Connected Society

Rural Connectivity Innovation Case Study:

Cellcard Cambodia and Solar Power

The GSMA represents the interests of mobile operators worldwide, uniting nearly 800 operators with more than 300 companies in the broader mobile ecosystem, including handset and device makers, software companies, equipment providers and internet companies, as well as organisations in adjacent industry sectors. The GSMA also produces industry-leading events such as Mobile World Congress, Mobile World Congress Shanghai, Mobile World Congress Americas and the Mobile 360 Series of conferences.

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GSMA Connected Society

The GSMA Connected Society programme works with the mobile industry and key stakeholders to increase access to and adoption of the mobile internet, focusing on underserved population groups in developing markets.

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Executive Summary

Mobile broadband (3G or 4G) coverage in the developed world is now almost ubiquitous. However, just over 1 billion people live in areas that are not covered by mobile broadband networks, with more than 95% of them living in low or middle-income countries. This is primarily driven by economics: the uncovered live in areas that are more expensive to supply, which typically have lower levels of demand.

One of the most significant expenses that operators face in providing users with mobile coverage is the cost of powering cell sites. Using a GSMA developed evaluation model, this case study illustrates how the Cambodian operator Cellcard has used renewable energy to bring down the cost of providing coverage, enabling them to spread the benefits of mobile broadband more widely.

Key Facts

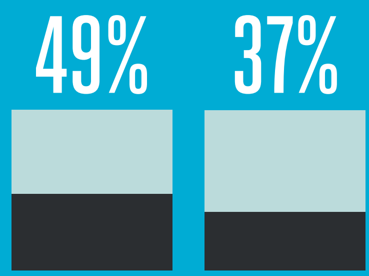
Mobile internet connections

4bn
not connected to mobile internet worldwide

1bn
lack mobile broadband coverage

Electricity grid connections

(% of population)



Operators largest costs

Power

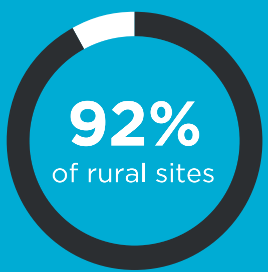
Backhaul

Site deployment

Cellcard is the 3rd largest operator in Cambodia

4.5m
mobile connections

Cellcard sites powered by hybrid-solar



Cellcard's savings with hybrid sites

as compared to diesel powered sites

$9.8m 1 Year → **$30m** 10 Years

Shifting all sites to full solar

Would increase profitable coverage by

+4%
of the population

Reduced carbon emissions

Using a solar-hybrid solution

↓100k
metric tonnes **over 10 years**

1. Rural Coverage: the need for innovation

1.1 The economic difficulty of providing rural and remote areas with mobile broadband coverage

At the end of 2017, the number of people subscribing to mobile services crossed five billion (or 66% of the global population) for the first time. 3.3 billion of them were connected to the mobile internet, a figure that has nearly doubled in the last five years.[1] This growth in access has brought a range of new jobs and services, information and opportunities to billions of people, spurring economic growth in the process.[2]

While this is hugely positive, more than four billion people remain offline, almost one billion of whom live in an area not covered by a mobile broadband (3G or 4G) network.[3] Progress is being made: the significant investments from mobile operators and the wider industry mean that the percentage of people uncovered has halved since 2014 (from 25% to 13%) and 800 million more people are now covered by mobile broadband networks.[4] However, while coverage in developed markets is now largely ubiquitous, many developing regions have large gaps. Over 95% of those lacking mobile broadband coverage live in low- or middle-income countries.[5]

For mobile operators, the market-led business model has proven effective in expanding coverage to current levels. However, the vast majority of the 13% of people who are currently uncovered, live in rural locations with low population densities, low income levels and weak or non-existent enabling infrastructure (e.g. roads or electricity). All these characteristics negatively influence the business case for mobile network expansion, in terms of higher capital investment costs per site, higher operating costs and significantly lower demand (which translates to lower average revenue per user (ARPU)).[6] As a result, connecting this group is principally an economic - as opposed to a technological - challenge.

1. GSMA Intelligence, Q4 2017. At the end of 2012, there were 1.8 billion mobile internet subscribers around the world.
2. A wide range of literature deals with the topic of the economic impact of internet access. See for example: Changkyu Choi, 2009; C.Z.W. Qiang, C.M. Rossotto, 2009; Deloitte (2012); 'What is the impact of mobile telephony on economic growth? A report for the GSM Association'; ITU (2012), "The Impact of Broadband on the Economy: Research to Date and Policy
3. GSMA, State of Mobile Internet Connectivity 2018 (Aug 18); GSMA Intelligence, Q4 2017
4. ibid
5. GSMA Intelligence, Q4 2017
6. GSMA, Unlocking Rural Coverage: Enablers for commercially sustainable mobile network expansion (June 16)

1.2 The role of innovation in increasing coverage

Bringing mobile broadband coverage to underserved areas will require one (or both) of the following:

1. A reduction in the cost of supplying coverage
2. An increase in demand for mobile services from those living in currently uncovered areas

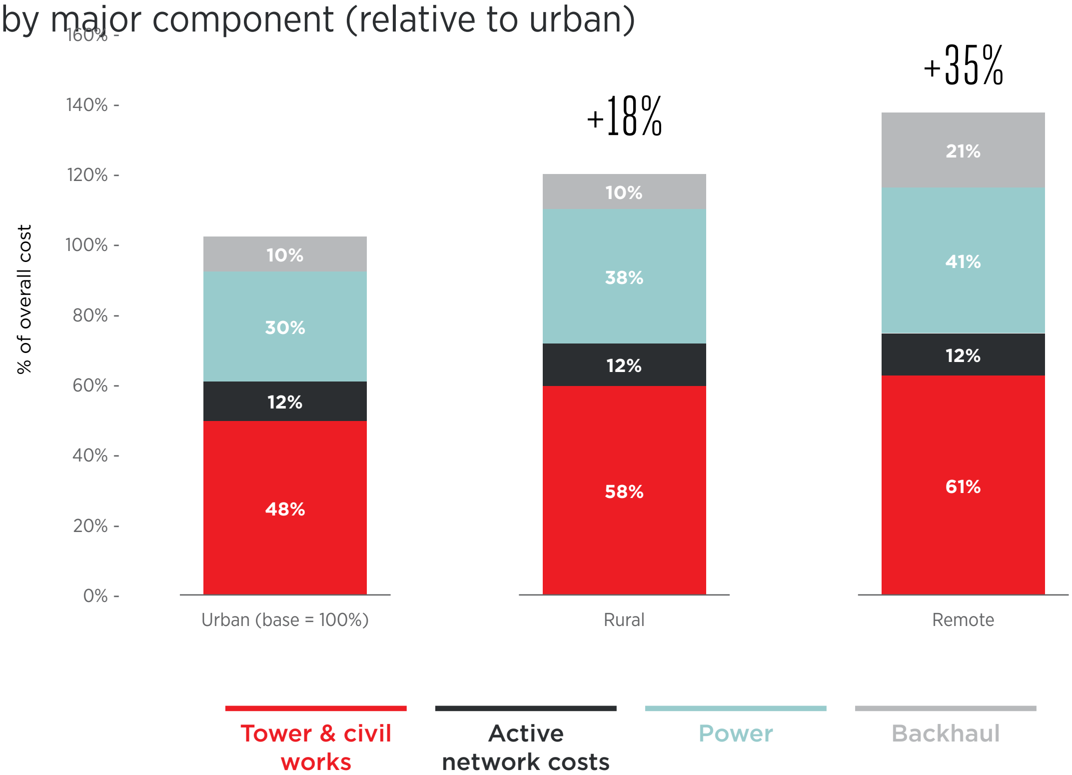
At present, the lower demand for mobile services that exists in rural and remote areas - driven by lower population density, lower incomes and lack of awareness or understanding about the benefits of mobile internet – is a critical barrier to building a commercially sustainable business case for expansion. Revenues per site are typically 80%-90% lower in rural and remote areas compared to urban areas.[7] There are various complex reasons for this - covered in other publications - which if addressed could drive an increase in coverage.[8]

This case study series - '*Innovations in Rural Coverage*' - focuses on the supply side of the equation, profiling innovations with the potential to bring down the cost of increasing coverage to currently underserved areas.

Figure 1

Source: GSMA Analysis

Annualised cost of mobile coverage sites in rural and remote locations split by major component (relative to urban)



GSMA generalised benchmarks. Rural areas are defined as low-density areas where agriculture dominates and with basic infrastructure. Remote areas have even lower population density and extremely limited infrastructure.

Active network costs refer to the 'active' elements in the mobile network infrastructure such as the Radio Access Network (RAN) or network roaming. They can be usefully contrasted with 'passive' elements such as the cell towers. Active costs are largely consistent between urban, rural and remote areas.

7. GSMA analysis (global benchmarks)
8. GSMA, Tanzania rural coverage pilots: Performance report (Jan 18), GSMA, Triggering mobile internet use in Cote d'Ivoire and Tanzania (July 2018); GSMA, Triggering mobile internet use among men and women in South Asia (Nov 17)

As Figure 1 demonstrates, the higher cost of providing coverage in rural and remote areas is primarily due to:

1. **Tower and civil works:** Typically, the cost of installing and maintaining a cell site in rural areas is higher due to the lack of existing infrastructure and the more challenging terrain. For example, transportation costs are significantly higher. In addition, rural locations are often more prone to political or security issues.
2. **Backhaul:** The connection of a particular cell site with the core network is typically accomplished through fibre or microwave networks. However, this can be logistically impossible in some rural and remote locations, meaning it is necessary to use costly satellite backhaul.
3. **Power:** Base stations require significant amounts of energy to function. Power represents a significant proportion of the on-going costs of running a site. In remote and rural areas, power costs are higher as connection to the electrical grid is unlikely to be available and alternatives are more costly (see section 1.3 below).

1.3 The different options for powering a base station

When it comes to powering mobile base stations, operators have four main options:

1. **Connection to the electrical grid:** Connecting the base station to the grid is the best option in terms of cost and reliability. While this represents the dominant choice in developed markets, many low- and middle-income countries have limited provision.[9] In some cases, the electricity may be inconsistent or unreliable (termed 'bad-grid'). Moreover, many rural and remote areas are not connected to the grid ('off-grid') meaning that operators need to seek alternatives.
2. **Diesel:** In 'off-grid' areas, the most commonly used source of power is a diesel generator. While CAPEX (capital expenditure) costs are relatively low, ongoing operational costs (OPEX) are higher due to cost of acquiring and transporting fuel, security costs (largely due to theft of the diesel) and general maintenance costs. Every year, the average off-grid tower consumes 13,000 litres of diesel and emits 35 metric tonnes of CO2.[10]
3. **Renewables:** Increasingly, renewable energy sources are now a feasible alternative to diesel, particularly in certain locations. Solar power is the most common, but wind, micro-hydropower or bio-fuel are also options. These solutions typically have higher upfront costs but lower operational costs (or OPEX). The environmental impact of renewables are also far lower than diesel.
4. **Hybrid:** Finally, 'hybrid' solutions combine two or more power sources. Hybrids combining a diesel generator and solar energy (including batteries for energy storage) are the most common.

Given that power is one of the largest costs that operators incur in providing coverage, understanding how to source electricity in the most cost effective way possible, is crucial.

9. Only 45% of the population of the Least Developed Countries (LDCs) currently enjoy access to electricity. Source: World Bank, 2016
10. GSMA, Tower Power Africa: Energy Challenges and Opportunities (Nov 2014)

2. Background and Context

2.1 Cellcard

Cellcard is a Cambodian mobile operator, owned by The Royal Group, a national conglomerate. With 4.5 million connections, it is the third largest operator in the country with a 19% market share.[11] Thanks to significant investments in their network in recent years, Cellcard's 3G network now covers 90% of the population, the most extensive of any operator in the country.[12] Additionally, its 4G network has grown from 300 sites in December 2016 to more than 3,000 sites today (representing coverage of 91% of the population), with plans for further expansion over the coming years.[13]

This expansion forms part of Cellcard's core strategy of increasing the number of data subscribers across their network, encouraging subscribers to transition from feature phones to using 4G smartphones in the process. This has involved both investing in increased network coverage as well as ensuring that data is affordable. Growth has been significant: Cellcard's mobile broadband subscriber base increased by 34% between the end of 2015 and 2017.[14]

Cambodia's tropical terrain is largely flat, aside from mountainous regions in the north-east and south-west, meaning that it is less challenging to expand mobile networks here than in other markets. However, 79% of Cambodians live in rural areas, a figure far higher than its nearest geographical neighbours.[15] Moreover, only 49% of the population are connected to the grid, a figure that falls to 37% in rural areas.[16] As a result, there is a clear need for operators to find alternative power solutions.

11. GSMA Intelligence, Q2 2018
12. GSMA Intelligence, Q2 2018
13. Cellcard, Network Coverage (July 18); GSMA Intelligence, Q2 2018
14. GSMA Intelligence, Q4 2015 – Q4 2017
15. World Bank, 2017 (Laos 59%; Thailand 47%; Vietnam 65%)
16. World Bank, 2016

SIDEBAR: GSMA Mobile Connectivity Index

The GSMA's Mobile Connectivity Index measures the performance of 163 countries against the four key enabling factors for mobile internet connectivity: infrastructure, affordability, consumer readiness, and content. It has data covering the years 2014-2017.

Cambodia performs below the average for countries in the Asia Pacific region. While performance is slightly ahead of neighbouring Laos, it is significantly behind regional peers Thailand and Vietnam (see Figure 2). The Content and Services enabler – which measures the number of locally produced or relevant websites or applications, is particularly low for Cambodia. Moreover, while the Infrastructure score improved considerably between 2014 and 2017, there is still significant room for growth.

Figure 2

Source: GSMA Mobile Connectivity Index

GSMA Mobile Connectivity Index Scores 2017 (100=max)

	Infrastructure	Affordability	Consumer	Content and Services	Overall
Cambodia	**44**	**67**	**57**	**31**	**48**
Laos	34	64	61	32	45
Thailand	63	78	79	65	71
Vietnam	49	72	74	60	63
Asia Pacific	51	69	69	51	60

2.2 Current mix of power across Cellcard's network

At present solar power is widely deployed across Cellcard's network: 54% of their sites are hybrid solar sites, compared to the 32% of sites that are connected to the electrical grid.[17] Grid-powered sites are largely concentrated in urban areas and most of them are located around the capital, Phnom Penh. By contrast, 92% of rural sites are hybrid-solar sites.[18]

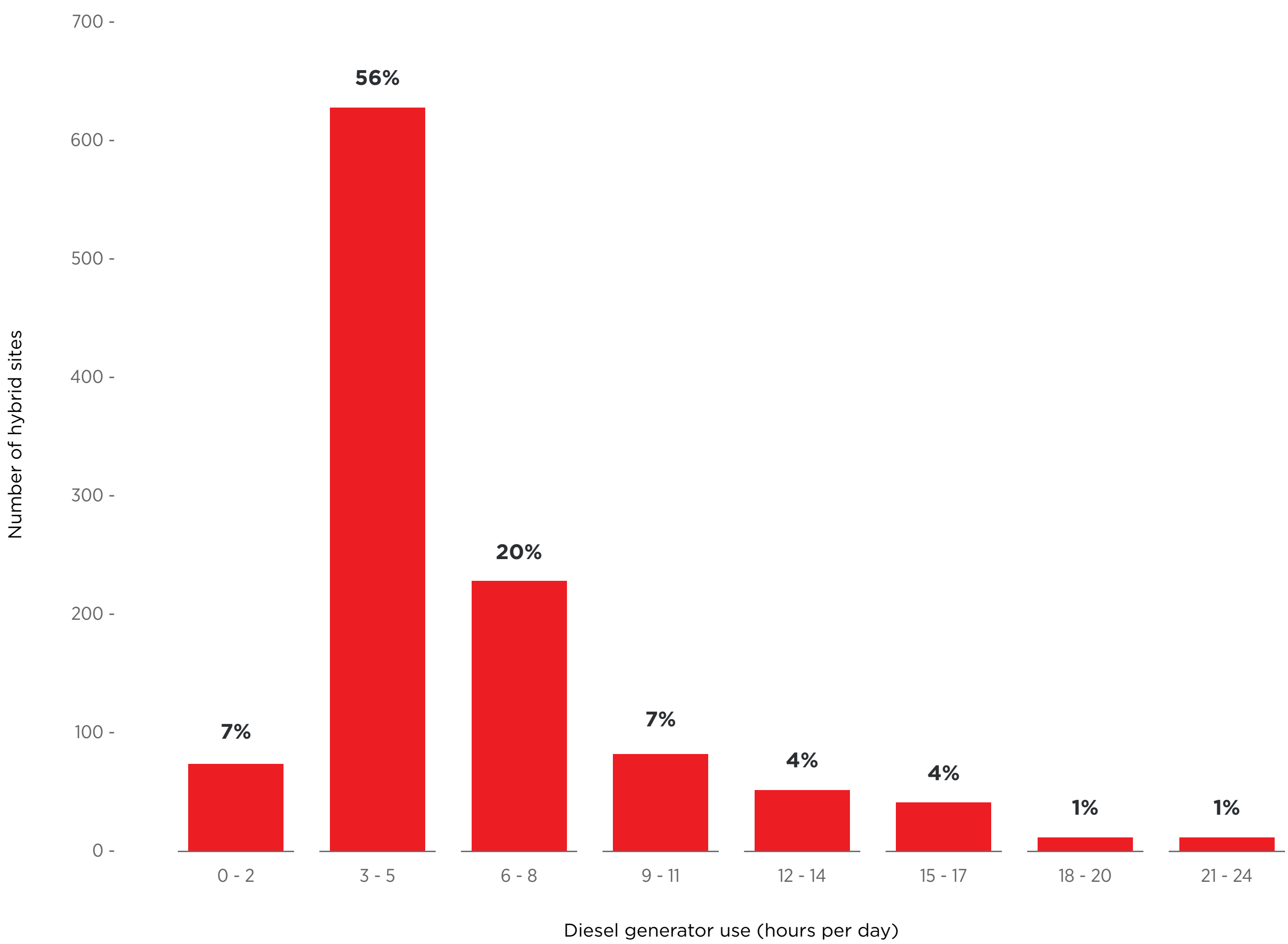
To date, Cellcard's approach has been to use solar to reduce, rather than eliminate diesel. This approach has the advantage of avoiding some of the higher upfront costs of pure solar sites as well as bringing down the operating costs of the diesel. As figure 3 details, 56% of sites ran diesel for between three and five hours a day, with the average (i.e. mean) site running diesel for just under six hours a day.

17. 78% of hybrid sites are solar-diesel hybrid and 22% solar-grid hybrid.
18. Cellcard data, GSMA Analysis

Figure 3

Source: Cellcard data; GSMA analysis

Hybrid sites running diesel (percentage of total)



Cellcard faces a number of challenges powering rural and remote sites. Firstly, transporting equipment and personnel to these locations is often challenging given the quality of the roads, increasing the OPEX of these sites, particularly given the need to maintain the generator periodically. For sites that run partly or wholly on diesel, security also represents a challenge, with fuel being such an attractive commodity for thieves. As a result, guards (and basic facilities for their use) have to be placed at remote sites, which increases the cost of the site significantly.

For solar sites, the main risk is that panels become damaged, therefore reducing site performance and incurring replacement costs. The transportation of the solar equipment to remote areas and the need for continual maintenance also represent a challenge.

3. Results of the GSMA Analysis

In order to optimise their mix of power sources, Cellcard invited the GSMA to analyse data from 2,360 sites. The key findings from this analysis are discussed below.

3.1 Cellcard is already reaping significant commercial benefits from their use of solar power

Cellcard already uses a relatively high proportion of solar energy to power its cell sites. We analysed the total cost of ownership (TCO) of the current hybrid sites against a 'diesel-only' site to calculate the commercial gains from doing so. Given that Cellcard does not have any sites powered this way, we hypothesised such a site using existing site performance data.

Our analysis confirmed that while solar does have higher initial costs than diesel, it ultimately pays back the investment – in this case within 2.6 years - due to the lower running costs. A typical diesel site would require 8.8 hours of diesel usage per day, as they are also equipped with batteries, which means the generator does not need to run all day. Cellcard's introduction of solar hybrid sites brought down diesel consumption to 6 hours, a 32% saving on fuel costs. In total, this translates into savings of around $7,600 and 38.4 metric tonnes of CO2 per site over a five-year period.[19] Across the entire network, we estimate that Cellcard made a saving of $9.8 million through the use of these hybrid sites. Over 10 years, this would increase to savings of $30 million and 100,000 metric tonnes of CO2.[20]

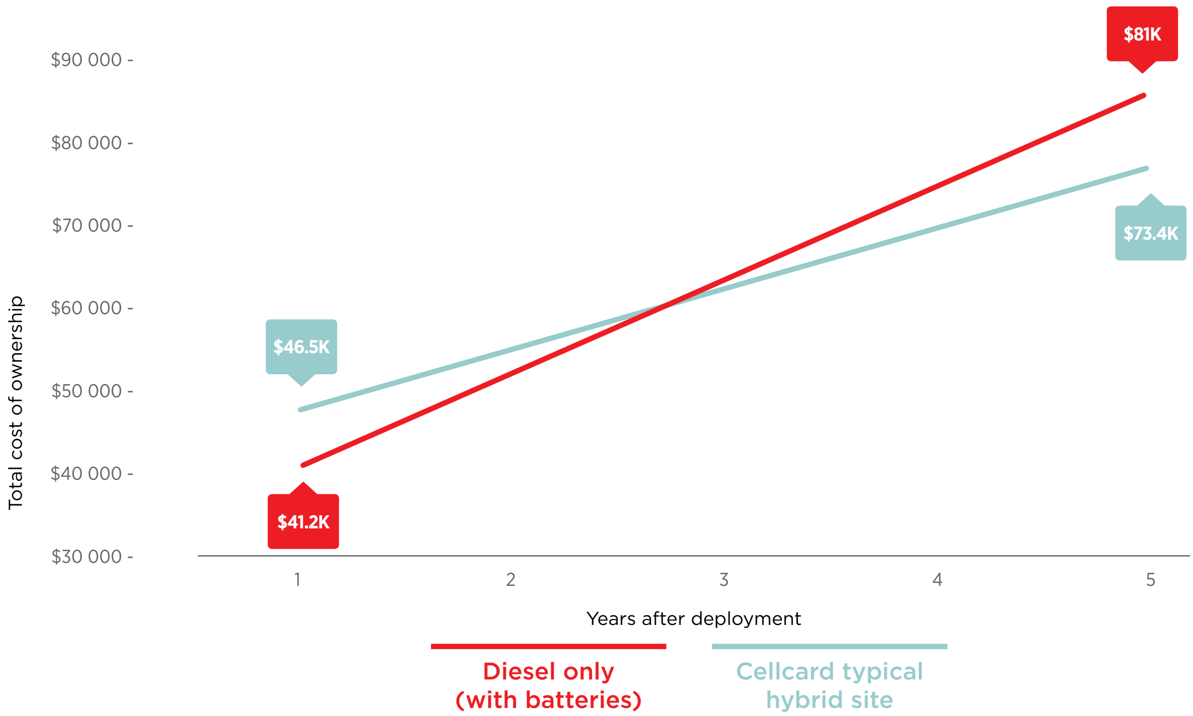
From a digital inclusion perspective, these savings are crucial, as they allow operators to invest in areas with lower revenues and still make a profit, resulting in higher population coverage. We estimate that the introductions of solar hybrid mean that Cellcard could cover 85% of the population in an economically sustainable manner, as opposed to 84% of the population under the 'diesel-only' scenario.

19. Assuming diesel usage of 2.8 hours a day. All calculations of carbon emissions from diesel made using: International Carbon Bank and Exchange
20. This calculation assumes an average yearly saving per site of 11.2 metric tonnes of CO2 emissions, across 1300 sites over 10 years. Where years=10 and sites =1300

Figure 4

Source: Cellcard data; GSMA Analysis

Total cost of ownership of a diesel-only site compared to a typical solar-hybrid site [21]



GSMA Infrastructure Evaluation Model

The estimates for the potential impact of using solar to power the cell sites on the total population coverage were made using the following steps:

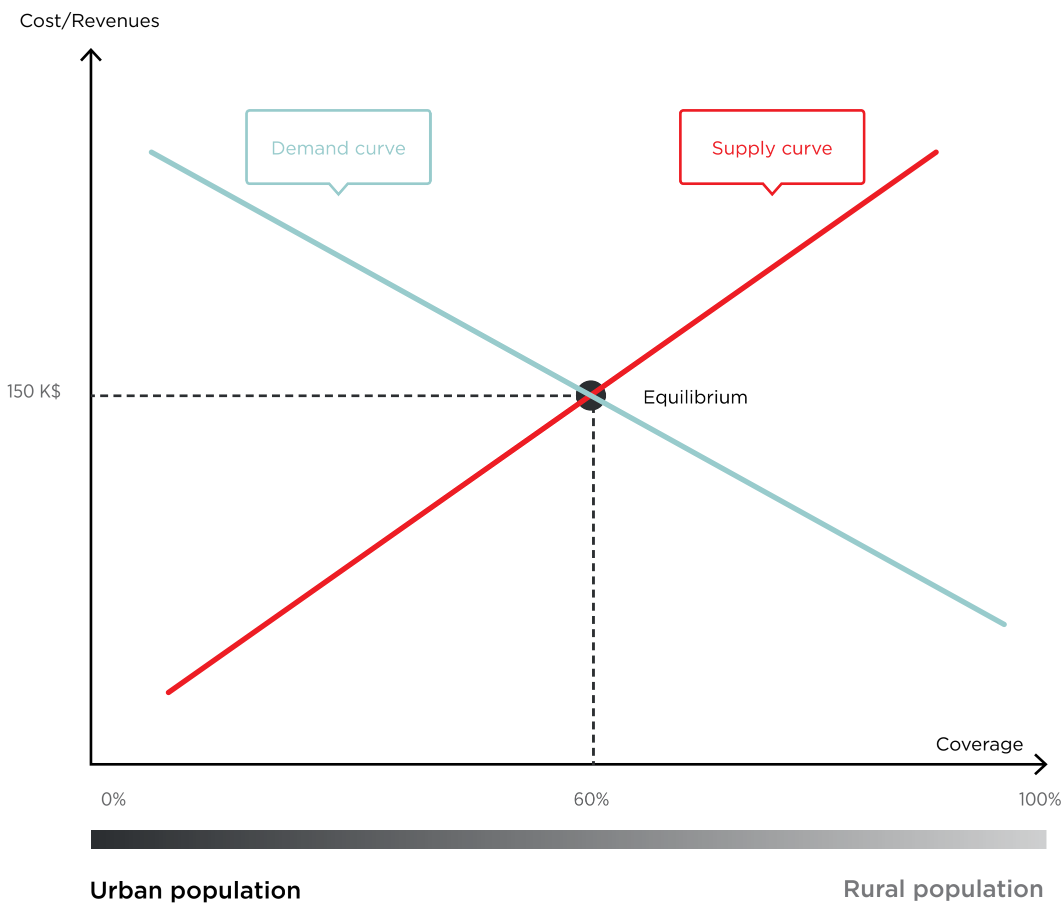
1. An economic supply and demand model (see Figure 5) illustrates the trade-off that operators such as Cellcard face when supplying mobile coverage. The supply curve – the incremental cost of providing coverage to an additional 1% of the population- is 'upward sloping', as it is more expensive to cover populations living in less densely populated areas (in part due to the higher number of sites required to cover additional people). By contrast, the demand curve – the incremental revenue accrued by covering an additional 1% – is 'downward sloping' (less dense areas are usually poorer, less educated and generate less revenues). Given that operators want to maximise revenues, they will cover any area where the potential revenues are greater than the cost of providing coverage. The point at which the curves meet (the 'equilibrium') is the point of sustainable coverage (e.g. 60% of the population in Figure 5).

21. Given that Cellcard don't have any 'diesel only' sites, the above is a hypothetical site modelled on existing site data. Given that Cellcard don't have any 'diesel only' sites, the above is a hypothetical site modelled on existing site data. This assumed the use of 8.8 hours of diesel per day, with 27kWh of battery capacity (the typical battery used in Cellcard's network at present) to lessen the need for continuous diesel usage. This was a conservative assumption as a diesel only site, continually using diesel would be much more expensive.

Figure 5

Source: GSMA Analysis

Mobile coverage supply and demand

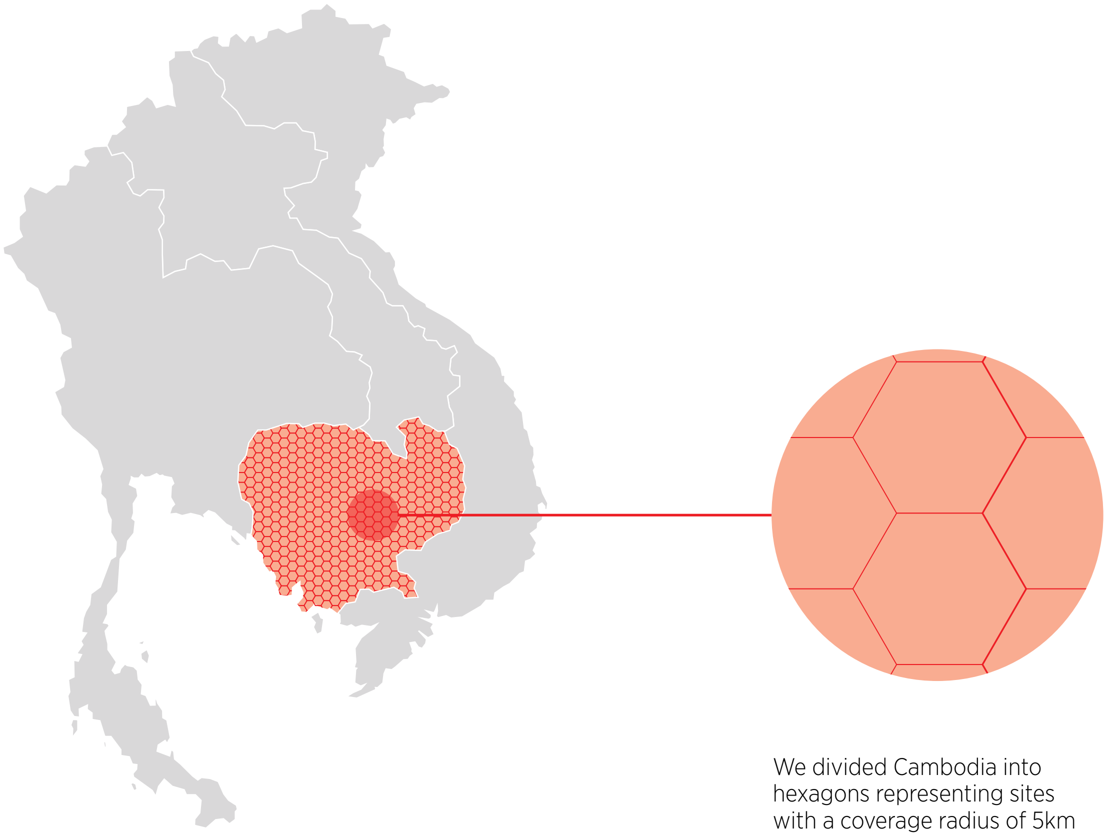


2. Using mapping software, we divided Cambodia into hexagons representing sites with a coverage radius of 5km (a conservative estimate of the reach of the typical coverage of mobile cell site).[22] We then estimated the population living in each hypothetical sites using a population distribution dataset.[23]

22. Each hexagon had a 5km distance from the centre to the vertex. Area represented is 64.95km²
23. The dataset used is the High Resolution Settlement Layer, a dataset developed by Facebook Connectivity Lab and the Center for International Earth Science Information Network (CIESIN) at Columbia University, which estimates human population distribution at a hyperlocal level, based on census data and high-resolution satellite imagery.

Figure 6

Mapping Cambodia



We divided Cambodia into hexagons representing sites with a coverage radius of 5km

3. We then estimated revenues over five years for each hypothetical site using GSMA Intelligence data on average revenue per user (ARPU) in Cambodia (nationally and in rural areas), current mobile internet penetration and Cellcard's current market share.[24] We then assumed that sites where revenues were higher than costs would be deployed by Cellcard, whereas sites where revenues are lower than costs would not.
4. Finally, we estimated the profitable coverage by adding up all the population living in profitable sites (those with revenues higher than costs). This coverage corresponds to the 'equilibrium' point in Figure 5 (i.e. the point of economically sustainable coverage). Note that this equilibrium will change as a function of the OPEX and CAPEX of sites, which allows us to compare the equilibrium when altering the costs based on the different power solutions (diesel-only, solar hybrid, and full solar).

Through this methodology we were able to identify which sites could only be reached in a commercially sustainable way using a solar-hybrid solution, versus a diesel-only powerbase.

24. Note that these estimates make the conservative assumptions that mobile subscriber penetration will note rise from the current level (67%) and that Cellcard will not increase their current market share (19%). Any increase in either of these parameters would increase the percentage of the country that it would be economically sustainable to cover.

3.2 Potential benefits of moving towards full solar

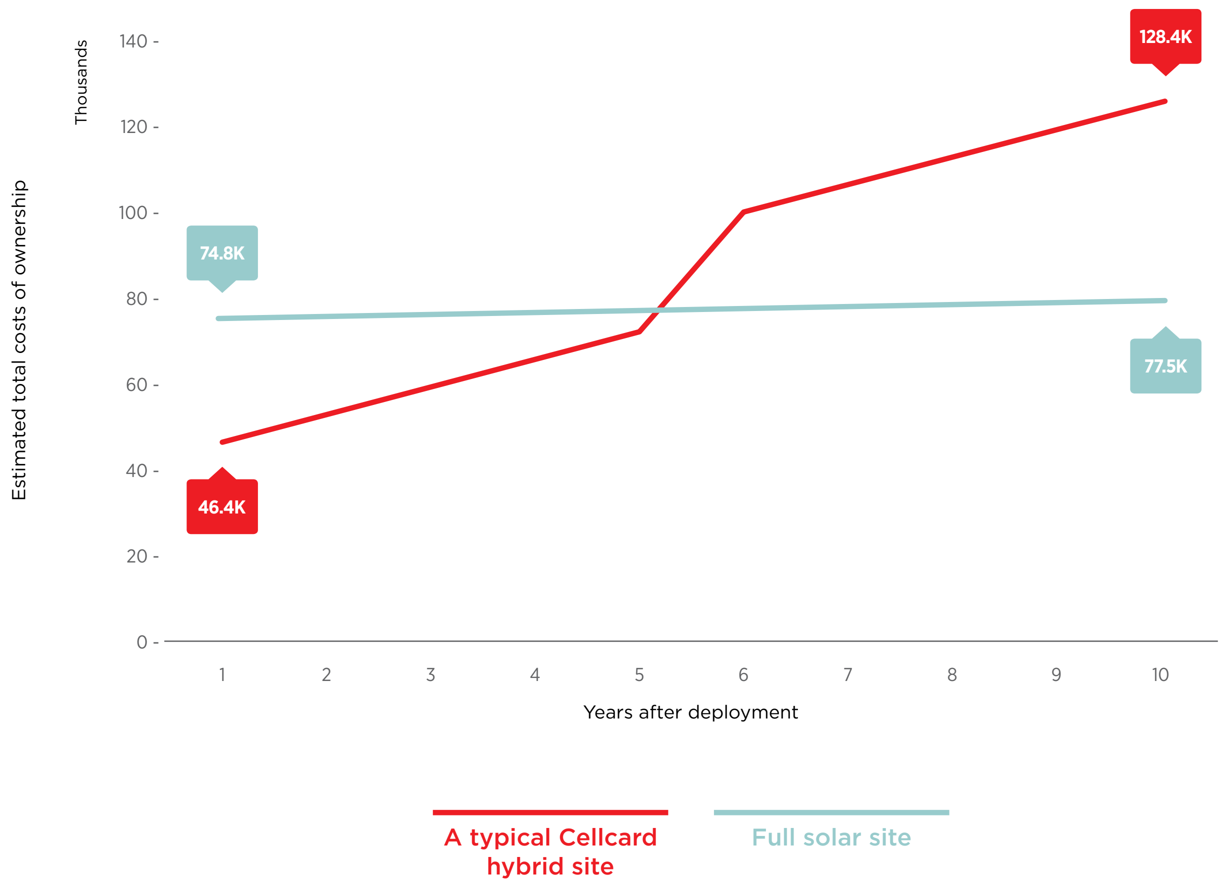
The average Cellcard hybrid site currently runs on diesel for just under six hours a day. Given the clear gains achieved from moving from diesel-only sites to hybrid sites, we also analysed the potential impact of shifting from the current hybrid model to fully solar powered sites.[25] The main issue with a fully solar site is the higher up-front costs (see Figure 7). However, the costs of shifting to fully solar sites would be recovered after 5 years (as compared to existing hybrid sites). Over a 10 year period, there would be a saving of $51,200 per site (or a 40% reduction in TCO per site).

As discussed, the use of diesel is a current pain point for Cellcard, given the threat of theft and the difficulties of transporting fuel to rural and remote locations. Switching to solar would remove this issue. An additional benefit would be that CO2 emissions would be reduced by an additional 82.2 metric tonnes of CO2 over five years compared to the current hybrid model.

Figure 7

Source: Cellcard data; GSMA Analysis

Total cost of ownership: Current typical 'hybrid' site compared to a fully solar site



25. This analysis was based on the following assumptions: 1. Existing energy consumption and existing power infrastructure (batteries and solar panels) were based on existing Cellcard data; 2. Coverage assumptions were based on High Resolution Settlement Layer (HRSL) population estimates; 3. Costs were based on latest solar and battery technology (lithium-ion batteries with a 5000 cycle life-span); 4. Advanced level energy management (e.g. in terms of site traffic or weather forecast)

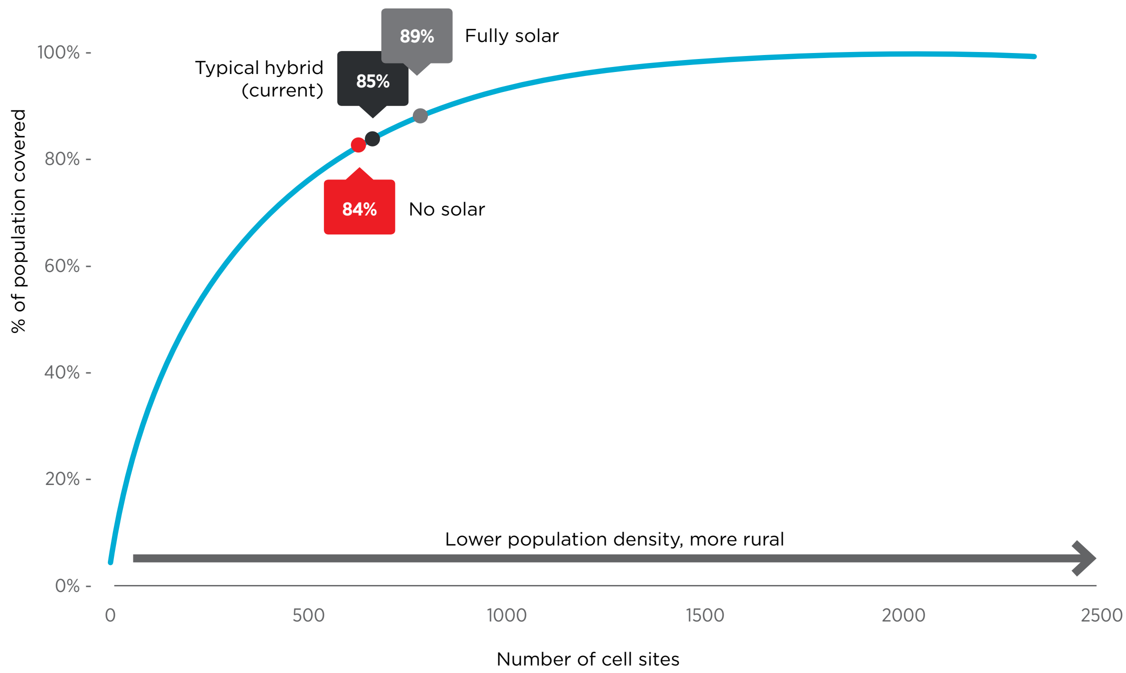
According to our analysis, transitioning to fully solar sites would allow Cellcard to cover an additional four percentage points of the population in a commercially sustainable manner. Under this scenario, 89% of the population could be covered in a commercially sustainable way, compared to 85% with the typical hybrid configuration. With new battery technology, these sites also have the advantage of being able to power sites for twice as long without recharge from the solar panels as the batteries used in Cellcard's existing hybrid sites. This means the system can continue to function for some time even if there are days with reduced levels of sunlight (an issue with earlier generations of solar battery technology).

Figure 8 demonstrates the difference that solar power can make in increasing the level of commercially sustainable coverage. The gain of one percentage point in moving from (a hypothetical) diesel only site to the current hybrid model, would be increased by a further four percentage points if all sites were made fully solar.

Figure 8

Source: Cellcard data; GSMA Analysis

Commercially sustainable coverage under three scenarios



4. Recommendations and Implications

4.1 Recommendations

As a result of our analysis, we made the following three recommendations to Cellcard:

1. **Continue to upgrade existing hybrid sites to full solar.** Our analysis concluded that 32% of the sites could be profitably upgraded - the majority requiring additional battery and solar panel capacity, with the remainder requiring an increase in battery capacity. We estimate that the break-even point in upgrading from the current hybrid site to full solar would be after five years, with these upgrades costing around $4.7 million but generating up to $17 million in savings over 10 years.

2. **Shift all new remote sites to fully solar sites.** This would reduce long-term costs and improve profitability. By doing this, we estimate that Cellcard could extend coverage by four percentage points in a commercially sustainable way. This would also have the added benefit of reducing the environmental footprint of the network – e.g. CO_2 emissions would be reduced by up to 16.4 metric tonnes per site, per year.

3. **Continue to improve telemetry capabilities.** Given the clear benefits that accrue from having a detailed analytical understanding of site performance over time (e.g. in terms of business planning), continuing to invest in enhancing their telemetry systems should allow Cellcard to improve network performance and reduce costs.

4.2 Wider implications from this analysis for increasing mobile coverage

Power costs form a significant proportion of the total cost of mobile coverage. The analysis contained in this case study demonstrates that the use of solar as part of the energy mix used to power cell sites has the potential to significantly reduce operating costs. For Cellcard, our analysis suggests that the current use of solar has increased the percentage of the population profitably covered by one percentage point; shifting further to solar could increase this a further four percentage points. These gains only take into account standard operating costs, leaving out other costs such as fuel theft or logistical impediments to refuel sites. Taking these costs into account would yield even higher gains for Cellcard than those estimated above.

The above figures are highly context specific and will differ depending on a host of factors, particularly the terrain, the proportion of the country connected to the grid and an operator's current use of technology. While solar (and renewables more generally) are currently unable to supply the entirety of an operator's power requirements, particularly at high-capacity sites, its ability to bring down the cost of coverage for an operator is evident. This is particularly true given that the vast majority of uncovered populations live in relative proximity to the equator, where solar irradiance – the power per unit area received from the sun – is at its highest. In markets where infrastructure costs and the price of diesel is higher, notably in Sub-Saharan Africa, gains could be even higher than those identified for Cellcard.

As a result, the use of solar in powering mobile base stations has the potential to make significant progress towards bringing the benefits of digital inclusion to all.

The GSMA Connected Society Programme and rural coverage

We believe that the GSMA has a critical role in supporting our operator members and our industry to increase the availability of mobile internet coverage in rural areas. However, while mobile operators have a pivotal role to play in driving digital inclusion in developing markets, they face two key challenges:

1. Extending coverage remains economically challenging given the high costs of increasing coverage and issues connected to consumer demand
2. Inconsistent and distortive regulation from governments, which restricts public and private investment in connecting the unconnected.

Overcoming these barriers will require focus, innovation and collaboration between the public and private sectors. The GSMA is committed to supporting the industry in both these areas. Over the coming year, we will be continuing to support operators to pilot innovate solutions that help bring down the cost of providing coverage. At the same time, we will continue advocating to governments for an enabling policy environment, that will create the right conditions for private sector investment.

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For more information, please visit the
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