Where There is No Light: A Mixed-Methods Exploration of Quality of Obstetric Care and Energy Access in Low and Middle Income Countries and the Impacts of a "Solar Suitcase" Intervention

By

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Abstract

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Maternal and newborn mortality remain pervasive problems in Sub-Saharan Africa and South Asia; annually, as many as 300,000 maternal deaths occur worldwide from complications of pregnancy and childbirth. One million newborns do not survive their first day of life. Interventions to reduce facility-based maternal and newborn mortality often assume the presence of continuous light and electricity. In 2018, a detailed review of 128,000 health facilities in 78 low- and middle-income countries (LMIC) showed 59% lacked reliable electricity. This dissertation analyzes in-depth interviews of frontline health workers in eleven countries to examine the impact of unreliable electricity on emergency obstetric and neonatal services. It recounts the design and dissemination of a scalable solar electric intervention, called the Solar Suitcase, and examines its impact on maternal and newborn care.

The Solar Suitcase intervention was developed as a result of formative ethnographic research in 2008 by the author at a state hospital in Nigeria. The author describes grim conditions in the hospital and her emerging conclusion that the lack of continuous electricity impaired the execution of life saving emergency obstetric and newborn care. She describes how she partnered with others to provide solar power to one hospital, and later, how the compact solar electric system she and her partners designed for frontline maternal health care sparked a non-profit organization–We Care Solar, dedicated to healthcare electrification in resource constrained LMIC countries—as well as an international movement to eradicate energy poverty in maternal healthcare.

This research utilized an existing database of in-depth interviews obtained by We Care Solar and partner organizations in 11 sub-Saharan African and Asian countries over the course of ten years (2010 – 2019). A total of 1,213 semi-structured interviews were conducted with health workers in energy-deficient facilities before and 3–18 months after the Solar Suitcase was installed. Interviews focused on current and/or past experiences conducting maternal-newborn health services in energy-deficient facilities. Topics included electricity reliability, alternative lighting sources, routine and emergency care, referral patterns, financial burdens, health worker morale,

and patient-provider relations. Responses were documented in written or audio formats, translated when necessary, transcribed, and coded using Atlas.ti. Analyses followed the principles of Grounded Theory.

Health workers in energy-deficient facilities reported their dependence on suboptimal light alternatives including kerosene lanterns, candles, torchlights, and cell phone lights, prohibiting efficient and effective care. They recounted difficulties in routine activities (reading medical records, writing notes, locating equipment, maintaining hygiene), and performing standard Emergency Obstetric and Newborn Care signal functions (treatment of hemorrhage, eclampsia, obstructed labor, sepsis, and newborn resuscitation). The lack of visibility reportedly affected patient health-seeking behavior and referral patterns. Health workers described personal frustration, stress, fear, and lack of confidence working without reliable electricity.

By contrast, the 607 health workers surveyed in facilities equipped with essential solar electricity and continuous medical lighting (via Solar Suitcases received 3-18 months before their interviews) reported a greater sense of confidence and efficiency, less fear of night time care, and a better ability to make medical decisions. With the improved lighting, health workers further described the provision of more timely procedures, enhanced management of obstetric emergencies and newborn care, improved sanitation and infection control, more appropriate referrals, and enhanced emergency communication. Health workers perceived increased utilization of maternal services after the solar intervention, and cost savings for patients and health workers. Yet they reported that other challenges remained despite the intervention, including: lack of running water, “stock-outs” of medication, inadequate equipment and supplies, insufficient remuneration and lack of adequate staffing. Some health workers also requested solar electricity for additional parts of their health facility.

Maternal health providers in LMIC health centers lacking adequate and reliable electricity face significant challenges conducting routine and life-saving care. The conditions they describe indicate that health facility electricity, and in particular light, play a critical role in the perceived quality of care, health worker experience, and patient health-seeking behavior. Health workers provided with access to reliable light and electricity via a compact solar electric system report greater confidence and ability to conduct routine and emergency obstetric procedures. Access to reliable lighting and basic electricity are a necessary, but not sufficient, component of quality maternal and newborn care. Energy access programs must be included in any comprehensive approach to improving quality of care and should complement other interventions designed to improve maternal and child health.

Dedication

I am dedicating this dissertation to my mother, Evelyn Stachel, who almost lost her life when she delivered my older brother in 1954. My parents were quite poor at that time, and my mother delivered in a public hospital where care was suboptimal. A piece of placenta was mistakenly left in her uterus, causing an infection within days that tried to claim her life. I'm told she survived because of a blood transfusion, antibiotics, and an anesthesiologist who made a third attempt to resuscitate her after two others had failed. She not only survived, she went on to have two more children, myself included, and sixty more years of life. As a clinical social worker, Evelyn instilled in all her children compassion, fearlessness, and a drive to "heal the world," or *tikkun olam* as it's known in Judaism. When she died in 2011, we donated a solar powered blood bank to Wudil Hospital in Nigeria in her name, believing that there could be no more appropriate way to honor her than to save the lives of other young mothers.

This work is also dedicated to the hundreds of thousands of maternal health workers who provide life-saving care under conditions that most people would find unfathomable. Their commitment to saving lives and dedication to their patients and communities is awe-inspiring, particularly considering the constraints within which they must work. This dissertation is a reflection of their voices, their dreams and their fears. And it is my hope that, through their openness and honesty, those of us with resources will use their stories to fight for a more just, equitable, and illuminated health care system.

Acknowledgements

The author would like to acknowledge not only the people and institutions that directly contributed to this report, but also those who helped create an organization aiming to fulfill an audacious mission. It is impossible for me to individually name every person who played a significant role in that journey, and for that I offer my sincere apologies. However, I will do my best to recognize many of the hardworking, insightful, and devoted individuals who shared their talents so generously.

At the onset of our journey, there were many who believed in our mission and gave us the confidence, oversight, and skills to take our first steps as an organization. Among those are We Care Solar founding board members including John Danner, David Bank, Karina Garbesi, Spencer Weisbroth, who has provided crucial legal support for a decade, and Jane Adams. They were joined later by Alan Saldich, Gigi Goldman, Kristiana Raube, Maame Afon Yelbert-Sai, Nina Richardson, Jim Rogers, and later still, Ndola Prata, Nwando Olayiwola, Ben Rogers, Barry Neal, Wadson Muchemwa, and Matt Rinaldi. Advisory Board members Kristina Johnson, Kathryn Johnson, Daniel Kammen, David Levine, Stasia Obremskey and Kandeh Yumkella all played pivotal roles in our success.

The first cohort of Solar Suitcase warriors included Melissa Ho, Christian Casillas, Abhay Nihilani, Michael MacHarg, Laurie Ferreira, Almaz Negash, and Drew Sproul; they were soon joined by Craig Buxton and Alan Saldich. We were grateful to be able to work under the fiscal umbrella of Inveneo until we were established as our own 501(c)3. Clay Atchison made our initial solar electric system drawings and Mike Strykowski helped source solar equipment. Charles Liu from Everbright Solar developed a customized solar panel to fit inside our Solar Suitcases and manufactured hundreds. Frances Rubinstein and his team at Lawrence Berkeley National Laboratory helped us design of our lights. Holly Solar fabricated customized LED brick lights for our first Solar Suitcases, and Morgan Royce Industries was our trusted contract manufacturer for years, under the direction of Larry Johnston, who put his heart and soul into this mission. IEEE also played an important role in our beginnings, thanks to the collaboration with colleagues from the Humanitarian Technology Challenge group, including Pritpal Singh and his colleagues at Villanova University. We received valuable mentorship from the *Global Social Benefit Incubator*, the *Global Social Venture Competition*, *Pop!Tech*, the *CNN Heroes* program, the *Lipman Family Prize* and University of Pennsylvania's *Center for Social Impact Strategy,* and the *Social Entrepreneurship Accelerator at Duke*.

Nicholas Kristof played a very important role in our story, inspiring me for years before there ever was a We Care Solar, and later, exposing our formative work to an international audience. We are grateful that he shared our mission with his readers at the *New York Times*, selected We Care Solar as winner of his *Half the Sky* competition, hosted a Facetime Live fundraising event at his New York office, and included We Care Solar in his exhibition at the Skirball Museum based on his book, *A Path Appears.*

None of our work could have occurred without the generous support of hundreds of individuals and dozens of institutions. The Bixby Center for Population, Health, and Sustainability at UC Berkeley supported my early research in Nigeria. The Blum Center for Developing Economies at UC Berkeley, under the leadership of Richard Blum, provided catalytic financial support for our very first solar installation in Nigeria, thanks for the magic of our fairy godfather, Thomas Kalil, who at that time worked for the Office of the Chancellor. The Blum Center for Developing Economies generously provided office space for our team, and continued to support our research and innovations; Maryanne McCormick and Phillip Denny were steadfast supporters as well as UC Berkeley's George Sharffenberger. The John D. and Catherine T. MacArthur Foundation provided instrumental support in our early years, taking a gamble on a small team with a big vision, and enabling us to design a Solar Suitcase that could be tailored to the needs of health workers in Africa before being replicated and manufactured. The UBS Optimus Foundation, likewise, provided critical support for our first major program in Liberia, and subsequently, instrumental support for our product research and development; solar health care programming in Ethiopia, Sierra Leone, Liberia, and Uganda; business development scale up strategy, and funding for our first RCT study (to be published later this year). UBS Optimus Foundation's Phyllis Costanza, Anne-Marie Sevcsik, Nicole Sebastian were early champions of our work and we wouldn't be here without them; we thank Marissa Leffler for picking up the baton. We appreciate Bonnie and Kara Weiss from CRI Foundation for supporting our West Africa programs. Major funders who have provided instrumental support include the Wells Fargo Foundation, the Starr International Foundation, and the Silicon Valley Community Foundation. The generous unrestricted funding afforded from these three institutions have allowed us to be nimble, innovative, and resilient. Linkin Park Band and their inspiring Music for Relief Foundation brought much more than funding; band members embraced us like family and promoted our work through concerts, special events, and social media. Whitney Showler, the executive director, along with Mike Shinoda, Dave Farrell, Brad Delson, Joe Hahn, and of course, our beloved Chester Bennington, will always be cherished members of the We Care family. Additional organizations that transformed our programs include Every Mother Counts, under the inspiring leadership of Christy Turlington Burns, the Global Health Foundation, under the magical and generous leadership of Amy Livingston, and the Meadow Fund, who remained our most important benefactor to date. The women at Greenlamp Foundation were more than funders; they became true friends and partners in our efforts to light up Ethiopia. Numerous family foundations gave our organization its legs. The Segal Family Foundation, and Barry Segal in particular, demonstrated generosity and modelled how philanthropy could become a collaborative effort between "doers and donors." Michael Marks was our first major donor and his family foundation, under Amy Dornbusch, provides ongoing support. The Montei Foundation uplifted our work in Zimbabwe. The MacFarlane Family Foundation enabled us to remodel and refine Solar Suitcase packaging and learning materials. The Edgewater Foundation supported our work in Africa as did The Hawaii Community Foundation and Rosanna Hsi, breathing life and light into many of our programs. We are grateful to the Zayed Sustainability Prize for providing international exposure and concrete financial support for our programs, to the Gilead Foundation for supporting our efforts in West Africa, and to the United Nations Foundation, for support of our work in Uganda.

Our linkages to UN agencies enabled us to expand our advocacy efforts and scale our growth. The UN Foundation and the SE4ALL movement played a critical role in raising the profile of the energy-health nexus. Richenda Van Leeuwen was our fairy godmother and my mentor, providing opportunities for me to advocate for healthcare electrification in front of international audiences. Later, Luc Severi and Jem Porcaro also became trusted allies. Ivan Vera and his colleagues at UNDESA including Minoru Takada, Nadine Salame, and Louise Gagne helped propel our work through the "Powering the Future We Want" award. At WHO, we worked with Elaine R. Fletcher, Susan Wilburn, Carlos Dora, Heather Adair-Rohani, Michaela Pfeiffer, and Maria Neira of WHO's Department of Public Health, Social and Environmental Determinants of Health (PHE) to better shape an international agenda around energy access and maternal-newborn health care. Kandeh Yumkella, the former undersecretary-general of the United Nations was an important ally and became an Advisory Board member for We Care Solar.

We Care Solar staff were heavily involved in every aspect of Solar Suitcase design, manufacturing, program planning, evaluation and execution. Hal Aronson conceived of the Solar Suitcase intervention and later worked with Brent Moellenberg to refine the design; Brent, as our Director of Engineering, later re-designed the Solar Suitcase for manufacturability and oversaw subsequent design revisions with support from Zebulon Engineering Solutions, Institute for Creative Integration, Arrow Electronics, and Rex Lu. This dissertation would never have been completed without my colleague, Christina Briegleb. After years of leading global programming at We Care Solar, Christina mobilized our data analysis and encouraged me to take a pause from the unending responsibilities of leading a nonprofit to work with her to digest the amazing stories we had collected over a 10-year period. Christina oversaw our health electrification programming from 2015 to 2020, with strong support by Kimberly Gordon. Both Kimberly and Christina trained partner staff to collect much of the data in these reports. Kimberly played a major role in organizing and using her masterful agility with spreadsheets to aggregate data for this dissertation. Samantha Parsons joined We Care Solar three years ago as Chief Operating Officer, and demonstrated how to juggle her roles of being a strategic leader, supportive manager, financial wizard, and true friend, even in the midst of logistical challenges and recent world chaos. Before her, Robin Wolaner, provided critical leadership and generated a strong environment in which our staff could thrive, and before her, Jane Coyne and Stasia Obremskey provided instrumental leadership of our programs and fiscal oversight. Other key staff members at We Care Solar who contributed to this work include Leslie Weir, who was always willing to help with a smile absolutely pulled me over the finish line for this dissertation, Jacinta Bouwcamp, who has played a strong role in our individual Solar Suitcase placements, and Amy Donhauser, who worked with us to analyze our programs and create best practices. Rachel Yanda and Ilinisa Hendrickson were trailblazers who helped with programming, research, and getting We Care Solar off the ground and Ilinisa personally traveled to the Philippines to gather first-hand stories from health providers.

International partners made much of this work possible. In Nigeria, my formative work began with colleagues, including Dr. Oladapo Shittu from Ahmadu Bello University Teaching Hospital

and the staff at Kofan Gayan State Hospital, including surgical technician Aminu Abdullahi, midwives Rhoda Zinom and Maimuna Muye, and hospital director, Dr. Haibla Shehu Muazu. Idris Jibrin kept me safe and brought me to every facility. My colleagues at eHealth Nigeria were instrumental in managing our first Solar Suitcase project in Nigeria and collecting our first health worker interviews in 2011. In Liberia, we worked in partnership with the Liberian Institute of Biomedical Research on our first research program. Dr. Jacques Sebisaho used an early Solar Suitcase to the DR Congo and demonstrated that the Solar Suitcase could be a life-saving instrument for general medical care; he also inspired me with his leadership and became a trusted colleague. The staff at WEEMA were instrumental in the collection of data from Ethiopia, in particular Lianna Tabar, Liz McGovern, Tewodros Belachew, Nigist Sebsible, Yohannes Bekele and Israel Mitiku. Our partners at Hamlin College of Midwives, the wonderful women at Greenlamp, and Samson Tsegaye, of Stiftung Solarenergie, made working in Ethiopia a joy. Duke University graduate student Beth Eanelli collected interviews and shared data from the Gambia; we were also supported by Saikou Gibba and Lynn McConville of Power Up Gambia. We are grateful for our strong multi-year partnership with Pathfinder International in Nigeria, under the direction of Farouk Jega. Midwife Isha Daramy Kabia was instrumental in launching We Care Solar programming in Sierra Leone in 2012 and introducing us to the Ministry of Health and Sanitation as well as UNFPA, with whom we executed early programs. Mr. Anael Hamilton was a significant lead in those programs and has continued to care for every Solar Suitcase he installed in the last eight years like they were his own children. CUAMM contributed qualitative information from Sierra Leone in more recent years. We are grateful to our Liberian implementation partners at Africare, EnDev, PHIL, as well as the Liberian Ministry of Health, especially Bentoe Tehoungue, Joseph Kerkula and Francis Kateh. Likewise, we were supported by the staff at UNFPA and UN Women in Liberia. Innovations for Poverty Action collected and analyzed qualitative data in Liberia that informed this report. Our Zimbabwe database resulted from the extensive effort of solar installers Wadson Muchemwa, of ZimEnergy EcoFoundation, and his wife, public health nurse Ellen Ndandarika Muchemwa. In Tanzania, the staff at TanzSolar, Pathfinder International, and Jhpiego provided program reports that informed this work. In Nepal, One Heart Worldwide, under the amazing leadership of Arlene Samen, and SunFarmer staff worked tirelessly to successfully implement We Care Solar Suitcase programs in remote mountainous regions, and we are grateful for their efforts, and in particular, Suraj Shah and his fellow solar warriors. One Heart's Surya Bhatta and Sajana Maharjan provided data that informed this research. In the Philippines, we are grateful for the extensive implementation activities by Stiftung Solarenergie, under the direction of Jim Ayala and Bambi Reyes, as well as the research prowess of Genesis Samonte, who conducted interviews. Robin Lim brought me to the Philippines shortly after Typhoon Haiyan and introduced me to many of the midwives whose stories have been shared here. In Malawi, Alex Kaombi from Innovation Africa worked with us to install Solar Suitcases and interviewed health workers to prepare important narratives. In Uganda, AMREF was our first institutional partner and provided support with importation, selection of facilities, and transport. Jacqueline Cutts of Safe Mothers Safe Babies, and her program manager, Medie Mukulu were early adopters of our programs. Jacqueline along with Brigham Young University students Hayley Pierce, Rachel Fisher and Ashley Larsen Gibby conducted in-depth health worker interviews that

were included in our analysis. Later, staff from UNICEF, Save the Children, and Pathfinder added to that database. Merritt Eby Gates shared her masterful storytelling after interviewing health workers in Uganda and Tanzania. And most recently, Ambrose Katungi Muhwezi, Feza Green, and Phionah Abaho—part of our We Care Solar team in Uganda—offered additional stories and insights.

This paper would not be complete without acknowledging the immense contributions of University of California staff and professors who inspired and mentored me, including Dean Steve Shortell, Dean Michael Lu, and Dean Stefano Bertozzi, all of whom cheered me on, as well as Cheri Pies and Ndola Prata. I received 14 years old unconditional support of my committee chair, professor Meredith Minkler. Merry is a gifted leader in community-based participatory research and as a professor, she mentored me throughout the entire DrPH process. Merry believed in my work before I did; in 2008, she recognized the potential significance of my early research and the role that solar energy could play in transforming maternal health care, encouraging me to share my findings with global audiences. Merry has shown up for me as a mentor, professional colleague, and friend, and despite my very erratic and circuitous path towards my DrPH, she remained patient, calm, and understanding—confident that I would one day complete this. Professor Malcolm Potts, the father of the Bixby Program for Population and Sustainability at University of California, Berkeley and world leader in reproductive health care, offered me the life-changing opportunity to conduct research on maternal mortality in Nigeria in 2008 and provided ongoing guidance, particularly when he chaired my Orals committee. Malcolm inspired me to pursue international public health, demonstrating how one individual could influence the field of reproductive health care, produce solid research, and remain kind, humble and open. None of this work would have been possible without University of California anthropologist Daniel Perlman, whose chance meeting with me in 2008 on a street corner in Berkeley led to an invitation to join the Bixby team in Nigeria. Daniel introduced me to participant observation in a Nigerian state hospital, inviting me to put aside formal books and articles and simply observe hospital life. It is through Daniel's guidance that I could free myself from traditional paradigms about maternal and child health, allow myself to experience the many constraints that impacted emergency obstetric care, and uncover the role that electricity was playing in maternal and newborn death and disability. Professor David Levine has been a trusted colleague since 2009, when I first began thinking about impact research in Nigeria. David encouraged me to ask the hard questions, to examine the learnings from my failures as well as successes, and to quantify the impacts I discerned. Professor Alice M. Agongino provided guidance for my oral exams, shared her enthusiasm for the Solar Suitcase and our user-centered design protocols, and directed many of her engineering students to work with our team. Professor Lia Fernald offered her support from the onset of my first efforts to bring Solar Suitcase to Nigerian health centers. As a dissertation committee member, she added a welcome level of rigor to my writing and reporting. And special thanks to Ndola Prata, Jennifer Lachance, and Judy Smithson for opening the doors to the DrPH program one again and enabling me to finish a program I started 14 years ago!

I am deeply indebted to my family. My father has inspired me through his own lifelong academic pursuits and assisted me by editing this dissertation. My children generously shared their childhood and young adulthood with We Care Solar and made our home welcome to streams of visitors from around the world. Two of them have participated in Solar Suitcase projects in Africa. They give me love, joy, inspiration and much needed diversion during the hard times. And they were a devoted cheering squad during my final weeks of this dissertation.

Most of all, I wish to acknowledge Hal Aronson, my life partner, who has problem-solving and human-centered design embedded in his DNA. When Hal first read my impassioned emails in 2008 describing the electricity challenges facing my hospital colleagues in Nigeria, he immediately conceived of a solar electric solution. Hal shared his time, talent, and treasure at every step of this journey, generously donating his personal solar equipment and additional resources to make early prototypes for Nigerian clinics, motivated by his conviction that each solar kit could help to save lives. We had no idea that what began as an ad hoc project in our backyard, fueled by several volunteers and our passion to help a handful of health centers, would eventually evolve into a multi-national organization equipping thousands of health centers with a compact rugged solar electric system that has now served millions. We didn't realize that I would spend much of my next decade globe-trotting to West Africa, East Africa, Nepal, and the Philippines, engaging with new organizational partners, visiting health centers, and overseeing the implementation of programs. And that my family along with Hal would indeed be sharing me with countless others, causing me to miss birthdays, anniversaries, performances, family vacations, and holidays. I am indebted to my entire family, who offered their selfless support, recognizing that we were indeed part of a much bigger family. But without Hal, this dissertation would have remained a story about the challenges faced by health workers in low-resource countries, ending with a description of the problem of energy poverty. Thanks to Hal's insight, creativity and dedication, we were truly able to transform my early research into action and can now reflect back on a decade of impact.

Finally, I wish to acknowledge all of the health workers in LMICs who show up for work night after night under conditions that most of us would find untenable. Their devotion, ingenuity, and persistence continue to inspire me.

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Chapter 1

Sea of Darkness

Tonight, as the sun sets, tens of thousands of maternal health workers will show up for work in health centers lacking electricity. Like me, they were trained to partake in one of the most meaningful experiences of human life—childbirth. They have the privilege of joining women during this critical life moment, supporting them as they transition from pregnancy to motherhood, bearing witness to a remarkable process and human feat, as the human body stretches and contorts to advance a baby through the birth canal. Like me, they had the privilege of learning enough about the unfolding of a healthy delivery to detect when that process deviates from normal, when expectant mothers with no obvious risk factors can suffer from blood pressure gone awry, when a baby's size and position are mismatched with the architecture of its mother's own pelvis, when a placenta erroneously plants itself in a location that blocks the baby's only passageway, or when the forces of childbirth overpower the mechanisms of homeostasis and "normal blood loss" becomes a life-threatening hemorrhage. Like me, they were trained to be vigilant, prepared, professional, caring, and "frighteningly efficient" (a term once assigned to me by a patient). Like me, they are all too familiar with the rapidity with which the profoundly beautiful journey of childbirth can transform into one of the most frightening, and sometimes deadly, nightmares. Unlike me, they must work in health centers lacking one of the most basic infrastructures: light. And how my life became inextricably linked to their plight is this story.

I became a doctor in 1985, choosing obstetrics and gynecology as my specialty because it provided the opportunity to engage with women and their families during some of the most personal and critical periods of their lives. By that time, I had already faced my own reproductive health challenge. As a teenager, originally on a trajectory to become a pianist and dancer, I had been diagnosed with an ovarian mass that prompted an emergency surgery. It was unclear whether the cause was a fertility disorder or cancer. My doctor arranged for a diagnostic laparoscopy and told me that if the condition was benign, I would awake with a small bandage over my navel. If cancer was detected, on the other hand, my abdomen would be covered with a large bandage, indicating that all of my reproductive organs had been removed. I was very scared, and I remember sliding my hand across my belly in the recovery room, relieved to discover the small bandage. But I was left with enough questions that it prompted my doctor to ask, "If you have so many questions, why don't you become a doctor?"

It may have been a simple quip to him, but the idea resonated and started me on a journey that has continued to this day. I shifted my studies from Oberlin Conservatory of Music to Oberlin College and changed my major from Piano and Dance to Psychology. I became a peer-counselor in reproductive health care, championed policy changes in the school's health plan, and co-taught a course on the history and politics of women's health. I eventually enrolled in medical school, and later became a physician specializing in obstetrics and gynecology. I was determined to enlist

my patients as equal partners in their healthcare, to invite rather than dispel questions, and to empower women as they faced their own health challenges. I particularly loved participating in the intimacy of childbirth and being part of a field where joy was abundant and almost all problems were resolved within nine months.

After my residency at University of California, San Francisco, I joined a women's collective, where midwives and doctors worked seamlessly together, sharing the midwifery philosophy that childbirth is a healthy and natural process rather than the traditional medical dogma focused on disease that views pregnancy through the lens of potential illness. I thought of myself as a midwife with a scalpel in my back pocket. I prided myself on compassionate and efficient care, including the ability to execute an emergency Cesarean section in minutes, when necessary.

When my own career was cut short by degenerative disc disease in my cervical spine (compressing vital nerves to my arms), I could no longer operate, deliver babies, or keep up with the physical demands of my profession. My hectic life as a physician came to a halt. No more waiting rooms filled with patients, emergency room requests for consultation, and phone calls through the night alerting me to impending deliveries. My job was to concentrate on my own healing and to learn to sit and stand without pain.

Within two years, I had found a new home—the School of Public Health at University of California, Berkeley, where I could nurture a long-held interest in population health. It was through the Maternal and Child Health program that I encountered startling statistics about the field that I loved. Around the world at that time, half a million women died each year from complications of pregnancy and childbirth, mostly in Africa and Asia. The causes of death were not unusual diseases but instead, common obstetric complications such as hemorrhage, obstructive labor, eclampsia, and sepsis. These emergencies cannot always be predicted, nor are they always preventable. But with prompt, appropriate and reliable medical care, they need not result in death.

Through a chance encounter on the Berkeley campus with medical anthropologist Daniel Perlman, I learned that University of California, Berkeley had a collaborative research program on maternal mortality with Ahmadu Bello University Teaching Hospital in northern Nigeria. Rates of maternal mortality in Nigeria were among the highest in the world; though Nigeria accounted for 2% of the world's population, it was responsible for 11% of the world's maternal deaths. And in the region of Nigeria in which Daniel was working, the lifetime risk of dying in childbirth for reproductive-age women was estimated at 1 in 13. Daniel was leading research efforts for the international program, sponsored by the Bixby Center for Population Health and Sustainability, and was seeking a graduate student to conduct ethnographic research in Nigerian hospitals. He shared with me 'verbal autopsies' that had been conducted by previous Nigerian research fellows—interviews with the family members of women who lost their lives in pregnancy and childbirth, unfolding the tragic sequence of events leading to their deaths. Reading these transcripts introduced me to the depth of the challenges facing pregnant women in need of

emergency care. The obstacles they listed are known as the “three delays” [1], an extremely helpful framework for understanding the high rates of maternal mortality.

The first delay—the decision to seek care—begins at home. Impoverished, far from a medical facility, and typically without decision-making authority, rural women often are reluctant to ask for help until labor is seriously compromised. Culturally, the male head of the household is the one to make the decision to seek medical care, a move that is likely to involve spending a significant sum of money on clinic fees and transportation costs. Much time is lost as the family weighs these factors.

Reaching the health facility is the second delay, as more time is lost while impoverished families try to identify and pay for transport to a facility that could be hours away. The solution could be a car, a motorcycle, an animal-led cart, walking, or some form of a human held stretcher to connect women to the hope of medical care. Some women failed to get transport. Others did not survive the arduous journey.

It was the third delay, though, that troubled me the most. According to the field notes from Nigeria, many women who sought medical care for severe complications of labor were turned away from health facilities – as many as four or five health centers in a single case – in their quest to get care. Some of those who were finally admitted to an appropriate facility were so critically ill that little could be done to save them. But the report suggested that sometimes the health facilities themselves failed to provide timely care.

Daniel suggested that ethnographic research inside the hospitals would help elucidate the reasons for the hospital delays. Being an obstetrician in public health school made me well qualified to help. I was invited to meet with the Nigerian team and conduct ethnography at a Nigerian hospital.

In March 2008, I boarded a plane to Abuja, Nigeria. It was my first time in West Africa and I was eager to utilize my obstetric knowledge in some way. I knew little about what to expect. As an anthropologist, Daniel suggested I keep an open mind and avoid excessive literature review in advance of my visit. My job was to observe obstetric care and to report on what I learned.

We drove four hours from the capital city of Abuja to Zaria, a predominantly Muslim city in the Nigerian state of Kaduna, before I was inside Kofan Gayan State Hospital, a large state hospital on the border of Zaria’s ‘Old City.’ Inside the metal gates I took note of the hospital layout. Each medical ward had its own building. Most of the divisions—maternity, gynecology, male medical and surgical, female medical and surgical, and pediatric—were familiar to me as an American doctor. What wasn’t familiar was the ‘VVF’ ward, occupied by women suffering from vesico-vaginal fistula – a dreaded complication of prolonged obstructed labor.

The maternity ward was a one-story building containing the labor and delivery room, the maternity room for antepartum and postpartum patients, and a separate room for patients with eclampsia, a condition where elevated blood pressure constricts blood flow to the brain, uterus, and other vital organs. The maternity room was where the nurses' station was based. The long rectangular room had a pungent antiseptic smell and offered 12 sparsely-covered patient beds lined in two rows. Newborn babies shared their beds with the mothers and family members were intermittently admitted to the ward to provide food and basic care to their loved ones. I learned that 150 deliveries occurred in this hospital each month, with significant loss of life. Between 3 and 8 women were listed in the Delivery Room Registry each month with the letters "R.I.P." next to their names, signifying "Rest In Peace," the only indicator that lives had been lost.

I was immediately struck by the grim conditions. The labor room had four bare metal delivery tables, a limited collection of obstetric instruments, a dusty newborn incubator that hadn't worked in years, a broken lamp, two newborn scales in questionable condition, and little else. Three plastic buckets were elevated on hospital stands across from the beds. The tattered signs taped to the walls above them indicated that the watery solutions they contained were meant to clean instruments between patients. The sink in the corner had long been broken; the 50-gallon plastic pail by its side was the only source of water for cleaning hands, equipment, and newborns. There were no mattresses, sheets, bright lights, fans, or electronic monitors characteristic of an American hospital.

But perhaps most striking to me were the frequent power outages that left the hospital in darkness, each day. I soon learned that electricity was rationed in Nigeria, that the public utility grid in Kaduna had to orchestrate a series of rolling blackouts in order to ration power to all who needed it. The hospital was only afforded electricity for a portion of each day– at most, 12 hours. When grid power was available, the hospital could use its lights, refrigerators, surgical suction machines and other energy-dependent devices. When the power was down, the hospital was incapacitated. A diesel-fuel generator tried to compensate during evening hours, but fuel was expensive, and the generator was used sparingly.

I had not anticipated the extent of challenges facing my Nigerian colleagues. At night, I observed maternity care, watching helplessly as doctors and midwives struggled to treat critically ill pregnant women in near-total darkness. The dim glow of kerosene lanterns often provided the only illumination. Without electricity, doctors had to postpone Cesarean sections until the morning and delay other critical procedures. Without power, phones could not be charged, and the only way for health workers to summon their colleagues for help was to send a human messenger to search the hospital compound. Midwives attempted to start intravenous lines by candlelight, sometimes unable to get lifesaving medication or blood transfusions to those in need. On occasion, I watched midwives turn patients away from the labor room door, despite their need for immediate care.

An upsetting example of this was when a woman in labor was brought to the hospital door late at night. She had a critically low blood pressure and from the family's story it was presumed that she had ruptured her uterus after a prolonged labor. Her only chance of survival was immediate surgery and a blood transfusion. The hospital was in darkness, unable to activate the operating theater. Without reliable electricity, the hospital laboratory had never been able to sustain a blood bank, so no immediate transfusion was possible. The midwife advised the family to go elsewhere for care, and the family was sent back into the darkness. It was hard to imagine she would survive.

Figure 1.1 A Nigerian midwife in the maternity ward at night

One night, I witnessed an emergency that set me on my current path. The labor room was in near darkness, and I settled at the foot of the bed of a seriously ill pregnant woman with eclampsia. Her family brought her to the hospital already unconscious, after suffering several seizures. Her family hovered at her bedside while her uterus rhythmically contracted, trying to effect a delivery. Although she had been given a single dose of magnesium sulfate, the standard anti-seizure medication for this condition, the woman sustained another convulsion and her family attempted to hold her body down. When the seizure was over, she lay still. Her breathing abated, and I thought she had died. Tears welled in my eyes. Anyone would have found this woman's suffering disturbing, but as an obstetrician, I found it intolerable. Eclampsia, although serious, was an eminently treatable complication of pregnancy. I stood by the bed, feeling helpless. Then she stirred. Still alive.

At that moment, I thought about all the women like her, suffering in silence, and fighting for survival in health centers lacking even the most basic requirement for healthcare: light. I

wondered how I might make a difference in their fate. I described the desperate hospital conditions in an email to my husband, Hal Aronson, who had been leading educational workshops in solar energy for ten years. Hal wrote back immediately, focused on developing a solar power solution for the hospital.

When I returned home to Berkeley, Hal sketched a design for the solar electric system. We decided to install four stand-alone solar electric systems targeting the areas of the hospital most important to maternal survival: the maternity ward, the labor room, the operating room, and the laboratory, where we hoped to install a solar blood bank refrigerator. In each system, solar panels would generate electricity that would be stored in a sealed lead-acid battery for nighttime use. Each system had a charge controller to regulate electricity going into and out of the battery, a load center to power appliances, and of course, solar panels. Included were 12V DC lights, a charging station for walkie-talkies, and power for other devices, such as surgical suction in the operating room and a blood bank refrigerator in the laboratory. With these systems, laboring women – and their care providers - would no longer have to be in darkness.

The project was compelling, but we needed funds. A campus-wide competition at University of California, Berkeley advertised a $12,500 grand prize for a technology providing a social good. The deadline for a proposal was 11 days after my return from Nigeria. This offered a great incentive to draft a paper and engage the talents of two other Berkeley graduate students: Melissa Ho, from the IT department, and Christian Casillas, from Energy Resources Group. I submitted a 'white paper' on our project and crossed my fingers. A few weeks later, we were thrilled to learn that our project was on the short list. I called together our newly formed group to craft a poster and prepare for the finals, where we would meet with the judges. Despite our best efforts, we only received honorable mention at the competition, carrying a $1,000 award. I was heartbroken. Although I appreciated the acknowledgement, I knew that the funding was not enough to support our dream.

I reached out to the head of the hospital in Nigeria, apologizing for the loss. "We didn't win enough money to do the project," I told Dr. Muazu, who remained unfazed. "Don't worry, Laura," he assured me. "You planted a seed, and from this a great tree will grow."

A few hours later, I received a call from Thomas Kalil, a campus official who had been at the competition. "You should have won," he told me. "How much do you need for your project?" Knowing that our true budget exceeded the competition grand prize, I hastily doubled the amount and requested $25,000. Within three weeks, Tom had found us funding through The Blum Center for Developing Economies. We could start. The project that would later become We Care Solar had begun.

We set to work mapping out the details of our installation. Our plan was to hire a Nigerian solar company to install solar equipment using Hal's design. We conducted research over the Internet,

contacted seven companies, interviewed key representatives by phone, and arranged to meet with a promising solar installer in Nigeria.

I wanted to include my Nigerian hospital colleagues in our planning. We had proposed a lighting and communication solution: Would they like to use walkie-talkies for mobile communication to reduce delays in assembling a surgical team? Would the LED lights we found be bright enough for surgery? Would doctors and nurses find our headlamps (powered with rechargeable batteries) acceptable for clinical care? Their responses would guide our design.

As I planned a return trip to Nigeria I needed something tangible to show my colleagues - something compact enough to fit in my suitcase. I didn't want the hassle (or potential danger) of explaining our project to customs officials at the Abuja airport. I needed this to be discreet as well as simple enough for me to showcase.

Hal's solution was a pre-wired demonstration kit. He packed my suitcase with compact solar panels, a solar electric control board, a sealed battery, high-efficiency LED lights, headlamps and walkie-talkies. I returned to Nigeria, unpacking my suitcase in front of the surgical staff and hospital administrator. I attached the wires and plugged in the battery as Hal had taught me. A doctor flipped the switch and the lights turned on, bringing wide smiles to the hospital staff. The light was indeed bright enough for an operating room. The rechargeable walkie-talkies meant that a surgical team could be assembled in minutes instead of hours, avoiding lengthy searches for doctors and surgical technicians on the hospital grounds. The headlamps with rechargeable batteries were immediately put to use.

Figure 1.2 Unpacking the first Solar Suitcase prototype in a Nigerian hospital

I met with the Nigerian solar installer whom Hal and I had interviewed by phone, and together we surveyed the hospital, measuring the power requirements for various medical devices. Dr. Muazu approved of our plans for a larger installation in six months. But one operating room technician, Aminu Abdullahi, had an additional idea.

"You must leave your suitcase here," he insisted. "This will help us save lives now." Aminu convinced me that he would care for Hal's equipment in my absence. Indeed, Aminu took charge of the solar devices, dutifully setting the solar panel outside each morning, taking it in at night, and using the system to keep batteries charged for headlamps and two-way radios. The first We Care Solar Suitcase had found a home.

Six months later, I returned to conduct the larger hospital installation, including the procurement of a blood bank refrigerator. The hospital was immediately transformed. Midwives could perform obstetric procedures throughout the night, surgical teams were assembled in minutes rather than hours, Cesarean sections were conducted regardless of time of day, and patients were no longer turned away for lack of power. One doctor joined us at the nurses' station one evening and exclaimed, "An island of light in a sea of darkness!" We celebrated the solar installation with a community event, including a ribbon-cutting ceremony from the Kaduna State Minister of Health. Over the course of the next year, the maternal deaths in that facility dropped by 70%, and the admissions increased by 16%. Although the hospital staff was clearly pleased with their facility upgrade, staff at one nearby medical clinic felt left out. "We conduct deliveries in the dark as well," the clinic manager lamented. "Why are you only helping the hospital?"

I was initially a bit defensive, explaining that we only had funds for the hospital. However, it soon occurred to me that the suitcase-size system Hal had made for the hospital demonstration could be transplanted to the clinic. We brought the cobbled-together system to the clinic, much to the delight of midwives who no longer needed to rely on candles and kerosene at night. I continued to conduct research at Kofan Gayan Hospital as part of my graduate studies, returning every few months to observe care. It wasn't long before additional local clinics asked for the 'solar doctor' and the suitcase that would light up their delivery rooms. Hal was glad to accommodate these requests, and started assembling small solar kits for each clinic. On each trip to Nigeria, I would include a Solar Suitcase or two in my luggage.

Figure 1.3 Bringing an early Solar Suitcase prototype to a Nigerian primary health center

Word continued to spread, and I was invited to talk about our experience at a global healthcare conference at Yale University. The *New York Times* writer Nicholas Kristof gave a stirring keynote address. After his talk, I told him how much his own articles had inspired my work in Africa. Unbeknownst to me, the next day Kristof wrote about our mission in his online blog, and requests for We Care Solar Suitcases began arriving from around the world. The need for reliable electricity for maternal health care extended far beyond Nigeria.

At that time, in fact, 1.2 billion people suffered from energy poverty. And within those statistics were hundreds of thousands of health facilities reliant on electricity for lighting, refrigeration, medical equipment, and autoclaves to meet the standard of care.

Each time I returned to Nigeria I visited clinics using our solar "prototypes," taking note of the failures as well as the successes. I saw wire connections that had come loose, watched as midwives inadvertently shut off the solar connection to the battery when they meant to turn on or off the lights, was repelled when I saw how insects had nested against the warmth of the solar charge controller, and noted the ingenuity of my colleagues who found innovative ways to anchor solar panels to their rooftops. Incorporating feedback from our field installations, we refined the design of the Solar Suitcase. We made the suitcase components more rugged and easier to use. Bare wires that needed screwdrivers for installation were replaced with plug-and-play connectors. Safety fuses were replaced with circuit breaker switches. Our simple wooden board was swapped for an acrylic panel that included straps to secure the battery. And seeing how dusty our equipment became as a result of the Harmattan winds prompted us to enclose our components in a plastic protective case that doubled as a wall cabinet.

Hal enlisted local volunteers to help with assembly in our backyard. Soon, our Solar Suitcases were travelling to midwives in Burma, clinics in Tibet, and doctors in Tanzania. Solar Suitcases would reach their destination by volunteer couriers who would arrive at our home for training, and then personally transport a Solar Suitcase to a remote clinic or hospital.

When the devastating Haiti earthquake struck in 2010, we had no choice but to get Solar Suitcases into the field as quickly as possible. Medical relief groups made numerous requests for our portable solar power systems, and small donations poured in as well. In four days, Hal had assembled a team of volunteers to assemble the Solar Suitcases, which we promptly dispatched to several medical groups.

Figure 1.4 Hal Aronson leading the backyard assembly of Solar Suitcases for Haiti

As the Solar Suitcase was introduced to new countries, we worked to adapt the suitcase configuration to meet local requirements. Sometimes we learned the hard way. We discovered, for example, that an initial design short-cut—using an American AC-style outlet for our DC lights in Nigeria—was confusing in Haiti, where AC wall outlets accepted (and overpowered) our 12V DC lamps. We redesigned the outlets, and I flew to Haiti with a volunteer engineer, Brent Moellenberg, to retrofit our Solar Suitcases with the new design.

After our experience in Haiti, it became clear to us that our program was gaining traction. Hal and I dived into the project, converting our home into a Solar Suitcase factory. Equipment was strewn all over the house and our living room became our shipping and packing line. We juggled

a steady stream of part-time volunteers, including many who were quite talented, but none who could sustain a hefty long-term commitment without remuneration.

We formalized operations in order to process donations and buy more equipment, utilizing the fiscal sponsorship of a non-profit engineering group on the Berkeley campus. Eager to gain increased exposure and support, we entered several competitions, enlisting the support of a talented UC Berkeley MBA student, Abhay Nihalani, and a recent MBA graduate from Duke University, Michael MacHarg. In 2010, we applied for (and won) ten competitions and fellowships, including the Global Social Benefit Competition at UC Berkeley, the Ashoka Changemaker's *Healthy Mothers, Strong World* Award, the Global Social Benefit Incubator at Santa Clara University, and a Pop!Tech Fellowship.

That whirlwind year brought me into contact with other social entrepreneurs and mentors, helping me to gain perspective about ways to extend our reach. As we shared our limited experience in Nigeria and Haiti within social entrepreneur boot camps, we were urged to scale up our operations.

Hal and I had no experience in this realm. Hal had been a solar educator for years, initially creating hands-on solar electricity projects for middle and high school students, and later, developing a robust curriculum for educators. My career in medicine demanded clinical and surgical acumen, not project management skills. We needed a thoughtful approach to scale up.

Some advisers suggested the best approach would be mass production of a simplified prototype. They encouraged us to immediately strip down some of the more costly features of our early design, and to manufacture a cheaper, less ambitious version of our product. "Fewer bells and whistles" was the recommendation. We were worried about this approach. The design of the Solar Suitcase had evolved to meet the needs of health workers working in unfathomable conditions. We didn't want to downgrade the functionality of our product, and we weren't ready to commit to one particular design without more field research. Our dream was to create an optimized version of the suitcase incorporating existing feedback from our field installations, and to conduct further research on this model in a limited number of health facilities. Since our formative experience began in northern Nigeria, we thought this would be a good testing site. But we knew this would require staff, time and money.

We decided to incorporate as a non-profit organization in order to ensure that under-resourced health centers would have access to reliable electricity. We recognized there was not a functional market for solar electricity in public health facilities in countries most in need of our product. Our beneficiaries were government health workers and the impoverished mothers they served. We would need to seek funding from third parties that were eager to support our mission.

The World Health Organization invited us to pilot a small Solar Suitcase program in Liberia, funded by UBS Optimus Foundation. Around the same time, we scored a coveted grant from the

MacArthur Foundation, specifically to bring our innovation to scale. Our grant targeted four areas: technology design, educational programming, field research, and scale-up of operations. We received additional support from the Blum Center for Developing Economies. We were on our way.

Our learning curve was steep. We had never run a non-profit organization, managed international programs, or interacted with contract manufacturers and government officials. We asked for help wherever we could find it, thankful to receive mentorship from business consultants, lawyers, industrial engineers, designers, social entrepreneurs and academicians. We are fortunate to be based in the San Francisco Bay Area, which enabled us to collaborate with a diverse talent pool: students and professors from UC Berkeley and Stanford, scientists from Lawrence Berkeley National Laboratory, other technology-oriented non-profits, and advisers from Silicon Valley.

Hal and I devoted ourselves full time to We Care Solar. We hired consultants to help lead operations and provide financial oversight. Brent Moellenberg, the engineer who had led our technical activities in Haiti, was brought on board full-time. As our organizational capacity expanded, we developed systems for accounting, data management and inventory. Hal and Brent met with lighting designers, solar manufacturers and contract manufacturers. Our aim was to "design for manufacturability," which meant fabricating user-friendly, rugged Solar Suitcases in a factory rather than our house! We found that our mission— to develop simple solar solutions to save lives in childbirth—attracted generous in-kind support. With a lean and passionate team, we were able to accomplish a great deal on a limited budget.

Figure 1.5 Brent Moellenberg, Hal Aronson and Christian Casillas preparing version 2.0

We realized that the technology alone was not sustainable without proper usage and long-term maintenance. In addition to developing photo-rich user manuals, we printed bright laminated posters, recognizing from our site visits that in rural clinics, posters were the most common form of written information. We created educational programs for health workers, and a basic curriculum on solar energy and optimal operation of the Solar Suitcase. We prepared more advanced materials on installation and maintenance for technicians. And we piloted this program in Liberia with 60 health providers, before extending our capacity-building workshops to Nigeria, Sierra Leone, Uganda and Malawi.

Figure 1.6 Training Nigerian health workers to use the Solar Suitcase

As we travelled from country to country, we conducted facility assessments at diverse health centers, which exposed us to a wide variety of health facility layouts, construction materials and energy needs. As a result of our research, we expanded the capabilities of the Solar Suitcase, and included hardware and tools to facilitate installation. Our newer version could accommodate larger solar panels and batteries, included a fetal heart rate monitor, and had the option for additional lights that could be plugged into a remote receptacle.

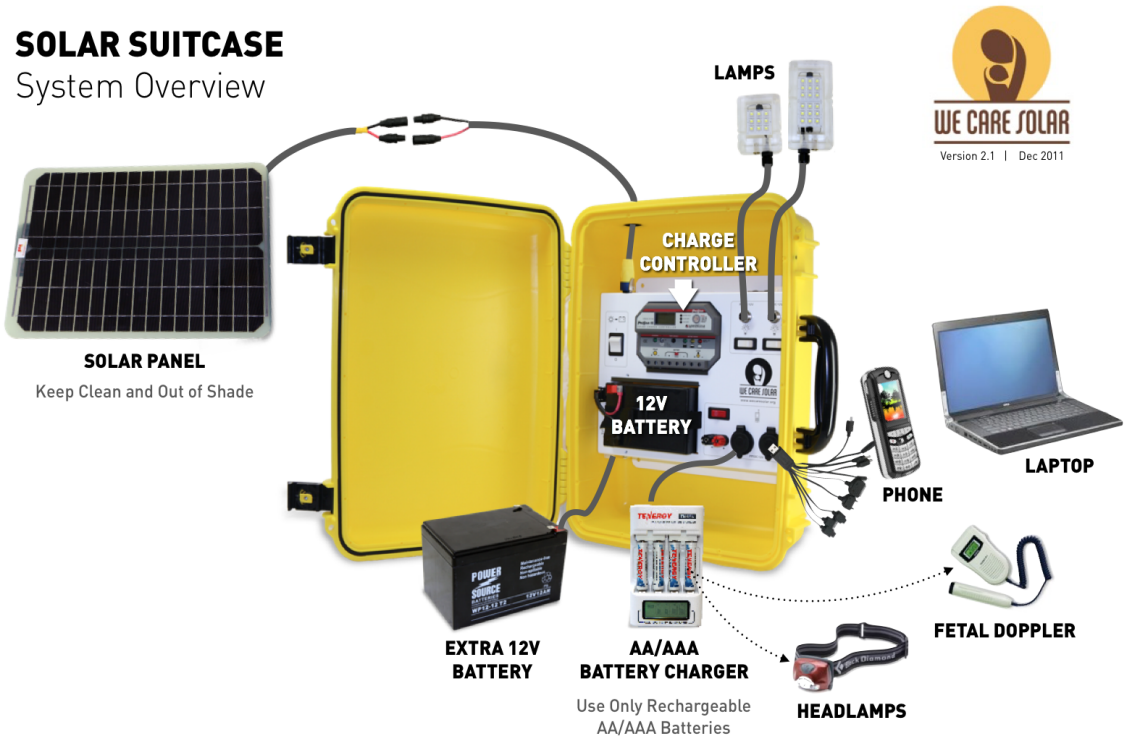

Figure 1.7 Solar Suitcase poster for Version 2.0 Solar Suitcase

We responded to inquiries from a range of countries. Sometimes the requests were for programs with dozens of health centers, leading to partnerships with international NGOs and UN agencies. Other times the requests were from individuals hoping to hand-carry a Solar Suitcase to a specific clinic.

We recognized the importance of sustainability, and developed programs to build local capacity in solar installation, operation and maintenance. We launched a *Women's Solar Ambassador* program calling upon women with technical proclivity to lead our international training programs. Our idea was to foster women's leadership and showcase women as change-makers in a field where women were also our prime beneficiaries. We developed systems to support larger programs that reflected our most and least successful practices, and hired enough staff to support district-wide deployments. Most often we would work with agencies already boosting maternal and child health services in a section of the country. Our team would provide technical training to enable local district technicians and NGO staff to lead their own solar installations. Newly minted solar installers developed the skills to safely conduct Solar Suitcase installations, teach health workers how to properly use our equipment, and then provide basic maintenance.

We became engaged with the 2011 UN Foundation Sustainable Energy for All (SE4ALL) [2] movement, and when we asked why health care was not a featured part of their mission, they invited me to lead a practitioner's group on this topic. I became a champion of healthcare

electrification, speaking about the nexus of clean energy and health care. My graphic examples of the repercussions of energy poverty on maternal and newborn outcomes made me a welcome invited speaker. Through associations that were made in the SE4ALL working group, we were able to convene a workshop in 2012 in Washington, D.C. on "Renewable Energy for Healthcare." We invited colleagues from the World Health Organization (WHO), as well as a diverse group of stakeholders from engineering, global health, and development. The meeting helped forge a partnership between the WHO and the UN Foundation, and thereafter, a platform for the United Nations called the "High Impact Opportunity" on Energy for Women and Children's Health, bringing together the UN Foundation, WHO, UN Energy, UN Women, as well as members of civil society, like We Care Solar. One of the most satisfying achievements was participating in the launch of this initiative both at the World Bank and later at the United Nations. [3]

Our work was showcased at UN events in New York, Ethiopia, and Thailand, at the World Health Organization, and at countless solar energy, health, and academic events. UN Secretary-General Ban Ki-Moon commended our work at Rio+20, and WHO Director-General Margaret Chan called We Care Solar "sunshine saving lives." We continued to win awards, including the prestigious "Powering the Future We Want" award from UN DESA, meant to showcase initiatives that highlighted interlinkages between energy access and other Sustainable Development Goals. Being a program that linked healthcare, energy access, climate action, gender equity, and partnerships, We Care Solar was a prime example. I was invited to speak at the United Nations and received a $1 million award from Secretary General Ban Ki-Moon. At that event, in 2015, I called for a coalition of solar practitioners and health providers to end the effects of energy poverty on maternal and newborn care. That speech was captured on video. [4]

Figure 1.8 Accepting the "Powering the Future We Want" award at United Nations

In 2017, our team and board devised *"Light Every Birth*," an international initiative that would call upon governments, NGOs, and UN agencies to ensure that every public health center is provided with clean, reliable light.

We were building a coalition united by three fundamental beliefs:

1. Every woman has the right to safe childbirth.
2. Every health center is entitled to reliable electricity, and
3. Solar electricity offers an immediate and sustainable solution to this global problem.

We first launched *Light Every Birth* in Liberia in partnership with the Ministry of Health, UNICEF, UNFPA, and several NGO partners. Within two years, we had reached every public health center that lacked reliable power at the time of our 2017 assessments, more than 430 health centers! For a country that had suffered public health setbacks as a result of civil war and then Ebola, it was a moment to be celebrated. Since that time, we have engaged three more countries as *Light Every Birth* partners—Uganda, Zimbabwe, and Sierra Leone.

To date, we have deployed more than 5,200 Solar Suitcases to more than 40 countries. We have conducted programs with 65 government and international agencies and instructed more than 20,000 health workers in our technology. We have trained more than 800 technicians to install our devices. Our partners have included ministries of health, UN agencies, International NGOS, local organizations, solar agencies, and of course, many, many funders. We estimate that more than six million mothers and babies have been served by health centers using We Care Solar Suitcases, a technology that promotes environmental health as well as safer deliveries.

While there is much that has been accomplished, we are humbled by the work ahead. The Sustainable Development Goals called for universal access to modern electricity by 2030. The hundreds of thousands of health centers that remain without reliable electricity must be included in that quest. With public health facility electrification often falling between fiscal silos of health and energy, financing this proposition will not be easy. This work is challenging, beset with logistical hurdles, and at times feels overwhelming. But we are spurred on by stories of the people for whom the Solar Suitcase was first designed.

One such story came from Dr. Jacques Sebisaho, a New York-trained doctor who operates a clinic on the island of Idjwi in the Democratic Republic of the Congo. The village had no power and at night it was impossible to provide adequate medical care. Dr. Sebisaho returned to his village clinic armed with a Solar Suitcase. It was quickly put to use to illuminate a twin delivery. Dr. Sebisaho's arrival coincided with the onset of a cholera epidemic. The clinic was flooded with patients in need of intravenous fluids, antibiotics and constant monitoring. The clinic had few beds and patients were soon positioned on mats placed outside on the clinic grounds. Solar Suitcase lighting was brought from patient to patient, enabling the medical staff to provide constant monitoring.

Figure 1.9 Dr. Jacques Sebisaho introducing the Solar Suitcase to Idjwi island, DR Congo

Although Dr. Sebisaho feared many lives could be lost, he and his team achieved something they considered a near-miracle. All the patients treated that month survived – not a single father, mother, or child was lost despite the severity of many of the cases. He had expected 50% of the patients to die, and said that in the past, 80% of deaths occur at night. The Solar Suitcase was a lifesaver, boosting the morale of health workers and inspiring the entire community.

> *"I believe the light was the force behind everything. I have no words to describe how confident we all were, knowing we could do anything anytime—day or night. This sounds obvious to a person here (in the USA), but the light meant the world there."*
>
> *"We are witnessing what light can do in a community and how it can save lives in regions where night means death if (you are) sick or in need of emergency care after the sun goes down! "*

The stories of Dr. Sebisaho, and those of hundreds of midwives, nurses and doctors like him instill us with the inspiration we need to continue our journey. This dissertation is a tribute to them.

Chapter 2 shares the experiences of health workers who have long suffered in dark delivery rooms. This paper is a qualitative review of more than 1,200 health worker interviews in energy-deficient health centers. The analysis draws upon 10 years of We Care Solar programming in 11 countries and addresses the question: how do health workers perceive access to and quality of obstetric care in health facilities lacking reliable electricity? Interview topics include routine and

emergency obstetric care, referral patterns, delays in care, patient-provider relations, and health worker morale.

Chapter 3 provides stories of hope from health workers whose health facilities have received a simple box of solar power. These stories were collected from the same programs, this time using interviews of 607 health workers 3-18 months after they received the Solar Suitcase. Topics included routine and emergency obstetric care, referral patterns, patient-provider relations and health worker morale. These two papers are offered with the hope that they will inspire others to take action.

Every day women and their infants are struggling through childbirth in the dark, in remote (and not so remote) corners of the world. It is within our reach to bring them light and power for essential medical services—through solar interventions that can leapfrog conventional grids and through advocacy for reliable energy as a vital intervention in maternal-newborn care. When no mother has to give birth alone in the dark, we will have fulfilled our mission

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Chapter 2

Where There Is No Light: The experience of maternal health workers in energy-poor health facilities

Abstract

Background

Maternal mortality remains a pervasive problem in Sub-Saharan Africa and Asia; annually, more than 300,000 deaths occur worldwide. Interventions to reduce facility-based maternal mortality often assume the presence of continuous light and electricity. A 2018 review of 128,000 health facilities in 78 low and middle income countries showed 59% lacked reliable electricity. This paper analyzes in-depth interviews of frontline health workers in 11 countries to examine the impact of unreliable electricity on emergency obstetric services.

Methods

This analysis utilized an existing database of in-depth interviews obtained by We Care Solar and partner organizations in 11 sub-Saharan African and Asian countries over the course of 10 years (2010 – 2019). Semi-structured interviews were conducted with 1,213 health workers in energy-deficient facilities before and 3–18 months after a solar electricity intervention. Interviews focused on current and/or past experiences conducting maternal-newborn health services in energy-deficient facilities. Topics included electricity reliability, alternative lighting sources, routine and emergency care, referral patterns, health worker morale, and patient-provider relations. Responses were documented in written or audio formats, translated when necessary, transcribed, and coded using Atlas.ti. Analyses followed the principles of Grounded Theory.

Results

Health workers in energy-deficient facilities reported their dependence on suboptimal light alternatives including kerosene lanterns, candles, torchlights, and cell phone lights, prohibiting efficient and effective care. They recounted difficulties in routine activities (reading medical records, writing notes, locating equipment, maintaining hygiene), and performing standard Emergency Obstetric and Newborn Care signal functions (treatment of hemorrhage, eclampsia, obstructed labor, sepsis, and newborn resuscitation). The lack of visibility reportedly affected patient health-seeking behavior and referral patterns. Health workers described personal frustration, fear, and lack of confidence working without reliable electricity.

Conclusion

Maternal health providers in health centers lacking adequate and reliable electricity face significant challenges to conducting routine and life-saving care. The conditions they describe indicate that health facility electricity, and in particular light, plays a critical role in the perceived quality of care, health worker experience, and patient health-seeking behavior. Comprehensive approaches to reducing maternal mortality must include the vital components of electricity and lights.

Figure 2.1 Ugandan health workers delivering baby by kerosene lantern

Introduction

The Sustainable Development Goals call for marked improvements in health outcomes for women and children by 2030, including a reduction of the global maternal mortality ratio to less than 70 maternal deaths per 100,000 live births from the current level of 216—a reduction of 68%— and an end to all preventable neonatal deaths [1, 2]. Although global progress has been made towards these goals, 295,000 mothers lose their lives annually from complications of pregnancy and childbirth including hemorrhage, hypertensive disorders of pregnancy, puerperal sepsis and obstructed labor [4-6]. Each year, an estimated one million newborns die during the first week of life [3]. For every woman who dies, an estimated 20 – 30 suffer debilitating complications such as uterine prolapse, fistula, and infertility [7, 8]. The SDGs will only be reached by accelerating international efforts to achieve universal access to health care and identifying effective and comprehensive strategies to prevent maternal and newborn death and disability.

The WHO defined nine signal functions for basic and comprehensive obstetric and newborn care that address preventable maternal and newborn mortality [9]. The signal functions describe specific actions necessary for treating the leading causes of maternal and newborn mortality, including treatment of hemorrhage, infection, eclampsia, obstructed labor, and unsafe abortion, retained placenta, and newborn asphyxia (see Table 2.1).

Table 2.1 Signal Functions for Basic and Emergency Obstetric Care

Basic Services
1. Administer parenteral antibiotics
2. Administer uterotonic drugs (i.e. parenteral oxytocin)
3. Administer parenteral anticonvulsants for pre-eclampsia and eclampsia (i.e. magnesium sulfate)
4. Manual removal of the placenta
5. Remove retained products of conception (i.e. vacuum extraction)
6. Perform assisted vaginal delivery (e.g. vacuum extraction, forceps)
7. Perform basic neonatal resuscitation (e.g. with bag and mask)
Comprehensive services
Perform signal functions 1 - 7, plus:
8. Perform surgery (e.g. Cesarean section)
9. Perform blood transfusion

Source: Managing complications in pregnancy and childbirth: a guide for midwives and doctors: http: www.who.int/making_pregnancy-safer/documents/9241545879/en/index.html

Basic Emergency Obstetric and Newborn Care (BEmONC) facilities should be able to (1) administer parenteral antibiotics to treat systemic infections, (2) administer uterotonic drugs to treat postpartum hemorrhage, (3) administer anticonvulsants to treat pre-eclampsia and eclampsia, (4) perform manual removal of the placenta, (5) remove of retained products of conception, (6) conduct assisted vaginal delivery (e.g. forceps and vacuum extraction), and (7) perform basic neonatal resuscitation (with bag and mask). Comprehensive Emergency Obstetric and Neonatal Care (CEmONC) should be available at hospitals, and includes all of the BEmONC functions plus (8) surgical care (e.g. Cesarean sections), and (9) blood transfusion. It is recommended that at least five EmONC facilities including at least one comprehensive facility be available per 500 000 population [9]. In addition to these emergency services, the signal function approach has more recently been expanded to include non-emergency, routine maternal and newborn care, including: use of the partograph to monitor labor, active management of the third stage of labor, thermal protection of the newborn, immediate and exclusive breastfeeding, and hygienic cord care [10]. All of these functions presume the presence of skilled care providers, basic medication, adequate supplies, and health facilities equipped with basic lighting and electricity.

Energy poverty, defined as the lack of access to modern energy services, affects an estimated 800 million people, predominantly in the global south [11]. Sustainable Development Goals (SDG) to attain universal access to modern, sustainable energy by 2030 include (1) universal access to modern electricity, (2) increasing the uptake of renewable energy, and (3) doubling energy efficiency [11]. Communities with unreliable grid electricity suffer from frequent interruptions and prolonged blackouts; many rural communities in sub-Saharan Africa and South Asia have no grid power whatsoever. Health facilities in energy-poor regions consequently have sporadic electricity or no electricity at all. At night, facilities are crippled by darkness, as overstretched grid operators cut off power in rolling blackouts. Some health centers rely on costly and polluting generators for primary or back-up power, and yet without sustained funding for fuel, maintenance, or repairs, generators often lie dormant. In the absence of reliable power, health workers cannot benefit from medical lighting or the use of electrical medical appliances [12].

In 2015, the WHO and the World Bank called for enhanced tracking and monitoring of energy access in healthcare [12]. Although health providers throughout LMICs are often stationed in energy-deficient health facilities, relatively little research has been conducted on the impact of unreliable electricity on routine and emergency obstetric care [13-16]. Apenteng [13] found a positive association between the frequency of health facility power outages in Ghana and facility-based mortality. Kruk et al. [14], reviewed national health surveys from 1,511 health facilities in five African countries (Kenya, Namibia, Rwanda, Tanzania, and Uganda) between 2006 and 2010 to examine the capacity to provide obstetric care, using five structural indicators (including electricity and safe water), and seven process indicators (including many of the signal functions already mentioned). They reported a very low quality of care, and noted that only 11% of primary care facilities and 66% of hospitals provided electricity. Suhlrie et al. [16] characterized the pathway linking energy use to health service outputs. Facilities with lower level energy supply

were more likely to be constrained in the provision of efficient and effective health services [16] While it is reasonable to infer from these studies that reliable electricity is an important factor in safe childbirth and the execution of the Emergency Obstetric and Newborn Care (EmONC) signal functions, there has been little attention to the provision of care from the perspective of health workers themselves. Essendi et al. [15] conducted focus group discussions with patients and health workers in rural Kenya to elucidate how infrastructure deficiencies present challenges to the provision and uptake of care; only two dozen health workers were sampled. While this Kenyan study began to explore the impact of energy poverty on maternal health services in one region, more studies are needed.

This paper seeks to address this need, drawing on an extensive database of in-depth interviews of health workers in regions of pervasive energy poverty in 11 countries. Specifically, this paper explores health worker perceptions on how unreliable electricity impacts efforts to provide obstetric and newborn care in LMIC. By analyzing qualitative interviews with midwives, nurses, and other skilled health providers in a variety of health settings in sub-Saharan Africa, Nepal and The Philippines, this research seeks to document the ways in which insufficient light and power influence health worker attitudes, behaviors, and perceptions about the quality of obstetric care.

Institutional Setting

We Care Solar, a non-governmental organization, addresses the energy needs of maternal health facilities in LMIC to improve maternal-newborn health outcomes, working with governments and organizational partners to equip thousands of health facilities with compact solar electric kits called Solar Suitcases. We Care Solar Suitcases include LED overhead lights, LED rechargeable headlamps, electronic fetal monitors, and 12V DC phone charging to provide delivery rooms, maternity wards, and operating theaters with primary and or back-up lighting and 12V DC electricity. We Care Solar conducts programs in countries with high rates of maternal mortality and low rates of energy access, collaborating with governments, UN agencies, and NGO partners to identify and select energy-poor maternal health facilities, install Solar Suitcases, and train health workers. Public health facilities are selected on the basis of electricity status (lack of continuous electricity), function (capability of performing around-the-clock emergency obstetric care), and structural feasibility (e.g. roof with unobstructed sunlight). As part of We Care Solar programming, health facilities undergo pre- and post-installation assessments, consisting of quantitative data collection and, in a subset of programs, qualitative assessments.

Methods

We Care Solar has provided solar electricity to more than 5,200 health facilities conducting maternal and newborn health for over a decade (2010-2020), working closely with partner organizations. The data used in this analysis were obtained from qualitative assessments conducted before and after solar installations by We Care Solar and its partners over the course of ten years. The data were drawn from 17 We Care Solar Suitcase programs in 11 countries. Appendix A lists We Care Solar program partners from 2011-2020.

Health workers from energy-deficient public health facilities in West Africa (The Gambia, Liberia, Nigeria, and Sierra Leone), East Africa (Ethiopia, Malawi, Tanzania, Uganda, Zimbabwe), South Asia (Nepal) and Southeast Asia (the Philippines) were included in the study population in programs ranging in size from 15 to 230 facilities. Multiple tiers of health facilities, from the lowest level dispensaries, to health clinics, to large hospitals, were represented.

All facilities qualified for Solar Suitcase installations by meeting the following criteria; (1) Provision of antepartum, intrapartum and postpartum obstetric services; (2) Availability of, or potential to provide, 24-hour care; and (3) Energy deficiency, either due to a lack of grid power, lack of other primary source of power (e.g. generator or solar), or unreliable and/or unpredictable power.

The analysis included more than 1,200 interviews of male and female health workers spanning ten years of Solar Suitcase programming (2011 to 2020). Demographic data were not always available, but for the 94% of health workers where occupation was collected, interviewees primarily self-identified as midwives (29.6%), nurses (38.4%), non-physician "others" (38.9%) a category that included community health extension workers (CHEW), community health officers (CHO), skilled birth attendants (SBA) and "in-charges," who represented midwives and nurses who had progressed to leadership positions (see Table 2.2). Traditional birth attendants were purposely excluded from the sample as the study was designed to exclusively evaluate facility-based obstetric care by skilled providers.

Table 2.2 Respondents by Occupation

	Number	Percent
Midwives	364	29.6%
Nurses	320	38.4%
Others (Community Health Extension Workers, In-charge, Health Officers, SBAs)	472	38.9%
Doctors	3	2.5%
N/A	54	4.5%
Total	1,213	100.0%

Interviews were conducted prior to the installation of Solar Suitcases or as part of follow-up evaluations conducted 3 to 18 months after the solar intervention. The interview guide included topics such as working without electricity, either as a current experience (for the pre-intervention group) or for a retrospective experience (for health workers who received the solar intervention).

At the time of the interviews, written or verbal informed consent was obtained after assuring subjects that their participation would not impact the implementation of the solar intervention and that personal identifiers would be excluded from any summary reports. Interviewers utilized semi-structured interview guides that were pre-tested in multiple countries. Interviews lasted 30

to 40 minutes and were conducted inside or adjacent to the health facility by We Care Solar researchers, staff from partner organizations, and paid research consultants. Interviews were conducted in English or in the local language. Solar Suitcases were provided to all the facilities included in this study, regardless of the health worker response or availability for being interviewed.

Topics were not completely consistent over the course of the ten years, but always included: (1) Personal demographics; (2) Sources and reliability of electricity and lighting at the health facility; (3) Experiences conducting obstetric care in low-lighting settings; (4) Perception of quality of care, and (5) Attitude towards work. For interviews conducted *after* the Solar Suitcase intervention, additional topics were included, such as (1) experience using the solar suitcase, (2) function of the solar suitcase and its parts.

Sampling technique

Solar Suitcase programs included in this analysis were conducted in partnership with NGO, solar companies, and UN agencies. The programs ranged in size from 15 to 230 health facilities, which represented approximately 20% of all We Care Solar program activities over a ten-year period. In most programs, interviews were conducted at every health facility. To reduce programmatic costs, some programs used convenience sampling on a subset of facilities. In most cases, only the most senior health worker (often called the "in-charge") was interviewed.

Eligibility criteria for health staff interviewees included the following: employment by the health facility, authorization by the government to assist or conduct deliveries independently, and experience with using the Solar Suitcase. Interviews were conducted by We Care Solar researchers, trained staff from partner organizations, and paid research consultants. Interviews were conducted inside or adjacent to the health facility in English or the local language after obtaining informed consent from all health workers prior to conducting the interviews. Health workers were assured that personal identifiers would be removed before sharing the findings with local or national governments.

The interviews were either audio-recorded for later transcription or had responses written out at the time of the interview, with quotations captured verbatim to the extent possible. Written transcripts and interview notes including quotations were provided to We Care Solar.

Data Processing and Analysis

Interview responses were recorded in real time with written notes or recordings that were later transcribed. Recorded interviews in languages other than English were translated and transcribed. All interviews were de-identified to remove the names of individual health workers and clinic locations. Country location, clinic tier and occupation were left intact.

The study team coded the transcription in ATLAS.ti or WORD using an open coding and iterative approach, in which codes and sub-codes were derived from the data. Preliminary codes were

based on the questions included in the semi-structured interviews [17,18]. Consistent with the Standards for Reporting Qualitative Research (SRQR) guidelines [18,19], we began with deductive codes (those pre-determined by our research questions). Among these codes were "quality of electricity," "quality of lighting," "routine care," "emergency obstetric care," "neonatal care," and "health worker attitude." Inductive codes that emerged from the process of coding the data included "breastfeeding," "safety" (including the unanticipated code of "reptiles," and "community attitude." The initial codebook was uploaded to an online software program for qualitative data management (Atlas.ti Version 8) to assist in coding the data. Themes were analyzed across countries and timeframes. In keeping with Grounded Theory's theoretical sampling approach [20], data saturation was reached when new themes or codes ceased to emerge. The codebook is in Appendix B and a sample of the questionnaire is in Appendix C.

Results

Programs in 11 countries were reviewed and qualitative data were obtained from 1,213 health providers. Health facility level data was available for 1086 health workers (89.5%) and unavailable in 127 facilities (10.5%). The tiers of health care represented included hospitals (N=52, 4.2%), level 2 health centers (N=470, 38.2%), and frontline clinics (N=564, 46.5%) in energy-deficient facilities that conducted, on average, 200 deliveries annually. Their experience represented a cumulative 1.5 million deliveries.

Health workers reported an average of 5.4 years of work experience. With an average of 200 births per facility per year, they represented a cumulative experience of 1,310,040 deliveries.

Five countries contributed interviews from more than 100 interviews each: Liberia (N=235, 19.3%), Nepal (N=139, 11.5%), Nigeria (N=291, 24.0%), the Philippines (N=135, 11.1%) and Zimbabwe (N=143, 11.7%). Programs from other countries had data from 20 or more patients, with the exception of Malawi, where the author and a colleague conducted a total of seven interviews (see Table 2.3).

Table 2.3 Respondents by Country

	Number	Percentage
Ethiopia	25	1.1%
The Gambia	108	8.9%
Liberia	235	19.3%
Malawi	7	1.0%
Nepal	139	11.5%
Nigeria	291	24.0%
The Philippines	135	11.1%
Sierra Leone	22	1.2%
Tanzania	40	3.3%

Uganda	66	5.4%
Zimbabwe	143	11.7%
Total	1,213	100.0%

Health Facility Electrification

As predicted, all respondents reported that their health facilities lacked continuous power. Almost 60% of participants (N=732, 60.3%) stated that their facility did not have functional grid power (see Table 2.4). The remainder reported a combination of some grid electricity (N=481, 40.0%), generators (N=204; 24.0%), or solar power (N=204, 16.8%). Most commonly, solar electricity was used exclusively for vaccine refrigeration and was not a source of lighting.

Table 2.4 Reported Energy Status of Health Facilities

	Number	Percent
No grid electricity	732	60.3%
Grid electricity with interruptions	481	40.0%
Generator	204	24.0%
Solar for lighting, other	204	16.8%

Health workers cited a variety of reasons for the lack of consistent grid power. Those with existing grid connectivity had power interruptions due to rolling black-outs (e.g. periodic planned outages for energy conservation called load-shedding) an inability to pay utility bills, hydroelectricity shortages (e.g. drought-induced reductions of hydroelectricity in Zimbabwe), or natural disasters (earthquake in Nepal, typhoons in the Philippines).

The lack of reliable electricity was thought to influence patient demand for care. As one Nigerian nurse commented, "*The health center is mostly dark at night as a result of irregular supply of electricity, and this is one of the reasons that discourage our women from utilizing the health center for delivery."* For health workers conducting around-the-clock care, the lack of continuous power was frustrating for all health workers, including this Ugandan midwife. "*Our UMEME [electric grid] is fluctuating and goes off at night. Most of the deliveries have been at night. Being a midwife, I feel not happy."* Respondents in facilities without grid connectivity either reported that the health facility geography was far from grid lines (e.g. Sierra Leone, Nepal) or that the facility lacked the resources to connect to established power lines (e.g. Malawi, Zimbabwe).

More than 200 health workers (Nigeria, Liberia, The Gambia, Uganda, and the Philippines) reportedly relied on diesel fuel generators for primary or back-up electricity. However, a combination of factors such as fuel shortages, mechanical breakdowns, and limited resources to pay for fuel resulted in frequent power interruptions or a complete lack of power. One midwife based in a health center in the Philippines described her electricity challenges after Typhoon

Haiyan. "*We did receive a generator after the tropical storm, but had a hard time finding and affording fuel. There was no power from November until April, and even after being reconnected to the grid we have brownouts at least twice a month for 10+ hours at a time."* A Ugandan operating room nurse was unable to use the hospital generator as a back-up source of power for surgeries due to mechanical failure and the cost of fuel. *"We used to have a generator. But then it broke. It's about sustainability. If there is no fuel, it is not sustainable. When power goes off, you have to operate by kerosene. Sometimes we don't have paraffin. Then we have to use cell phones… and that is not enough light."*

Alternative Sources of Light

Without reliable modern electricity, health workers reportedly relied on a variety of alternative light sources, including candles, kerosene lanterns, oil wick lamps, torchlights, battery-operated lanterns, and cell phone lights. Erratic power supply could cause power outages for days, weeks or even months. This was true at every tier of health care. A skilled birth attendant described how she turned to candles when grid power failed. "*Earlier we were totally dependent on the national grid and that was very unreliable with huge power outages. Then we used candles."*

Figure 2.2 A midwife in a rural health center in Uganda preparing for childbirth by candlelight

Energy-deficient health facilities throughout Africa relied on kerosene lanterns and even candles for a range of obstetric care procedures, such as starting intravenous lines or repairing lacerations after deliveries. *"We have the lanterns but sometimes there is no kerosene. Sometimes the patient will tear and we have to suture using a candle."* Midwife, Nigerian health center. And many health workers reported that one candle was not enough.

The light generated from candles and kerosene lanterns was deemed inadequate for medical care by health workers in every country surveyed. They could make rooms feel hotter, air seem smoky, walls get soiled with soot. Furthermore, lanterns and candles could not direct light towards a specific location, making it difficult to use them to conduct vaginal procedures, identify the source of postpartum hemorrhage, or repair cervical and vaginal tears resulting from childbirth.

> *I had a serious case of a mother who developed secondary postpartum hemorrhage. She was bleeding profusely and had an undetectable blood pressure. Her veins had collapsed. I had a difficult time in putting two running liters (of fluid). I ended up lighting five candles to have enough lighting.* Nurse, Rural Health Center, Zimbabwe

When no conventional lights were available, health workers sometimes resorted to unusual and even dangerous practices. In Uganda, a midwife demonstrated how she lit matches within the maternity ward to achieve short bursts of light. In a hospital in Malawi, an operating room nurse recounted a Cesarean section where shrubs were set on fire in front of the operating room window to provide nighttime illumination. In Nigeria, a health center midwife described how she instructed her assistant to use a match to burn the calendar on the delivery room wall in order to have enough light to complete a breech delivery. A Liberian midwife in a rural health center asked a patient's husband to hold burning palm leaves which she cared for a woman with eclampsia.

As one could imagine, flame-based sources of light were neither safe nor reliable. One midwife in a rural health center in Zimbabwe described her frustration when an expectant father accidentally blew out the candle he was holding to light the delivery; she could no longer visualize what she was doing at the moment the baby was being born. There were many instances when hand-held lights fell and were soiled by blood or amniotic fluid, creating a hazard for health workers who were required to re-use them. And one in Uganda, where the midwife reported that a candle set the bedsheets on fire and she needed to move the patient to the floor to complete delivery. Without proper lighting, health workers recounted their fear and their challenges. A seasoned midwife working in a rural health center in Zimbabwe shared this anecdote.

> *We had an incident when the candle fell down, the baby was coming out, you're alone, you're now in the dark, you have to attend to the baby, you have to see if everything is ok with the mother. It puts us at risk – the mother and the nurse. Because in the dark, you'll be afraid that maybe you touch the sharps that have been used. And the child, you'll be afraid that maybe the baby will fall while you're looking for the candle or matches to light the candle.*

The sudden loss of light in the delivery room was disorienting and dangerous. Many health workers described scenes where they had to leave their patients mid-delivery to search for light; some even left the facility to purchase candles or batteries. A midwife in a Nigerian primary health center described one such incident. "*The head of the baby was coming out when the light went off. I had to leave the pregnant woman to look for torch light. Before I came back the placenta and baby were already out. That short break made me feel I wasn't relevant to the patient."* Midwives in three separate facilities in Uganda and Ethiopia described instances where newborn babies had been dropped when lights suddenly went out; in one case, it was the mother herself who dropped the baby when a flashlight lost power. Other dangers included the risk of injury and fire. Health workers in Uganda and Zimbabwe described wax burns suffered by mothers and infants when candles were held close to the site of deliveries.

> *The battery in the phone went out. The baby's head was almost out. We were saying "push, push, push" in the dark, but couldn't see at all. I got a candle. The wax spilled on the patient during the delivery. The patient almost was in shock. She almost fell from the bed, because of the wax burn during the delivery.* Health Worker, Rural Health Center, Zimbabwe

An older midwife in a rural facility in Zimbabwe recounted her personal fear of being burned. "*The candle needs to be about 30 cm away to see. It's dangerous because it causes dirt, and the wax drips on the sheet, floors and even I have to bend to suture. You can get burnt on the head. Your weave, hair extensions can burn. We are afraid we are going to get burned. The person with the candle they are afraid, the person can burn your hand. They are not familiar with the process."*

The most dramatic stories were those of health centers that had actually caught on fire from candles that were used during labor. A midwife brought me to see an abandoned health center in the Philippines. During a nighttime delivery, a candle had inflamed the delivery room curtain and the entire room caught on fire. The laboring mother was rushed out of the building and luckily was unharmed, but the incident was frightening for all who were involved.

Figure 2.2. This clinic in the Philippines burned down when a candle set the building on fire

Battery-operated lights, such as flashlights (called torchlights in Africa), cell phone lights, and small "Chinese" lanterns found in West Africa, avoided the risk of fire, but offered their own challenges: they required a steady supply of batteries and someone to hold and direct the lights. Midwives who attempted to hold the lights with one hand and work with the other found the situation challenging. A birth attendant in Nepal recounted, *"It was difficult to hold down the mother while she tries to move during the delivery as we had to hold light in the one hand. It used to be hectic. The guardian used to get angry with us regarding the electricity situation. It was tough."*

A midwife in the Philippines described her efforts to deliver patients while simultaneously holding a flashlight. "*I would put one glove on and hold the flashlight, or both gloves on and wouldn't know where to put the flashlight. It was very hard to hold the flashlight and keep one glove sterile. I learned to deliver with one hand and hold the flashlight. Or I would have to call people to come help me – it's inconvenient to go to someone's house and ask people to help. Or deliver with one bare hand. It was very difficult."*

Most midwives working alone at night found alternative ways to hold battery-powered lights without their hands. In Nigeria, Muslim midwives steadied cell phones on the top of their heads under their hijabs. In Liberia, Sierra Leone, and Nigeria, health workers propped flashlights and battery-operated lanterns between the side of their chin and shoulder.

Figure 2.3. Liberian and Nigerian midwives demonstrating how they hold lights without using their hands

But perhaps the most troubling solution was one that was seen in every country—holding the light by mouth. A community health extension worker in a Nigerian health center described her experience after her patient sustained a tear during a nighttime delivery.

> *There was no light, and [the patient] was bleeding profusely. I was looking for light everywhere to suture the tear to no avail. I had to send the husband to town to buy a torchlight. The husband was afraid to assist in holding the torchlight because of the bleeding, I had to manage to hold the torch in my mouth to enable me to suture the tear.*

In East and West Africa, holding cell phone lights by mouth was surprisingly common. Health workers could direct the beam of light wherever they were looking. However, they acknowledged the inherent risks in this technique: they lost their ability to verbally communicate, they risked infection by placing a potentially contaminated object in their mouth, and they risked dropping the phone if they inadvertently opened their mouth. A midwife in Malawi gasped when the amniotic sac ruptured and sprayed fluid in her direction. Her mouth opened, the phone she was holding dropped to the floor and broke, and she was left to complete the delivery in the dark. A midwife in a Zimbabwe rural health center delivering an average of 17 patients a month described her concerns about infection.

> *I have put the cell phone in my mouth – it's not good to do this. The phone can drop and become full of blood. And there are many risks, to the nurse, to the patients and even to the other person who can touch your phone when it drops to the blood. Or the phone goes off and can't work and they pick it without gloves. And with HIV infections, it is risky.*

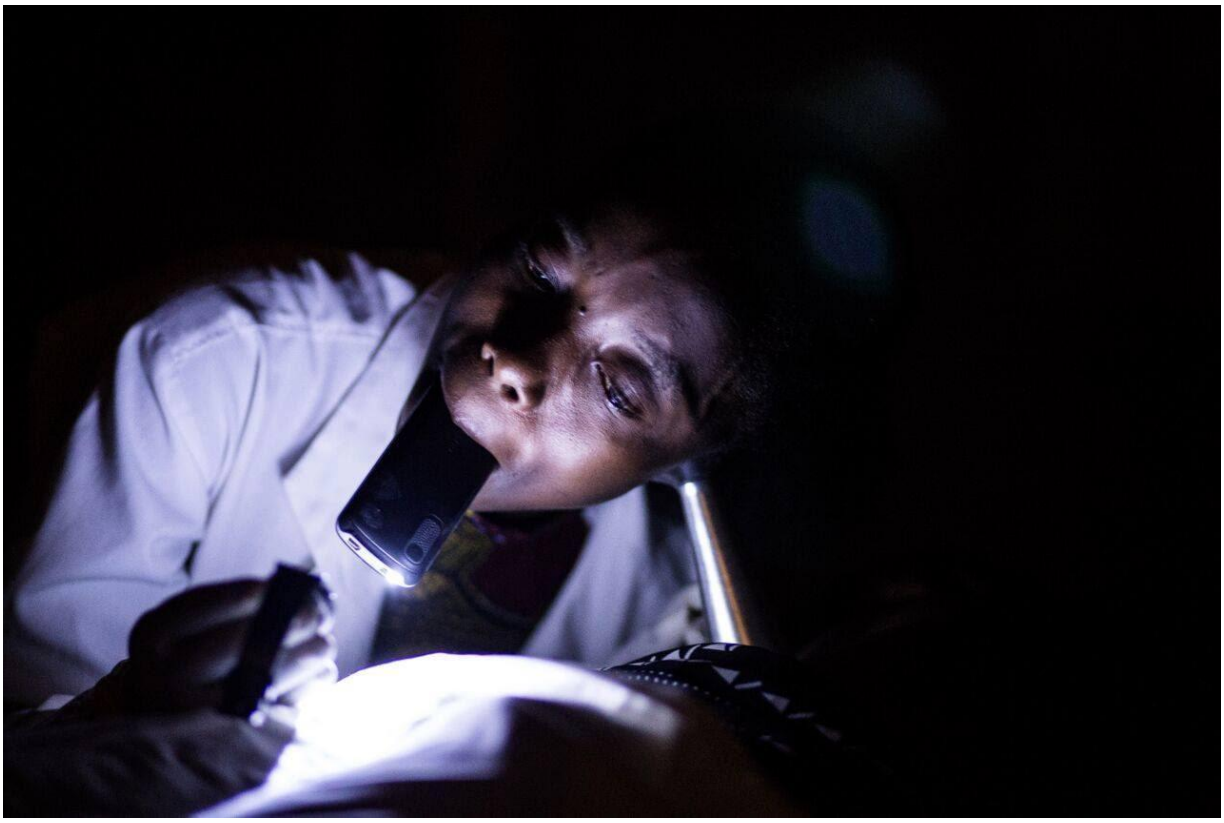

Figure 2.3 A Tanzanian midwife using her cell phone and fetoscope to check the fetal heart beat

The health workers who tried strapping cell phones to the top of their heads, either with their hijabs (Nigeria) or with rubber bands (The Gambia), knew this method was not fool-proof. One Nigerian community health extension worker (CHEW) in a health center explained, *"We use a torchlight or our phone tied to our head to conduct deliveries which can mistakenly fall off or we have to call the patient's relative to hold the phone for us while we work."*

In addition to the problem of holding the devices, battery-operated lights offered yet another challenge: the solitary beam of light they produce only illuminated one patient at a time. The lack of ambient room lighting often meant medical problems could be missed. This had tragic consequences for a Nigerian hospital midwife who struggled through a complicated delivery by torchlight. She rejoiced when the baby was born healthy, but her happiness was temporary. "*When I finished the delivery, I covered the mother and went to care for the baby. I didn't notice the mother was bleeding. When I turned my light towards her, I saw that the mother's clothes were soaked in blood and that she had died. Only because the place was dark, I could not notice that her clothes were soaked, that she was bleeding.*" She cried as she spoke, and later described the measures she could have taken to save the mother's life if electricity had been available.

Loss of Privacy

Another downside reported by health providers was the lack of privacy that ensued when medical attendants, family members, and sometimes unrelated community members were asked to assist with handheld lights. In addition to the challenge of having an untrained assistant know where to properly direct the light, health providers voiced concerns for their patients' privacy, the perceived discomfort when non-medical personnel witnessed an intimate medical event, and the risk of contamination by having extra people in the delivery room.

> *Once in the middle of the delivery, the power was cut off and there was the battery in the emergency light and I was the only staff available at that time. I had to call one of the visitors and ask her to take out my mobile from my pocket and help me perform the delivery by showing the mobile phone's light. It was very stressful to conduct deliveries in such a situation.* –Skilled birth attendant, Nepalese Health Post

These challenges were not confined to night time care. In many facilities without electricity, health workers needed to maintain patient privacy by drawing the curtains together, blocking the ambient light from windows. One Nepalese skilled birth attendant in a village clinic explained that she kept the delivery room curtains closed to keep children from the adjacent school from peering inside.

Challenges of Routine Care

Without reliable electricity, health workers in every country reported the challenge of conducting routine and emergency medical services. The lack of lighting impaired proper visualization for basic medical tasks, such as admitting patients, taking vital signs (temperature, blood pressure, respiratory rate), inserting a Foley catheter to empty the bladder, starting an intravenous line to provide hydration or administer medications, reading bottle labels to select appropriate medication, making phone calls to patients or colleagues, writing progress notes, preparing equipment for procedures, maintaining hygienic conditions, and sterilizing equipment. Even something as basic as moving through the health facility became challenging, as one hospital midwife from Nigeria explained. "*We find it difficult to move from point to point. Sometimes the lantern will run out of kerosene and we become stranded."*

Time and time again, health workers described lack of light as one of their biggest hurdles, echoing the sentiments of another Nigerian midwife, who delivers 10 babies a month. *"The hardest part of my job is taking deliveries in the dark."* Health workers cited difficulties conducting clinical exams, performing vaginal deliveries, and suturing episiotomies. A midwife in Uganda described her struggle like this: "*It is hard to conduct a delivery at night with a kerosene lamp. It is hot and does not even provide sufficient light, let alone for a delivery. It is even harder to suture a patient or conduct an episiotomy without sufficient light."* Health workers also recounted challenges of postpartum and newborn care. They struggled to assign APGAR scores (which require visualization of the baby's respiratory effort, muscle tone, and skin color), checking for birth anomalies, reading the scale when they weigh newborns, and providing newborn cord care.

They also needed light to support breastfeeding, using the light to show first-time mothers how to help their babies latch on to the breast.

Medical and Surgical Errors

Health workers described their difficulties in conducting familiar tasks without bright lights. Inserting an intravenous line and establishing the correct rate of flow became difficult without bright light, as a midwife working in a Zimbabwean health center explained. "*There's fear of losing a patient, or pricking the vein and putting the IV in the tissues. I feel that you can make complications because [you] can overload the patient instead of helping the patient."* Suturing in near darkness can have even more risks. Several health workers described the perils of suturing the wrong tissue layers together. *"You may sometimes cause secondary complications for patients like suturing the bladder, vaginal opening or perineum. You may even harm your fingers with the needles,"* recounted a clinic health worker in Liberia. A health worker in Uganda admitted that sutures might need to be completely removed and replaced when better lighting revealed that the wrong layers had been sewn together.

Emergency Obstetric Care in Low-Light Settings

Poor visibility is particularly deleterious in the treatment of high-risk complications, such as obstetric hemorrhage, breech presentation, obstructed labor, and eclampsia, where accurate and timely care is essential. Health workers cited suboptimal performance in low-light settings, as they struggled to administer parenteral medication in women with eclampsia and sepsis, measure blood loss and identify the source of bleeding in women with hemorrhage, and handle complicated deliveries. In Tanzania, a midwife described the challenges of caring for a patient with postpartum bleeding in her health center. "*The mother needs lots of intervention. You must rule out whether it is a tear, a piece of placenta, or something else. To search for the source of bleeding or provide life-saving care, light is imperative*."

The blood loss following a delivery could be rapid and severe. In these situations, health workers raced to provide intravenous hydration, such as this Nigerian community health extension worker caring for a patient who arrived in the clinic after substantial blood loss. *"It was a case of postpartum hemorrhage and we had to use a torchlight in order to locate her vein which had already collapsed following a home delivery. It took several attempts before we could locate the vein due to poor light."*

Newborn Care Depends on Reliable Lighting

Neonatal care is equally at risk in energy-poor settings. Without proper lighting, health workers were unable to conduct thorough newborn exams, assign Apgar scores, assess for newborn asphyxia (oxygen deprivation), locate appropriate sized masks and resuscitation equipment, and perform the resuscitation. Many health workers expressed the challenge of providing immediate newborn care, including this Liberian health worker. "*It is difficult to care for a newborn if there is no electricity because we need to see the entire body movement and color and this should be done immediately after birth to avoid any complication."* Another Liberian rural health worker

emphasized that in caring for newborns who are trying to breathe, time is of the essence. *"[Caring for the newborn] is very hard for us because you may not give care in the right time, for you need to breathe for a baby within 1-5 min. Without light, these things will be delayed leading to infant death*."

In delivery rooms with scant lighting, some health workers described their challenge discerning whether a newborn baby is alive or not. One Philippine midwife at a rural health center cried as she recounted the delivery of a preterm infant during a power outage. Using a flashlight, she examined the limp baby and assumed it was stillborn. *"I'm sorry your baby is dead,"* she told the mother and laid the baby on the delivery table. She moved closer and only then realized the baby was taking occasional breaths. In the darkness, she grabbed the large Ambu bag (too big for the baby's face) to begin the resuscitation and then switched to the preterm size to continue her efforts. The baby survived—an example of a "near-miss"— and is now called the "Miracle Baby."

In Malawi, a male midwife in a center conducting 20 deliveries a month recalled two tragic newborn outcomes in the months prior to his interview. "*I lost babies in the past because the [torchlight] batteries were down, and I couldn't look for the instruments, I couldn't find them and unfortunately at that time the woman was also bleeding. I thought to resuscitate – I didn't want to lose the baby. The baby was floppy – I knew the baby needed resuscitation – but the mother was bleeding, and I had to attend to the mother first. By the time I finished the mother and found the equipment, the baby was already dead."*

In addition to resuscitation equipment, high-risk newborns in hospital settings without reliable power could not benefit from other medical equipment designed for life-saving care, including infant warmers, oxygen concentrators, suction devices, and phototherapy units that lay dormant when grid electricity was down.

Referral Patterns Affected by Electricity

In public health systems with multiple tiers of service provision, only basic services are provided at the lowest level facility; more complicated cases often require transfer to higher-level facilities. Primary health workers need to identify which patient can receive complete treatment at their own facilities and which patients should be stabilized and then referred to a higher-level facility for care. A health worker in Sierra Leone in a primary health care facility shared her experience caring for a new mother with a retained placenta. *"After the administration of oxytocin, the placenta was expelled but 2-3 mins later [she] started experiencing postpartum hemorrhage. There was no light at this time to find out the cause of the hemorrhage. It became very difficult as there was no light to check the placenta, perineum for tear, etc."* The patient was transferred to a district hospital and thankfully survived with a blood transfusion. But without adequate lighting and/or reliable transportation for immediate hospital transfer, postpartum hemorrhage can have dire consequences. A midwife in Malawi recounted how she struggled to treat a patient with antepartum hemorrhage and vasoconstriction. Without proper lighting, the midwife was unable to insert an intravenous cannula to provide parenteral fluids while waiting to transfer the

patient to a hospital. The patient failed to get IV hydration and died before the ambulance arrived. Maternal death and "near-miss" stories were all too common.

Health workers at all level facilities described how lighting affected their decision-making around who they could treat and who they should refer. Health workers described their best attempts to provide services in near-dark conditions. But some admitted that they immediately referred any patient arriving at night when the power was down. The officer in-charge of a Nigerian health clinic serving a catchment population of 7,000 expressed his approach. "*What I do in the facility if there is any case of labor that comes in the night and there was no sufficient lighting, I always refer immediately."*

Turning away a critically ill patient may seem more sensible than admitting a patient to a health facility incapable of performing obstetric services due to lack of electricity, but referrals can be a gamble. A hospital midwife in Nigeria described a tragic incident where a patient with obstructed labor needed an immediate Cesarean section when the power was down. Despite a fully-equipped operating theater and adequate staffing, the patient was referred to another hospital. The family returned hours later, reporting that the patient had died *en route* to the other facility. Presumably, she died from uterine rupture resulting from prolonged obstructed labor. If the first hospital had been equipped with power, her life could have been saved.

Delayed Procedures

Without adequate nighttime lighting, procedures were often delayed until morning. Patients with complications, including postpartum hemorrhage, were unable to receive definitive treatment until morning when the ambient light improved visibility. One Nigerian hospital midwife was unable to examine the patient well enough to find the source of postpartum hemorrhage. "*We had no light to determine the cause of PPH in order to know if it's something we could handle. We had to wait until morning for the doctor's intervention."* Nurses and midwives reported delaying intravenous medication for the same reason. In Zimbabwe, several midwives reported deviating from the standard of care when they managed HIV positive mothers at night. Without adequate light, they could not weigh babies, calculate dosages, and measure precise quantities of Nevirapine (HIV prophylaxis medication) to administer to babies exposed to HIV. Instead, they delayed giving the medication until the morning.

When midwives deferred the repair of nighttime episiotomies and lacerations until the morning, it meant that they sent patients to the postpartum ward with open wounds, increasing their risk of bleeding and infection. Only after sunrise could they return to the delivery room for suturing. Such delays increased the risk of problems, as one Malawi health worker acknowledged. "*If you wait until morning it can cause more pain and can cause infection, so it is not safe."* Delaying care caused distress for health workers and patients alike. A senior midwife in a Ugandan Health Center III expressed her feelings this way. "*If you have a cervical tear, you must postpone to tomorrow. It is so painful to do the procedure to the tomorrow. A midwife feels it to tomorrow."*

Beyond the emotional burden, health workers knew that delaying procedures could have life-threatening consequences. "*The patient [can] go in to shock or even die because of darkness and delay in doing the right procedure,"* a Liberian health worker acknowledged.

Increased Risks of Infection and Injury

Health workers in darkened facilities perceived an increased risk of infection and injury. In addition to the previously mentioned fear of infection from holding contaminated cell phones in their mouths, they expressed concern about risks from needle pricks and other injuries. "*Suturing in darkness is very difficult in the sense you may not suture the laceration properly and you may have a needle prick and expose yourself to HIV and Hepatitis B,"* a Liberian health worker, based in a community clinic located in the capital city, reported.

It was not uncommon for health workers to postpone delivery room clean-up until morning hours when visibility improved. Maintaining proper sanitation was particularly challenging in the delivery room. In Nepal, a skilled birth attendant explained, "*There will be blood and placenta spilled all over the place and sometimes the health staff or mothers used to step on this and the room would feel very unsanitary."* This experience was described by health workers in every country we assessed. In Uganda, a health center midwife put the situation this way, "*You need to disinfect, but there's no light. You need to use the charcoal stove but there's no light. You need to wash, clean and disinfect and there's no light. You postpone what you're doing."*

Accidents were more likely to occur at night, both from conducting medical procedures and from moving in darkened rooms. In Malawi, a health worker had injured himself by stepping on a needle at night. In Ethiopia, health workers described multiple accidents including a health worker falling and breaking her teeth. "*When there is no light, we are forced to use our phones for lighting and sometimes when rushing in the darkness we are prone to accidents like falling down or hitting our leg against bed."* Fear of snakes and rodents, especially when going outside at night to the latrine or placenta pit without adequate lighting, was common in West Africa.

Reduced Health-Seeking Behavior

Health workers reported that patients also expressed concern about safety in low-light situations, impacting patient health seeking behavior as well as the ways in which patients and health workers interacted.

An auxiliary nurse in a Nepalese health post shared her personal observations.

> *Most of them [mothers] used to get scared all the time. It was very hard for us to calm them. They were scared that in the lack of proper light we might make mistakes and they would constantly scream at us…Even though we are confident of ourselves, the patients and their visitors used to undermine our capacity.*

Health workers reported that patients did not want to come to facilities without lighting.

The hardest part of my job is working alone at night with no light. With no light in the facility, patients don't even want to come here. They would rather visit other providers that may not even be health workers. Community Health Extension Worker, Nigerian Primary Health Center

Challenges with Phone Charging and Emergency Communication

In addition to light, electricity was vitally important for keeping cell phones charged for emergency consultations, medical transport, data transfer to district offices, and hospital referrals. Without a reliable source of power, some health workers were unable to summon emergency transport or call other health workers, as described by this Nepalese skilled birth attendant. *We did not have constant electricity supply so we used to have our mobile switched off most of the time and in an emergency situation, it used to be hard to contact the Ambulance or another health facility for support.* As long as her phone remained switched off, this meant that she could not be promptly reached by her patients or the district.

In order to charge their phones, many health workers had to travel to distant locations, or find a courier to do this task for them, a situation that was time and resource intensive. Depending on the location of the nearest charging station, the entire process could take hours or longer. A senior midwife in a Health Center III in Uganda told us she needed to travel 26 kilometers away to charge her phone. "*I need to get a taxi to go to town, wait for my phone to be charged, and then come home. Sometimes the shop is closed. The phone charge lasts 3 to 4 days."*

When a nighttime emergency occurred, the challenge of darkness was compounded by being cut off from communicating with colleagues, as this Nigerian community health extension worker recalled. "*The patient arrived with a complicated labor in the night and all phones were down for me to call my co-worker to come and assist me for us to attend to and there was no light as of then in the clinic and she was crying."* Without the ability to get help from his co-worker, the patient was asked to go to another health center. The health worker said he had *"no other option than to refer."*

Financial Burdens to Health Workers and Patients

Charging cell phones was only one of the financial repercussions of working without electricity. Health centers were burdened with the cost of kerosene, candles, and batteries. Health workers either absorbed these expenses themselves, or turned to the patients and their families for support. In Zimbabwe, midwives reportedly asked mothers to bring three to six candles to the health facility for childbirth. In Liberia, midwives asked family members to pay for kerosene. In Sierra Leone at a community health post, mothers were asked to pay for the cost of batteries. Health workers acknowledged the risks of asking patients to pay for light. As one health worker in Sierra Leone explained, *"The community is very poor if you tell them to come with light they may even decide to give birth at home.*

The expense of purchasing candles, kerosene, and batteries were substantial, made even worse by inflation and COVID-19. In Zimbabwe, a candle cost one Zimbabwean dollar, which in 2017 was equivalent to a USD. In 2017, a nurse might be expected to earn the equivalent of $500 a month for salary and allowances, and could spend $30 on candles in that period. At the time of this writing, with devaluation of the currency and in the midst of the COVID pandemic, the same nurse is receiving $125 USD and candles cost $1.25 [31].

Health workers juggled their desire for patients to absorb the costs of lighting with their desire to support impoverished families. *"We had light before but it was not enough light. We had to ask the family to buy batteries but sometimes they don't have money so we have to afford the batteries yourself*." For health workers working in poor-resource environments who often made little money or waited months for their paychecks, alternative lighting expenses became unsustainable. The discussion of whether patients would pay for lighting could create antagonism between providers and their patients. For families living in extreme poverty, these confrontations were another deterrent to seeking facility-based care. Despite mandates for free health care during pregnancy in the countries we studied, health workers reported that expectant mothers often chose between delivering at home without skilled care or traveling to a darkened health center where they could be asked to pay for a source of lighting. Many opted for a home delivery.

Emotional Burden to Health Workers

The personal cost to health providers of working in near darkness extended well beyond finances. Health workers described the emotional burden placed upon them and the demoralization of working under these conditions. "*I feel so sad when working in the dark, the torch light is not bright enough to take deliveries at night,"* reported one Nigerian health worker. Uniformly, health workers reported a loss of confidence, motivation, and efficiency when working without good lighting. In describing their feelings, they used words like "discouraging," "stressful," "frightening," "uncomfortable," "unbearable," and "unprofessional." A health worker in The Gambia thus commented, "*delivering patients in the dark is very uncomfortable because if a complication occurs such as postpartum hemorrhage, managing it in the dark can be very distressing."* Several admitted to crying as a result of the challenges they face working in the dark. Many described their fear of night duty and concern about their own safety. Some wished they could transfer to another facility. An Ethiopian midwife in a clinic conducting 33 deliveries a month said she was angry and discouraged. *"I am risking my life caring for mothers,"* she lamented. Many expressed regret that they could not perform the standard of work they were trained to do nor fulfill their purpose in choosing a career in healthcare. In addition to disappointment about working at an un-electrified health center, some questioned their choice of profession. One said she prays to get out of her health facility. A Nigerian community health extension worker with six years of experience in a primary health center remarked: "*The most annoying and difficult task for me is when a woman has a tear during delivery. Suturing it using my phone's torch light or lamp is terrible and makes me sometimes feel like running away from my duty post."*

Underutilized Medical Devices

In addition to a lack of lighting, health workers working in facilities with sporadic power could not utilize diagnostic equipment (e.g. microscopes) and autoclaves for sterilizing instruments. Facilities with sporadic electricity at larger medical facilities sometimes faced an inability to use suction machines, surgical cautery, and anesthetic machines for surgical care. Surgeons described their inability to perform emergency Cesarean sections when grid power was down and generators lacked fuel. Without an independent power supply, laboratory equipment and radiology machines were also rendered useless at times. As one Gambian health worker put it: "*The appliances are difficult to use. The quality of service is compromised, and observation and monitoring of patient care is difficult."*

Other Structural Problems

Beyond deficient electricity, health workers in public settings described a range of health facility challenges: the lack of running water, stock outs of medication and supplies, poor ventilation, lack of privacy, and unsatisfactory sleeping quarters. Health workers in Liberia clinics shared the following grievances, familiar to health workers in many countries.

> *"It is difficult because when there is no light while conducting deliveries at night. It is also difficult if I don't have medication and tools at the facility to work with."*
>
> *"The hardest part of my job is the lack of material such as drugs, ledgers, pen, sheets, and delivery material."*
>
> *"The hardest part of all is no water in my facility for drinking and other work."*
>
> *"Staff incentives are not paid on time."*
>
> *"There is no time to rest."*

Some challenges might be unimaginable for clinicians in higher income countries: the need to deposit placentas in an outdoor pit with the risk of encountering snakes and other reptiles, health facilities without ceilings or with leaky rooftops, and delivery room infestation with bats, rats, snakes, and other creatures.

A Nigerian Community Health Officer from a primary health center shared this anecdote:

> *"A woman in labor walked to the facility in the company of relatives. She was received and examined in the labor ward with a lantern, while a kerosene lamp was at the nurses' station. When a rechargeable lamp finally was brought by one of the relatives, we discovered that there was a very big snake under the resuscitation table and so the crowd that came with the woman in labor helped us to kill the snake."*

Undoubtedly, these types of environments were not conducive to the highest standard of care and compounded the problems created by a lack of electricity. Even when lighting and electricity are addressed, the quality of care will remain poor when health facilities lack adequate supplies of medication, supplies, instruments, medical equipment, and emergency transport.

Despite the challenges described thus far, however, health workers readily shared what they liked about their jobs, including their ability to overcome challenges. They cited their personal pride in saving lives, their joy in delivering healthy babies, and their connection to their communities.

> *"The job is lifesaving."*
>
> *"I like the interaction with mama and babies especially after delivery to hear the baby cry."*
>
> *"The job makes me popular."*
>
> *"I love to conduct deliveries. I love challenges sometimes with pregnant women to give them care."*
>
> *I love challenges, it makes me strong to work."*
>
> *"I love the good outcome of my patients."*
>
> *"I love giving care to my patients."*

Clearly, these health workers entered their fields to help others and save lives, but likely unaware of the extent of infrastructure challenges they would encounter.

Discussion

This qualitative analysis of maternal health worker interviews from 11 countries reveals the challenges of working in health centers without reliable power and electric lighting. Health workers in energy-deficient settings in LMIC depend upon inadequate, inferior, and dangerous forms of lighting. Flame-based lights such as candles, oil wick lanterns, and kerosene lanterns do not allow for adequate visibility, cause soot and smoke, and increase the risk of fire. Battery-operated lights fail to fully illuminate a room, and without the aid of an assistant, health workers struggle to hold these lights in ways that allow them to keep their hands free: in their mouth, pinned between their neck and shoulders, or secured on top of their head. Health workers conducting deliveries provided numerous examples where lights fell into areas soiled with blood or amniotic fluid, causing lights to fail and raising concerns about contamination and infection.

Health workers perceived the care they were able to provide in low-light settings as substandard in low-light settings. Routine activities—like reading labels, measuring medication, writing notes, reading patient charts, taking vital signs, and cleaning delivery rooms—were extremely challenging in near-darkness. Efficient execution of the signal functions required for the provision of life-saving obstetric and newborn services were close to impossible. Although health workers described their attempts to start intravenous lines, search for the cause of bleeding, suture lacerations, maneuver difficult deliveries, and administer life-saving medications, their stories revealed how darkness led to delays in services, inefficient and ineffective care, mistakes, and an inability to meet international standards. Compounding these issues, the lack of electricity for phone charging meant that health workers could not reliably call for help and consultation, or request transport for patient transfer.

The lack of reliable electricity caused emotional stress for health workers and the people they cared for. While some health workers accepted sporadic electricity as the reality of working in regions with multiple infrastructure challenges, most expressed a combination of fear, anger, disappointment, and discouragement. Many worried that they were putting themselves and their patients at risk, and several questioned their choice of profession.

From this analysis of more than 1,200 interviews, it appears that the problem of energy poverty was not only affecting the supply of maternal and newborn care. Health workers reported that the lack of power impacted the demand for services as well. In remote communities where health centers appear dark at night, families were less inclined to travel long distances to seek skilled care. In impoverished communities where patients were expected to purchase candles, or pay health workers for kerosene or batteries for lighting, these fees could serve as an additional barrier to care. These observations could have important implications in efforts to achieve universal health care.

While no health facility in the 21st century would be intentionally designed without electricity, the sobering reality is that hundreds of thousands of health workers go to work every day facing the same conditions described by health workers in this study. In 2013, the WHO reported that 72% of health facilities in sub-Saharan Africa lacked reliable electricity; one in four had no electricity at all [21]. Although conditions in some of these countries have been improving, a 2018 review of environmental conditions in health care facilities in 78 low- and middle-income countries revealed that 59% of health facilities still lacked access to reliable electricity [22]. Challenges in the energy sector include the failure of utility grids to reach rural geographies, overstretched utility grids forced to conduct intermittent load shedding through rolling blackouts, inadequate centralized production of electricity, insufficient financing for fueling and maintaining generators, and an inability of end-users to pay for utilities. Until these issues are addressed, or distributed renewable energy sources are widely disseminated, the problem of energy poverty will remain a major challenge in the health sector.

In each of the 11 countries we surveyed, health workers provided evidence of the many ways in which lighting and essential electricity is imperative for maternal and newborn care—and the consequences when it is not available. These included adequate light and energy for: (1) patient admission and triage, (2) assessment, diagnosis, and monitoring, (3) medical and surgical procedures, (4) postpartum care, (5) clinical hygiene, and (6) personal safety. The findings from these interviews were remarkably consistent across geographies and time frames. Health workers in Nepal faced challenges similar to those of their colleagues in Uganda and in Sierra Leone. Sadly, the findings of interviews in 2012 were for the most part consistent with those from interviews in 2019. Narratives from health workers in rural health posts, larger health centers, and hospitals illustrated the importance of light and power at every tier of health care.

A growing body of literature underscores the need for comprehensive approaches to improving facility-based emergency obstetric care, with core components including (1) education and mentorship of health providers [23,24], (2) prevention and treatment of obstetric hemorrhage [25], (3) treatment of hypertensive disorders of pregnancy [26], (4) surgical intervention for obstructed labor [27], (5) prevention and treatment of puerperal sepsis [28,29], and (6) the provision of essential equipment and supplies[5,30]. All of these interventions are necessary, yet they are predicated on health workers having light and electricity. Indeed, no medical intervention should be expected to succeed without light. The tragic reality is that light and electricity are not available 24 hours a day in many countries, and therefore, health workers in regions of energy poverty cannot fully leverage important investments in maternal-newborn care.

This study had several limitations. First, there was methodological heterogeneity in the interview protocols. Interviews were conducted as part of separate programs across many years. They were conducted by interviewers with different skill levels in partnership with multiple international organizations. The more seasoned researchers may have extracted greater levels of detail and storytelling than less skilled interviewers, as well as more verbatim quotations from participants. Yet despite these differences, the type of information reported remained remarkably consistent. It is unlikely that this limitation affected the directionality of the findings.

Second, some of the interviews were conducted in languages that were not the primary language for health providers, which may have limited the understanding of some of the questions and the accuracy of the quotations. Some details of health worker experiences may have been missed.

The semi-structured questionnaire was revised over time; it was adapted to add additional topics and include specific probes for the interviewers. These iterative changes, however, are standard practice in Grounded Theory [20] and many other qualitative research traditions [18, 19] and would not be expected to change the directionality of the findings.

An additional limitation of the study is selection bias. The health centers targeted for the study met the criteria for a solar intervention; health workers in facilities with reliable electricity were

not included. Without a comparison group, it is possible that the emotional burdens experienced by health workers in low-light settings were due to infrastructure and other challenges beyond electricity.

There is also the possibility of reporting bias. The interviews were conducted by We Care Solar staff or its proxies. It is possible that the health workers exaggerated the difficulties of working without electricity, either to ensure their facility would receive a Solar Suitcase (pre-intervention interviews) or to please the interviewer (post-intervention interviews). Health workers were asked to describe the challenges they faced in general, and then to describe challenges related to the lack of electricity. They were asked to recall "memorable experiences," where the lack of light may have affected their work. Recall bias also may have distorted descriptions of past challenges that respondents attributed to problems with light and electricity. This means that the most dramatic cases were included in the database, and the most vivid examples were often highlighted in this paper.

As tragic as some of the stories were, health workers may have adjusted the outcomes of some situations in order to avoid appearing incompetent, negligent, or responsible in some way for a bad outcome. They may have been concerned that their stories could reach local or national authorities, and this could harm their careers or health centers. It wasn't uncommon for health workers to describe a harrowing medical case with the conclusion that everything turned out well and "the mother and baby survived."

During my own observational research in Nigeria in 2008-9, I saw ways in which health workers distorted medical events and recounted challenging situations in ways that put themselves in the best light. Bad outcomes were attributed to "bad patients" whom health workers blamed for being *too late, too uneducated*, and *too naïve* for accepting the advice of local healers before coming to the hospital. I personally reviewed medical records that missed pertinent information (such as the failure to order a blood transfusion in a hemorrhaging patient) and medical registries that failed to give an accurate count of every stillbirth, neonatal death, and even maternal death. In this light, it is possible that some of the outcomes described by health workers were sanitized.

This exploratory study was designed to elicit examples of the ways in which energy poverty affected care. It gave clear evidence of the existence of tragedies due to the lack of lighting. However, qualitative research of this sort cannot quantify the impact of energy poverty on maternal-newborn health outcomes or indicate whether lack of electricity is a major contributor to death and disability.

The 1,213 health workers included in this database had on average 5.4 years of work experience in energy-deficient facilities conducting more than 200 births per year. Their experience represented a cumulative 1.3 million deliveries. One could argue that the negative accounts described in this report were exceptional cases, representing outliers. However, the stories from one health worker to the next were so consistent and far exceeded the capacity of this author to

capture the extent of challenges related to energy limitations. An unpublished review of quantitative data from the same institutions suggested that obstetric and neonatal complications were common, and further quantitative study is warranted.

Finally, the study was limited by its narrow focus on lighting and electricity for obstetric services. It failed to investigate the importance of lighting and electricity for a more complete range of medical services and equipment, including surgical care, pediatric care, vaccine refrigeration, blood banking, radiology, and security. These topics also merit further investigation.

Despite these limitations, however, this study was unique in its inclusion of health worker perspectives from hundreds of facilities across eleven countries. Given the fact that these health workers had different levels of training (nursing, midwifery, medical officers), and that their experiences were in multiple tiers of health care (health clinics, health centers, hospitals), multiple geographies and time frames, there was a remarkable consistency of findings. Health providers in Nepal, the Philippines, Ethiopia, Zimbabwe and Sierra Leone all encountered similar challenges in un-electrified facilities, and their obstetric and newborn patients faced similar risks. In addition, with interviews collected from 2011 to 2019, we are led to the unfortunate recognition that energy poverty remains a persistent barrier in health facilities in LMICs in Africa and Asia.

Conclusion

Energy poverty and maternal mortality do not exist in isolation. When health facilities lack electricity, the provision of signal functions for routine and emergency obstetric and neonatal care are severely compromised. Health workers struggle to conduct services in near darkness, unable to adequately prevent or treat complications. Efforts to provide emergency care without bright light and electricity may fail to prevent death and disability. In addition, though many expressed their enthusiasm for providing care to mothers and babies, this study demonstrates that health workers themselves suffer the consequences of energy poverty, enduring stress, frustration, anxiety, economic hardship, and an increased risk of infection and injury.

Despite these realities, however, lack of energy access remains a largely underreported barrier to the delivery of safe and effective care. Across such vital domains as perceived quality of care, referral patterns, infection control, patient and health worker safety, and even women's utilization of health services, the role of energy poverty in maternal health must receive far greater attention if mortality rates in LMICs are to be significantly reduced.

Building on the WHO's recognition of energy as an important enabler of health care [12], comprehensive 21st century approaches to reducing maternal and newborn mortality must include electricity as a vital intervention. While electricity alone will not solve all the problems facing health workers in LMIC health facility settings, other interventions designed to improve maternal and newborn survival rates are unlikely to succeed without it.

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Chapter 3

Where there is light: health worker perceptions of the impact of reliable light and basic electricity on routine and emergency obstetric care in low and middle income countries

Key Message: Without light and electricity, identifying and treating the major causes of maternal mortality becomes challenging and at times impossible. Access to reliable lighting and basic electricity are a necessary, although not sufficient, component of quality maternal and newborn care.

Abstract

Background

Global rates of maternal mortality remain unacceptably high. WHO estimated in 2018 that 300,000 women die each year from pregnancy and childbirth complications. One key factor contributing to poor outcomes is the lack of reliable electricity, affecting the ability of caregivers to work effectively and safely. Our goal in this study was to examine the effects of a solar intervention on perceptions of maternal health care.

Methods

The intervention is a We Care Solar Suitcase, a solar electric system designed to provide essential light, basic electricity, and fetal monitoring for obstetric care. The analysis utilized a database of 607 interviews with maternal health workers obtained by We Care Solar and partner organizations in 11 countries across ten years (2011 to 2020). Semi-structured interviews were conducted 3-18 months after the solar intervention, focusing on maternal-newborn health services, referral patterns, health worker morale, and patient-provider relations. Responses were documented in written or audio format, translated when necessary, transcribed, and coded using Atlas.ti. Analyses followed the principles of Grounded Theory.

Results

Several major themes emerged from our interviews with health workers, including effects on job efficiency, job effectiveness and health worker morale. Specifically, health workers provided with essential electricity and continuous medical lighting reported a greater sense of confidence and efficiency, less fear of night time care, and a better ability to make decisions. With an improved working environment, health workers further described the provision of more timely procedures, enhanced management of obstetric emergencies and newborn care, improved sanitation and infection control, more appropriate referrals, and improved mobile communication. Health workers perceived increased utilization of maternal services after the solar intervention, and cost savings for patients and health workers.

Conclusion

Health workers provided with access to reliable light and electricity report greater confidence in their ability to conduct routine and emergency obstetric procedures. Access to reliable lighting and basic electricity are a necessary, although not sufficient, component of quality maternal and newborn care. Energy access programs are an essential component of any comprehensive approach to improving quality of care and should complement other interventions and efforts to improve maternal and child health.

Figure 3.1 A midwife in Uganda using the Solar Suitcase lights for a delivery

Introduction

The Sustainable Development Goals (SDG) established in 2015 by the United Nations have set an ambitious target for goal 3.1: reduce the global maternal mortality ratio to less than 70 per 100,000 live births and reduce neonatal mortality to as low as 12 per 1000 lives births by 2030 [1]. In order to achieve this goal, countries with high rates of mortality must institute comprehensive maternal and newborn interventions with demonstrated meaningful impact.

Despite efforts to achieve SDGs for health, rates of maternal and newborn mortality remain unacceptably high. Although the maternal mortality ratio dropped by 38% worldwide between 2000-2017, the World Health Organization report that approximately 810 women die every day from complications of pregnancy and childbirth [2]. Most of these deaths can be prevented. More than one million newborns die on the first day of life and almost one million more die within the first week [2]. Maternal deaths are disproportionately high for certain countries; 94% of all maternal deaths occur in low and lower-middle income countries [2]. Sub-Saharan Africa and Asia have the highest neonatal mortality rates, at 28 deaths per 1,000 lives births and 25 deaths per 1,000 live births respectively [2].

To date, maternal and newborn interventions have focused on improving access to obstetric care by overcoming the three delays that inhibit the provision of care [3. 4], and on improving the provision and quality of care [5–11]. The signal functions for Emergency Obstetric and Neonatal Care (EmONC) represent life-saving procedures targeting the common causes of maternal mortality (hemorrhage, sepsis, obstructed labor, eclampsia, and unsafe abortion) and one preventable cause of newborn death (birth asphyxia) [12]. These crucial actions include the administration of parenteral antibiotics, anticonvulsants, and uterotonic agents (i.e. medications that contract the uterus), manual removal of placenta, removal of retained products of conception, assisted vaginal delivery (using forceps or vacuum assistance), newborn resuscitation, assisted vaginal delivery, Cesarean section, and blood transfusion [12].

The WHO, UNICEF, and UNFPA defined population based standards of emergency care that should be available at different levels of health care [12]. Basic Emergency Obstetric and Neonatal Care (BEmONC) facilities should have the capacity to perform seven of the signal functions, whereas Comprehensive EmONC (CEmONC) health facilities—usually hospitals—should be able to perform all nine functions [12] (see Table 3.1).

Table 3.1. Signal Functions recommended for Basic and Comprehensive Emergency Obstetric services

Basic Services – Lower Level Facilities and Hospitals
1. Administer parenteral antibiotics
2. Administer uterotonic drugs (i.e. parenteral oxytocin)
3. Administer parenteral anticonvulsants for pre-eclampsia and eclampsia (i.e. magnesium sulfate)
4. Manual Removal of the placenta
5. Remove retained products of conception (i.e. vacuum extraction)
6. Perform assisted vaginal delivery (e.g. vacuum extraction, forceps)

7. Perform basic neonatal resuscitation (e.g. with bag and mask)

Comprehensive services - Hospitals
Perform signal functions 1 - 7, plus: 8. Perform surgery (e.g. Cesarean section) 9. Perform blood transfusion

Far too often, the role of energy poverty is an overlooked factor impacting obstetric care. The World Health Organization reported in 2013 that 72% of health facilities in sub-Saharan Africa lacked reliable electricity; 1 in 4 had no electricity at all [13]. A 2018 review of infrastructure in 129,557 health facilities in LMIC countries reported that 59% lacked reliable power [14]. Obstetric deliveries occur 24 hours a day, and efforts to improve maternal health care cannot fully succeed if health workers do not have access to reliable lighting and electricity. Without electricity, health workers struggle to conduct essential and life-saving procedures in near-darkness, using unreliable and inappropriate sources of light [15].

Eight hundred million people are estimated to lack access to modern energy services [16]. Although Sustainable Development Goal (SDG) 7 targets universal access to modern, sustainable energy by 2030, global efforts are substantially off-track [16]. Specific goals include (1) universal access to modern electricity, (2) increasing the uptake of renewable energy, and (3) doubling energy efficiency [16]. Efforts to achieve universal energy access have been boosted by the Sustainable Energy for All (SE4ALL) movement established in 2011 (www.SE4All.org). SE4ALL brought attention to the role that energy access could play in the delivery of healthcare, and recently established a website devoted to power for healthcare. (https://poweringhc.org/about-us/). In 2015, the World Health Organization and World Bank examined the energy needs of health facilities in resource-constrained countries and proposed an approach toward tracking and monitoring energy access [17].

There is a nascent body of literature about energy access and health care [18-21]. Kruk et al. (2015) assessed facility infrastructure in 1,511 facilities in 5 African nations and found that only 11% of primary care facilities and 66% of hospitals had electricity [20]. When Koroglu et al. [18] used state electric utility data and Indian Demographic Health Survey data to explore the association of power outages in Maharastra, India with birth outcomes, they found a negative association between power outages and skilled birth attendance. Chen et al. [19] reported that a rural electrification program in India had a positive effect on health care operational capacity and health care utilization, including antenatal care. Apenteng [22] demonstrated a positive association between the frequency of health facility power outages in Ghana and facility-based mortality. Recently, Suhlrie and her colleagues [21] proposed a conceptual framework to characterize the pathway linking energy use to health service outputs and patient outcomes, including infection control, efficiency, and staff working conditions. Their model included energy characteristics such as availability, reliability, quality, and acceptability of the energy source;

facility outputs such as lighting, medical devices, ICT, HVAC, and facility outcomes; and health service outputs such as hours of operation, patient diagnostics, facility effectiveness and staff working conditions. Applying this model to more than 900 health facilities in Malawi revealed that health facilities with lower quality electricity supply demonstrated lower functionality, concluding that the provision of efficient and effective health services was likely to be constrained by inadequate energy access [21]. While these studies suggest that reliable electricity is an important factor in the provision of emergency obstetric and newborn care, none of them include the actual experiences of health workers who provide obstetric and newborn care.

This study examines the impact of solar electricity on maternal and newborn services in order to answer the question: how do maternal health care workers perceive changes in the quality of obstetric and newborn care as a result of receiving solar electricity? The study utilizes a large, multi-year database of health worker interviews conducted across multiple countries as part of a program to deliver solar light and essential power to last mile health workers.

Background

We Care Solar, a United States non-profit organization, aims to improve maternal-newborn health outcomes in countries with high rates of maternal mortality and low rates of health facility electrification. Since 2010, We Care Solar has been studying the impact of unreliable electricity on obstetric care. The organization designed a compact, rugged solar electric kit for maternity care, called a Solar Suitcase, which has been deployed to thousands of energy-deficient health facilities in more than 11 countries in collaboration with local implementation partners (international NGOs, local NGOs, district governments, and UN agencies). The main purpose of the Solar Suitcase is to provide essential light and basic electricity for obstetric care. Solar Suitcases have been installed in delivery rooms, maternity wards, and operating theaters, and depending on facility, either function as the primary source of light and power or as backup.

Methods

The Intervention: A Solar Suitcase

The intervention for this study is the We Care Solar Suitcase, a complete solar electric system providing essential medical lighting and 12V DC power for charging phones and small medical devices. The system, most of which fits inside a specially designed carry-on suitcase, contains a photovoltaic solar panel for roof-top installation; a lithium ferrous phosphate (LFP) battery; two to four high-efficiency, moveable light-emitting diode (LED) lights for maternity rooms; two headlamps; a fetal Doppler with rechargeable batteries; two 12 V DC accessory sockets; two USB ports for charging cell phones; and a AA/AAA battery charger.

There have been several iterations of the Solar Suitcase in the last decade in response to user feedback and technology improvements. Over time, the Solar Suitcase gained more lights, an improved battery technology, a fetal Doppler, and larger solar panels. The first Solar Suitcase provided only two medical procedure lights in most programs until four LED lights became the

standard in 2015. The fetal Doppler began to be included in 2012. The original sealed lead-acid battery was replaced by LFP batteries in 2015, increasing the time interval for battery replacement from two to five years. Solar panel size was increased over time; 40 watt panels were placed with 100 to 240-watt panels, allowing the LFP batteries to recharge fully each day and ensuring more lights could remain powered throughout the night. The Solar Suitcase, now in its third generation, is the only portable, compact, renewable power source designed specifically to provide electricity to remote maternal health centers.

Figure 3.2 Version 2.0 Solar Suitcase (2011-2018)

Figure 3.3 Version 3.0 Solar Suitcase, introduced in 2019

The LED lights were designed and engineered specifically for medical procedures, and can be installed directly to the ceiling or wall, or remain mobile. Each LED light comes with a wire hook that allows it to attach to an IV stand or hang on the wall. The 10-meter length cord allows health workers to move the LED light to where it's most needed for medical procedures. The Solar Suitcase case itself can be mounted directly on a wall or remain mobile and portable.

This immediately-deployable Solar Suitcase was designed to be simple to use, avoid failure, and require only minimal maintenance. The main battery requires replacement every two to five years depending on battery type. The LED lights are designed to last 70,000 hours. When LED lights in early models began to dim from overheating, We Care Solar re-engineered customized lights with a large heat-sink, eliminating the problem. The appliances included with the Solar Suitcase (headlamps, fetal Doppler, phone chargers, AA/AAA battery charger, etc.) have variable life-spans and need replacement when no longer functional.

Installer and Health Worker Training

In addition to the technology, We Care Solar worked closely with implementation partners to select health facilities with electricity needs (based on criteria described below) and conduct program activities, including solar installation technical training and health worker instruction. We Care Solar staff provided instructional training for partner organization staff and government technicians to build local capacity in solar installation, operation, and maintenance. Trainees received technical instruction on how to safely install Solar Suitcases and additional pedagogy on how to teach health workers to effectively use the Solar Suitcase and its appliances. Thereafter, solar installations were conducted by certified trainees at energy-deficient health facilities selected by the partner organization and typically required 3 to 6 hours to complete. On the day of installation, health workers were taught how to operate the Solar Suitcase, use the lights and each accessory, how to conserve energy, and how to provide basic maintenance. Health facilities did not incur any costs during the study period for installation, operation, or maintenance of the Solar Suitcase.

We Care Solar Program Intervention

We Care Solar utilized this partnership methodology with non-government organizations (NGOs), governments, and UN agencies in 11 countries, providing solar electricity to thousands of health facilities conducting maternal and newborn health over the 10-year period. Health facility criteria for selection included (1) Documentation of unreliable electricity or no evidence of a power source, (2) Ability to provide emergency obstetric care (i.e. skilled MCH personnel and capacity for 24-hour care), (3) Structural characteristics that made it feasible to accept the solar installation (i.e. roof integrity) (see Table 3.2). Using these criteria, partner organizations selected health centers for program activity. Typical programs ranged in size from 15 to 230 health facilities.

Table 3.2 Health Facility Selection Criteria for Solar Suitcase

Criteria	Description
Health	Performs at least 10 deliveries per month Has skilled health providers Can operate 24 hours a day
Energy	No access to grid electricity, or Has interrupted power supply
Structure	Roof has an area with unobstructed sunlight Labor and Delivery suite is within a one story-building Roof is strong enough to support installation team

Health centers that received Solar Suitcases represented three levels of health care provision, though specific naming protocols varied between countries (see Table 3.3).

Table 3.3 Respondents by Health Facility Level

Level	**Number**	**Percent**
Level 1 (dispensaries, health posts, etc.)	250	41.2%
Level 2 (health centers, primary health clinics)	283	46.6%
Level 3 (hospitals)	47	7.7%
N/A	27	4.4%
	607	100.0%

Level I facilities (N=250, 41.2%) offered primary care and were facilities serving the smallest catchment area with the fewest number of staff members. These facilities primarily offered outpatient services, limited obstetric care for normal deliveries, and typically referred complicated cases to higher level facilities. These were classified as Health Posts, Health Clinics, Health Center IIs, Dispensaries, and Barangay Health Stations, depending on the country. *Level II facilities* (N=283, 46.6%) had more staff, a limited number of inpatient beds, a greater range of services, and offered most or all of the elements of Basic Emergency Obstetric and Neonatal Care but could not care for the highest risk patients or perform Cesarean sections. These institutions included Health Centers, Rural Health Centers, Primary Health Centers, Rural Health Units, Peripheral Health Units, Health Center III. *Level III facilities* (N=47; 7.7%) were hospitals that received referrals from Level I and Level II facilities. These institutions had inpatient beds, a wider array of staff members included doctors, and the capacity to perform Comprehensive Emergency Obstetric and Newborn Care, including Cesarean sections.

Research Methodology

This study involved a qualitative analysis of health worker interviews collected by We Care Solar over the course of ten years (2011-2020). Data were analyzed from 17 We Care Solar programs in 11 countries in Africa and Asia (Ethiopia, The Gambia, Liberia, Malawi, Nepal, Nigeria, The Philippines, Sierra Leone, Tanzania, Uganda, and Zimbabwe) where health workers were interviewed between 3-18 months after a solar electric system had been installed. Each program included in this study served between 15 and 230 health centers and was implemented in partnership with local and international maternal health NGOs (Africare, AMREF, CUAMM Doctors for Africa, eHealth, Hamlin Fistula Ethiopia, Jhpiego, Medical Research Centre, One Heart Worldwide, Pathfinder International, Public Health Initiative Liberia, SAFE, Jhpiego, Save the Children, WEEMA); solar companies (EnDev, PowerUp Gambia, Stiftung Solarenergie Philippines, SunFarmer); government agencies (Ministry of Health Gambia, Ministry of Health Liberia), and UN agencies (UNFPA, UNICEF).

The analysis included 607 interviews of male and female health providers spanning a decade of programming. In some programs, interviews were conducted in every health facility as part of standard follow-up post Solar Suitcase installation. In other programs, convenience sampling was used, such as sampling health facilities in a given region to reduce program costs.

Eligibility criteria for health staff interviewees included the following: employment by the health facility, authorization by the government to assist or conduct deliveries independently, and experience with using the Solar Suitcase. Interviewees self-identified as doctors, midwives, nurses, “in-charges,” and skilled birth attendants (traditional birth attendants were not included in the samples). Interviews were conducted by We Care Solar researchers, staff from partner organizations, and paid research consultants using a semi-structured questionnaire pre-tested in multiple countries. The interviewers obtained informed consent from all health workers prior to conducting in-depth interviews. Health workers were assured that all identifiers would be removed before sharing the findings with local or national governments.

Interviews were conducted inside or adjacent to the health facility in English or the local language. Responses were either audio-recorded for later transcription or written out at the time of the interviews, with quotations captured verbatim to the extent possible. Written transcripts and interview notes were provided to We Care Solar. The interviews were de-identified to remove the names of individual health workers.

The study team coded the transcription in ATLAS.ti or WORD using an open coding and iterative approach, in which codes and sub-codes were derived from the data. Preliminary codes were based on the questions included in the semi-structured interviews [23, 24] Consistent with the Standards for Reporting Qualitative Research (SRQR) guidelines [24, 25] we began with deductive codes (those pre-determined by our research questions). Among these codes were “quality of electricity,” “quality of lighting,” “routine care,” “emergency obstetric care,” “neonatal care,” and “health worker attitude.” Inductive codes that emerged from the process of coding the data

included “breastfeeding,” “safety” (including the unanticipated code of “reptiles”), “community attitude,” and “non-obstetric uses of the Solar Suitcases.” The initial codebook was uploaded to an online software program for qualitative data management (Atlas.ti Version 8) to assist in coding the data. Themes were analyzed across countries and timeframes. In keeping with Grounded Theory’s theoretical sampling approach [26], data saturation was reached when new themes or codes ceased to emerge. The protocol was submitted to the Office of Human Subjects Protocol at UC Berkeley for review; it did not meet the requirements for formal IRB review.

Results

The analysis included 607 interviews of male and female health workers spanning ten years of Solar Suitcase programming (2011 to 2020) and 11 countries (Ethiopia, The Gambia, Liberia, Malawi, Nepal, Nigeria, Sierra Leone, Tanzania, Uganda, and Zimbabwe), with the greatest representation being from Nigeria (19.8%), The Philippines (22.9%), The Gambia (11.2%), Uganda (10.9%), and Nepal (9.6%) (see Table 3.4).

Table 3.4 Distribution of Respondents by Country

Country	Number	Percent
Ethiopia	25	4.1%
The Gambia	68	11.2%
Liberia	20	3.3%
Malawi	12	2.0%
Nepal	58	9.6%
Nigeria	121	19.8%
Sierra Leone	15	2.5%
Tanzania	40	6.6%
The Philippines	139	22.9%
Uganda	66	10.9%
Zimbabwe	43	7.1%
	607	100.0%

Demographic data were not always available, but for the 95% of health workers where occupation was collected, interviewees primarily self-identified as midwives (44.5%), nurses (29.2%), non-physician “other”, a category that included community health extension workers (CHEW), community health officers (CHO), skilled birth attendants (SBA) and “officers-in-charge” (25.9%), or physician (0.5%) (see Table 3.5). It is possible that the “in-charges” may have included nurses and midwives as well. Traditional birth attendants were purposely excluded from the sample as the study was designed to exclusively evaluate facility-based obstetric care by skilled providers.

Table 3.5 Respondents by Occupation

Job Title	Number	Percent
Midwife	270	44.5%
Nurse	177	29.2%
Non-MD "Other"	157	25.9%
Physician	3	0.5%
	607	100.0%

Electricity Status and Lighting Sources before the Solar Intervention

All of the 607 facilities selected for the solar intervention either had no electricity (N=208, 34.3%) or grid power that was unreliable (N=343, 56.6%), Some facilities had generators (N=183, 30.1%), or pre-existing solar energy for lighting (N=23; 4.7%). (Solar exclusively for vaccine refrigeration was not assessed.) For those with access to grid power, the availability of electricity was unpredictable, as one Ugandan officer-in-charge at a Health Center III described*. "At times it is there, it is on and off. 12 hours. 2 days, then in a day it can be off for 8 hours, 9 hours. Or even take 24 hours without going on."*

Prior to the intervention, health workers relied on portable, hand-held sources of lighting, such as candles, kerosene lanterns, torchlights, and cell phones, either as primary sources of night-time light or as back-up lighting. Health worker perceptions of using these alternative light sources are described in a separate paper [15]. After the solar intervention, medical lighting was reported as brighter, safer, and more convenient. The mobile LED lights included were especially appreciated because they could be directed wherever lighting was most needed, and could be suspended from an intravenous stand for hands-free task lighting. A Tanzanian nurse working in a health dispensary preferred the LED lights to the grid-powered overhead lights. "*We were connected to the grid a few months ago. But I like the Solar Suitcase lights more because I can move with them around the maternity room, having light everywhere I go. The tube-light from the grid is not bright enough to do my work properly and it can go off at any time, while the bright solar light makes it easier to take care of the mother and care for the newborn babies."*

With the solar intervention, health workers stated they could work with greater ease and efficiency, asserting that (1) their hands could remain free for procedures, (2) room illumination was better allowing the visualization of multiple patients at once, and (3) they no longer needed to recruit family members or other attendants to hold lanterns, candles, or flashlights in the delivery room. As one Nigerian hospital midwife reported, *"With the brightness of the light, with nothing in our hands while conducting delivery our hands are free, we work faster now. It has helped us to care for both mother and baby."*

Perceived Improvement in Quality of Lighting

The medical LED lights included in the Solar Suitcase were used in delivery rooms, maternity wards, and operating theaters. Health workers reported better visibility and an improved

capacity to examine, treat, and monitor mothers and newborns. Activities that had been difficult pre-intervention, such as reading reports, reading medication labels, entering data into patient charts, completing labor partographs, locating equipment and supplies, moving around the facility, and assigning APGAR scores, were easier to do.

> *The lights have helped a lot, like when we want to fix IV lines, using candle we don't see properly. The lights have helped us to see clearly what we are doing, to see the patient's expression and communicate with them clearly while conducting delivery, to monitor the progress of labor with the lights. We can do the immediate assessment of newborns (Apgar score) and to know if the baby needs resuscitation. The light enables us to tie the cord and wrap the baby.* Midwife, Primary Health Center, Nigeria

The LED headlamps within the Solar Suitcase were used to augment existing lighting for suturing, surgeries, and movement around the health facility. One hospital midwife from Zimbabwe described their importance for patient examinations. "*The headlamp…helps with examination of a pregnant woman on admission as well as post-delivery to exclude jaundice, anemia, cyanosis, clubbing, edema and lymphadenopathy to mention a few. It provides good light thereby preventing complication."* These benefits extended to newborn exams as well, where visualization was particularly important to determine whether resuscitation was needed. Operating room staff reported using the headlamps to assist during surgical procedures, providing light that could save lives. One Nigerian nurse described when the lights were used to save an expectant mother who arrived at the hospital bleeding after a failed home birth. "*A client came in from a traditional birth attendant around 12:30 am with a ruptured uterus. We had to do an emergency C-section with the aid of the solar light and headlamp."*

For health workers accustomed to working in near-darkness, having a reliable source of light was a dramatic change. One Nigerian health worker described, "*I had a woman in labor with her first baby. As I conducted the delivery, she had a lot of tear[ing]. Suddenly the [grid] lights went off. Using the headlamp to suture has this exciting feeling it gives me, because I can see clearly and move my head to focus the light as I desire. The procedure was so easy because I could see clearly."*

Figure 3.4 Nepalese midwives with their new headlamps (credit: Suraj Shah, One Heart Worldwide)

Perceived improvements in Access to Care

The Solar Suitcase intervention improved access to care by extending working hours and boosting health facility "readiness" for care. At night, health workers would be inclined to send patients away rather than struggle in near-darkness. As one Gambian midwife explained. "*When light goes [off] at night, we would close the facility because of no light and when we'd have labor cases, we would refer those cases to other facilities."* With the solar intervention, facilities previously limited to daytime hours now extended operations throughout the night. A Nigerian health worker echoed the sentiments of many. *"Before now, the kerosene lamps were absolutely like working in darkness, and sometimes we would send patients away. Our capacity to handle patients has increased, and [care is] more efficient and effective."*

Improvement in Execution of Signal Functions

Health workers reported an improved capacity to perform basic and comprehensive emergency obstetric and newborn care, including the signal functions. Health workers stated that the lights helped them assess whether patients were bleeding, as this Nigerian midwife reports, "*With the brightness of the light, we can detect if there is a tear or bleeding…we can access and monitor the mother and baby, to check and see if the baby is bleeding from the cord, we observe the mother."* She then described how important the lights were for assessing the color, breathing

pattern, and anatomy of each baby at the time of delivery. *"Without lights, you can't do these observations."*

Respondents reported greater facility to identify and treat major complications of childbirth such as hemorrhage, eclampsia, and breech deliveries, as this Ethiopian rural health center nurse described,

> *One laboring mother came to our health center and she was having very high bleeding. I was able to secure two IV lines in both of her hands and resuscitate the newborn. They both take very long to recover but I was able to do all this because there was a light.*

In every country, health workers reported that numerous conditions—lacerations, sepsis, eclampsia, fetal distress, breech presentation, retained placenta, retained products of conception, obstructed labor, and newborn asphyxia—were easier to identify and treat with the Solar Suitcase.

Perceived Greater Ease with Patient Assessment

Health workers reported greater facility in assessing patients for complications. They could examine the patient for anemia, check blood pressure accurately, and identify complications such as meconium stained amniotic fluid, nuchal cord (umbilical cord wrapped around the newborn neck), and breech presentations.

Perceived Improvements of Ability to Treat Complications

In the case of hemorrhage—the most common cause of maternal mortality—the solar intervention reportedly enabled health workers to see how much bleeding was occurring and determine the course of action. "*We Care Solar lights helps us to see how much blood a patient is losing and if we can't handle it we refer,"* explained a Nigerian CHEW (community health extension worker). The lights facilitated the setting of intravenous lines for hydration, administration of uterotonic agents, and, in some cases, the use of an anti-shock garment to stabilize the patient while awaiting definitive care. All of the signal functions for Emergency Obstetric and Newborn Care require light. A male midwife at a dispensary in Tanzania described how the solar lights helped him treat an expectant mother who delivered a stillborn infant and then began to hemorrhage.

> *You can see everything properly and move around the room easily. I used my headlamp to see her vein well and quickly started her on oxytocin. After that I put her in an anti-shock garment, called for an ambulance and sent her to the referral hospital. They gave her two units of blood and she survived.*

The ability to address other complications, such as eclampsia, breech deliveries, uterine rupture, and infections were similarly improved. As one Nigerian midwife explained. "*For patients with pre-eclampsia, we use the light to take her blood pressure. If she is fitting, using the lights we give*

her Magnesium Sulfate to calm her down. For patients with infection, we examine her and treat. And for breech deliveries, we use the lights to see the presentation of the baby." The solar intervention became indispensable for all deliveries, reported a Gambian midwife. *"All the complicated deliveries, all the breech deliveries I do here are with the help of the solar system. All the deliveries. Complicated and not complicated."*

Perceived Improvements in Surgical Care

When patients developed obstructed labor or fetal distress, the solar intervention allowed surgical teams to conduct Cesarean sections throughout the night and eliminated the need to transfer patients to other hospitals based on a lack of light. In Nigeria, hospital staff recounted benefits to a range of surgical procedures. "*The surgical lights have been used to conduct c/sections and other emergency surgeries. Surgeons reported that patients requiring nighttime C-sections are no longer transferred to other facilities."*

Some hospital staff reported they would use the Solar Suitcase light continuously with every surgical procedure to avoid blackouts. Others reserved the Solar Suitcase for occasions when grid power failed, saving valuable time that was previously needed mid-operation to call for a technician to fuel and turn on the hospital generator, and/or avoiding a reliance on inferior light sources, such as flashlights, cell phone lights, or candles. An operating nurse explained, *"The Solar Suitcase has helped to substitute the electricity during operations which has help to rescue more lives than before when we used to use phone lights (when there was no fuel for the generator)."* Health workers reported that patients and providers alike were reassured to know that reliable lighting was available in the operating theater. A Ugandan anesthesiologist reported, "*In the past, patients had a fear that when electricity goes down during an operation, they will die, but now they have confidence."*

The benefit of continuous surgical lighting for timely resolution of obstetric emergencies cannot be overemphasized. Prior to the solar intervention, several health workers described maternal deaths that resulted from an inability to perform Cesarean sections due to power outages [15].

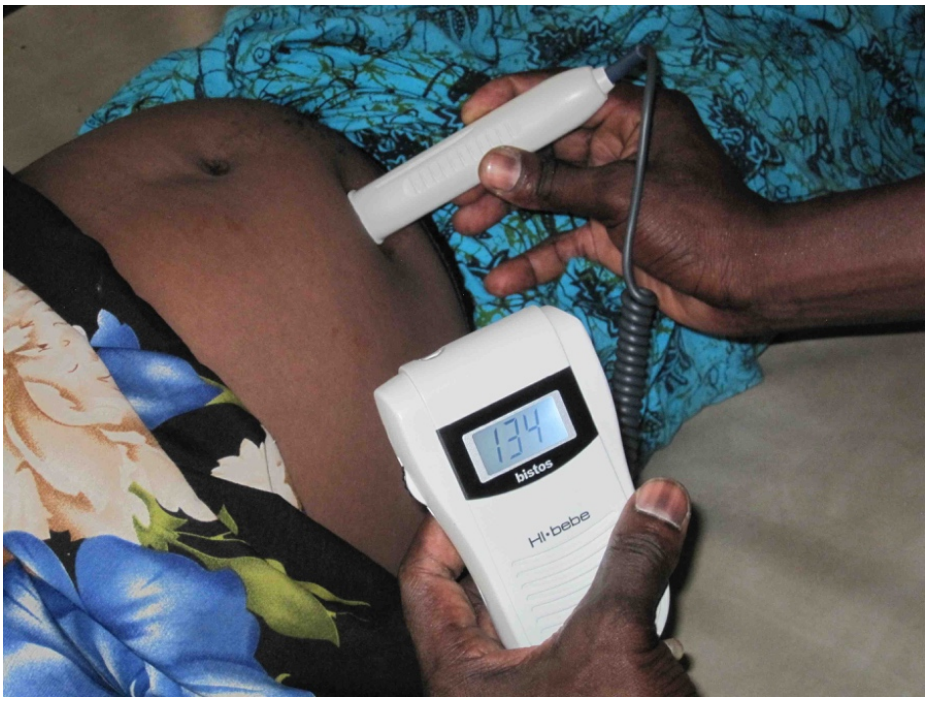

Figure 3.5 Fetal Doppler being used to assess fetal heart rate

Enhanced Fetal Monitoring

Another area where the solar intervention had impact was in fetal heart rate monitoring during pregnancy and labor. The fetal Doppler included in the solar kit improved the accuracy and ease of monitoring the fetal heart rate; it replaced the standard non-electronic fetal stethoscope (fetoscope). By amplifying the sound of the fetal heart rate, and displaying the numeric beats per minute on an LCD screen, the fetal Doppler enabled health workers to ascertain when the heart rate was too fast or too slow, indicative of fetal distress. Mothers, too, could hear the fetal heartbeat for the first time. A hospital midwife based in Zimbabwe relayed how this was increasing uptake of antenatal care. "*It is now very easy to monitor fetal heart since the fetal Doppler provides accurate readings of the fetal heartbeat. There is an increase in the number of pregnant mothers coming for ANC visits because they are comfortable with care. They can also hear fetal heart sounds from the Doppler and they can read the fetal heart range on their own.*" Another Zimbabwean midwife added, "*With the fetoscope, sometimes if you don't check properly well, you count the pulse of the mother. But with the Doppler, it's easy. You say to the mother "your child is well." The Doppler is encouraging to the mother when they hear the sound.*"

By enhancing the ability to detect fetal distress, the Doppler helped health workers decide which pregnancies were most at risk, distinguishing those patients who could be managed from lower tier health centers and those in need of transfer to referral hospitals. A skilled birth attendant in a health post in Nepal found this very helpful. *"Before we were totally dependent on the fetoscope and sometimes the readings would not be accurate so we used to refer those. But, now with the*

fetal Doppler we can recheck the readings and properly monitor the fetal heart rate so it has made it easier to detect the real complicated cases."

A health worker in a Nepalese health post elaborated on why the Doppler stimulated greater demand for services, "*This has greatly improved the turnout in the facility. The mothers now show up exactly on [the scheduled] date of the visits. We don't have to call mother repeatedly to ask them to visit the health post for their ANC visits. The mothers, fathers and even their relatives show up to hear the sound of the heartbeat of the infant which is a new thing for us."*

The audible fetal heart rate made it easier for midwives to help patients understand the rationale for Cesarean sections or other referrals, because mothers could themselves hear when the heart rate became abnormally slow or fast.

> *One mother was in labor for almost three hours. Then the fetal heartbeat started to go down. At first, we told her, 'Listen mother this sound is okay,' but when the fetal heartbeat began to go down, she was the one who said, 'Why is it now slow? Why is it slow?' We explained to her this is an emergency, we have to refer you to the hospital because something is wrong. We referred her to the hospital. This was around 11 PM. It took 45 minutes for the ambulance to come and she delivered at the hospital. We called the hospital the following morning and found out she was okay and delivered safely.* – Health Provider, Rural Health Center, Zimbabwe.

Mothers who worried about the viability of their unborn baby (following an accident or after a natural disaster, for example) could come to the facility for reassurance. In Liberia, a rural health worker used the Doppler in this way. "*Some of the pregnant women who come at the facility as a result of accident or fall and worried about their baby's wellbeing can have the opportunity to listen to their own baby's heartbeat using the Doppler and won't have to worry."* In Nepal, a skilled birth attendant described how she used the Doppler to confirm a fetal demise. *"A woman came a week after her expected date of delivery. She was checked on every side of her abdomen but fetal heart sounds were not heard. It was a stillbirth and she was referred to the district hospital. The fetal Doppler was helpful to give the correct diagnosis."*

Timely Appropriate Newborn Care

Management of newborn care was also improved with the intervention. Light was especially important for evaluation of neonatal asphyxia, requiring an accurate assessment of the APGAR score, and performance of neonatal resuscitation, which necessitated locating appropriate equipment, correctly positioning of the Ambu bag over the newborn mouth and nose, and observing the rise and fall of the newborn chest to assess the adequacy of ventilation. A Ugandan midwife explained, "*With the Solar Suitcase lights, a healthcare worker can assess the baby properly, see the baby's skin color and make diagnosis. In the dark, healthcare workers can only hear the cry of the baby but other assessments which are through observation can only be done with lights."* The solar lights not only improved visualization, they improved the ability to conduct

newborn procedures with both hands—tasks that were challenging to do while holding a flashlight or other source of light. A health worker from a rural health center in the Gambia explained it this way,

> *[After] a normal delivery, the child was born having difficulties to breathe. I was doing certain procedures like ventilating the child and trying to make some compression. I was alone and had it been that I was having a torch over my shoulder or in my mouth, it would be difficult. But I was seeing exactly from the lights, and I could see the chest movement of the child and then I was very happy. I knew what I was doing.*

Being able to appropriately care for newborns was a relief for health workers who had previously lost newborns due to asphyxia. An Officer-in-charge at a health clinic in The Gambia credited the Solar Suitcase lights for enabling him to save the life of a baby with poor Apgar scores. He suctioned the baby at the time of delivery and continued to resuscitate for almost two hours until he could breathe on his own. One Malawi midwife told us he no longer feared nighttime duty because he had the capacity to locate and utilize newborn resuscitation equipment. A midwife in Nigeria had a similar response and provided this example of a woman who delivered a baby with asphyxia before dawn. *"With the help of the solar LED light, the baby was resuscitated and the baby responded, sneezed, and cried. We were overjoyed for without the solar light this wouldn't have been possible."*

Perceived Changes in Referral Patterns

The Solar Suitcase was perceived to have impacted patient referral patterns of lower level facilities. Health workers described an improved ability to assess and treat patients, and a more appropriate pattern of referrals after the solar invention. As one Nigerian health worker confessed, "*Before the Solar Suitcase, there was nothing we could do for them [at night] and we just referred them out."* The solar lights allowed health workers in lower level facilities to handle routine cases, even in remote geographies such as the mountainous regions of Nepal. *"Previously I used to transfer cases due to lack of electricity at night. I used to think it would be more difficult to handle cases at night because of the absence of light. But now as the Solar Suitcase is available, I keep the normal cases and refer only the complicated ones."*

Health workers described several benefits of avoiding unnecessary referrals: it prevented delays, lengthy journeys, and patient expenditures for transport costs. One Liberian health worker in a rural clinic explained the challenge of transferring patients to higher level facilities. *"The car does not reach at this facility. We walked for hours to the river and the distance is about two hours walk. When there is a case for referral, it's a difficult one."*

In addition to better lighting, the phone charger was an essential tool for patient transfers. Health workers reported the importance of having charged phones at the time of an emergency to summon an ambulance, speak to health workers at the receiving hospital, and inform relatives about the medical plan. In communities where electricity was sparse, phone charging took time

and money, and the charging capacity of the Solar Suitcase was a welcome alternative to leaving the facility to locate a phone charging station.

> *During referral, you will have to communicate to the facility you are referring the patient to, and we don't have a charging booth around here, so the Solar Suitcase helps us to charge our phones for us to be able to communicate.* —Health Worker, Rural Health Center, Liberia

Reduced delays

Prior to the Solar Suitcase installations, health workers reported postponing critical procedures like suturing until the morning, when they had the benefit of daylight [15]. With the solar intervention, health workers reported more timely care. As one Nigerian midwife reported, "*The light enables us to do all the observations and suture, even at night. We no longer leave it until mornings."* In addition to suturing, clinicians reported more timely insertion of intravenous cannulas, administration of intravenous medication, repair of vaginal, vulvar, or cervical lacerations, removal of products of conception, inspection of placentas for completeness, and a range of other activities. For many health workers, the presence of continuous light shifted the experience at night, as a Nigerian hospital nurse recounted. "*It has really changed things for our health center. Cases like suturing and MVA [manual vacuum aspiration] that were left for the morning periods are no longer delayed. Instead of referring them or leaving these procedures overnight, we do them immediately."*

Perceived Changes in Breastfeeding and Postpartum Care

Better lighting was a benefit for postpartum care and breastfeeding. Health workers reported that the solar intervention improved their ability to care for newborns and support new mothers. The lights helped mothers initiate breastfeeding within an hour of birth by making it easier for midwives and mothers to position the baby to securely latch on to the maternal nipple.

> *It has helped mothers to breastfeed their babies and to monitor them since newborns need timely assessments and monitoring. This used to be hard for mothers and care takers since they used to do it in darkness or during use of poor energy sources like candles.* –Midwife, Health Center IV, Uganda

Perceived Improvements in Sanitation and Safety

Health workers in every country described improvements in sanitation and safety. They reported a lower risk of contamination and infection when lighting was assured. One Sierra Leone midwife working at a health post exclaimed, "*I am no longer scared of blood contamination for me and my staff because we can clearly see at night!"* Health facilities with the Solar Suitcase could adopt better hygiene and infection control protocols. Clean-up of the delivery room could happen immediately after procedures rather than waiting until morning, as one Nepalese provider shared. "*Previously we needed to wait until morning, but now we don't need to wait. We can clean the room immediately after delivery and also during the time of power cut."* With bright lighting, there was an improved ability to see blood, amniotic fluid, and debris on the floor,

enabling a higher standard of hygiene. At an active rural health center in Zimbabwe, the midwife in charge stated, "*Blood stains on the floor are now visible, so that we can clean to avoid cross infections for the nurse, patient and baby. Delivery utensils are easily dropped and are easy to see during deliveries using the both lights during delivery."*

Health workers were also relieved to no longer need to hold contaminated light. When one Gambian midwife received the Solar Suitcase, she immediately reported, "*It can prevent me from infections because now I'm not using any torch light or using my mobile phone. I'll just put on the solar lights and see whatever I want to see and do whatever I want to do without touching anything."* She went on to describe ways in which cross-contamination was reduced for her patients. *"It's also safe for the mother. It will also prevent cross infection between me and the mother because I will not be touching this and touching that."*

General safety was another area of reported improvement. Health workers reported they were less likely to fall, have accidents, or sustain injuries. They could see clearly to identify snakes, rodents, and insects that could be discovered both within and outside of the health facility. Health workers felt more confident going outside with the headlamp at night, required for discarding the placenta in the outside "placenta pit" or using an outdoor latrine. They also reported less fear of being robbed. One health worker reported an unusual case before the Solar Suitcase was installed, where she mistakenly let in a robber who was dressed as a pregnant woman. She said the lack of visibility before the Solar Suitcase made it difficult to see who was at the door.

Perceived Changes in Patient-Provider Relations

The benefits of continuous power extended to patient-provider relations. With better visibility and ability to communicate orally (compared to when they held light sources in their mouths) health workers remarked on having better interactions with their patients. *"You can communicate with your patient eye-to-eye unlike when you are using the candle,"* explained a midwife in a rural health center in Zimbabwe. Patients, in turn, appeared calmer when they could see their providers during labor and were assured that the health center had adequate lighting. One Nepalese health worker explained that the intervention "*has also been helpful in keeping the mother calm while we operate because if the mother gets nervous then it can affect the procedure."*

Health workers were more likely to share information about the pregnancy (the fetal heart rate, the condition of the placenta, the sex of the baby) when all parties had adequate visibility. *"We use the light to show her the sex of her baby,"* explained a Nigerian health worker. And some health workers reported that when patients could see problems—such as an excessive amount of blood loss—they were more likely to comply with the recommendations of the provider.

Patients are stubborn, because in the dark they don't see how much blood they have lost and they refuse to be referred. Now the women and the caretaker can see how much blood they lost and they see the need to be referred. –Health Worker, Sierra Leone

Perceived Benefits of Phone Charging

The phone chargers were very important to many of the health workers in this study. With charged phones, health workers could consult with outside providers, call for assistance during emergencies, and refer patients with complications to hospitals. They could summon an ambulance and alert hospital staff when transfers were needed. This was very important for lower level facilities that needed to refer complicated cases to larger facilities. One midwife in Zimbabwe described how important it was to refer an antepartum patient with a serious complication to a hospital facility for a Cesarean section. *"The Solar Suitcases has helped us to refer one critical patient who had a placenta previa. It was easy to call an ambulance in time since our phones were fully charged and she was transferred to a hospital in time to treat her."*

In less urgent settings, health workers used their phones to remind patients of upcoming appointments, provide test results, and/or call patients' relatives. In some cases, health centers allowed patients and their relatives to also make use of the solar phone charger. One Nepalese health provider said she appreciated the phone charger because it enabled her to call the ambulance and district hospital for consultations, and added, "*It has also helped the guardians to charge their phones and call for additional help if the patient needs to be referred."*

As electronic medical records, SMS messaging and WhatsApp became more normative, health workers began using their phones to transmit a range of information to district health offices. Phones were used to convey information about facility utilization, health outcomes, re-stocking medication or supplies, and to receive critical messages from district officials.

We had challenges before charging our phone. Usually we'd have to depend on other people. We would go to neighboring stalls to request them to charge our phones. Usually we send our health statistics through the phone. We had delays in sending out statistics. We had delays in communicating when we want drugs, when we want to refer a patient. It would take us time to call an ambulance. But now you can easily charge your phone. Our phones are usually always full. - Midwife, Rural Health Center, Zimbabwe

Perceived changes in utilization of maternal services

Health workers reported greater patient demand for institutional deliveries and antenatal care visits after Solar Suitcase installation. As one Nigerian health worker recounted, "*Solar Suitcase lights have really changed things here at the health center. We found out that mothers now prefer coming at night to give birth; before we [healthcare workers] come out of our rooms, the security guard takes them in and puts on the lights."* Many health workers reported an increase in night time admissions. Several factors seemed to account for increased utilization. First, bright light in the health center reduced fear and inspired confidence in patients about the ability of health

workers to deliver more safely. "*The lights attract patients because they know they won't be staying in darkness or asked to buy candles to use during delivery,"* explained one hospital matron in a Nigerian hospital. Second, solar lighting obviated the need for patients to purchase candles, paraffin, or batteries. With the Solar Suitcase, health workers no longer expected patients to pay for paraffin or other lighting supplies, reducing expenses as well as conflict between patients and providers. This was true throughout Africa, with similar reports from health workers in all the countries we surveyed.

Perceived Community Benefits

In smaller villages, the solar intervention not only improved the visibility of the health facility at night; it also elevated its status in the community. Community members were more likely to send family members for nighttime care, and to stay with patients through the night. In an area with erratic grid power, a community member reported. "*With the installation of the solar lights, the news has gone 'round and the whole community is happy of the new development. Now women can visit the health centers to deliver at any time of the night without any fear."* Some health workers in lower level facilities boasted that the bright lights and electronic fetal monitoring made their facility seem like a hospital to community members. A clinician at a health center in Ethiopia reported, *"the community is considering the health center as a hospital and mobilizing mothers to come for delivery service because of the Solar Suitcase."* Others reported that the lights attracted patients from faraway communities. And in some communities, the reliability of solar lighting at the facility made it conducive for community meetings, socializing, and for nighttime studying.

> *The Solar Suitcase has been of great benefit… now even students in the community come here to sit and read at night. Community members come to the health center to sit and chat, no more fear of darkness.* Community Health Extension Worker, Primary Health Care Center, Nigeria

Cost Savings for patients and health workers

The expectation that health workers and patients needed to provide, and therefore pay for, their own light sources before the solar intervention, was not an insignificant issue. Health workers and patients in many countries felt this as a burden and noted that the solar intervention resulted in meaningful cost savings. Health workers no longer spent their earnings on fuel for the generator, batteries for torchlights, or kerosene for lanterns.

> *When mothers came without candles, it was a burden on us because we'd have to buy them ourselves. We had to negotiate with the shop owners, "please will you help us with the candles." We had to reassure mothers. Sometimes we had funds from the facility to use, sometimes not*. –Midwife, Rural Health Center, Zimbabwe

Health workers also no longer had to plead with patients to pay for kerosene, batteries and candles. These costs could amount to a lot of money, especially in light of the salaries afforded to health workers. In Zimbabwe, for example, a candle costs the equivalent of $1 USD (2019) and $1.25 USD (2020). The salary of a health worker in 2019 was $500 USD per month; with ongoing inflation and the devaluation of currency [27] the salary in 2020 is $125 USD per month. Health workers who used to purchase 30 candles at a time can no longer afford to do so. In Zimbabwe, it is standard for midwives to ask mothers to pack candles as part of their birthing kit. With the Solar Suitcase, midwives reported that they were released from needing candles or other forms of light. "*We are no longer encouraging mothers to bring candles…We have few home deliveries – mothers can just come, we don't demand extra candles or items because we now know we have everything,"* a Zimbabwean midwife remarked.

Additional cost savings resulted from the phone charging provided by the Solar Suitcase. Health workers in Uganda, Liberia, Nepal, and Sierra Leone reported that they no longer needed to pay someone to charge their phones, nor do they need to pay the transportation costs to reach that person.

In facilities that had set aside a budget for electricity from the utility grid or generators, the solar intervention reduced monthly expenses and liberated resources for other critical needs. In Nigeria, several health workers commented the facility no longer needed to pay light bills. This was also true in the Philippines, where the Solar Suitcase displaced the need to purchase fuel for generators. One midwife who was based in a Barangay Health Station, reported these savings: *"Our main source of electricity now is the Solar Suitcase. We rarely use the electrical grid except for outside the health facility. Our bill before was 1400 php/month [$28 USD] and now after using the Solar Suitcase lights it's about 35/month [70 cents] per month."*

Non-obstetric uses of the Solar Suitcase

Health workers in energy-deficient settings used the Solar Suitcase lights for emergencies beyond maternal-newborn care. Some health workers reported using them to set intravenous lines for non-obstetric patients, bandage patients, provide wound care, and give nighttime vaccines. A Nigerian Community Health Extension worker in a primary health center relayed, "*We usually use the [solar] lights to set IV lines and treat accident victims, when there is no light or generator supply."* In the Gambia, a nurse described how the Solar Suitcase light aided the rehydration of a male patient with gastroenteritis, diarrhea and vomiting, and avoided an unnecessary referral. She moved the patient from the male ward to the postnatal ward in order to start an intravenous line and administer fluids. "*If it hadn't been [for] the Solar Suitcase, that patient must have been referred because there was no light in this place*." Another midwife from a health clinic in the same country recounted the time she sutured a young boy with a snake bite using the Solar Suitcase lights.

In larger facilities, health workers described how they used the surgical lights to treat trauma patients and other emergency conditions. *"We can operate when they are not [doing] C-sections.*

We can do intestinal obstruction and still use the solar," stated a hospital nurse in Uganda. Other hospital workers reported that the location of the lights in the maternity ward made it impractical to routinely use these lights for non-obstetric cases, and expressed their desire for additional Solar Suitcases.

Health worker morale: Improved confidence, less fear, and reduced stress

Health workers described a number of ways in which lighting and essential electricity improved their personal experience, particularly at night. They reported feeling empowered, better able to provide care, and more confident in their work and ability to make decisions. The perspective of this Nigerian midwife was echoed by others: "*The fact that we now have light always gives us the confidence to accept labor cases at night. No unnecessary light interruptions. Previously it was the rechargeable lantern which you know is not enough and someone has to hold it. You struggle with getting a focus."*

There was widespread relief among health workers that they were no longer dependent upon inadequate and unsafe sources of light. A Nepalese midwife said that the reliable lighting "*greatly helped us to remain calm and make proper decisions so we can deal with the complicated cases*." Many health workers reported they no longer feared nighttime duty. A male midwife at a Level II health center in Malawi described the change in his experience before and after the solar intervention. Shortly before the Solar Suitcase installation, he had been unable to resuscitate three newborns in large part because of the lack of light. That changed completely when he received the Solar Suitcase.

> *For me personally, I can go to work with no fear. I used to be afraid of working at night. I was worried that the delivery would be long, and I would lose the torch light. Now I can go to work without fear. I can use the light when I want and there are no blackouts.*

Health workers across the board described greater confidence, less frustration, and improved morale working with the solar intervention. As one Ethiopian midwife shared, "*We used to carry mobile phone lights with our mouth and deliver with frustration but now we deliver without any problem and with more confidence. It has made our job easier."*

Discussion

For health workers accustomed to working in health facilities with intermittent or no electricity, the provision of a simple solar electric system positively impacted their attitude, confidence, and ability to provide routine and life-saving care. Following the solar intervention, health workers reported greater efficiency, less fear, fewer delays, and greater capacity to provide nighttime care. They expressed great relief to be released from their dependence upon handheld (and mouth-held) lights while conducting procedures, and recounted improved abilities to conduct procedures and make decisions. Health workers reported that the fetal Doppler improved the accuracy of fetal heart rate detection and allowed both patient and provider to hear and discuss the implications of fetal heart rate abnormalities. Health workers reported that patients and

health workers saved money when they no longer need to pay for fuel, lighting sources, and phone charging. Health workers also perceive an increased utilization of maternal services. With respect to clinical care, health workers perceived an improved environment for conducting routine and emergency care after receiving reliable light. The consistent availability of light reduced delays and improved timeliness of procedures, management of obstetric emergencies, sanitation and infection control, reliability of communications, and decision-making about referrals.

The results of this qualitative research further indicate that the nine signal functions for basic and emergency obstetric and neonatal care services [12] are improved when reliable light and electricity are present. Treatment of hemorrhage, prolonged or obstructed labor, retained product of conception, pre-eclampsia or eclampsia, ruptured uterus, and newborn distress was possible when lighting was assured.

There may be unintended consequences of providing improved light and electricity to an under-resourced health facility. When around-the-clock care becomes feasible, health workers may become resentful of having to work at night and getting less sleep – they can no longer turn mothers away due to lack of light. With reliable light, there may be increased demand for services and not enough staff to handle cases. Although this was not expressly examined in this research, the author has anecdotal evidence from conducting participatory observations in Nigeria supporting this claim. After a hospital solar intervention was conducted, for example, one physician told this author, "*There's no hiding anymore."* The availability of reliable energy could encourage higher level decision makers to take advantage of this positive development. In a Ugandan Health Center III for example, after deliveries doubled subsequent to the solar intervention, the Ministry of Health assigned an additional midwife to the facility. With improvements in health facility electricity, health ministries in many countries may need additional staff to keep up with demand for services.

Health workers with better lighting may be tempted to handle difficult cases that, in the past, they referred to those with more experience and training. On the other hand, as several health workers pointed out, patients may be reluctant to leave a well-lit facility when a referral is recommended.

Finally, in larger health facilities that receive the Solar Suitcase for obstetric care, non-maternity health staff may be resentful that the delivery room was selected for the solar intervention while other parts of the facility remain in the dark. In some facilities, the maternity ward offered the best lighting in the entire facility, and it was not uncommon to bring pediatric or other emergency cases to the labor room when lighting was needed for setting IVs or other procedures, as was previously mentioned in the case of the Gambian health worker who treated an adult male with gastroenteritis.

Despite such concerns, this study demonstrates that simple, immediate solutions like the Solar Suitcase can be meaningful for maternity care. When light is added to other interventions, the impact is likely to be even greater.

Lack of lighting and electricity do not occur in isolation—health facilities experience many challenges such as inadequate staffing, lack of potable water, and insufficient supplies or commodities, to name a few. The lack of lighting compounds other problems, and the solar intervention left many problems untouched in the facilities we studied.

The study had limitations. The perceived benefit of lighting and electricity on healthcare provision beyond maternity care was not investigated; the Solar Suitcase was primarily focused on obstetric and newborn care. However, the need for light and electricity is ubiquitous in health care, and it is very likely that clean reliable electricity for the entire facility would have improved the perceived quality of care and morale of facility health workers throughout.

Another limitation is that in some We Care Solar programs, the Solar Suitcase was part of a larger set of interventions to improve maternal and newborn health. The program with Pathfinder in Nigeria, for example, included health worker education, while the Pathfinder program in Tanzania, included health education, improvement in supplies, and an emergency referral and transport scheme. Both of these multi-year programs showed significant reductions in maternal and perinatal mortality [28]. Some of the benefits ascribed to the Solar Suitcase may have been the result of the complete set of interventions. To minimize the chance of over-attribution, health workers were asked specifically about the components of the Solar Suitcase: the lights, fetal Doppler, and phone charging, and their impact on maternity care.

Third, since all study participants were working at facilities that received the solar equipment as donations, there may be a reporting bias. Health providers may have wanted to please the interviewer and overstate the benefits of the intervention. They may have been reluctant to report problems. And, in cases where multiple interventions occurred at the facility, such as an education program for midwives, improvements in confidence may have been attributed to the Solar Suitcase without mentioning the role of other important interventions. Before consenting, health workers were reminded their participation would not lead to additional donations, and that their answers would not affect the status of the current solar system. However, reporting bias still may have occurred and inflated the positive findings.

Fourth, the database used for this study had personal identifiers removed and limited demographics of study participants were available. This meant that not all of the data could be stratified by gender, occupation, and years of experience, which is a weakness of the study. Given the consistency of findings across participants with the data that were available, however, it is unlikely that the added information would have changed the overall conclusions of the study.

Finally, the 100% reliance on interviews is a weakness of this study. An observational study and quantitative data would have strengthened the findings. The author has spent considerable time observing obstetric care in many of the countries represented in the study, including Nigeria, Sierra Leone, Liberia, Uganda, Tanzania, Zimbabwe, the Philippines, and Nepal, and her first-hand observations of labor-room challenges, surgeries, referral patterns, and health worker frustration, fear, and demoralization are consistent with the qualitative interview findings of this study. Additional ethnographic research would be worthwhile and quantitative analyses are warranted, particularly to understand the contributions of reliable electricity to improvements in childbirth outcomes in quantitative terms.

A strength of this study is the length and scope of data collection. The 607 participating health workers had an average of 5.4 years of professional experience and collectively accounted for 655,560 deliveries. The themes that were shared in this report were reported over and over by health workers at every tier of service provision and in every country. Findings were similar across the 11 countries and consistent across the ten years of data collection, suggesting that the findings are likely applicable to a wide range of countries. Sadly, the themes remained constant over time, indicating energy poverty in health care remains relevant even today. The perceived improvements in maternal and newborn care borne from this study suggests that improved access to energy should be accelerated in LMIC countries.

Conclusion

This large qualitative study of health workers' perceptions about a solar intervention, while not without limitations, showed substantial consistency of findings across time, geography and level of care facility in the role that light and electricity were perceived to play in the provision of obstetric care. Hundreds of health workers reported improvements in routine medical services, emergency obstetric care, utilization of skilled birthing care, and personal confidence and morale when continuous lighting and essential electricity were provided.

Access to reliable lighting and basic electricity are a necessary, although not sufficient, component of maternal and newborn care. Such access complements other interventions and efforts to improve maternal and child health. This study demonstrates the advantages and benefits of smaller, compact solar systems in a diverse range of LMICs. If the global community is to reach SDG goals, and universal health care is to become a reality, maternity interventions must include the important component of energy access. Light and electricity alone are not enough, but their importance is clear.

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Chapter 4

Conclusion: Island of Light

Universal access to health care and universal access to modern efficient energy services are interlinked Sustainable Development Goals [1]. When the World Health Organization released Access to Modern Energy Services for Health Facilities in Resource-Constrained Settings in 2015, highlighting the important role energy can plays an enabler of health services, they called for a "better understanding of the multidimensional linkages between energy and health service delivery" [2]. This dissertation answers that call by providing vivid evidence of ways in which energy access is vitally necessary, although not sufficient, for the execution of prompt, appropriate emergency obstetric care.

My early observations of obstetric care in a Nigerian state hospital along with more than 1,200 interviews conducted over the last decade with doctors, nurses, midwives, and community health workers have confirmed that energy access and quality health care are indeed interlinked. Though nobody would deny that light and electricity are requisite for admitting patients, performing diagnostic tests, enacting medical procedures, conducting surgeries, storing vaccines and blood, and creating a safe, hygienic medical environment, an estimated 59% of health facilities in low- and middle-income countries lack reliable electricity, according to a 2018 report [3]. Furthermore, the WHO reported in 2013 that 25% of health facilities in sub-Saharan Africa had no electricity at all [4]. Sadly, the experience of We Care Solar over the last decade confirms the WHO findings. Extrapolating from these data, we estimate that hundreds of thousands of health workers provide medical care when electric lights may be unavailable, equipment may lay dormant, autoclaves may be inactive, and a whole host of hospital functions (well outside of the scope of this research) cannot occur.

The two studies in this dissertation provide a deeper appreciation of the *meaning* of the above statements. Through the words of health workers across eleven countries—representing three tiers of health facilities and multiple job titles—we heard personal perspectives about the role of energy in the provision of maternal and newborn care as well as the personal and professional implications of withholding or providing medical procedure lighting.

In Chapter 1, *Where there is no light,* 1,213 health workers tasked with providing frontline maternal health care offered their perspectives on working where there was little or no access to reliable electricity. Lower-tiered health workers reported that energy poverty had a negative impact across several domains including perceived quality of care, referral patterns, infection control, patient safety, health worker safety, and health-seeking behavior by patients. As health workers told powerful stories of the ways in which the lack of medical lighting interfered with routine services as well as emergency care, we could hear and observe their frustration, stress, anxiety, economic hardship and fear. By understanding the extraordinary ways in which health workers attempt to maneuver candles, kerosene lanterns, flashlights, and even cell phones, we could appreciate their drive to overcome infrastructure hurdles in order to uphold their

professional commitment to saving lives. When patients with complications arrived in lower-level facilities, health workers without good lighting had to decide whether to "do their best" using the resources at hand, or turn patients away, often sending them into the darkness, with the hope that transfer to a referral hospital would result in a better outcome. At the same time, we heard from hospital staff who *also* faced power outages, underscoring that a hospital referral was no guarantee that lifesaving services would be provided.

We heard about the economic challenges that health workers and patients face when facilities cannot ensure electricity for lighting and phone charging. In order to avoid childbirth in complete darkness, they spent their limited personal funds on candles, kerosene, batteries for flashlights, charging for cell phone lights, and poor-quality "Chinese lanterns." For health workers, these financial stressors further compounded concerns about inadequate pay and served to further de-motivate health workers assigned to rural facilities.

In Chapter 2, *Where there is light,* our qualitative research surveying 607 health workers in health facilities that had received a "Solar Suitcase" intervention revealed that even a modest amount of solar electricity markedly improved perceptions of health care. The Solar Suitcase is a compact, complete solar electric system designed for maternal health care. This pre-wired system includes medical quality lighting, a fetal Doppler, two headlamps, phone charging, and 12V DC outlets for additional charging and provides around-the-clock lighting, seven days a week. Midwives, nurses, and community health workers with the Solar Suitcase expressed their relief in no longer relying on inferior sources of light. They could use both hands, see every patient in a room, and call for assistance when needed, knowing their phones were fully charged on site. They described situations where continuous lighting enabled them to resuscitate babies, respond effectively to obstetric emergencies, conduct surgeries throughout the night, and maintain a cleaner and safer environment. Health workers reported an increase in demand for obstetric services, as community members recognized improvements in service delivery afforded by enhancements in lighting and electricity. Perhaps most compelling were health worker reports that they no longer feared night time duty and that their confidence and morale were raised. Stories of frustration and demoralization from the first study were replaced with tales of pride and empowerment. These findings could have profound implications for the retention of rural health workers in countries where turnover is rampant. Similarly, the descriptions of improved patient-provider relationships raise the possibility that electricity and lighting could play an important role in efforts to reduce disrespectful and abusive care.

In addition to the qualitative research briefly summarized above, this dissertation reflected upon the journey of my organization, We Care Solar, and how we aimed to address the challenge of energy access in remote health centers. From its modest beginning, we set out to understand the conditions affecting health workers and design a scalable solar electric system tailored to their needs. From our initial experiences supporting individual deployments to our later management of large-scale programs (involving the collaboration of governments, UN agencies and international NGOs), we absorbed valuable lessons about product innovation, partnership,

business, and international program development. At this juncture, I can reflect upon some of the lessons learned from my unexpected journey.

1. **Embrace the unexpected**. I purposely did NOT read a lot about the topic of Nigerian maternal hospital care before my first trip to conduct ethnographic research. By becoming a participant observer, I was able to share the experience of my Nigerian colleagues and see things from a new vantage point. Because I spent nights at the hospital, I understood the literal and figurative powerlessness of being a health provider where electricity is not assured.

2. **Learn from failure.** There is so much to learn from making mistakes. The first Solar Suitcases needed lots of improvements. Connectors failed, solar panels fell from rooftops, light bulbs browned, equipment was damaged during transport, insects damaged circuitry, rain water carried along cables from rooftops corroded our hardware, and health workers using the suitcase made mistakes that dispelled our naïve belief that we had made an intuitive product. Likewise, understanding the contextual factors that work against maintenance and servicing were crucial learnings that influenced how we designed programs for sustainability. Seeing what parts of the Solar Suitcase failed in the field helped us to design a better Solar Suitcase.

3. **Perfect is the enemy of the good.** Although I am by nature a perfectionist, Hal's drive to get Solar Suitcases into the field—even if they didn't look pretty or have the best user interface—gave us valuable experience. If we had waited for the perfect Solar Suitcase to be designed, I am not sure whether we would have ever conducted a field trial. By having health workers in Africa and Haiti use our early imperfect prototypes, we obtained important feedback that we incorporated into subsequent designs. We used this lesson over and over as the team needed to balance a desire for engineering perfectionism with the imperative to get our products into the hands of those who needed them The business adage, "fail early, fail fast" was never more relevant than in designing long-lasting equipment for rural health care.

4. **Don't travel solo.** Surround yourself with the best team you possibly can. I knew nothing about business models, designing a product, manufacturing, and logistics at the onset, let alone how to manage international programs. We learned so much from other social entrepreneurs, from mentors, and from partnerships we created around the world. I have found teachers in every location and at every level: from NGO drivers in Uganda to skilled birth attendants in Nepal to medical equipment technicians in Sierra Leone to other non-profit leaders and even to ministry officials and to politicians. Be humble, recognize your strengths and weaknesses, and find talented people to complement your skills.

5. **Non-profits face many of the same challenges as for-profits.** We Care Solar has a very similar environment to many startups. We had to ask ourselves: How do we scale and continue to serve customers? What is our target market? Who are our competitors? How do we best communicate our message effectively to attract investors (donors)? We were faced highly dysfunctional market. The clinicians in frontline rural health centers often lacked funds for

basic supplies and medication. We needed to understand that they were our beneficiaries rather than our target customers. In our case, our customers are the governments, UN Agencies, international NGOS and foundations that support the work of these underserved health centers. The social entrepreneurship "boot camps" I attended through University of Pennsylvania's Center for Social Impact Strategy and the Global Social Benefit Incubator at Santa Clara University were invaluable.

6. **Choose something you love.** In becoming a social innovator, select a domain that ignites your passion because the work is hard. Trying to conduct business in Africa and Southeast Asia is challenging, particularly for Westerners lacking experience and longstanding relationships in countries where face-to-face relationships are essential. Furthermore, in the countries in which we chose to work, infrastructure may simply not be there. You cannot guarantee you will find roads, working internet, phone service, or even proper tools. The logistical challenges we faced would give anyone nightmares. But keep in mind that hurdles encountered the implementation of new programs are likely some of the very same challenges at the root of the problems you may be trying to solve. So, immerse yourself in the local context, learn from people who have spent their lives in these environments, let go of trying to control every outcome, and be prepared to experience some very deep fulfillment.

7. **Start small.** If you are passionate about a problem that needs solving, you don't need to map out an entire master plan at the beginning. Take small steps. Each time you cross a threshold, you'll get some results and the opportunity to make new decisions and new choices. Hal and I had no idea that our efforts to solve the electricity problems of one hospital would ever lead to designing hardware and programs to address energy poverty on an international scale. At each step of the way, by solving one problem, we gained an opportunity to solve another. We took it one step at a time. By linking together small steps, our path became clearer. Small things can lead to big things.

8. **Don't underestimate the power of a good story.** Much of the support we received over the years was the result of learning to effectively communicate our mission. Forget about traditional slide decks filled with long narratives and multiple bullet points. Tell stories accompanied by photos that illustrate your mission and emotionally connects to your audience. I found this to be true even when speaking at high-level institutions. I remember on one occasion at conference on sustainability at the United Nations, I followed a series of speakers who gave very formal presentations. I wondered if my story-telling would be seen as inappropriate. When I finished, not only did I receive enthusiastic applause, but soon had a line of ministers and ambassadors waiting to speak with me.

9. **One size does not fit all.** Our approach to programming in one country was not necessarily easily transposed to another. Even though we understood how to import pallets of Solar Suitcases into Uganda, it didn't mean we were successful in Tanzania. Getting the buy-in of government ministries is not for the faint of heart. Understanding who held critical levers in

each institution was part of the issue. But cultural issues, mores and the structure of local internal systems are distinct in each country. To achieve success in different locales, we conducted research in each country, developed new allies, and hired local staff who were adept at working with local institutions.

10. **Prepare for the unexpected.** Finally, not everything can be strategically planned, especially for an early stage company. It was great to have some idea about the direction we were heading, but much of our success was due to unexpected opportunities, chance encounters, and our ability to pivot midstream. Being a small enterprise kept us nimble and resilient, even during unprecedented world events, like the COVID-19 pandemic, where we adapted our Solar Suitcases appliances to include infrared thermometers to support health workers screening for infection.

While our work in the field showed us the value of light and a small solar electric system, we also learned that health workers in LMICs not only face the challenge of energy poverty. They are simultaneously battling a host of barriers to quality care including: lack of access to running water, insufficient equipment stockouts of drugs, inadequate staffing, lack of supervision and continuing education, insufficient and/or delayed remunerations, and poorly constructed facilities that may harbor insects, rodents, bats, and even snakes. Resolving the problem of insufficient light and electricity alone will not solve these and other challenges.

Access to reliable lighting and basic electricity are a necessary component of maternal and newborn care. Such access complements other interventions and efforts to improve maternal and child health and indeed, should be seen as a vital component of any comprehensive approach to uplifting obstetric and newborn services. This dissertation demonstrates the numerous and often profound ways in which energy poverty can impact on both clinical care in maternal health, and the health and well-being of health workers trying to provide such care where there is no light. But it also explores the value and advantages of small, compact solar systems in a diverse range of LMICs. If the global community is to reach the SDG goals, and universal health care is to become a reality, maternal-newborn interventions must include the provision of clean, reliable electricity. Light and electricity alone are not enough, but their importance is foundational.

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Appendix A

Program by Partners

Country	Program Partners	Date	Number of Facilities	Number of Interviews
Ethiopia	WEEMA	2015	25	25
The Gambia	Gambian Ministry of Health	2016-2019	40	108
Liberia	The Liberian Ministry of Health, UN Women, UNICEF, Africare, EnDev, PHIL (Public Health Initiative Liberia), Innovation for Poverty Action	2016-2019	235	235
Malawi	Jhpiego, CARE, Save the Children, PLAN, Innovation Africa	2013-2015	40	12
Nepal	One Heart Worldwide, Sun Farmer	2013-2019	230	139
Nigeria	eHealth Nigeria, Pathfinder International	2012-2019	320	291
Sierra Leone	CUAMM, Ministry of Health	2017-2018	141	15
Tanzania	Tanzsolar, Pathfinder International, Jhpiego	2013-2018	320	40
The Philippines	Stiftung Solarenergie	2014	139	139
Uganda	AMREF, CUAMM Pathfinder International, Safe Mothers Safe Babies, Save the Children, UNICEF	2012-2020	137	66
Zimbabwe	ZimEnergy Eco-Foundation	2016-2018	130	143
			1,729	1,213

Appendix B. Codebook for *Where there is light*

Solar Suitcase Master Codebook		
Code	**Subcode**	**Definition**
Electricity	Grid	Reference to grid/utility electricity
	Other Solar	Previously installed solar electric system including vaccine refrigeration
	Generator	Diesel generator for electricity in health center
	No Electricity	No pre-existing electricity in facility
Alternate light	Cell phone light	Use of cell phone light for health care services
	Candles	Candlelight for health care services
	Lanterns (Paraffin, Kerosene)	Use of lantern for health care services
	Torchlights/flashlight	Use of flashlight for health care services
	Battery Lantern (Chinese Lantern)	Use of battery-powered lantern for health care services
	Light Challenges	Problems encounted keeping hand-held lights working, such as lack of batteries or lack of kerosene
Safety/Sanitation	Snakes/Reptiles	Related to reptiles within or around the facility
	Sanitation	Related to keeping the health facility clean
	HIV Precautions	Related to HIV contamination/infection
	Contamination	Related to contamination with infectious agent
	Accidents	Related to lack of light, including bumping into things, problems movement
	Accidents, Candle	Problems related to wax burns, fire
	Injury	Related to being injured during medical procedures, needle pricks, exposure to body fluid
	Cleaning	
	Robbery	
Privacy	Patient Privacy	Related to privacy during delivery
	Patient Respect	Related to respect of patient
Quality of Routine Medical Care	Tears (Cervical/Vulvar/Vaginal)	Related to lacerations of the cervix, etc from the delivery
	Suturing	Related to suturing lacerations during deliveries
	Episiotomy	Related to cutting or repairing episiotomy
	Monitoring Mother and Baby	Related to ability to see and monitor more than one patient
	Reading (Notes/Medication Label, Scale)	Discussion about ability to read chart
	Writing	Related to ability to write, take notes, medical documentation
	Movement around facility	Related to mobility and visualization around the facility
	Examination	Related to examination of patients
	Placement of Foley Catheter	Related to ability to insert foley catheter
	Postpartum care	Related to postpartum care including breastfeeding, wound care
Quality of Emergency Obstetric Care	Use of partograph	Related to ability to use the partograph (labor curve)
	Antibiotics	
	Blood tranfusion	Related to HW arranging for blood transfusion
	Diagnosis of Hemorrhage	Related to diagnosis or treatment of obstetric hemorrhage, both antepartum and postpartum
	Treatment of Hemorrhage	Related to treatment of obstetric hemorrhage, including suturing, and use of uterotonics (ergotomine, oxytocin, misoprostil)
	Eclampsia	Related to diagnosis or treatment of eclampsia and pre-eclampsia
	Retained Placenta	Related to retained placenta after delivery
	Setting IV	Related to HW inserting intravenous line
	IV hydration	Related to intravenous resuscitation of mother or baby.
	Cesarean Section	Related to cesarean section (diagnosis, treatment, etc)
	Placenta Previa	Related to cases of placenta previa - where the placenta covered the cervix
	Near-Miss	Related to a near-miss of a maternal death
	Cord Prolapse	Related to diagnosis and treatment of cord prolapse
	Ruptured Uterus	Related to diagnosis of ruptured uterus
	Maternal Mortality	Related to death of a mother
	Newborn Mortality	Related to death of a newborn

Fetal Monitoring		
	Fetal Viability	Related to the viabiity of the pregnancy
	Fetoscope	Comparison of fetoscope compared to Fetal Doppler
	Fetal Doppler, Benefits	Related to use/benefit of fetal doppler
	Twins	Related to twin pregnancy
	Breech	Related to breech pregnancy
	Fetal Distress	Related to fetal distress detected by monitor
	Fetal Demise	Related to fetal demise during pregnancy
Neonatal Care	Clean/dry/immediate postpartum care	Related to standard neonatal care activities after delivery
	Meconium	Related to meconium stained amniotic fluid
	Fetal Distress	Related to evidence of fetal distress during labor
	Bradycardia	Related to fetal heart rate too slow
	Tachycardia	Related to fetal heart rate too fast
	Stillbirth	Related to stillborn infant
	Asphyxia	Related to inadequate oxygen after delivery
	Newborn Mortality	Related to death of newborn
Communication	Call for Ambulance/Transport	Related to ability to call ambulance
	Call Mothers/Relatives	Related to abiity to call mothers and relatives
	Call for Help	Related to ability to call others for medical help
	Call for Second Opinion	Related to ability to call others for a secondary medical opinion
	Appropriate transfer	Related to ability to call hospital for transfer of patient
Timeliness/Availability of Care	Referral Out	Related to referral patient to another health facility
	Postpone/Delay	Related to delaying care and/or postponing care until daylight
	Turn Away	Related to refusing admission to a patient due to lack of light/electricity
No pre-existing electricity in facility		
Health Worker	Morale	Related to health worker morale/attitude
	Decision Making	Related to ability to make decisions
	Fear	Related to fear of working/fear at night
	Unhappy	Related to emotional unhappiness or sadness
	Confidence	Related to level of confidence at work
	Gratitude	Related to gratitude for lights/solar suitcase
	Retention	Related to attitude about staying at work in facility
	Stress	Related to stress at work
	Efficiency	Related to HW efficiency at work
	Provider-Patient relationship	Related to interactions between patients and providers, non medical
	Empowerment	Related to personal sense of power
	Night Management	Related to management of cases at night
Mother	Gratitude	Related to gratitude for lights/solar suitcase
	Patient Benefit	Reflections on how the Solar Suitcase is benefiting patients
	Provider-patient relationship	Related to interactions between patients and providers, non medical
	Breast feeding	Related to breastfeeding newborn infant
	Trust	Related to incidents that reflect sense of trust with provider
	Hearing heart beat	Related to hearing the fetal heart beat with the Fetal Doppler
	Deciding to come for care	Decision-making about coming to the helath facility for care
	Bonding with baby	Related to bonding with baby
Financial Burden	Cost Savings	Related to money saved by having Solar Suitcase
	Savings Generator	Related to cost of generator of saving post solar suitcase
	Savings Batteries/Candles/Kerosene	Related to money saved by not buying hand-held lights, batteries, candles, or kerosene
	Savings Transort	Related to money saved by not having to use transport
	HW expense	Relating to money spent by health worker
	Patient Expense	Related to money spent by patient

Additional Codes for *Where there is light*

Utilization	Increased Deliveries	Mentioning of increased deliveries at health facilities
	Increased Family Planning	Mentioning of decreased deliveries at health facilities
	Increased Antepartum Care	Mentioning of increased prenatal care visits
Solar Suitcase Benefits	SS Lighting	
	SS Health Worker Benefits	Health Worker Benefits from SS
	SS Patient Benefits	Patient benefits from SS
	SS Community Benefits	Community Benefits from SS
	SS Health Facility Benefits	Health Facility Benefits from SS
Quality of Solar Suitcase light	Compared to Grid	Metnion that Solar Suitcase ligting is better quality than utility lighting
	SS Bright	Mention of the brightness of Solar Suitcase LED lighting
Solar Suitcase Components	SS LED Lights	Related to LED lighting that comes with Solar Suitcase
	SS Headlamps	Related to the LED headlamps that come with the Solar Suitcase
	SS Doppler	Related to the Fetal Doppler that comes with the Solar Suitcase
	SS Charger	Related to the phone charger that comes with the Solar Suitcase
		Related to other uses of the Solar Suitcase for charing
Solar Suitcase Performance	SS Reliability	Related to the Reliabtility of the Soalr Suitcase
	SS Challenges	Related to any breakage of solar suitcase and parts
Solar Suitcase Recommendations	SS Improvements	Ways to improve the Solar Suitcase (more lights, etc.)
Solar Suitcase - Non-OB Care	SS Pediatric Care	
	SS Trauma	SS use for trauma and suturing

SN	Questions	Responses
A	**IDENTIFICATION**	
A.1	Date of Interview (DD/MM/YY)	
A.2	Name of Interviewer	
A.3	Name of Health Facility	
A.4	Type/condition of Health Facility ***(Circle One)***	1. Tent/Temporary Facility 2. Health Post 3. Primary Health Care Center 4. Hospital 5. Other (Specify) _____
A.5	Address of Health Facility	
A.6	District	
A.7	Region	
A.8	Name of Health Facility In-charge	
A.9	Contact Information for the Facility-in-charge	
A.10	Name of Respondent	
A.11	Title of Respondent (Facility in-charge, nurse, midwife, etc.)	
A.12	Phone Number of Respondent	
A.13	Duration of Service of Respondent in the HF	
A.14	No. of Solar Suitcase Installed	
A.15	Solar Suitcase Installation Date	

B.	Key Informant Interview Guideline

1. **How long (in years and months) have you been working in this health facility? What are your major roles and responsibilities in this health facility? How many and what types of other health workers are working with you?**

2. **What do you like most about your work?**

3. **What are the greatest challenges about your work?** *(Probe based on working environment, adequate staffing, availability of medicine and equipment, remoteness of facility, home deliveries)*

4. **What is the major source of electricity at this health facility?** *(Probe based on connected to grid, Solar Suitcase, other solar)*
    a. **How frequently do you have outages? For how long? What times?**
    b. **Do you have scheduled outages? If so, what days and times?**

5. **What happens if a mother needs to deliver at night and there are no staff at the facility?** *(Probe to explain with examples of specific times this happened)*

6. **What was it like to work here before the Solar Suitcase installation?** *(Probe based on working condition/environment and difficulties, sanitation, writing/reading, problems during night)*

7. **How does having the Solar Suitcase change how you feel about working in your health facility?** ***(Select all that apply)***

    a. Easy to manage mothers during childbirth using headlamps and LED lights at night
    b. Able to handle cases that previously would have been referred
    c. Easy to monitor fetal heart sound using fetal Doppler
    d. Easy to charge cell phone to make calls for referrals
    e. Improved safety and sanitation for myself and patients
    f. Increased delivery cases
    g. Increased antenatal care cases
    h. Other (Specify):

    Please explain your selections with examples:

8. **In what way do you think the Solar Suitcase is useful in the delivery room? Explain how. If you think it is not useful explain why not.**

9. **What is the most useful part of Solar Suitcase? Why?** ***(Select one)***
    a. LED lights
    b. Head lamps
    c. Fetal Doppler
    d. Mobile phone charger
    e. Battery charger
    f. Other (Specify):

Do you use the fetal Doppler during each ANC visit? If no, why not? If yes, why? *(Probe based on unfamiliarity, prefer fetoscope, broken, no gel)*

1. **How has the fetal Doppler made a difference in your care of pregnant mothers and their babies?** *(Probe based on easier to monitor, more accurate, increase number of women coming to ANC visits)*

   Describe an instance in which fetal Doppler made a difference in your care of a pregnant patient:

2. **How have the headlamps made a difference in your care of pregnant mothers and their babies?** *(Probe based on suturing, seeing vaginal tears, moving around the health facility)*

   Describe an instance in which headlamps made a difference in your care of a pregnant patient:

3. **How has the Solar Suitcase been helpful during referral of a pregnant or laboring patient to higher facilities?**
   a. Who was the patient?
   b. What was the cause of referral?
   c. How did you handle the situation?
   d. How was the LED lights, headlamps, phone charging or fetal Doppler helpful?

4. **How would you feel if the Solar Suitcase was taken away?**

5. **What feedback/suggestions have you heard about the Solar Suitcase from patients or community members?**

6. **What challenges have you had in using the Solar Suitcase?**
   a. Do both LED lights work when you need them at night?
   b. Are both headlamps still working?
   c. Does the fetal Doppler work?
   d. Does the phone charger work?
   e. Are there any other parts of the Solar Suitcase that are not working?

7. **Is there anything else you would like to share?**

Thank you for your time and cooperation!