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The ‘low power’ revolution: rural off-grid consumer technologies and portable micropower systems in non-industrialised regions.

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ABSTRACT
This review analyses the growth in small ‘low power’ renewable energy and consumer product technologies and their potential utility in rural and remote economic development. The historical legacy of increasingly industrial-scale and expensive centralised high voltage alternating current (AC) systems contrasts starkly against the dynamic plethora of energy efficient portable low power direct current (DC) devices and consumer goods that underpin a modern economy. Advantages of portable DC devices are their inherent utility as a deferrable load and imbedded storage, enabling the appliance to become the balance of system (BOS) component and the power management system when coupled to portable renewable energy system or a microgrid. These developments present the opportunity to revise broad assumptions of appropriate energy system investment models for non-industrialised nations without an expensive historical centralised high voltage AC industrialisation legacy. It also presents the opportunity to revisit appropriate rural clean energy stand-alone or microgrid system designs and configurations, and engage the information and communication technology (ICT) sector as a major new investor in energy services and infrastructure.

Keywords: renewable energy; stand-alone; DC; low voltage; rural; economic development.

1. Introduction
Today billions of portable information and communication technology (ICT) devices, including smartphones, tablets, lights, MP3 players, electric gardening equipment, PCs and many accessories with rechargeable batteries are now in circulation worldwide, and are increasingly associated with user energy autonomy and energy efficiency (Schuss and
Rahkonen 2012; Didier, Toshimitsu et al. 2013; Ruutu, Nurminen et al. 2013; Willems, Aerts et al. 2013). This includes the most non-industrialised regions of the world. For example, when around 63% of people in sub-Saharan Africa have access to improved drinking water (United Nations 2013), and only around 30% have access to centralised electricity services (Welsch, Bazilian et al. 2013); access to mobile phones have grown from practically zero to around 50% in only a decade (GSMA Intelligence 2013; The World Bank 2013). Why is this so? In contrast to the ‘hard won’ capital-intensive conventional electricity and water infrastructure investments by governments and international agencies (The World Bank 2013; United Nations 2013; Welsch, Bazilian et al. 2013), the swift adoption of ICT and the roll-out of the associated infrastructure has occurred relatively autonomously on a largely commercial basis in a very short timeframe.

The relatively low population-wide levels of access to water and electricity services is much more extreme for those living in rural ‘off-grid’ areas in non-industrial areas. The vast majority of rural poor populations in non-industrialised nations have no access to reliable, safe, healthy, and affordable centralised electricity services (Karekezi 2001; Schultz, Platonovaa et al. 2008; Welsch, Bazilian et al. 2013). Where access does exist, economic barriers often predominate, as many rural poor households cannot afford to connect to a centralised electricity network (Adkins, Eapen et al. 2010; Soto, Basinger et al. 2012; Adkins, Oppelstrup et al. 2013). For these households to enjoy the benefits of modern utility services, small-scale systems must become, and are becoming, a cost-effective alternative in remote areas (Seeling-Hochmuth 1997; Vandenbergh, Beverungen et al. 2001; Edenhofer, Pichs-Madruga et al. 2011; Soto, Basinger et al. 2012). Much of the global focus and effort has been on simple cost-effective technologies like basic lighting, as there remains two billion people without access to modern lighting globally (Schultz, Platonovaa et al. 2008). Sadly households in rural developing areas using traditional biomass lighting pay a similar proportion of their household income for lighting as the average American family, yet only receive around 0.2% of the lumen-hours (Irvine-Halliday, Doluweera et al. 2008). Clearly, the economic capacity of families using traditional biomass for lighting will likely find it a challenge to afford the high costs of conventional centralised electricity services when ‘it arrives’.

In industrialised and non-industrialised nations alike, conventional electricity infrastructure and networks themselves are becoming viewed as a major limiting factor in the provision of efficient and cost-effective electricity services (McHenry 2013). However, at the small-scale, fundamentally new models of low cost and flexibility of
(re)configuration/expansion of small-scale ‘smart’ and microgrid power systems offer major advantages in multi-user systems for rural areas at lower costs (Vandenbergh, Beverungen et al. 2001; Welsch, Bazilian et al. 2013). This research focuses on the unique options of including the storage capability and deferrable load options that enable demand side management (DSM) from ‘low power’ consumer goods and ICT devices as a new form of the continually evolving DC microgrid infrastructure and control system to foster creative electricity system design rethinking (McHenry 2013; McHenry 2013; Willems, Aerts et al. 2013). This new ICT consumer good infrastructure includes the improved functionality, connectivity, and portability of devices such as ‘plug and play’ balance of system (BOS) components with distributed and portable appliances, effective DC bus regulation, imbedded energy storage, all with major safety benefits and an attractive and user-friendly interface unseen in the traditional energy sector. This enables small-scale renewable energy and smart microgrid concepts to cost-effectively enter the home to enhance both personal and economically productive uses, and reduce the past issues of poor user-friendliness, capacity limitations, and high cost of the previous generations of renewable energy technology.

The historical inability of conventional renewable energy systems to be a cost-effective means to supply traditionally inefficient tools and equipment in rural small-to-medium enterprises (SMEs) has resulted in energy efficiency and low power systems becoming a major unmet market need (Karekezi and Kithyoma 2002; Schultz, Platonova et al. 2008; McHenry 2009; McHenry, Doepel et al. 2014). For example, with the development of light emitting diodes (LEDs), using personal portable photovoltaic (PV) modules and batteries in small lighting systems is a practical and more affordable ‘disruptive technology’ (Mills 2010; McHenry, Doepel et al. 2014). Advancing improvements in ruggedness, low voltage tolerance, small size, high optical efficiency, and low cost of LEDs have enabled small-scale lighting and PV-battery combinations to flourish (Mills 2010). These advances have sustained the belief that DC renewable energy will eventually become the preferred generation technology for small stand-alone systems in non-industrialised regions (Schultz, Platonova et al. 2008), particularly with low wattages and voltages (Karekezi and Kithyoma 2002; Willems, Aerts et al. 2013). However, LEDs may be simply the first example of a disruptive low power and micropower technology, particularly in terms of facilitating productive applications such as communication, reading, and night-time education. ‘Back lit’ portable personal devices are largely replacing conventional books and desktop computers as learning and communication mediums of choice. It is also common to use the brightness of
some screens and inbuilt LEDs for basic task lighting (making LEDs themselves out-dated in many cases).

In addition to the social benefits of energy and ICT service integration, economically productive rural applications arising from such services (commerce, communications, electronics, agri-business, etc.) will assist further economic development and innovation to capture the greater benefits of improved rural supply chain opportunities (Martinot, Chaurey et al. 2002; McHenry, Doepel et al. 2014). At present, small-scale rural development, energy infrastructure, production, communications, capacity building, extension services, and agri-marketing activities remain disaggregated, and their integration is under-emphasised in current approaches (Jayne, Govere et al. 2002; Edenhofer, Pichs-Madruga et al. 2011; Lynd and Woods 2011). Conventional models of rural energy infrastructure, mechanisation, education, and extension investments have typically long lead time horizons, and are separated into distinct and isolated fields of planning and funding. In contrast, modern rural development activities requires an acceleration of new technology and knowledge adoption and must connect the diverse rural supply chains and inputs (knowledge, energy, agricultural inputs, technology, commodity prices, etc.) (Jayne, Mather et al. 2010). As rural subsistence regions traditionally have poor access to new technologies and productive inputs, a greater focus on creating a suitable environment to enable participation in economically productive applications with appropriate energy and ICT technologies is key (Opara 2011; McHenry, Doepel et al. 2013; McHenry, Doepel et al. 2014).

2. Innovative portable ICT networks, generation, and portability

Many portable personal devices are powered through a computer universal serial bus (USB). Indeed the ICT sector has advanced the USB to already become a pervasive yet largely unplanned DC microgrid rolled out in many global modern workplaces (Figure 1). The continued development of low voltage DC and USB device coupling multiple small-scale generation for personal ICT device charging is yielding higher efficiency and lower power options suitable for rural and remote regions (Wong 2013). The most common USB ports are USB 2.0 and 3.0, and in terms of power the nominal voltage of the USB is 5V, (USB 2.0 maximum 5.25V and minimum 4.75V, with a nominal power of 2.5W), with a maximum current of 0.50A. The more recent USB 3.0 is also 5V, (maximum 5.25V and minimum 4.45V, with a nominal power of 2.5W), and exhibits current variants of 0.150A, 0.900A, and 1.5A. (The 1.5A port is limited to charging only with no data transfer capability,
and the USB charging ports are able to deliver up to around 5A). Recent developments in the USB standards include the USB Power Delivery protocol, delivering a maximum 20V and minimum 5V, (with variable voltage capability) and with a limited output of 5A, enabling a maximum nominal power of 100W. The new protocol can provide power in both directions, optimise power management between appliances, and several other advanced enabling capabilities (usb.org 2014). As such, the ICT sector is now a major new investor in and producer of low voltage DC electricity network infrastructure as a byproduct of their business model.

[Insert Fig 1 approximately here]

Many new portable ICT goods for the relatively wealthy ‘western’, ‘consumer’ or ‘adventure’ market are becoming available and now leading the development of many new renewable energy system configurations and designs. For example, the company Goal Zero produces the ‘Nomad 27’, a $0.151m^2$, 1.5kg monocrystalline PV array rated at 27W, $V_{sc} \sim 19V$, with dimensions of 113 x 57cm unfolded, and able to be folded into a portable package with dimensions 26.7 x 18 x 5cm (and exhibits a buck regulated USB output of 5V, 0.5A, 2.5W maximum, or a 13-15V 1.6A, 24W maximum DC unregulated output). The product is aimed at the adventure/camping market and has is designed for portability, interconnectivity, and to power multiple ICT devices. The same company produces the ‘Sherpa 50’ - a 0.50kg lithium-ion (nickel manganese cobalt oxide, NMC) 9-13V DC battery-charger unit, with dimensions 11.4 x 3.8 x 12.7cm, and a capacity of around ~56Wh comprising of six 3.6V, 2.6Ah cells. The battery-charger unit can utilise 15-25V DC (30W maximum) charging, and has a USB port output (able to provide a regulated 5 V 0-1.5A (7W maximum), and can be coupled to the ‘Nomad 27’, an AC wall adapter, or a 12V DC system. These technologies enable owners to carry a DC microgrid literally on their back, and it provides a new perspective of suitable energy infrastructure in rural regions.

Portable technology developments present a challenge to the renewable energy sector of how to customise small-scale hybrid power supply system designs that consider creative interdependent and operational strategies for non-linear characteristics of portable components and site/load characteristics (Seeling-Hochmuth 1997). For example, portable PV panels on vehicles and personal clothing are exposed to complex orientation, illumination, and shading patterns (Gao, Dougal et al. 2009). Amorphous silicon modules are impacted by partial module shading to a lesser degree than polycrystalline or monocrystalline PV modules (Architectural Energy Corporation 1991), and direct technology substitution
may be a simple solution. Alternative conventions may also play a role in system design for
efficiency and robustness under conditions associated with being portable. PV arrays are
conventionally connected in series to produce a desired voltage, and any PV cell shading will
inhibit the collection of energy from the remaining array that may be under full illumination
conditions (Gao, Dougal et al. 2009). When one or more PV cells are damaged, or when
modules are partially shaded, the increased temperatures in the damaged/shaded cells act as
inefficient conductors and seriously reduces module output (Architectural Energy
Corporation 1991). Partial (cloud, tree, or moving objects/infrastructure) shading of PVs can
lead to rapid fluctuations in output, and series-connected wiring results in either impedes the
ability to collect the output from fully illuminated cells when one in the string is partially
shaded, or the partial output of the shaded cells (if diode bypassed) (Rohouma, Molokhia et
al. 2007; Gao, Dougal et al. 2009). Most available consumer PV products use series
configurations, and at present bypass diodes are used at PV module electrical terminals to
enhance power production and prevent the high levels of resistance from impacting the entire
string when series-connected modules are damaged or shaded (Architectural Energy
Corporation 1991; Gao, Dougal et al. 2009). In practice PV outputs act like extremely fast
‘ramp-up’ and ‘ramp-down’ of traditional generation (Naoto, Satoh et al. 2006). Rapid
fluctuations in PV shading patterns makes maximum power point (MPP) tracking a challenge
with each system string MPP value dependent on upstream PV module characteristics,
making it difficult to identify the global MPP for diode bypass PV systems as multiple local
MPPs exist with each changing rapidly (Gao, Dougal et al. 2009; Manfredi and Pagano
2011). Many existing MPP algorithms use DC/DC converters that are insufficiently fast (a
few seconds) to cater for MPPs change rapidly (over a tenth of a second), particularly in
series-connected PVs (Patel and Agarwal 2008; Gao, Dougal et al. 2009). Non-conventional
configuration of a highly parallel PV array wiring configuration engenders a relatively
consistent MPP voltage of all cells largely independent of irradiance levels, and small
deviations from the MPP does not reduce power output to a great extent, with the system
voltage becoming weakly related to temperature changes (Rohouma, Molokhia et al. 2007;
Gao, Dougal et al. 2009). Nonetheless, advancements in MPP algorithms will required faster
response times to changes in PV responses when portable or for variable meteorological
conditions, in addition to increases stability, robustness, and efficiency (Manfredi and Pagano
2011).
3. A revolution of low power DC and energy systems and payment options

Much conventional large rural equipment such as variable speed drives, industrial lighting, power electronics, batteries, flywheels, and other storage mechanisms are generally DC systems that require conversion from AC (Anand and Fernandes 2010; Willems, Aerts et al. 2013). Low voltage PV energy systems are by no means new, as 48V has long been used by the ICT sector for remote systems, improving the general availability of low voltage BOS components (Anand and Fernandes 2010; Boroyevich, Cvetkovic et al. 2013). Continued developments in converter/inverter and step up converter technology have enabled numerous non-conventional energy system designs (including parallel PV module configurations and step up converters for grid-connect systems, and small single PV cell converter systems as low as 0.3V) (Gao, Dougal et al. 2009). For low voltage system applications the combination of a reduction in net load through higher appliance efficiency and the reduced DC/AC and AC/DC conversion losses enables the selection of smaller and less costly generation and storage components. Coupling of multiple low voltage generation and appliances on a common DC bus controlled by DC/DC converters enable improved system regulation to achieve more energy efficient conversion, and enables system components to be introduced to allow a cost-effective evolution of the system to meet changing needs (Vandenbergh, Beverungen et al. 2001; Brenna, Tironi et al. 2004; Ortjohann, Omari et al. 2007; Welsch, Bazilian et al. 2013). The DC system bus voltage is important because the efficiency of conversion between generation and loads increases with less conversion stages, and is also fundamental safety parameter (Anand and Fernandes 2010; Willems, Aerts et al. 2013). In general a 48V DC system is considered very safe for humans when grounded. Ensuring unity power factor (UPF) is an important consideration for DC systems, as the energy potential of DC bus terminal with respect to ground varies at high switching frequency, leading to the voltage variation leaking current and causing equipment damage and user safety concerns (Anand and Fernandes 2010). Notably the employment opportunities in the sector are a massive potential new industry, particularly considering the skills and training required to install/maintain low voltage equipment does not require a lengthy four-year electrical apprenticeship.

Portable ICT device charging from small-scale renewable energy systems and microgrids has the potential to introduce additional savings to households in off-grid rural areas (Schuss and Rahkonen 2012; Didier, Toshimitsu et al. 2013). For example, local mobile phone charging services in non-industrialised countries without quality energy service provision generally costs around US$1–2 per week, and the travel time to reach charging
stations is often considerable (Irvine-Halliday, Doluweera et al. 2008; Adkins, Eapen et al. 2010). Yet, mobile phone battery capacities are commonly only between 1 and 2 Ah with voltages of only a few volts. This associated cost per unit of energy is expensive for individuals with no charging services at home. Furthermore, the conversion efficiency of conventional AC voltages in the home to low power DC mobile devices is commonly very low (~15%) (Ruutu, Nurminen et al. 2013). Therefore, in general distributed small-scale stand-alone home system DC bus networks are recommended when higher user loading at night is combined with renewable energy generation systems that have a high solar fraction. Similarly, home system AC bus networks are preferable with high daytime loads and high liquid fuel generation penetration (Vandenbergh, Beverungen et al. 2001). Research by Anand (Anand and Fernandes 2010) found 48V DC with DC/DC converters to be an optimum voltage when comparing between 400V, 325V, 230V 120V and 48V) to efficiently meet energy needs in a residential home consuming 7.9kWh d⁻¹, even with standard appliances (ceiling fan, air conditioning in summer, refrigeration, LED lighting, computers, washing machine, and TV). Anand (Anand and Fernandes 2010) found that meeting an equivalent load demand using 48V and 120V DC systems will require less (~15%) electricity than AC systems due to lower losses converting from DC to AC and vice versa for standard residential loads in industrialised nations(Boroyevich, Cvetkovic et al. 2013). Without the historical legacy and sunk capital of industrialised nations developing a centralised high voltage AC generation and distribution model, it seems unlikely that that this model would be the default choice for establishing electricity services today. It is a failure of imagination to propose ‘traditional methods’ of using copper and fibre cables in rural developing areas, and is wholly inappropriate when stand-alone, mobile, and satellite options are available. This conventional lack of science and innovation is akin to being creatively stuck in the same ‘rut’ as the historical legacy of the rail/tram/cart wheel gauges following the original imperial roman war chariot gauge. A more recent example is the path dependency of the QWERTY keyboard (Page 2006), yet as we also know with ICT devices there have been many successful alternatives that co-exist with the QWERTY, including mobile phones. Thus, we need not follow the same development path/rut, or have one successful model, and have multiple opportunities in the relative ‘greenfields’ of development needing new solutions using more flexible state-of-the-art technology.

Installing state-of-the-art technology in rural poor regions generally raises the hard questions of technical limitations, who will pay, commercial arrangements, regulation, tariffs, donors, and subsidies (Tenenbaum, Greacen et al. 2014). Yet there is growing interest in
fostering development pathways through commercial ‘trade’ rather than ‘aid’ globally, particularly to sustain the investment momentum of initiatives once they commence (McHenry, Doepel et al. 2014). For example, research at Stellenbosch University and with Specialized Solar Systems in South Africa has focused on low-cost appropriate options to supply informal housing with domestic electricity services using low power DC systems and appliances. In 2011 the first ‘iShack’ was constructed with effective passive thermal management, solar hot water, and a ~20W PV module-battery-distribution system with efficient LED lighting and mobile phone charging points to be affordable, modular, robust, minimise conversion losses, and be upgradable for fridges, microwaves, stereos, TVs and ICT devices. The iShack initiative is now incorporating alternative commercial financing, asset ownership, and low power DC ‘Watt-hour’ metering options (as opposed to AC kWh metering common globally) (Figure 2) (Keller 2012; Taverner-Smith 2012). Complimentary research by Soto et al. (Soto, Basinger et al. 2012) on small-scale microgrid payment systems in ~200 households (in Mali and Uganda) implemented a successful cost recovery model. Known as ‘micrountilities’, electricity supply (with customised control options) and associated communication information automatically sent to consumers who purchase cards from local vendors on a prepaid basis using a toll-free SMS account recharging comparable to mobile phone payment systems (Soto, Basinger et al. 2012). These and many other comparable advances demonstrate that it is technically feasible for conventional utilities to rethinking their infrastructure approach towards a smarter customer interface in a very large and distributed low power DC energy market in rural non-industrialised regions, and in parallel recoup infrastructure investment costs while adhering to governmental commercialisation and regulation impetuses (Soto, Basinger et al. 2012; Boroyevich, Cvetkovic et al. 2013; McHenry 2013).

[Insert Fig 2 approximately here]

4. Novel low power DC storage and hybrid capabilities/applications

Conventional battery storage systems in stand-alone power supply systems are generally less reliable than most other components and are oversized relative to the daily load in the attempt to maximise battery lifespan to minimise replacement costs (McHenry 2009; McHenry 2009). Lead-acid batteries remain the most common storage technology use in stand-alone power supplies (Lambert, Holland et al. 2000; McHenry 2009; McHenry 2009), and lead-acid battery replacement and disposal are serious economic and environmental
issues (Martinot, Chaurey et al. 2002). Energy storage technologies ideally should be reliable over numerous cycles, have a low self-discharge rate, minimal maintenance requirements, a high charging efficiency, robust, low cost, high energy density, good environmental/storage/safety characteristics, and an ability to withstand periods of low charge (Lambert, Holland et al. 2000; Lazarov, Zarkov et al. 2012; Boroyevich, Cvetkovic et al. 2013). Indeed the portable LED lighting system component with the shortest life is often the battery (Mills 2010). While most batteries are low voltage DC technologies, the concept of a battery bank in a stand-alone power system as a separate useful component and an integral ‘imbedded’ storage capacity with multiple utility in a system is now possible. For example, rather than a passive component that stores generated energy and assists variable generation, it is now incorporated within appliances themselves as a novel storage design consideration for new low voltage DC microgrid systems. For an unusual example, the high power production available from portable supercapacitors (a presently uncommon technology in ICT devices and low power DC microgrids) can supply some storage and supply large currents (as when motors start) (Seo, Kim et al. 2010; Glavin and Hurley 2012). Supercapacitors have little or no maintenance requirements, high energy densities, high power ratings, long lives (around 1 million charge cycles at rated temperatures), are composed of environmentally benign materials, and can be totally discharged and charged with practically zero memory effect (Robbins and Hawkins 1997; Karandikar, Rathod et al. 2009; Kim, Chang et al. 2010; Fahad, Soyata et al. 2012; Das, Das et al. 2013). Supercapacitors can be totally discharged and charged at very large amperages at almost 100% cycle efficiency, and can be designed to meet daily load requirements without concern for the supercapacitor lifespan, and only consideration of the maximum voltage and current, the solar resource, the load, and the operating temperature (Kim, Chang et al. 2010). For instance, Maxwell’s BCAP3000 has a rated capacity of 3,000F, maximum ESR of 0.29mΩ, a rated voltage of 2.70V (2.85V maximum), with a large maximum continuous current of 210A at operating temperatures 40-65°C. The weight of a single BCAP3000 is 0.59kg, with a length of 130mm, and a diameter of 61mm, with the ability to store 3.04Wh. Demonstrating creative applications of such small DC supercapacitor components by enthusiasts is their adoption in home electronic component spot welding, being a portable low cost and low power (yet high amperage) capacitive discharge appliance (among other uses).

Supercapacitors have also been demonstrated to be an effective storage option and also a compensatory component to PV output variability. As a rough indication, cycling a supercapacitor through half of its voltage range provides or stores around 75% of its available
energy capacity, and can be charged/discharged at a rate of around 60% of fully charged/discharged in one second, and 80% by two seconds, and be totally charged/discharged (>99%) by around four-to-five seconds. Short interval storage enables and expanded suite of options for more effectively using intermittent PV generation capacity in stand-alone systems (Maranda and Piotrowicz 2010). PV-supercapacitor system simulations by Lazarov et al. (Lazarov, Zarkov et al. 2012) included a 820Wp PV array, a 1000W single-phase inverter, two supercapacitors with a total capacity of 166F and a nominal voltage of 48V connected to a 50V DC bus. The voltage of the supercapacitor bank varied from 50V (at around 100% SOC) to approximately 10 V (around 0% SOC), and effectively maintained the DC bus voltage to the nominal 50V, apart from a small reduction to around 49V at the zero SOC point. The simulations by Lazarov et al. (Lazarov, Zarkov et al. 2012) showed that the fully charged supercapacitor bank was able to fully compensate for total loss of an assumed 800Wp PV generation output for 228 seconds, or 366 seconds for an assumed 500Wp PV output (Lazarov, Zarkov et al. 2012). The use of actual electrical storage as compensatory components and as appliances, and also in combination with conventional notions of ‘virtual storage’ from deferrable loads (such as water pumping and refrigeration) can be incorporated into system control scheduling and load hierarchies. The additional flexibility in including storage capacity of all types is also bolstered by the advancing appliance efficiencies such as new generations of low voltage pumps (also operating on USB) and more efficient magnetic and hybrid-fuel thermal refrigeration options (McHenry, Doepel et al. 2013). Even relatively inefficient small conventional compression fridges (~200L) often consume less than 100W (including using low voltage DC versions) when the compressor is on and usually only operate at 25% of the time depending on usage patterns. Yet, the advancements of new low power and clean energy technology capabilities and applications will certainly not be without their own teething issues, as we have seen in the past, some of which are detailed below.

5. Ongoing issues with the traditional renewable energy development paradigm

It still remains common for relatively little long-term small appliance and renewable energy product testing to occur prior to the introduction of new products (particularly in non-industrialised nations and commonly inspired by various donor programme embodiments). This is often because testing is deemed to be too time consuming and expensive (Adkins, Eapen et al. 2010). Even when ‘bundling’ several existing commercial products into a new
energy systems that individually meet high standards and minimum performance requirements, the new bundled system still requires appropriate technical validation of safety and performance over time with ongoing technical support (Martinot, Chaurey et al. 2002). As an example, it is commonly thought that LED lanterns have been successfully introduced to several poor countries (Schultz, Platonova et al. 2008). However, LED technology can vary considerably in terms of technical performance, as poor-quality LED products are known to have reduced end-user trust in the technology (Mills 2010). LED lifetimes are commonly falsely overgeneralised as consistently long-lasting, yet can vary markedly between ‘low power’ (~0.2 W) LEDs lasting between 250 and 2,500 hrs and ‘high power’ (~1-5 W) LEDs lasting up to 50,000 hrs (Mills 2010). Ensuring availability of replacement component and appliances is notoriously difficult in many non-industrialised regions, and wider dissemination is limited by poor product support and high upfront capital costs (Apte, Gopal et al. 2007; Adkins, Eappen et al. 2010). Without a sustained presence of an effective technical support structure for new products and services, and a critical mass in technology adoption in a location to support these commercial services, sustaining access to replacement parts and maintenance services is a fundamental limitation. The variable voltage of technologies is also an issue with the lack of standardisation for the suitable application (Willems, Aerts et al. 2013). However, with the evolution of the USB capabilities and the management of variable Low voltage DC energy and data delivery over one single cable (usb.org 2014). When introducing commercial (unsubsidised) new technologies, it is commonplace to hear discussions of microfinance, payment plans, rental options (etc.), all in the aim to create a sustainable local industry and guide it through initial sensitisation, capacity building, and barrier removal processes (Adkins, Eappen et al. 2010). The international aid/donor sector agencies often have developed detailed, targeted, and comprehensive stand-alone financial mechanisms to assist some technology dissemination in non-industrialised regions. However, the ICT sector already incorporates a comparably detailed and globally successful sales model in such regions, and it may be more appropriate to also collaboratively partner with ICT companies to meet development aims. Just as mobile phone networks are rapidly expanding in non-industrialised nations (Didier, Toshimitsu et al. 2013; GSMA Intelligence 2013; The World Bank 2013), partnering with ICT companies is becoming a practical alternative to partnering with financial, donor, and government sectors for developing microfinance for development projects, and may neatly fit into existing ICT company corporate social responsibility (CSR) programmes.
6. Conclusions

Smart grids and microgrids have been likened to a merger of energy, ICT, and telecommunications sectors which will necessitate numerous revisions of technical and governmental assumptions regarding how this new major sector will advance economic growth and global competition (McHenry 2013). In the context of the renewable energy and ICT industrial expansion into the non-industrialised countries, it is important to view developments within the existing paradigm of players and supply chains, including donor agencies, government policy, existing conventional product manufacturers, rural entrepreneurs, households, community organisations, conventional energy service providers and the associated regional service availability and financial capacities in the regions. (Martinot, Chaurey et al. 2002). Partnerships between ‘low power’ renewable energy, ICT, and other sectors in rural and remote energy development has the potential to become a major competitor and complement to the industrial-scale and centralised high voltage AC network model of development (Boroyevich, Cvetkovic et al. 2013). The recent revolution in USB standards to include data and increasing levels of useful bi-directional power flow with variable voltage has the potential to become a major low voltage DC microgrid backbone. With increasing availability of ‘personal power systems’, the portability of connecting renewable energy generation with appliances that include imbedded battery storage and advanced interfaces will require creative design that improves system performance under variable conditions. This will require an unprecedented level of modularisation, robustness, upgradability, energy efficiency with variable configuration, and also consideration of end-of-life safety, storage, and disposal due to the growth and rapid turnover of personal ICT and energy devices. Many of these advances are occurring at an rapid pace backed by the large and growing global consumer device market in both industrialised and non-industrialised nations.

Despite intentional and planned development activities, the increasingly dynamic market in energy efficient and portable low power DC ICT devices is likely to support an autonomous level of unplanned development in non-industrialised countries. Significant revision of conventional thinking will be necessary, particularly when fast-paced ICT product lifetimes and advances are juxtaposed with multi-decade relative stagnation in electricity industry infrastructure models. Armed with the advantages of portable DC devices, imbedded storage, and portable renewable energy systems, individuals have the opportunity to customise their own systems to suit their unique needs and capacities for innovation. The
stand-alone power supply system and ICT sectors also have a major economic opportunity
with literally billions of rural people seeking creative systems and designs that ‘revolutionise’
their energy services and development paradigm, rather than simply ‘industrialise’ it.
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Figure captions

Figure 1: The PC-USB-dominated workspace is a low power portable DC microgrid. The PC is the AC/DC interface (100-240VAC, 0.8A/19VDC 1.58A) with ‘island mode’ using only DC utilising the battery to power the USB network (5VDC) to several consumptive appliances, five of which have their own imbedded battery storage (tablet, phone, camera, MP3 player, and speaker), and four powered only by the USB ports (flexible second keyboard, thumb drive, external hard drive, and LED light).

Figure 2: An upgraded low power DC microgrid home with solar hot water, PV array incorporating battery storage, LED lighting, small domestic appliances and ICT devices, including Specialized Solar Systems unique DC Watt-hour metering suitable for small-scale home DC microgrids. Courtesy of Professor Mark Swilling at Stellenbosch University, South Africa.