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Adoption of energy-efficient televisions for expanded off-grid electricity service

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ABSTRACT

Even though they dominate the global television (TV) market, light-emitting diode backlit liquid crystal display (LED-LCD) TVs have received little attention for use with off-grid household-scale renewable energy systems, primarily because of high up-front costs. However, technological advances and price declines mean that these TVs can now provide the same level of electricity service as standard LED-LCD TVs offer but at lower total energy cost. Moreover, LED-LCD TVs are inherently direct-current (DC)-powered devices and therefore well suited for use with off-grid solar home systems. We estimate that DC-powered energy-efficient LED-LCD TVs can decrease the retail purchase price of solar home systems by about 25% by allowing use of 50% smaller photovoltaics and battery capacities than would be needed for the same energy system to power a standard LED-LCD TV. We recommend that policies such as awards, bulk procurement, incentives, and energy labels be considered to facilitate the adoption of these energy-efficient TVs in off-grid settings.

1. Introduction

Televisions (TVs) are among the most commonly used household appliances. Estimates indicate that more than 80% of the world's 1.9 billion households owned TVs in 2014 (Digital TV Research, 2014). Although TV penetration in developed economies is already saturated, TV ownership in developing countries is still low, e.g., estimated at less than 40% in sub-Saharan Africa (Digital TV Research, 2014); as a result, demand for TVs is high in these countries, including in off-grid regions where an estimated 1.2 billion people worldwide lack access to electricity and in unreliable-grid regions where an additional 1 billion people reside (Global LEAP, 2016a; International Energy Agency (IEA), 2015). A recent market survey of anticipated off-grid consumer demand found that TVs were in the top three household end uses (along with light emitting diode [LED] lamps and mobile phone chargers) (Global LEAP, 2015a). Another recent analysis estimated that the number of off- and unreliable-grid households for TVs in Asia and Africa would grow from about 50 million in 2015 to about 200 million by 2020 as the distribution of energy systems increases (Global LEAP, 2016a).

In regions with no grid connectivity, deployment of small solar power systems can be a key short-term electricity supply strategy. Falling solar home system (SHS) prices (driven by decreases in the cost of photovoltaic panels and batteries) and several market approaches (including piecemeal purchasing strategies, micro-finance loans, and pay-as-you-go schemes) have increased off-grid solar systems' affordability over time (Phadke et al., 2015). Research also indicates that a primary driver of uptake of off-grid power systems is desire for TVs (Jacobson, 2007). Use of highly efficient appliances could dramatically increase solar system affordability because efficient end uses can be served by a smaller system than would be required to power less-efficient versions of the same products. For example, a highly efficient color TV, four LED lamps, a mobile phone charger, and a radio that together require approximately 18 W [W] can be supported by a small solar power system with 27 W peak [Wp] (Phadke et al., 2015).

In particular, flat-panel TVs, such as liquid crystal display (LCD) TVs, are appropriate for direct current (DC) power systems because these TVs inherently convert alternating current (AC) input to DC inside the system. As their prices and unit power consumption have dramatically decreased, these products have begun dominating global TV sales (Park et al., 2013a). Research also indicates that incremental costs and prices of efficiency in TVs have declined rapidly (Desroches and Ganeshalingam, 2015). Regardless, primarily because of high up-front costs, flat-panel TVs have received little attention for use with off-

Abbreviations: A, ampere; ABC, automatic brightness control; AC, alternating current; Ah, ampere hour; BOS, balance of system; CCFL, cold cathode fluorescent lamp; cd, candela; CRT, cathode ray tube; DC, direct current; LEAP, Lighting and Energy Access Partnership; IEC, International Electrotechnical Commission; in^2, square inch; kW h, kilowatt-hour; LCD, liquid crystal display; LED, light-emitting diode; LED-LCD, LED backlit LCD; Li, lithium; m^2, square meter; PV, photovoltaic; SHS, solar home system; USB, universal serial bus; V, volt; W, watt; W_p, watt peak

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grid, household-scale, renewable energy systems, and the number of DC flat-panel TV products available in the off-grid market is limited. In some cases, off-grid households use inverters to enable residents to install widely available AC-powered TVs even though this results in power conversion losses (from DC provided by the energy system to AC produced by the inverter to power the TV and back to DC in the TV system. The efficiency gains from LED technology, which has been rapidly adopted in lighting products and TVs, could make off-grid solar power systems feasible and affordable in developing economies (Casillas and Kammen, 2010; Phadke et al., 2015).

In this paper, we assess the technical potential and cost to reduce the electricity consumption of small LED backlit LCD (LED-LCD) TVs using commercially available technology and evaluate whether these TVs offer the potential to reduce the cost of TV use in off-grid energy systems. The remainder of the paper is organized as follows: Section 2 presents an overview of the off-grid TV market. Section 3 discusses TV energy consumption trends. Section 4 describes our data sources, assumptions, methodology, and analysis results regarding the potential to reduce the cost of TV use in off-grid energy systems by improving TV efficiency. Section 5 presents our conclusions.

2. Overview of off-grid TV market

An estimated 1.2 billion people worldwide lack access to electricity (the "un-electrified" population) and an additional 1 billion people have unreliable electricity access (the "under-electrified" population) (International Energy Agency (IEA), 2015). Of the global population, 17% is un-electrified. The majority of off-grid households are in sub-Saharan Africa and India (International Energy Agency (IEA), 2015). Although it is estimated that more than 80% of the world's households own TVs, TV ownership in developing countries is estimated to be low, e.g., less than 40% in sub-Saharan African countries (Digital TV Research, 2014). It is difficult to break down current TV sales between grid-connected and off-grid regions in developing countries, but we estimate that TV penetration in off-grid rural areas is low.

LCD TVs are estimated to account for more than 95% of new TV shipments in both emerging and developed economies (DisplaySearch, 2014a; Park et al., 2013a; Park et al., 2014). In new TV shipments, cold cathode fluorescent lamp (CCFL) backlit LCD TVs have been replaced by LED-LCD TVs, which account for nearly 100% of LCD TVs (DisplaySearch, 2014a; Park et al., 2013a). Cathode ray tube (CRT) TVs were estimated to account for less than 3% of shipments in emerging economies in 2014, and no new shipments of these products were expected from 2016 onward (DisplaySearch, 2014b; Park et al., 2014).

Very little research has focused on the off-grid TV market (defined here as comprising both un- and under-electrified populations) because it is currently a niche market with uncertain growth potential. Demand for DC TVs in off-grid regions is currently driven by existing distributors of solar power systems and low-power energy products (Dalberg Research, 2013). However, un- and under-electrified households could become a large appliance market as economies grow and electricity access improves. In particular, increasing opportunity for off-grid populations to access digital TV content is expected to support future demand for TVs in off-grid regions. For example, the direct-to-home industry, which provides TV content by satellite, is growing, largely to serve rural customers who do not have access to cable service (Dalberg Research, 2013; Digital TV Research, 2014; DVB.org, 2015). Although current TV penetration in off-grid rural areas is still low, a recent analysis estimated that the number of off- and unreliable-grid households seeking TVs in Asia and Africa would grow from about 50 million in 2015 to about 200 million in 2020 as the distribution of energy systems increases (Global LEAP, 2016a). Recent market transformation programs promote and help consumers identify energy-efficient, quality-assured, off-grid TVs. For example, the Global Lighting and Energy Access Partnership (LEAP) Outstanding Off-Grid TV competition recognized several TV products based on a combination of expert evaluation and quantitative assessments of energy and cost (Global LEAP, 2014a, 2016b).

3. TV energy consumption trends

This section gives a picture of commercially available energy-efficient TVs and analyzes technical improvements that are feasible in the short term. We do not analyze long-term technical efficiency improvements that would require research and development investment.

3.1. Electricity consumption by AC LCD TVs

Rapid improvements in cost and efficiency of LED technologies have driven the adoption of LED backlights for LCD TVs and other applications. In addition to improving LED performance, other viable options for improving LCD TV efficiency include optimized combinations of optical films in LCDs, improved LCD panel transmittance and brightness control functions, and energy-efficient power electronics (Park et al., 2013a, 2014). Major TV manufacturers have been offering new designs of LED-LCD TVs at lower prices than previously to decrease the price gap between conventional CCFL-LCD TVs and LED-LCD TVs. Price reductions are also made possible by decreasing the maximum luminance level, adjusting color-reproduction capability, and introducing "low-cost LED direct backlighting"[1] (Park et al., 2014).

TV manufacturing is highly globalized and concentrated, so a given size of TV will be similar in different regions of the world (Park et al., 2013a). Therefore, we can use the energy consumption of TVs sold in major economies such as the U.S. and Europe to represent the energy consumption of TVs elsewhere. For example, ENERGY STAR-qualified TVs can represent the majority of TVs sold in the U.S. because their market penetration is significant, i.e., nearly all LCD TVs met ENERGY STAR requirements in 2015 (US EPA, 2015a).[2] Fig. 1 shows on-mode power consumption trends of recent U.S. ENERGY STAR-qualified LCD TVs (less than 45 in.). Recent 23- and 24-in. LCD TVs, regardless of backlight technology, consume 15–34 W in on mode (United States Environmental Protection Agency (US EPA), 2013a; US EPA, 2015b).

3.2. Electricity consumption in DC LCD TVs

One of the technical differences between AC and DC TVs is the AC-to-DC conversion in the former. An estimated 5–15% of electricity is lost in this conversion (Garbesi et al., 2011; Park et al., 2011), and losses can be even greater than this.[3]

The Global LEAP Outstanding Off-Grid TV Awards (http://www.globalleapawards.org/) tested a number of DC TVs designed for off-grid use to identify the world's highest-quality and most energy-efficient and affordable off-grid TVs. The 9 DC TVs tested in 2014 were

[1] "LED-direct" or "LED full-array" configuration means that the LEDs are uniformly arranged behind the entire LCD panel. Unlike LED-direct models, "LED-edge" or "Edge-lit" configuration means that all of the LEDs are mounted on the sides (or edges) of the display. LED-edge backlit TVs are the mainstream technology particularly for small and medium screen sizes because their manufacturing costs are lower than those of LED-direct backlit TVs. LED-edge backlit TVs also have a better aesthetic profile, i.e., a slimmer body. Some medium and large screen sizes use LED-direct backlight for high-end products because these devices can employ local dimming technology that can independently control each LED lamp, resulting in higher contrast ratio and better picture quality (Park et al., 2011).

[2] U.S. ENERGY STAR Version 6 and Version 7 requirements for TVs went into effective on June 1, 2013 and October 30, 2015, respectively. The market penetration of ENERGY STAR-qualified LCD TVs in 2013 and 2015 was 84% and 89%, respectively (US EPA, 2013b, 2015a).

[3] We tested a 19-in. AC-DC-compatible TV model sold in Kenya by measuring on-mode power consumption. The on-mode power consumption (13.2W) in AC input is about 35% higher than the consumption in DC input (9.8W). The TV model we tested had a power factor (defined as actual power to apparent power) of 0.44 in on mode. Low power factor appliances with a stand-alone off-grid power system could require more power than high power factor appliances do, while consumers in grid-connected systems are not charged for such unused power.