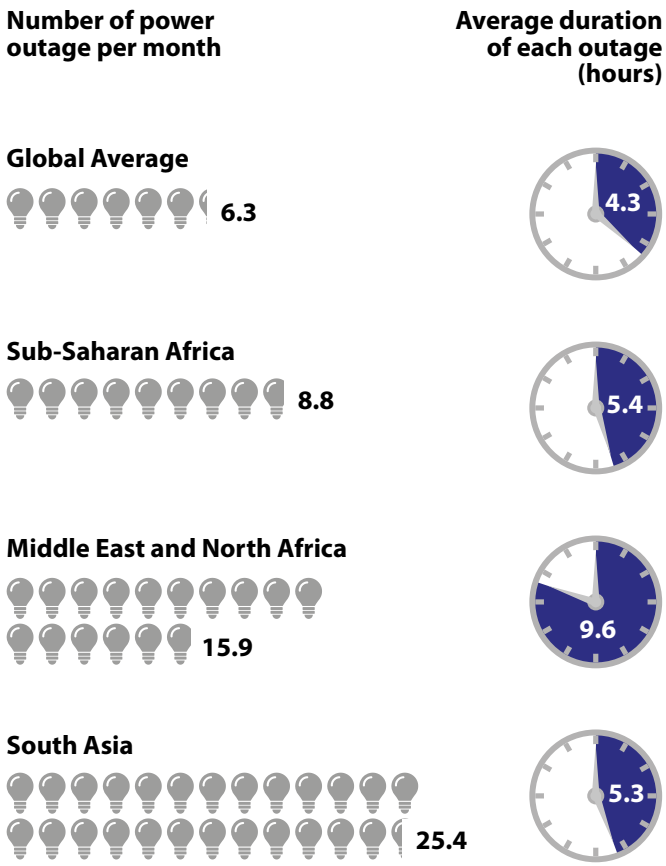
A company established by the project employs staff from the settlement and is responsible for the deployment and maintenance of the system. This business model has now been adopted by some municipal authorities for other informal settlements in South Africa.[36-38]

Pop-up solar kiosks are another unique form of business innovation that exploits solar energy to serve off-grid communities outside of their homes. A small mobile solar kiosk is equipped with a few solar panels and a lithium-ion battery unit that can power 10-80 mobile phones simultaneously, and some even offer Wi-Fi services.[39,40] Larger solar kiosks are stationary and fitted with rooftop solar panels.[41] Functioning like a grocery store, it offers a range of goods such as solar products, mobile phones, consumables, medicine, as well as phone charging and internet services. A variety of solar kiosks are spreading across Africa where 135 million mobile subscribers live without electricity in their homes.[42]

Video: In high demand: Solar Kiosk in Rwanda

Video Link: https://www.youtube.com/watch?v=QpukLasOnSo *© DW English*
Photo courtesy of Henri Nyakarundi/African Renewable Energy Distributor

Frequency and duration of grid power outage
(showing only regions above global average)



Data source: The World Bank's Enterprise Surveys, http://www.enterprisesurveys.org

Continuing on the pathway of renewable energy

A pico-solar system is only the first step for a family to lift themselves out of energy poverty. Whether supplying electricity to dwellings in rural, peri-urban or urban locations, a small system may be sufficient at first, but once their purchasing power grows and the price continues to drop, people will look for more capacity. This presents an array of opportunities to continue along the solar pathway, rather than turning to grid power sourced from coal and oil. In 2016, fossil fuel accounted for about 80 per cent of electricity generation in Africa and 60 per cent in South Asia.[43,44]

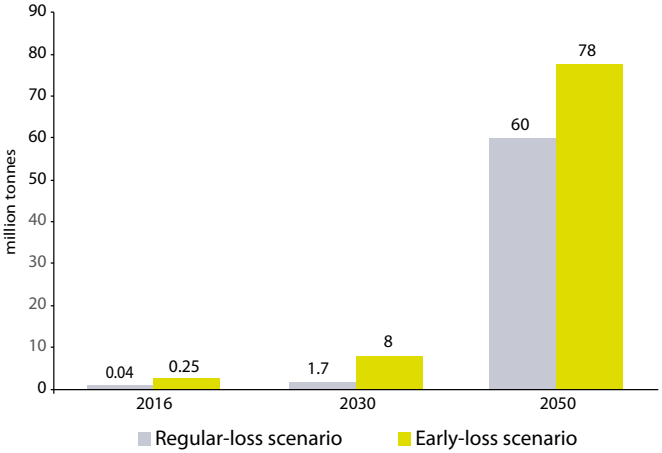
To remain on the sustainability pathway and reinforce renewable energy solutions, some factors should be considered, given their influence on solar market expansion. These include needs for quality standards, consumer awareness, financial assistance, e-waste management, and re-orientation of government policies.[17,25]

In many developing countries, solar products have been available for years, if not decades. Often the products were of low quality or short life span. Decisions to stay with off-grid solar may depend on today's impression of the products available in the market. Negative experiences with substandard generic products could damage the receptivity of today's and tomorrow's potential consumers. Two concurrent paths could help remedy the problem: One is to establish higher quality standards for the products themselves and take-back and recycling guarantees by the service providers. The second path is to raise awareness among consumers about the higher quality that is now standard for the products themselves, for the services that accompany the transaction, and for the extended and enabling payment schemes.[25]

Video: Solar energy for Africa by 2030

Video Link: https://www.youtube.com/watch?v=Bb8Su6OeWYw *© CGTN Africa*
Photo credit: MrNovel / Shutterstock.com

Overview of global PV panel waste projections 2016-2050



Source: Adapted from IRENA and IEA-PVPS (2016)[47]

A lack of working capital for companies, particularly those that provide end-user financing, may limit market development. Supportive programmes can be devised to mitigate these challenges and the innovative business models already in play are good examples of what is possible.[5,16,17,25] Future demand for solar home systems with higher capacity will also help expand the current markets and further prompt commercial interest and investment from private investors, development banks and donors. In 2016, at least US$60 million was invested in two companies in Africa that offer larger and higher priced solar home systems than the original pay-as-you-go operators.[45] These pay-as-you-go solar companies are likely to aim at creating a new market of higher income consumers who may already be connected to an unreliable electricity grid.

Another challenge involves the e-wastes generated by the growing volume of products in use. While lithium-ion batteries are considered less toxic compared to lead acid, they still have the potential to pollute the environment, given the variety of chemical materials contained in the batteries.[46] Currently few manufacturers are supplying replacement parts or recycling old batteries at the end of their life cycle.[47,48] Similarly, crystalline silicon panels are a cause of concern as they also contain toxic substances, such as cadmium and lead. If customers could upgrade their consumer goods for better products through take-back programmes, recycling markets could become viable and reduce the risk of contamination. It should be noted also that e-waste regulations might not exist to deal specifically with solar panels in many countries where small solar systems have gained popularity.[47]

The challenges involving government interventions include uncertainties about possible future policy choices regarding off-grid electrification in national, regional and municipal strategies and implementation. Also, many countries have a long history of subsidizing citizens' kerosene purchases to quell dissatisfaction over unmet promises for grid supply. While some recommendations push for elimination of kerosene subsidies, another path is to allow off-grid customers to apply the subsidies to the purchase of their solar power systems. Once those are paid off, questions remain whether the subsidies should then continue. As well, off-grid power supply companies suggest an end to fiscal and import barriers, such as high import tariffs and value-added tax on solar power products, which may significantly increase the price of the products.[19,25]

Finally, there are challenges regarding capacity development, beyond the public awareness effort. Companies, and communities need a qualified and skilled workforce to support the development of the sector. Training courses and apprentice programmes, especially for members of the local community that will make up the market, should be available.[3,25] Off-grid systems will provide hundreds of thousands of jobs throughout the value chain in the near future and could provide a path out of poverty for those who learn about installation and maintenance of larger home solar systems.[25,49] A UN Environment's study in West Africa estimates that the transition to efficient off-grid lighting is likely to create 30 times more jobs than fuel-based lighting does.[50] With the right policies and regulations on renewable energy and a clear vision of future possibilities, today's distributed solar powered systems could remain the energy of choice for off-grid communities in the rural and urban areas. This could be a key component of accomplishing Sustainable Development Goals for universal access to affordable, reliable and modern energy services by 2030 and for eliminating poverty.

A woman trained by the Barefoot College to install, repair and maintain solar systems for her home in Rajasthan, India

Photo credit: Knut-Erik Helle, licensed under CC BY-NC-ND 2.0

References

1. GEA (2012). *Global Energy Assessment – Toward a Sustainable Future*. Cambridge University Press, Cambridge, UK and New York, NY, USA, and the International Institute for Applied Systems Analysis, Luxembourg, Austria. http://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/Global_Energy_Assessment_FullReport.pdf
2. International Energy Agency and the World Bank (2015). *Sustainable energy for all 2015—Progress toward sustainable energy*. The World Bank, Washington DC. http://www.se4all.org/sites/default/files/GTF-2105-Full-Report.pdf
3. UNEP (2015). *Developing effective off-grid lighting policy: Guidance note for governments in Africa*. United Nations Environment Programme, Nairobi. http://www.enlighten-initiative.org/portals/0/documents/Resources/publications/OFG-publication-may-BDef.pdf
4. UNDESA (2014). *World Urbanization Prospects: The 2014 Revision, Highlights*. United Nations, Department of Economic and Social Affairs, New York. https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.Pdf
5. Gaunt, T., Salida, M., Macfarlane, R., Maboda, S., Reddy, Y. and Borchers, M. (2012). *Informal Electrification in South Africa: Experience, Opportunities and Challenges*. Sustainable Energy Africa, Cape Town. http://www.cityenergy.org.za/uploads/resource_116.pdf
6. Reddy, Y. and Wolpe, P. (2015). *Tackling urban energy poverty in South Africa*. Sustainable Energy Africa, Cape Town. http://www.sustainable.org.za/uploads/files/file72.pdf
7. Kazerooni, Y., Gyedu, A., Burnham, G., Nwomeh, B., Charles, A., Mishra, B., Kuah, S.S., Kushner, A.L., Stewart, B.T. (2015). Fires in refugee and displaced persons settlements: The current situation and opportunities to improve fire prevention and control. *Burns*, 42, 1036-1046. http://www.sciencedirect.com/science/article/pii/S0305417915003861
8. Kimemeia, D.K., Vermaak, C., Pachauri, S. and Rhodes, B. (2014). Burns, scalds and poisonings from household energy use in South Africa: Are the energy poor at greater risk? *Energy for Sustainable Development*, 18, 1-8. https://www.researchgate.net/publication/259519739_Burns_scalds_and_poisonings_from_household_energy_use_in_South_Africa_Are_the_energy_poor_at_greater_risk
9. Jacobson, A., Bond, T.C., Lam, N.L. and Hultman, N. (2013). *Black carbon and kerosene lighting: An opportunity for rapid action on climate change and clean energy for development*. Global Economy and Development Policy Paper 2013-03. The Brookings Institution, Washington DC https://www.brookings.edu/wp-content/uploads/2016/06/04_climate_change_clean_energy_development_hultman.pdf
10. Lam, N.L., Smith, K.R., Gauthier, A. and Bates, M.N. (2012). Kerosene: A review of household uses and their hazards in low-and middle income countries. *Journal of Toxicology and Environmental Health, Part B, Critical Reviews*, 15(6), 396–432. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3664014/pdf/nihms447641.pdf
11. Mills, E. (2016). Identifying and reducing the health and safety impacts of fuel-based lighting. *Energy for Sustainable Development*, 30, 30-59. https://www.researchgate.net/publication/290975529_Identifying_and_reducing_the_health_and_safety_impacts_of_fuel-based_lighting
12. Mukwaya, P.I. (2016). Urban Adaptation to Energy Insecurity in Uganda. *Current Urban Studies*, 4, 69-84. https://file.scirp.org/pdf/CUS_2016032414011321.pdf
13. Ghanem, D.A., Mander, S. and Gough, C., 2016. "I think we need to get a better generator": Household resilience to disruption to power supply during storm events. *Energy Policy*, 92, pp.171-180.
14. Frame, D., Tembo, K., Dolan, M.J., Strachan, S.M. and Ault, G.W. (2011). A community based approach for sustainable off-grid PV systems in developing countries. In The Electrification of Transportation and the Grid of the Future, the report of the 2011 IEEE Power and Energy Society General Meeting, Detroit, MI, United States, 24-28 July 2011. https://www.strath.ac.uk/media/departments/eee/cred/Conference_Paper.pdf
15. UNDP (2004). *Solar Photovoltaics in Africa: Experiences with financing and delivery models-Lesson for the future*. Monitoring and evaluation report series, Issue 2. United Nations Development Programme, New York and Global Environment Facility, Washington DC. http://www.undp.org/content/undp/en/home/librarypage/environment-energy/sustainable_energy/solar_photovoltaicsinafricaexperienceswithfinancinganddeliverymo.html
16. Nygaard, I., Hansen, U.E. and Larsen, T.H. (2016). The emerging market for pico-scale solar PV systems in Sub-Saharan Africa: From donor-supported niches toward market-based rural electrification. UNEP DTU Partnership, Copenhagen.
17. REN21 (2016). Renewables 2016 Global Status Report. REN21 Secretariat, Paris. http://www.ren21.net/GSR-2016-Report-Full-report-EN
18. UN-HABITAT (2016). Urbanization and Development: Emerging Futures. World Cities Report 2016. United Nations Human Settlements Programme, Nairobi. https://unhabitat.org/wp-content/uploads/2014/03/WCR-%20Full-Report-2016.pdf
19. Lysen, E.H. (2013). Pico Solar PV Systems for Remote Homes: A new generation of small PV systems for lighting and communication. Report IEA-PVPS T9-12: 2012. International Energy Agency, Paris. http://iea-pvps.org/index.php?id=299&eID=dam_frontend_push&docID=1433
20. SolarAid (2013). Facts about kerosene, solar and SolarAid. SolarAid factsheet. https://www.solar-aid.org/assets/Uploads/Publications/Facts-about-kerosene-solar-and-SolarAid.pdf
21. BNEF and Lighting Global (2016). Off-grid solar market trends report 2016. Bloomberg New Energy Finance, New York and Lighting Global, Washington DC. https://data.bloomberglp.com/bnef/sites/4/2016/03/20160303_BNEF_WorldBankIFC_Off-GridSolarReport_.pdf

22. UN-HABITAT (2009). Promoting Energy Access for the urban poor in Africa: Approaches and Challenges in Slum Electrification. United Nations Human Settlements Programme, Nairobi. http://mirror.unhabitat.org/downloads/docs/8292_16690_GENUS%20AFRICA.EGM%20Final%20Report.pdf

23. UN-HABITAT (2012). Enhanced Energy Access for Urban Poor Practice Casebook. United Nations Human Settlements Programme, Nairobi. http://www.avsi-usa.org/uploads/6/7/4/2/67429199/avsi___coelba3.pdf

24. Phadke, A.A., Jacobson, A., Park, W.Y., Lee, G.R., Alstone, P. and Khare, A. (2015). Powering a Home with Just 25 Watts of Solar PV. Super-Efficient Appliances Can Enable Expanded Off-Grid Energy Service Using Small Solar Power Systems. Lawrence Berkeley National Laboratory, Berkeley.

25. Diecker, J., Wheeldon, S., and Scott, A. (2016) Accelerating access to electricity in Africa with off-grid solar: Policies to expand the market for solar household solutions. Overseas Development Institute, London UK.

26. McKibben, B. (2017) The Race to Solar Power Africa. *The New Yorker*, 26 June 2017. http://www.newyorker.com/magazine/2017/06/26/the-race-to-solar-power-africa

27. IEA and World Bank (2015). Sustainable Energy for All 2015 – Progress Toward Sustainable Energy. World Bank, Washington, DC. https://openknowledge.worldbank.org/handle/10986/22148

28. Corrigan, G. and Di Battista, A. (2015). 19 charts that explain India's economic challenge. World Economic Forum website. https://www.weforum.org/agenda/2015/11/19-charts-that-explain-indias-economic-challenge/

29. PRIA (2014). Government led exclusion of the urban poor: A greater contribution though a lesser recipient. Delhi Study Report 2014. The Society for Participatory Research in Asia, Delhi. https://terraurban.files.wordpress.com/2014/01/delhi-study_april-2014.pdf

30. Pollinate Energy (2017). Pollinate Energy website. https://pollinateenergy.org/

31. Davidsen, A., Pallassana, K., Singh, J., Shiv, J., Walker, P., Parrish, S. and Sitsabeshan, S. (2015). The business case for off-grid energy in India. The Climate Group. https://www.theclimategroup.org/sites/default/files/archive/files/The-business-case-for-offgrid-energy-in-India.pdf

32. Department of Energy (2012). A survey of energy-related behaviour and perceptions in South Africa: The residential sector. Department of Energy, Government of the Republic of South Africa. http://www.energy.gov.za/files/media/Pub/Survey%20of%20Energy%20related%20behaviour%20and%20perception%20in%20SA%20-%20Residential%20Sector%20-%202012.pdf

33. Lemaire, X. and Kerr, D. (2014). The iShack Project in Enkanini, Stellenbosch, South Africa. Supporting Africa Municipalities in Sustainable Energy Transitions (SAMSET) website. https://samsetproject.wordpress.com/2014/12/20/the-ishack-project-in-enkanini-stellenbosch-south-africa/

34. SM and CORC (2012). Enkanini (Kayamandi) household enumeration report. Stellenbosch Municipality and Community Organisation Resource Centre. http://sasdialliance.org.za/wp-content/uploads/docs/reports/Enumerations/Enkanini%20Final%20Report.pdf

35. Wilde, S. (2015). iShack delivers power (and television) to the people. Mail & Guardian, 13 March 2015. https://mg.co.za/article/2015-03-13-ishack-delivers-power-and-television-to-the-people

36. Kovacic, Z., Smit, S., Musango, J.K., Brent, A.C. and Giampietro, M. (2016). Probing uncertainty levels of electrification in informal urban settlements: A case from South Africa. Habitat International, 56, 212-221. http://www.sciencedirect.com/science/article/pii/S0197397515302356

37. Lemaire, X. and Kerr, D. (2016). Informal Settlements – Electrification and Urban Services.
SAMSET Policy Brief. UCL Energy Institute, London.

38. Murugan, S. (2013). Solar energy lights up Ekurhuleni's informal settlements. Vuk'uzenzele, June 2013. http://www.vukuzenzele.gov.za/solar-energy-lights-ekurhuleni's-informal-settlements

39. ARED (2017). Our solutions. African Renewable Energy Distributor. http://www.a-r-e-d.com/

40. Juabar (2017). Our design process. Juabar Design. http://juabar.com/

41. SOLARKIOSK (2017). One Solution—Various Purposes. SOLARKIOSK. http://solarkiosk.eu/product/

42. Nique, M. (2013). Sizing the opportunity of mobile to support energy and water access. GSMA, London. https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2013/12/Sizing-the-Opportunity-of-Mobile_Nov-2013.pdf

43. UNEP (2017). Atlas of Africa Energy Resources. United Nations Environment Programme, Nairobi. http://wedocs.unep.org/handle/20.500.11822/20476

44. Shukla, A.K., Sudhakar, K. and Baredar, P. (2016). Renewable energy resources in South Asian countries: Challenges, policy and recommendations. Resource-Efficient Technologies, 1-5. http://www.sciencedirect.com/science/article/pii/S2405653716302299

45. Bloomberg New Energy Finance (2017). 1Q 2017 Off-grid and mini-grid market outlook. Climatescope 2016 website. http://global-climatescope.org/en/off-grid-quarterly/q1-2017/

46. Wang, X. (2014). Managing end-of-life lithium-ion batteries: An environmental and economic assessment. Thesis, Rochester Institute of Technology, New York. http://scholarworks.rit.edu/cgi/viewcontent.cgi?article=9337&context=theses

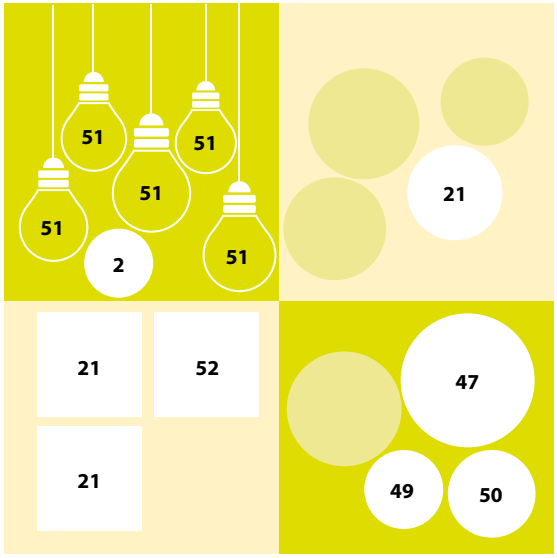
47. IRENA and IEA-PVPS (2016), "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems. http://www.irena.org/DocumentDownloads/Publications/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf

48. Industry Opinion on Lifecycle and Recycling (2014). The Global Off-Grid Lighting Association, Utrecht, https://www.gogla.org/sites/default/files/recource_docs/gogla-industry-opinion-on-lifecycle-and-recycling1.pdf

49. Mills, E., 2016. Job creation and energy savings through a transition to modern off-grid lighting. *Energy for Sustainable Development*, 33, pp.155-166.

50. UNEP (2014). Light and livelihood: A bright outlook for employment in the transition from fuel-based lighting to electrical alternatives. United Nations Environment Programme, Nairobi. http://www.ecreee.org/sites/default/files/light_and_livelihood_-_a_bright_outlook_for_employment.pdf

Graphic references



51. World Bank (2017). World Development Indicators. The World Bank, Washington DC. http://databank.worldbank.org/data/

52. GOGLA (2017). *Global off-grid solar market report July-December 2016: Semi-annual sales and impact data*. Global Off-Grid Lighting Association, Utrecht. https://www.gogla.org/sites/default/files/recource_docs/final_sales-and-impact-report_h22016_full_public.pdf

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