SMART VILLAGES
New thinking for off-grid communities worldwide

Making Smart Villages a Reality

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Smart Villages

We aim to provide policymakers, donors, and development agencies concerned with rural energy access with new insights on the real barriers to energy access in villages in developing countries—technological, financial and political—and how they can be overcome. We have chosen to focus on remote off-grid villages, where local solutions (home- or institution-based systems and mini-grids) are both more realistic and cheaper than national grid extension. Our concern is to ensure that energy access results in development and the creation of "smart villages" in which many of the benefits of life in modern societies are available to rural communities.

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1. Introduction

Access to reliable, affordable and clean energy is a cornerstone of sustainable development. Despite this 1.2 billion people continue to have no access to electricity and a further 3 billion are energy poor. Often cited reasons for the lack of progress include the technological and financial difficulties associated with bringing electricity to rural areas due to low population density, as well as political, institutional and social barriers (Sovacool 2012).

The lack of progress in rural areas in the developing world is consistent with the role of 'the rural' in the seminal models and theories found in the development economics literature. These theories and models see the rural sector essentially as an input of labour and resources to the urban sector, which is considered the engine of economic growth and development. Despite this, many countries have successfully provided electricity to their rural populations and improved development outcomes. Many of these cases have largely passed under the radar of current energy for development practitioners. As will be seen later in this report, successful cases of rural electrification and development have, by and large, benefited from a holistic and integrated development framework or guiding vision. This is akin to the smart villages concept.

This technical report seeks to draw out lessons from theory and successful country-case studies of rural electrification and development to reflect on what needs to be done to make smart villages a reality and meet the twin goals of providing electricity access to all and improving rural development outcomes. Section 2 begins by setting out the smart villages concept and is followed by Sections 3 and 4 providing an overview of seminal theories, models and approaches in the academic literature. Particular emphasis is given to the Thunen model of economic location which provides a useful framework for implementing the smart villages concept. Section 5 draws on successful case studies of rural electrification and development, and teases out shared success factors. Section 6 then reflects on the lessons learned and how such lessons can be incorporated within the smart villages concept, and Section 7 applies this new thinking to the contemporary case of Kaseke village in Rwanda to show what needs to be done to make smart villages a reality. Finally, Section 8 provides a discussion and the conclusions of the report, and Section 9 gives the bibliography of reports and papers referred to in the report.

2. The Smart Villages Concept

Smart villages are rural analogues to 'smart cities'. They are necessary in order to ensure the fulfilment of the Sustainable Development Goals for the (approximately) 47% of the world's population and 70% of the world's poor that live in rural communities. The smart villages concept can be broadly categorised as an integrated and holistic rural development strategy, where access to modern energy services along with complementary investment in both hard and soft infrastructure leads to improvements in food security, political enfranchisement, health, education and incomes (Holmes and van Gevelt 2015).

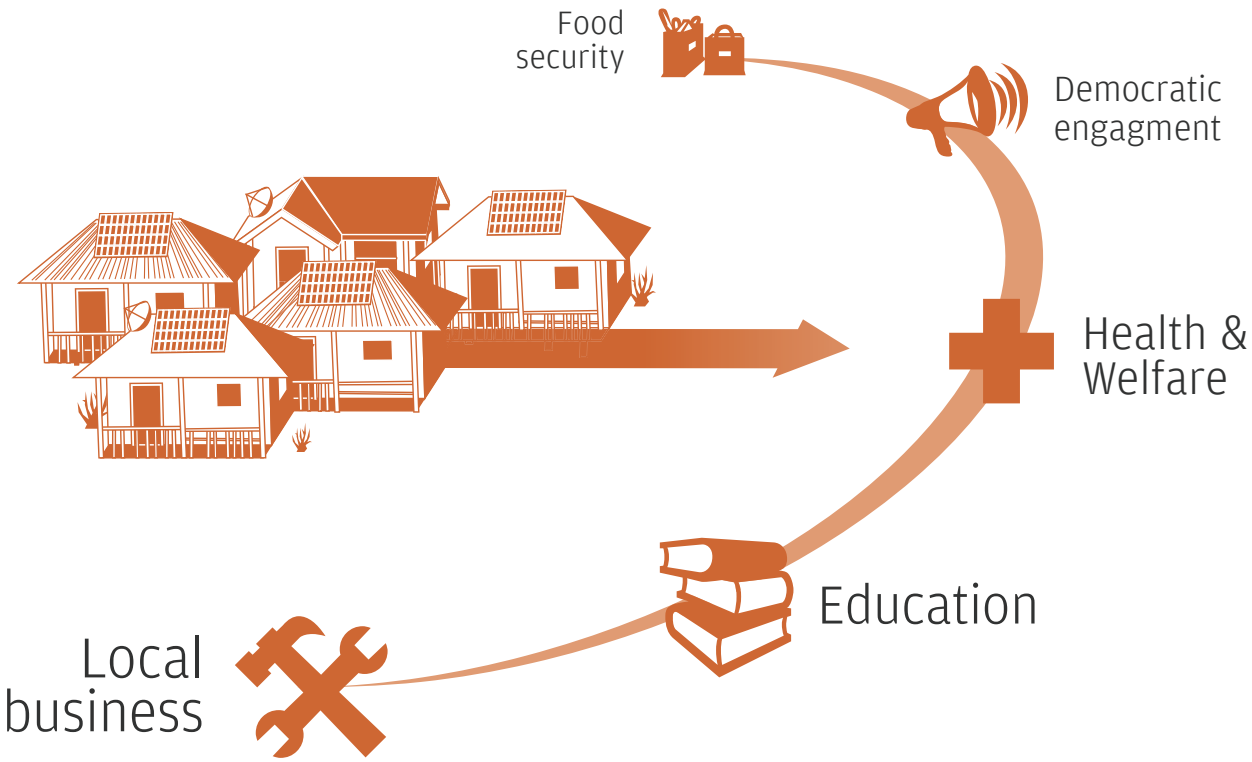


Figure 1: The Smart Villages Concept

As can be seen in figure 1, access to modern energy is central to smart villages. Indeed, access to affordable, reliable and clean energy can be thought of as a catalyst to development in many rural areas. Access to modern energy services can improve food security, political enfranchisement, health, education and income through a number of channels. For example, access to electricity will allow households to improve yields from farming and to store enough food to consume during annual growing seasons. Political enfranchisement can be improved through the use of energy to allow information to be disseminated through media that use modern information and communication technologies (ICT). For example, access to mobile phones, televisions and the internet may enable levelling change in the information asymmetries in societies that tend to hold back the social and economic mobility of villagers. It can also allow villagers to become more aware of their social, economic and political rights and engage in governance processes at all levels (Holmes and van Gevelt 2015).

Access to modern energy can improve health outcomes in a number of ways. At the most basic level, access to clean cooking fuels will make it easier for households to consume potable water and a nutritious diet without being subject to harmful indoor air pollution. Similarly, moving away from incumbent energy technologies, such as kerosene lamps, will also reduce the incidence of respiratory illnesses. Access to electricity will also overcome major stumbling blocks facing rural health clinics that currently frustrate the provision of modern preventative, diagnostic and medical treatments. Additionally, access to electricity will make it easier to attract and train skilled health care workers. It also enables the use of effective information and communication technologies for disseminating information and raising awareness about epidemics and hygiene (Guruswamy 2011; Kaygusuz 2011; Sovacool 2012; Soboyejo 2015).

Education outcomes can be improved through access to modern energy. For example, children will have more time available to study as the time spent collecting traditional biomass and the number of days absent from school due to illness will be reduced. Additionally, study hours will be lengthened due to having better lighting in the evenings. This will positively affect the ability of students to acquire the knowledge and skills necessary to achieve economic goals and improve the productivity of labour. Additionally, access to modern electricity is a precursor for enabling schools to be equipped with ICT – an increasingly important medium of information for students in the modern age and a pull-factor in providing incentives for school attendance. Schools with ICT and basic amenities, such as lighting, are also more likely to be able to attract and retain good teachers (Birol 2007; Gonzales 2015).

Incomes can be improved as a result of access to modern energy. Economic activity in rural areas can be disaggregated broadly into agriculture and rural industry. Without access to modern energy, rural households engaged in both sectors are likely to have low productivity and growth prospects, and therefore, low incomes. Specifically, households engaged in agriculture will be able to benefit from agricultural modernisation (for example, improvements in yield, increased cropping intensities, decreased labour and time costs) and to increase the value added captured by rural households through the ability to store crops, avoid spoilage, undertake post-harvest processing, and access market information through ICT. Rural industry will benefit from access to electricity in order to provide lighting and adequate driveshaft or mechanical power, and make use of ICT to obtain market information and better integrate into more complex value chains (Cabraal et al. 2005; Kirubi et al. 2009).

Lastly, access to electricity in smart villages can alleviate the drudgery that is pervasive in many lives in rural villages. Indeed, access to modern energy can have a transformative impact on many villagers through saving time and effort in collecting biomass, and allows household appliances to take the role of routine, laborious and time consuming tasks. It enables villagers to enjoy entertainment through TV, radio and the internet, and it means public lighting can be provided at night so that people, particularly women, can enjoy social interaction without fear of danger (Cecelski 2000; Cabraal et al. 2005; Sovacool 2012).

Smart villages provide a new framework for making progress on achieving the Sustainable Development Goals in rural communities. In particular, the education, health, economic and quality of life improvements that a smart village can achieve can help eradicate extreme poverty and hunger, achieve universal primary education, promote gender equality and empower women, reduce child mortality rates, improve maternal health, combat diseases such as HIV/AIDS and malaria, and support environmental sustainability in rural areas.

3. Rural Development – Theories And Models

The majority of economic development theories and models focus on industrialisation and therefore see urban areas as the main economic unit at a macro-scale. This focus on urban areas is primarily due to economies of scale and agglomeration that allow for increased economic productivity, technological progress and economic growth. Turning specifically to rural development, there are a number of seminal models that provide insights into the role of the 'rural' in development. As will be seen, the majority of these models see the 'rural' sector as an input into the 'urban' sector and see development primarily as an urban phenomenon. While these models provide useful insights, the smart villages vision outlined in Section 2 cuts across the assumptions on the divisions between the rural and urban that underpin these models.

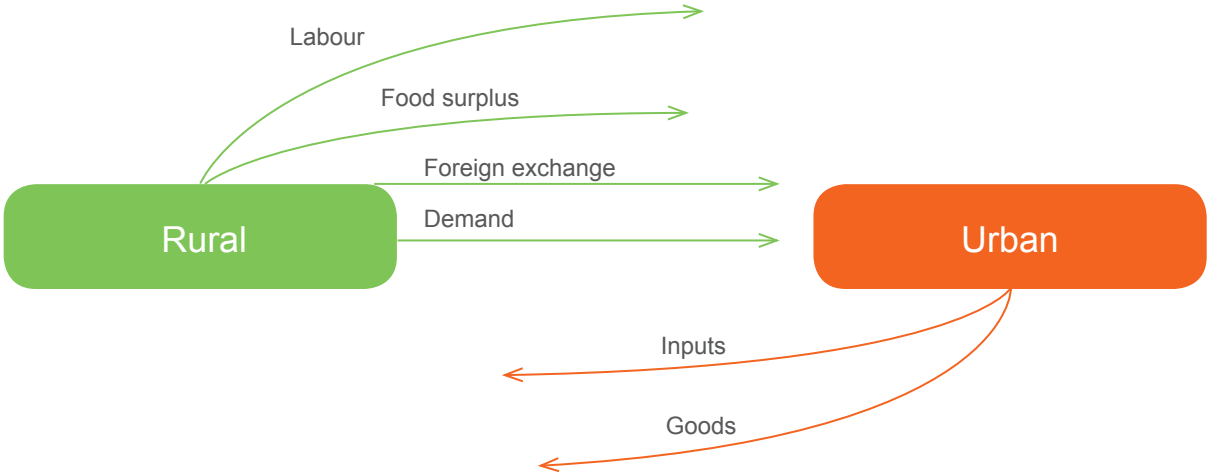


Figure 2: Rural and Urban sectors

3.1. The Lewis Model

The Lewis model conceptualises the economy as comprising two sectors: rural and urban. As seen in Figure 2, labour, food surplus, foreign exchange[1] and demand for industrial goods flow from the rural to the urban sector. Meanwhile, inputs (for agriculture) and goods flow from the urban sector to the rural sector. In the Lewis model, economic development proceeds by the transfer of labour from the rural sector to the urban sector and the simultaneous transfer of surplus food, which sustains that part of the labour force engaged in urban (industrial) activities. The rural sector is therefore viewed as a supplier of labour and the urban sector as an absorber of labour. Underlying this are four assumptions and one proposition. The assumptions are that labour is unlimited in supply, all rural labour is agricultural and all urban labour is in industry, the rate of savings and investment limits the rate of growth, and land available to agriculture is fixed. The proposition is that there is a large labour surplus in the rural sector that can be removed at little or no opportunity cost.

[1] *Agriculture is an important source of foreign exchange for developing countries, generating foreign exchange by the exports of agricultural products or reducing the imports of agricultural products.*

The augmented Lewis model (the Lewis-Ranis-Fei model), in which capital accumulation in the urban sector is the growth engine for the economy, is presented in Figure 3. More capital leads to an increase in the demand for labour and an increase in the transfer of labour from the rural to urban sectors. In this process, terms of trade gradually turn against industry as the price of food increases as a smaller number of farmers must support a greater number of industry workers. This increases the price of food which consequently increases the industrial wage rate. In sum, the Lewis model's contribution to the economic development literature is that the pace of development is driven by the accumulation of capital but is limited by the ability of the economy to produce a surplus of food.

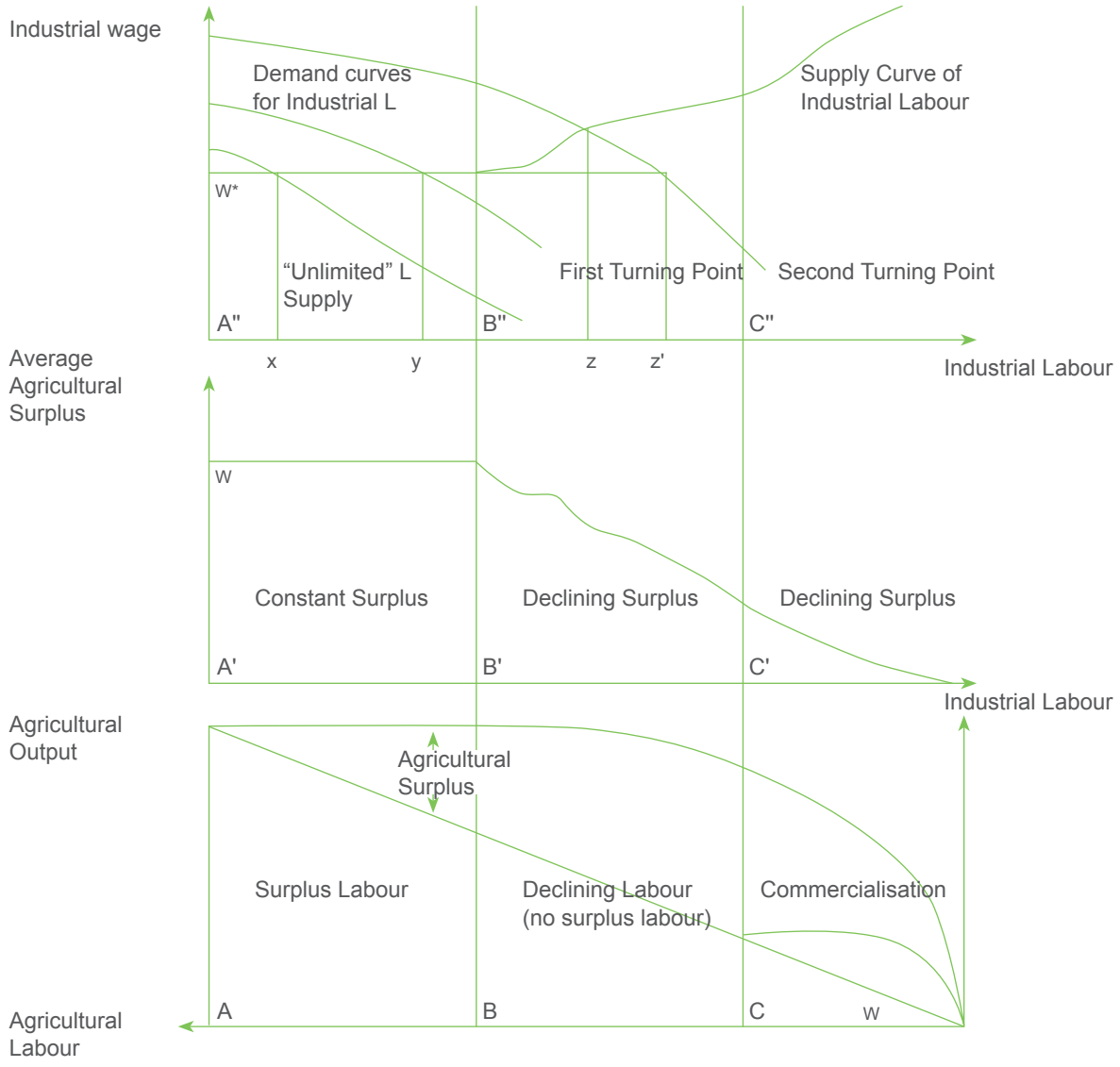


Figure 3: The Lewis-Ranis-Fei model

3.2. The Harris-Todaro Model

In the 1960s, many developing countries started to experience something that the Lewis-Ranis-Fei model cannot explain – the dilemma of severe urban unemployment alongside large continuing migration from the rural sector. In this situation, the migration of surplus labour does not generate growth, rather it is a burden on the economy. In order to explain such circumstances, the Harris-Todaro model augments the Lewis model by further examining the process of labour migrating from the rural to urban sectors. The Hariss-Todaro model assumes that there are three sectors in the economy with different wages: rural (agriculture), formal urban and informal urban. The formal sector is assumed to pay a relatively high 'sticky' wage ($\overline{w}$). The informal (w_i) and rural sectors (w_a) have low wages that fluctuate. Individuals are assumed to decide to migrate from the rural sector to the urban sector on the probability of obtaining an urban wage, given the certainty of a rural wage. As depicted in Figure 4, the Harris-Todaro model assumes that individuals compare the expected value of urban wages to the current rural wage. The individual weighs each outcome by its probability of occurrence and sums up all outcomes. This results in an expected urban wage of $E(w) = p\overline{w} + (1 - p)qw_i$. The individual then compares the expected wage, $E(w)$, to the rural sector wage, w_a.

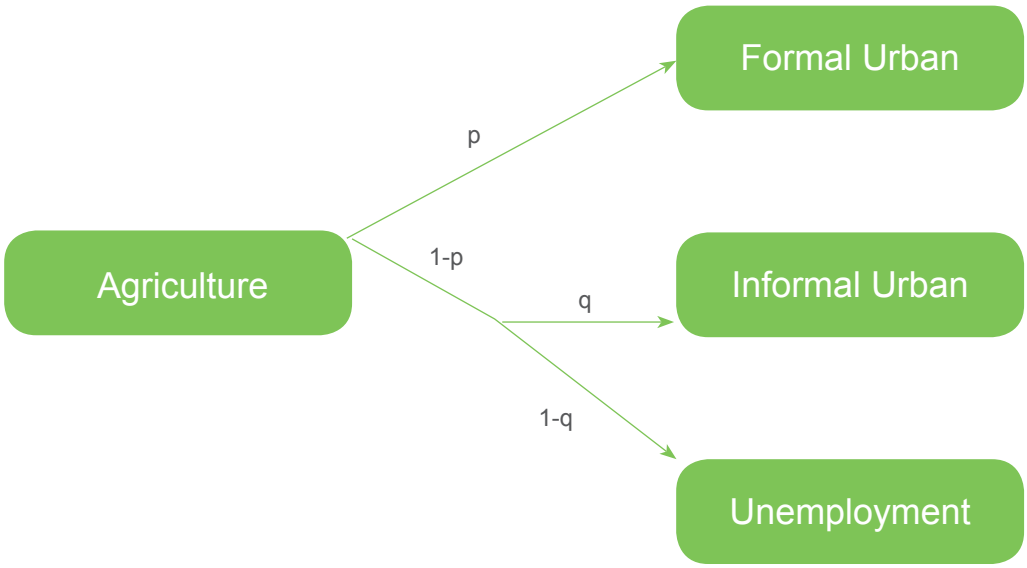


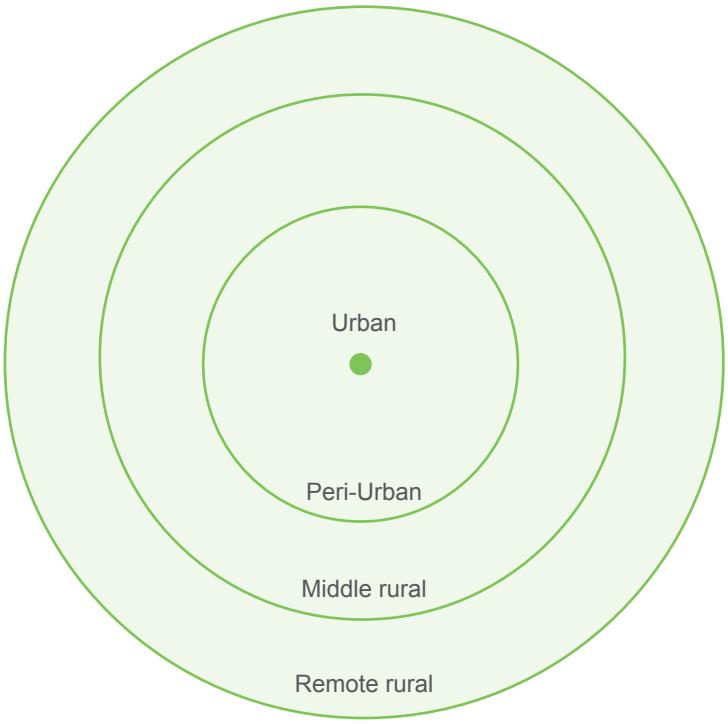
Figure 4: The Harris-Todaro Model

3.3. The Thunen Model

Turning next to economic geography, we examine the highly influential Thunen model, which provides an analysis of the economic disadvantages faced by rural communities and provides insight into what is required to achieve the smart villages vision. Specifically, the Thunen model is able to explain the economic activities of rural communities at a particular time through a vector of economic distance and the ways in which innovations are able to alter this vector.

The Thunen model of economic location provides a useful framework to understand rural development. In this model, rurality can be understood as remoteness from an urban centre and is therefore measurable along a vector of economic distance (Hite 1997). As illustrated in Figure 5, moving outwards from an urban centre in concentric rings, the Thunen model shows that there are degrees of rurality. The first ring refers to rural areas that are located relatively close geographically to the urban centre. These are rural areas that are often considered peri-urban. Moving further out, the second concentric ring captures what can be conceptualised as middle rural areas. The final ring represents remote rural areas (Wiggins and Proctor 2001).

The Thunen model suggests that there is an economic disadvantage of distance that increases the



Peri-urban	Middle rural	Remote rural
High value commercial farming	Commercial farming	Subsistence farming
Employment in urban centre	Rural industry	Tourism
Rural industry	Tourism	

Figure 5: Thunen model and typically associated economic activities
Based on Hite (1997) and Wiggins and Proctor (2001)

further away rural communities are from urban centres. This economic disadvantage manifests itself through limiting the available set of stylised economic activities. For peri-urban areas the set of economic activities tends to include high-value commercial farming, employment in urban centres and rural industry. For middle rural areas, the set of activities includes commercial farming, light rural industry and tourism. Remote rural areas – the most economically disadvantaged by distance – tend to be limited to subsistence farming and tourism (Hite 1997; Wiggins and Proctor 2001).

In the original application of the Thunen model in 19th century Germany, it was the introduction of a national railroad network that altered the vector of economic distance. By altering the vector of economic distance, the set of economic activities available to rural communities shifts. While not detracting from the fundamental importance of physical capital and the impact that, for example, good roads can continue to have, the Thunen model suggests that we can expect the implementation of the smart villages vision to effectively alter the vector of economic distance. As seen in section 2, access to electricity enables the use of ICT which plays a key role in the smart villages vision. As seen in the ICT for Development literature, there has been significant discussion concerning the impact that information and communications technology (ICT) can have on rural development in remote rural communities (e.g. Unwin 2009). A broad term, ICT consists of devices ranging from radio and telephones to computers and the internet. Its proponents argue that this range of devices has the ability to benefit remote rural communities through the provision of education (eLearning), health (telemedicine/mHealth), employment opportunities (eCommerce) and a range of governance services (eGovernance) (Unwin 2009, Yeo 2015).

In terms of the Thunen model, ICT can be conceptualised as an innovation with the potential to alter the vector of economic distance for remote communities both directly, through eCommerce, and indirectly through eLearning, mHealth and eGovernance. In turn, this can both strengthen existing economic activities and lead to the creation of a new set of feasible economic activities for remote rural communities. We can therefore expect ICT to facilitate the development of modern industrial clusters in more remote areas.

3.4. Smart Villages and Rural Development

As detailed in section 2, smart villages are rural analogues to smart cities and will bring opportunities into rural areas that were previously limited to urban areas. This blurring of the distinction between 'urban' and 'rural' suggests a challenge to traditional economic models of development. While agriculture will continue to be the primary economic activity of most smart villages, energy access, connectivity and improved farming techniques will lead to the production of higher value products through post-harvest processing and the capturing of a larger proportion of value at the rural-level. Additionally, new technologies for distributed manufacturing (e.g. 3-D printing) will likely lead to competitive manufacturing in rural clusters. Once smart phone ownership and internet connectivity become universal in rural areas, economic distance may become largely irrelevant in a number of service areas including, for example accountancy, consultancy, and legal practice. Internet-based recruitment can, in principle, match opportunities with individuals based in rural areas.

Additionally, smart villages challenge the prevailing trend of rural-urban migration implicit in the seminal economic development models. Indeed, the opportunity of substantially increased incomes and employment opportunities, the availability of key amenities and services (education, healthcare, clean water) and the provision of entertainment (TV, internet etc.) in smart villages will substantially alter the calculus with respect to individuals making the decision to migrate to urban areas as depicted in the Harris-Todaro model.

4. Rural Development – Big Push And Incremental Approaches

Moving on from the theories and models of rural development in Section 3, this section addresses the two dominant approaches to 'doing' development: the incremental approach and the Big Push approach. This is followed by a discussion of how the big push and incremental approaches to rural development relate to the smart villages concept.

4.1. Incremental Approach

The incremental approach for rural development can be considered the traditional approach to 'doing' development. The incremental approach sees the development process as one of addressing barriers to development gradually. In this approach, rural areas develop along their unique trajectories in a progressive and organic process. The incremental approach rests on the assumption that development is a 'natural' process that should not be directly interfered with by external actors. Instead, external actors are limited to helping support the development process. This tends to take the form of assistance in financing and implementing hard and soft infrastructure, helping develop financial services, and improving human capital. Crucially, however, the external actors do not endeavour to shape the development process but instead support it along its natural course.

4.2. The Big Push Approach

The Big-Push approach has its theoretical origins in the work of Rosenstein-Rodan (1943) and Murphy et al. (1989). Put simply, the Big-Push approach states that the process of development can be catalysed and sustained through an initial phase of significant external support. Underlying the Big-Push approach is the idea that agents in development are unable to overcome the vicious circle of underdevelopment without external intervention. In many ways, the Big Push approach represents the classic narrative of economic development theory and has been the main justification behind the divestment of foreign aid.

There is a fierce debate in the academic literature as to whether the Big Push approach is systematically associated with economic development. For example, Easterly (2006) finds that there is very little evidence to support the narrative. At the same time, other prominent development economists have continued to advocate the big push approach as central to catalysing economic development. For example, Sachs (2005) argues that a combination of well-tuned interventions needs to be applied systematically in order for African economies to overcome the poverty trap. This needs to be done systematically as each intervention reinforces the other and cannot have the desired impact independently.

4.3. Smart Villages

The Smart Villages concept incorporates elements of the incremental and big push approaches. In particular, the Smart Villages concept sees the need for a 'big push' in the form of creating an enabling framework that overcomes the barriers to energy access and rural development. In line with the incrementalist approach, however, the Smart Villages Initiative subscribes to external actors playing only a supporting role. For example, creation of an enabling framework should be driven by local actors at the different levels in which rural communities are embedded. This is achieved through, for example, the leveraging of public and private sector resources to invest in energy infrastructure. Within this enabling framework, rural communities are then able to take their villages forward following an incremental approach according to their own 'visions' in a sustainable manner.

5. Rural Electrification And Development – Lessons From History

Section 5 adds to the theoretical models and approaches detailed in Sections 3 and 4 by providing an overview of historical experiences of the rural electrification process in Chile, China, Costa Rica and South Korea and how rural electrification translated into improved development outcomes in these countries. Success factors are drawn out through understanding rural electrification and development initiatives in historical perspective.

5.1. Rural electrification in historical perspective

5.1.1. Chile

The Chilean experience demonstrates the possibility for subsidies to be used as an effective instrument to encourage the private sector to undertake rural electrification. In Chile, rural electrification programmes go back to the 1930s, when electricity cooperatives were established to support agriculture. Due to the small size of cooperatives – a function of low population density and difficult terrain - expansion of electricity infrastructure was slow. In the 1980s, national electricity distribution companies were privatised. This meant that, in theory, private distribution companies could compete with rural cooperatives for rural customers. In practice this did not happen for rural consumers meaning that by the 1990s, the rural electrification rate was less than 50%.

As a result, from 1994, the government encouraged private companies to engage in rural electrification. To do this, the government set regional and national goals and used government subsidies to encourage private companies to achieve the goals. This initiative became known as the Chile Rural Electrification Program (PER). Arguably, the centre-point of the PER is the subsidy programme that provided the appropriate incentives for private sector companies to engage in rural electrification. Subsidies were allocated through a process which began with an evaluation methodology designed by the Ministry of Planning and Coordination. Specifically, the methodology specified that a particular rural electrification project would only be eligible for subsidy if its wider economic benefits exceeded total costs within the project lifespan, but only if the financial benefits accruing to the utility were less than total investment and operating costs over the lifespan of the project. Subsidies were therefore only awarded to projects that demonstrated no ability to generate a sufficient positive financial internal rate of return to the developer. At the same time, subsidies were limited to a maximum amount that equalled the project's up-front capital costs. This meant that projects had to at least cover operational and maintenance costs. Taken together, the government's subsidy funds led to the creation of a competitive market where private companies bid competitively for rural electrification projects.

Broadly speaking, the Chilean case has been a success due to a number of key factors. Firstly, the private sector distribution companies were mature due to their activities in urban areas. This meant that distribution companies worked on the basis of established construction practices, and that distribution companies only required incentives to nudge their coverage into rural areas rather than to build capacity. Secondly, the programme was overseen by a competent government planning agency that had the authority to develop and make amendments to the national electrification initiative. Importantly, the programme had the backing of government with a political commitment being made that allowed private sector companies to invest with confidence (McAllister and Waddle 2007).

5.1.2. China

Over the past fifty years, China has overseen a tremendously successful rural electrification programme that has now reached over 98% of China's

large rural population. In the Chinese experience, local and central government have played key roles. Specifically, the central government set out policy objectives, and provided both financing and technical assistance. Local governments, in turn, worked extensively with local electricity companies to implement the central government's policy objectives. The Chinese experience can be divided into four unique stages that reflect the changes in the political economy of the country. In the first stage (1948 – 1957), the government invested in large-scale hydroelectric plants to reach rural areas with relatively high population density. The more remote rural communities were expected to raise funds, undertake construction of small coal, diesel and hydro-electric power stations and secure the technical assistance required to ensure satisfactory construction and management of these plants

The second stage (1958 – 1978) saw the government target productive uses of electricity: irrigation, agricultural mechanisation and light manufacturing. This was followed in stage 3 by a programme to further electrify rural areas due to the realisation that the electricity supply was insufficient to meet the needs of productive uses (1979 -1987). In the final, fourth stage (1988 – present), China shifted to a market approach to rural electrification with the government continuing to provide support for the overall rural electrification process through creating incentives at the local level.

Broadly speaking, China's rural electrification experience was based on a bottom-up approach, where local actors were responsible for identifying and implementing local solutions. This meant that the approach could be flexible and pragmatic. Crucially, however, local level actors were accountable to central government in terms of meeting policy objectives. Financing of rural electrification came mostly from central and local governments, with contributions from rural communities. Despite this, the pricing system put in place almost recovered the full cost of investment. It is this pricing strategy that allowed for expansion of rural electrification and helped China avoid the high electricity subsidy trap. Notably, the ability to have a pricing system that was almost full cost recovery was a result of promoting the productive use of electricity at an early stage during the rural electrification process (Yao and Barnes 2007; Bhattacharyya and Ohiare 2013).

5.1.3. Costa Rica

Costa Rica has achieved a rural electrification rate of 87% over a period of 40 years. This is despite the number of households increasing by a factor of four during this same time period due to both social changes and population growth. Uniquely, Costa Rica's success has been through a combination of efforts by the national utility, rural cooperatives, municipal companies and private suppliers. Notably, all four modes of provision have been highly successful, however it has been the rural electricity cooperatives that have been the most long-lasting and which are the focus of this overview.

The Costa Rican experience unfolded within a context of genuine government commitment to rural development that was largely the result of an egalitarian tradition. After successfully electrifying urban areas, the Costa Rican government focused on obtaining the necessary financial resources for rural electrification. With the World Bank only willing to fund urban initiatives, Costa Rica was able to obtain support from the US Agency for International Development (USAID). This was largely due to the track record that Costa Rica had with respect to having successful agricultural cooperatives and the preference that USAID had to support a rural electric cooperative model given the positive US experience of such a model in the early-mid 20th century.

The success of the Costa Rican cooperatives is largely due to two factors. The first had to do with the training of cooperative staff that lacked both administrative and technical skills. Fund-

ing from USAID and a programme of twinning arrangements with counterpart rural electric co-operatives in the USA helped provide the training for cooperative staff. This included, for example, courses in line inspection and stringing distribution. The second, and arguably most important factor, concerned the fundamental principle of cost recovery. Although the initial start-up capital was obtained through concessionary loans from USAID, cooperatives were obliged to cover their operating costs, debt repayments and interest. By ensuring that the cooperatives abided by the principle of cost recovery, the cooperatives were able to undertake maintenance work effectively, extend their distribution network and earmark a proportion of funds to undertake social objectives without being dependent on continued subsidies (Foley 2007).

5.1.4. South Korea

In fifteen years, South Korea went from having a rural electrification rate of 12% and an average annual rural household wage of USD 189 to a wage of USD 1,493. This was largely the result of a novel top-down and bottom-up approach that involved elements of local control and participation but was principally coordinated by the central government. This approach was able to overcome the key challenges of financing electricity infrastructure and ensuring that rural electrification translated into economic and quality of life improvements.

By the 1960s, Korean industry was sufficiently strong that the government was able to invest significantly in rural areas. This included investment in agriculture, as well as rural infrastructure. Interestingly, villagers were expected to contribute labour and, in some cases, land to the majority of infrastructure projects. This occurred under the banner of *Saemaul Undong* (the New Village Movement), an integrated development strategy through which the government committed to improving the living environment and rural infrastructure, generating income and building human capacity in rural areas. This was to be undertaken through a rural ethos of diligence, self-help and cooperation.

Providing electricity for lighting and productive uses was considered a key prerequisite for rural development. Unlike the majority of rural infrastructure initiatives undertaken in South Korea, rural electrification was not financed directly by the government. Instead, the state-owned Korea Electric Power Corporation (KEPCO) and end-users were both tasked with raising sufficient funds. KEPCO was responsible for financing rural electrification through reinvesting its own profits from providing electricity to urban areas and through foreign loans. To this end, KEPCO was successful in securing government-backed loans from the Italian and Japanese governments, the Korea Development Bank, the Agency for International Development and the Asian Development Bank. End-users were tasked with covering the cost of internal wiring, as well as a monthly usage fee. With the cost of internal wiring exceeding the ability-to-pay of almost all rural households, low-interest government loans were offered to end-users. The loans originally had a repayment period of 19 years. This was quickly realised to be too high a burden on rural households and was amended to be repaid over a period of 35 years. Loans for internal-wiring were initially covered by the government. As the number of households electrified increased, the government took out a loan from the International Bank of Reconstruction and Development to continue to offer loans to households.

The Ministry of Commerce served as the hub for implementing rural electrification. Specifically, both local governments and KEPCO reported directly to the ministry allowing for central planning and coordination of budgets and project plans. After the Ministry allocated each local government's budget, local governments were mandated with selecting which villages would be electrified first. Selection was supposed to be undertaken according to a criteria disseminated by the Ministry to ensure maximum return-on-investment.

The criteria mandated that selected villages be: located in an area where distribution did not require transmission and substation facilities to be built, and populated by rural households with sufficient electricity demand and able to afford monthly electricity fees to allow KEPCO to make at least normal profit in the medium to long run. Additional priority was given to villages that could demonstrate current engagement, or the potential to productively engage, in economic activities that required electricity (e.g. sericulture, light manufacturing). This effectively excluded smaller and poorer villages, as well as the more remotely located mountain villages. After villages were selected by the local government, KEPCO surveyed the village and drafted construction plans. These plans were reviewed by the local government and, when approved, KEPCO undertook construction immediately. Internal wiring – paid for by end-users – was installed by independent private contractors hired by individual end-users (van Gevelt 2014).

5.2. Linking rural electrification and rural development

5.2.1. South Korea

In South Korea, rural electrification was accompanied by a number of other significant investments in rural areas by the government. In agriculture, the government:

- strengthened agricultural extension services
- undertook land reclamation projects to increase the area available for cultivation
- launched a nation-wide reforestation campaign to deal with soil erosion and improve soil fertility
- implemented an agricultural subsidy to improve the terms of trade for agriculture
- promoted the mechanisation of agriculture
- developed and rapidly deployed high-yield rice and barley varieties.

Additionally, the mandate of the national agricultural cooperative was expanded to include the provision of affordable credit to rural households which, along with legislative changes, eliminated usurious loans in rural areas. Alongside agriculture, the government invested significantly in rural infrastructure (see table 1).

Type of infrastructure	Output
Expansion of village roads (Km)	43,558
New village roads (Km)	61,797
Small bridges	79,513
Irrigation (Km)	13,622
Village centres	37,012
Warehouses	22,143
Housing improvements	225,000
Sewage systems (Km)	15,559
Telephone lines	345,240
Saemaul factories	717
Reforestation (Ha)	347,153

Table 1: Rural infrastructure in South Korea 1970-1979. *Source: van Gevelt (2014)*

Table 2 shows the dramatic increase in rural household income from an annual income of USD 249 in 1970 to USD 2,172 in 1979. Notably, the increase in household income is attributable to both increases in income derived from agriculture and non-agricultural activities . Although it is difficult to tease out the direct contribution of electricity to household income improvements, it is possible to see how electricity – when combined with improvements in rural infrastructure and government support in agriculture and rural industry – helped improve household incomes and contributed to the overall economy.

Year	Household income	Agriculture income	Non-agricultural income
1970	US$ 249	US$ 189	US$ 60
1973	US$ 469	US$ 381	US$ 88
1976	US$ 1,128	US$ 898	US$ 229
1979	US$ 2,172	US$ 1,493	US$ 649

Table 2: Annual rural household income (1970 – 1979) in 2014 US dollars. *Source: van Gevelt (2014)*

The late 1960s saw the introduction of new high-yield varieties of rice and barley, the strengthening of extension services, land reclamation, and reforestation to improve soil fertility. Within this context, electricity contributed by helping enable a significant increase in agriculture productivity. For example, electricity powered the majority of water and draining pumps which were used to irrigate rice fields and enabled cultivation of rice and barley, among other crops, in periods of drought and poor weather. Additionally, electricity helped improve agricultural productivity through electric-powered processing of crops and by enabling seedlings to be nurtured in polyethylene greenhouses which allowed early harvesting and multiple cropping. Another key contribution of electricity to agricultural productivity was achieved through television programmes targeted towards farmers that addressed different agricultural technologies and methods to improve yields. Viewing statistics recorded in 1978 suggest that approximately 85% of rural households tuned in to these programmes at some point.

Another key channel through which electricity enabled agricultural income to increase was through allowing households to diversify their crop portfolio. The time and labour saved by electric motors, the opportunity to work in the evening with electric lighting, and the introduction of greenhouses and electric-powered dryers combined to enable households to cultivate cash crops, such as tobacco, ginseng, high-value mushrooms, and silkworms. Furthermore, electricity made investment in livestock profitable for many rural households. For example, feed pulverisers enabled households to engage in larger-scale ranch management, and electric milking machines helped improve the productivity of milk production. Electrified chicken farms are also recorded to have seen a significant increase in egg production.

Electricity helped rural households capitalise on high market demand from an increasingly large urban population and government guarantees of relatively high purchase prices for staple crops. Firstly, electricity permitted crops to be processed and appropriately stored before being transported. This reduced crop losses from the point of harvest to the point of consumption. Secondly, increased information on market structure and conditions through television helped improve the bargaining power of rural households with middlemen and traders.

In addition to enabling improvements in agricultural productivity, diversification and access to market, electricity contributed to the development of rural industry in the 1970s. In particular, a number of companies manufacturing light industrial goods – for both export and domestic markets – were moved into rural areas by the government and 717 cottage industries – known as *saemaul* factories – were constructed. There are conflicting reports in the literature regarding the

success of rural industry and its contribution to household income and the economy. Some reports note that with few exceptions, the *saemaul* factories have been largely unsuccessful and offered a minimal contribution to rural household income, while others note that *saemaul* factories and other rural-based industry contributed significantly to both the rural economy – primarily through generating an additional income stream for rural households – and to the national economy by contributing approximately one-third of the country's total export earnings in 1980.

Further economic benefits were felt throughout the wider economy with government estimates suggesting that investment in rural electrification and other rural infrastructure offered a three-fold return on investment costs. For example, more than 80% of children from rural areas were being sent to junior high school at private expense and the number of students continuing to senior high school, vocational schools, and university was approximately four times higher than in 1970. Additionally, increased rural incomes created a new market for urban producers of consumable goods who consequently established rural distribution channels (van Gevelt 2014).

5.2.2. Thailand

Thailand went from having a rural electrification rate of approximately 10% in 1972 to 99% in 2001. Like South Korea, the Thai electrification story is notable for its active promotion of rural electricity use. In the Thai case, the Provincial Electricity Authority (PEA) – which was responsible for distribution to all rural areas outside of the Bangkok Metropolitan Area – saw the promotion of rural electricity use as integral to its rural electrification strategy. This was reflected in the PEA monitoring both electricity demand load and whether rural villages used electricity productively. The PEA had two main reasons for their promotion of productive use of rural electricity. Firstly, the thinking was that this would improve rural incomes and therefore revenue growth, which would enable the PEA to expand connections to more rural communities. The second reason had to do with ensuring that electricity was used efficiently.

For example, the PEA dispatched 'load promotion' teams to villages identified as using less than the expected amount of electricity. Identification was on the basis of monthly monitoring of load growth, connection rates and revenue. Load promotion teams consisted of a mixture of PEA staff and staff from the local customer service office. This ensured that load promotion teams were familiar with local conditions and norms, therefore allowing the teams to engage directly with villagers. This further involved the use of mass media (television, radio and newspapers) to disseminate information about the potential benefits of using electricity productively to rural communities.

Load promotion teams focused first and foremost on encouraging villagers to convert from diesel to electric engines to power rice mills, the processing of agricultural crops and various cottage industries. Additionally, electric power tools and irrigation water pumps were incentivised. To do this, the load promotion teams would work together with local electric engine dealers to target rural villagers. For villagers, the PEA worked with the Bank of Agriculture and Agricultural Cooperatives to create loan products for villagers wishing to purchase electric engines for productive use. The PEA also helped villagers through the process to obtain loans.

Thailand's efforts to ensure the productive use of electricity had a number of beneficial outcomes. Firstly, for villagers switching to electric motors to power rice mills or cottage industries, the gains were significant. For example, the PEA estimated that a rice mill's operating costs were approximately 20% lower when using electric engines compared to diesel engines. Secondly, as most villages had at least one or two rice mills and cottage industries, the daytime load in villages increased significantly. This improved the load

factor – previously skewed towards evening use – and improved the rate of return thereby allowing for more villages to be electrified (Tuntivate and Barnes 2007).

5.2.3. Tunisia

Independence from colonial powers brought with it a rural electricity revolution in North Africa. With the colonial period seeing only urban areas sporadically electrified, the North African states of Algeria, Egypt and Tunisia made universal access to electricity in both urban and rural areas a priority (Showers 2011). Turning specifically to Tunisia, the rural electrification rate went from 6% of rural households in the mid-1970s to approximately 88% of rural households by 2004. This achievement is especially impressive given the definition of rural areas as only including households located beyond incorporated areas. In practice, this means that what many other countries would define as rural villages or towns may be defined as urban in Tunisia.

In the Tunisian experience, rural electrification was explicitly seen as one of three pillars of rural development, with the other two pillars being education and health. Education initiatives consisted primarily of addressing gender inequality and making heavy investments in the education of women. Health initiatives, again, focused heavily on addressing gender inequality by, for example, improving access to health services and mainstreaming a women's right to make family planning decisions. Electricity was included as the third pillar as the Tunisian government recognised how access to electricity underpinned the provision of improved education and health outcomes. As a result, rural electrification was mostly funded through regional development funds from the government, along with domestic and international loans.

To do this, the Tunisian government implemented a succession of five-year plans. These plans incorporated complementary initiatives focusing on offering rural households assistance with irrigation and agricultural processing. Broadly speaking, the five-year plans incorporated rural electrification within a broader framework of integrated rural development. This meant that rather than being implemented in isolation, rural electricity infrastructure was deployed in a way that led to synergistic effects. For example, rural electrification and a range of development indicators have been found to be strongly correlated. In addition, surveys suggest that rural electrification led to improvements in health, education, economic opportunities and better security, with the impact being especially felt by women (Cecelski et al. 2007).

6. Reflections On History

The historical examples in the previous section have demonstrated how some countries have been able to meet the formidable challenge of providing rural electrification and improving development outcomes in rural areas. What is striking is that the historical examples have shown that the institutional model for providing rural electricity is not as critical as is often thought by development theorists. Instead, our recounting of the Chilean experience highlights the success of a private approach while Costa Rica shows how a rural electric cooperative approach can be effective. China, South Korea, Thailand and Tunisia all demonstrate how a public-based approach can be equally effective. Although each historical example is rooted in its own particular context, guiding principles can be teased out that may prove to be of benefit to countries which have to date been less successful in their efforts to achieve rural electrification and development.

Principle 1: Sustained government commitment

A critical success factor in all of the examples in Section 5 was that there was a sustained government commitment to rural electrification and development. This is particularly important to ensure that the typical political cycle does not derail electrification and development initiatives. Usually, this takes the form of the creation or designation of new institutions to plan and implement rural electrification and development initiatives. These institutions can take different forms but successful institutions tend to: operate with a high degree of autonomy; have dynamic leadership, strong management processes and motivated staff; and work effectively across government enabling the integrated approach required to ensure that development benefits from access to electricity

Principle 2: Planning and prioritisation

A second principle concerns the importance of effective planning and prioritisation. Particularly important is the development of, and adherence to, a project-selection methodology to determine which areas are to be prioritised for electrification. This often involves initially prioritising communities that require the least investment in infrastructure for maximum economic and social return. This process helps ensure that rural electrification is not captured by short-term political interests and also ensures that limited resources are invested in as effective a manner as possible. Furthermore, rural electrification strategies need to be planned in conjunction with other rural development policies in order to take advantage of synergistic effects. A further characteristic of successful case studies was careful consideration of system design which enabled reductions in construction costs of between 20% to 30%, as well as consideration of expected loads. This careful planning can improve the impact of a rural electrification initiative significantly, especially in its initial wave.

Principle 3: Sustainable finances

Arguably the most important principle concerns the need to ensure sustainable financing for rural electrification programmes. Specifically, it is important to pursue a policy of cost recovery for operational costs. By covering costs, electricity providers are less dependent on subsidies. This means that when there is a downturn in the economy and subsidies are reduced, electricity providers are relatively unaffected and remain able to extend their rural electricity network. To achieve cost recovery, it is important to set appropriate tariffs for rural consumers. The appropriate tariff will be

country-specific but needs to achieve an important balancing act. Specifically, the tariff needs to be subsidised to a price that rural end-users can afford while ensuring that the electricity provider draws the majority of its revenue from customers instead of subsidies. This is important not only to ensure cost-recovery but also to help create incentives for the electricity provider to provide a quality service to end-users. Of further importance is the need to encourage productive use of electricity among rural end-users. This can help improve both the willingness-to-pay and ability-to-pay for electricity. Regarding capital costs, all of the successful cases described in Section 5 relied substantially on public sector resources to meet the high initial capital costs. This was achieved through a number of vehicles, including capital subsidies and capital investment funds.

Principle 4: A focus on the community

The final principle is to ensure that the rural electricity provider works to understand the non-technical side of rural electrification provision. In particular, the successful case studies in Section 5 saw numerous efforts made to allow end-users to take advantage of electricity. For example, a large barrier to many rural end-users was the relatively high connection charge. By allowing end-users to repay the connection charge over a number of years, rural electricity providers were able to facilitate the provision of electricity to end-users. Additionally, many of the cases in Section 5 emphasised the utility of community involvement. Indeed, engaging communities led to the contribution of labour and other resources, as well as being able to both disseminate the benefits of electricity and encourage and facilitate the productive use of electricity.

7. Making Smart Villages A Reality: Kaseke Village, Rwanda

In this section, the four principles from Section 6 are applied to a contemporary case study in order to understand what is required to make smart villages a reality. The case study is the un-electrified rural village of Kaseke in Western Province, Rwanda. Kaseke village is located in Binana Cell, Ngororero District in Western Province, Rwanda. The village was established in 1930 and consists of 314 households (approximately 1,238 people). The village has no access to electricity and villagers are dependent on kerosene lamps and dry-cell battery torches and laps for their lighting needs. Despite this, the village is located near the Rubagabaga river and has the potential to benefit from hydro-electric power. The village is agricultural with the majority of crops being consumed for subsistence. As of 2016, there were 16 small businesses (for example, bars, restaurants, general stores, and hair salons) providing goods and services within the village economy. Lighting needs for these businesses were met primarily by kerosene lanterns and lead-acid batteries (van Gevelt et al. 2016).

Principle 1: Sustained Government Commitment

Rural electrification is regarded by the Rwandan government as an essential component of a larger strategy to connect rural communities to economic opportunity through investment in infrastructure, skills development, and extension service provision. Specifically, the country's second Economic Development and Poverty Reduction Strategy (EDPRS 2) aims to extend grid coverage to rural areas, serve 22% of rural households through off-grid solutions and ensure that 100% of schools and health facilities have access to electricity by 2018 (van Gevelt et al. 2016). Energy policy in Rwanda is under the jurisdiction of the Ministry of Infrastructure. In 2015, The Ministry of Infrastructure set out a white paper for Rwanda's Energy Policy. While the white paper notes the need for cooperation between different ministries in order to integrate planning and implementation efforts, a specific institution or set of institutions have not been created or delegated the responsibility of leading the rural electrification effort. The lack of a spearheading institution is, according to historical experiences, likely to hinder the effectiveness of providing rural electricity to villages like Kaseke.

Principle 2: Planning and Prioritisation

A village such as Kaseke is estimated to require around 50 kW_p in order to provide basic lighting services to homes, the village centre and small businesses, and to allow for the potential diversification of economic activities into carpentry and milling. The village is only 1km from the nearest grid connection. Engineering surveys have suggested that a grid-connected mini hydro-electricity plant could meet the needs of Kaseke village while also feeding approximately 350 kW_p into the national grid. Despite this, there is currently no national-level project-selection methodology to determine which areas are to be prioritised for electrification. Instead, Kaseke village has so far only been addressed by private energy suppliers who have highlighted the potential of mini hydro-electricity in the area but struggled to obtain concession licenses and negotiate power purchase agreements with the government. Additionally, there are currently no other development initiatives targeting Kaseke village. In order for rural electrification to lead to significant development benefits, this will need to be coordinated with appropriate policies in, for example, education, health and agriculture.

Principle 3: Sustainable finances

Households in Kaseke village expressed an average willingness-to-pay for electricity of USD 3 per month. Their ability-to-pay, however, is estimated to be an average of USD 1.3 per month – a sharp difference. These figures suggest that monthly tariffs for Kaseke will initially need to be set at a rate

similar to USD 1.3 per month for basic household uses. This is likely to put a strain on the ability to achieve full cost recovery for operational costs and suggests the need to encourage productive use of electricity among households in Kaseke in order to improve their income and ability-to-pay for electricity. Additionally, a higher tariff rate could conceivably be charged for productive uses. It is estimated that the capital costs for construction of a suitable mini hydro-electricity plant equate to approximately USD 1.2 million. For isolated cases, it is possible to receive grant funding to cover capital costs from international donor bodies. However, it is unclear how such capital costs will be met systematically for villages like Kaseke.

Principle 4: A focus on the community

In the case of Kaseke village, it will be highly beneficial to engage with the community for two main reasons. Firstly, households in Kaseke reported a willingness-to-pay of USD 23 for the initial connection fee – an amount that almost no household is able to meet through existing savings. This means that it will be crucial to work out a method to allow end-users to repay the connection charge over a number of years rather than in one go. Additionally, villagers in Kaseke have demonstrated a willingness to contribute in terms of labour and resources to the construction of electricity infrastructure in the village. Qualitative interviews with villagers in Kaseke have brought to light the need to engage with the community to raise awareness of the benefits of electricity and to encourage appropriate productive uses of electricity. As it stands, villagers lack the skills needed to undertake carpentry or steelworks, for example, and require both training and access to capital. It is also important to establish supply chains to ensure that products are sold outside of the village and that value is brought into the village.

8. Discussion And Conclusions

Smart villages represent a powerful concept in rural development. A holistic vision, where access to electricity leads to improvements in health, education, food security and economic outcomes, the smart villages framework helps to plug the gap in development theory concerning rural development, where the rural is overwhelmingly seen as an input into the urban sector – the engine of economic growth. In particular, Smart Villages bring opportunities into villages that were previously only available in cities and therefore challenge the traditional economic models of development. By blurring the distinction between 'urban' and 'rural' in traditional economic models of development, the smart villages concept suggests that development no longer be subject to an urban-bias.

This technical report has drawn on successful case studies of rural electrification and development to tease out principles that can help inform what needs to be done in order to make smart villages a reality. Drawing on the exemplary cases of Chile, China, Costa Rica, South Korea, Thailand and Tunisia, this technical report first and foremost gives hope that rural electrification and integrated rural development is achievable within a myriad of developing country contexts. What is particularly striking is that among these case studies, no one institutional model for providing rural electricity is superior. Indeed, private, public and cooperative approaches are all capable of delivering electricity to rural areas and the particular vehicle will therefore be dependent on local context and governance preferences.

The historical case studies overviewed in this technical report allow for four main principles to be extracted. The first principle is the need for sustained government commitment. In particular, there is a need for the creation or designation of new institutions to spearhead the rural electrification and development process. These institutions will do best when allowed to operate with a high degree of autonomy. The second principle concerns the need for effective planning and prioritisation in both selecting areas to be prioritised during the initial waves of rural electrification and the integration of rural electrification strategies with other development policies. The third and arguably most important principle concerns the need to achieve sustainable financing of rural electrification. In particular, the historical case studies have shown the importance of pursuing a policy of cost recovery for operational costs. The fourth and final principle established from the case studies refers to a need to focus on the community. Specifically, it is important to engage with the community to improve the efficiency of the rural electrification process and to ensure that electricity will be used productively.

This technical report applied these four principles to the real-world village of Kaseke in Western Province, Rwanda to see what needs to be done to enable Kaseke to transform into a smart village. This resulted in four policy suggestions. Firstly, rural electrification efforts in Rwanda would be strengthened by the creation of a specific government institution to spearhead rural electrification strategies. Secondly, there is a need to develop and implement a national-level project-selection methodology to determine which areas are to be prioritised and in order to coordinate electrification efforts with other development policies (e.g. education, health, agriculture). Thirdly, it will most likely be difficult to achieve full cost recovery for operational costs in Kaseke village without encouraging the productive use of electricity to raise income levels. Additionally, there is a need for the government to identify and implement a strategy to meet initial capital costs at scale. Finally, it will be highly beneficial to engage with the community to harness contributions to infrastructure development, understand the need for flexible finance arrangements to meet the cost of connection fees, and disseminate the benefits of electricity to encourage appropriate productive uses of electricity among households.

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