Can Smart Villages help to stem biodiversity loss?

Brian Heap, John Holmes, and Bernie Jones

Technical report 15

February 2017

Key words:
Smart Villages, Biodiversity, Deforestation, Biomass, Cookstoves, Agriculture, Biofuels, Sustainability, Agroecology, Genetics, Bioengineering, Livestock, Organic, Barriers, Education, ICT, Ecosystems, Rural development, Renewable energy

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.

www.e4sv.org | info@e4sv.org | @e4SmartVillages

CMEDT - Smart Villages Initiative, c/o Trinity College, Cambridge, CB2 1TQ

Publishing

The Smart Villages Initiative is being funded by the Cambridge Malaysian Education and Development Trust (CMEDT) and the Malaysian Commonwealth Studies Centre (MCSC) and through a grant from the Templeton World Charity Foundation (TWCF). The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the Cambridge Malaysian Education and Development Trust or the Templeton World Charity Foundation.

MALAYSIAN COMMONWEALTH STUDIES CENTRE

CAMBRIDGE MALAYSIAN EDUCATION AND DEVELOPMENT TRUST

TEMPLETON
World Charity Foundation, Inc.

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Summary

Biodiversity is important at various levels, including the economic, social and environmental. It is critically important for rural communities through the provision of ecosystem services, including energy access, a link that is often overlooked. The concept of 'Smart Villages' is that modern energy access in the form of sustainable renewable energy can contribute as a catalyst for development—education, health, food security, environment, productive enterprises, and participatory democracy—and for the alleviation of poverty. Seventy per cent of the poorest people live in rural areas and are farmers, of whom about half are women. One of the key ideas is that while biodiversity preservation and the alleviation of abject poverty are seen as two distinct objectives, smart villages can contribute to both since there is considerable overlap in practice. By an integrated approach, smart villages can help to stem biodiversity loss by the skilful adoption and integration of modern technologies that improve biomass utilisation, agricultural practices, and genetic conservation; priorities that are compatible with several of the 17 Sustainable Development Goals. Smart villages enable rural communities to take an active role in preserving their environment instead of depleting natural capital for their day-to-day survival.

1. Introduction

Global urbanisation generates 80% of global GDP[1,2,3] and no country anywhere has developed without it, according to Paul Collier[4,5]. Just 2% of the world's population was urbanised in 1800; the figure passed 50% by 2008, and on current trends it will reach 60% by 2030. Virtually all this urban future growth will take place in developing countries, emulating Western Europe and North America, so that by 2025 it is estimated that 235 million households earning more than US$20,000 pa ppp will live in the emerging economy cities, compared to 210 million in developed region cities[6]. Good cities are able to harness economies of scale and specialisation through the economies of agglomeration, but they consume 75% of the world's energy and are responsible for up to 70% of global greenhouse gases (GHGs)[7].

With the focus on smart cities and the global conversion process of land use away from natural capital and towards human-selected capital[8], much greater attention needs to be given to the world's population of c.46% that lives in rural communities. About 1.1 billion people live off-grid without any form of modern energy access or a reliable supply of energy, 2.5 billion live in households that depend primarily on an agri-based economy, and seventy per cent of the global poor live in the countryside[9]. In India, the 2011 census data show that around 833 million people (69% of the population) live in rural areas, compared to 377 million people (31%), in urban areas. By 2050 it is projected that the population will be 1.6 billion and the urban figure will jump to about 800 million. This implies that around a similar number of people will continue to live in villages. There is a definite need to convert these villages into smart villages thereby respecting the UN principle[10]—'leave no one behind'. It will help to ensure the development of the entire country, including rural areas which is where biodiversity can be found and needs to be maintained, not in cities. So the living conditions and prospects of rural populations will remain a key global concern for decades to come. Therefore, growth in rural economies will be a major factor in overall economic growth of developing countries and will play a central role in achieving the Sustainable Development Goals.

A lack of affordable energy access is one of the deprivations of the global poor, where the primary causes of poverty have been identified as the exploitation of natural resources that reduces local investment on agriculture, [delete and the impact of subsidies], inadequate access to international markets by landlocked countries, national and international conflict, and poor governance[5,10,11,12]. These poverty traps have roots, though not exclusively so, in the global North where the insatiable demand for resources such as oil makes the natural resource trap so potent, and where agricultural protectionism and perverse subsidies deny the poor opportunities for which they would otherwise have competitive advantages[7,9]. A grand vision is needed to tackle these challenges, and one that originates in the global South[9], provided that such a solution does not imperil the remarkable biodiversity that we still enjoy and consign it to what has been called an 'evolutionary dustbin'[8]. The question is whether 'Smart Villages' could become an invaluable analogue of 'Smart Cities'—a grand vision that would help to preserve biodiversity because of its value and long-term benefits, elements that are normally never as powerful as the immediate need for survival of the bottom billion[9].

2. The Smart Villages Initiative

The concept of the smart village is that affordable modern energy access in the form of sustainable renewable energy, when appropriately integrated with other development initiatives, can help as a catalyst for development—education, health, food security, environment, productive enterprises, and participatory democracy. This in turn supports further improvements in modern energy access, ensuring sustainable electricity supplies to meet rural needs and the availability of clean and efficient appliances for cooking, communication, irrigation, food processing, etc. As such, energy access can provide a much-needed driver for sustainable economic development, social justice, and the mitigation of risks for a major, but neglected, sector of the world's economy in reversing the direct and potentially damaging impact of energy poverty in the rural environment[13].

In recent years, the concept of energy poverty has resurfaced in international and national public policy discussions[14]. Between 1.5 and 3 billion individuals in the world today are defined as energy poor—'*people who live on less than US$1.15 per day and have no access to reliable, safe, and efficient energy for cooking, lighting, space heating and mechanical power…[and] who rely upon harmful energy like biomass-generated fire for their cooking and heating*'[15]. Energy poverty is most severe among rural communities living off the grid in developing countries and it has negative effects on the environment, health, education, productivity, and the quality of life of villagers.

The aim of the Smart Villages Initiative is to bring together frontline players in the global South—entrepreneurs, scientists and engineers, villagers, rural poor, NGOs, financiers, civil society, development and environmental organisations, sociologists, economists, policymakers, and regulators—who are engaged in off-grid rural communities in order to identify the barriers to progress, and how they can be overcome. The focus is on off-grid villages where local solutions are cheaper than national grid extension, and the purpose is to identify the framework conditions necessary to foster entrepreneurial initiatives that ensure that governments and donor funding achieve maximum leverage of private sector investment. An underlying premise is that activities to enable energy access need to be integrated with other development initiatives, taking a holistic and community level approach, to maximise social benefit and sustainable environmental development[15,16,17].

Technology	Generation capacity (kW)	Energy sources	Services available	Estimated economic cost per household
Pico-power systems	0.001 – 0.01	Hydro, wind, solar	Lighting, radio communication reception, two-way mobile communication	US$10-100
Stand-alone home systems	0.01 – 1	Hydro, wind, solar	Same as above plus additional lighting and communication, television, fans, limited motive and heat power	US$75-1,000
Mini-grids	1 – 1000	Hydro, wind, solar, biomass, diesel, hybrid combinations	Same as above plus enhanced motive and heat power, and ability to power community-based services	Medium-large capital cost, low marginal cost to end-user
Regional grid connection	1000 – 1000000	Gas, hydro, wind, solar PV, biomass	Assuming high quality of connection, same as above up to a full range of electric power appliances, commercial and industrial applications	Medium-large capital cost, low marginal cost to end-user

Table 1: Smart villages and the energy escalator[15].

Renewable sources of energy can play a key role in providing for many of the basic services that are required in 'off-grid' communities, as seen in an 80% fall in the cost of solar panels since 2010 and the spectacular growth of home solar systems in East Africa. The nature of the energy escalator illustrated in Table 1 stresses the fact that energy access should not be limited to attaining the most basic level, as fossil fuels can be progressively replaced by renewable energy sources or by hybrid combinations. Compared with fossil energy, renewable energy for smart villages will be sustainable, local and less polluting in terms of greenhouse gas emissions and therefore it will help to mitigate climate change, one of the key threats to biodiversity. Globally, renewable electricity generation is gradually increasing, and by the end of 2015 it was enough to supply an estimated 23.7% of global electricity with hydropower providing about 16.6%. Renewable energy has therefore become a mainstream energy source and this has been signalled by the United Nations General Assembly's adoption of a dedicated Sustainable Development Goal—SDG7[10].

In the Smart Villages Initiative we consider how energy-poor people depend on, and affect, biodiversity and ecosystem services and functions, and some of the practical ways by which smart villages could help to stem the threats to biodiversity losses in rural communities, which are largely of humanity's making. Many of these losses comprise land and forest degradation, unsustainable agricultural practices, and the erosion of genetic resources in different regions of the world.

3. Stemming losses arising from energy demands

Agroforestry helps to reduce biodiversity loss by providing a protective tree cover and a habitat for a diversity of flora and fauna[18]. But with three billion people in the world using direct energy in the form of wood and agricultural waste for heat, burning, and cooking, deforestation and biomass can destroy biodiversity and ecosystem functions (BEF) and services (BES), encourage poverty, accelerate climate change, and expose emerging infectious diseases—many of which have been traced to tropical rainforests and specifically to freshwater aquatic systems. For many of the 33 million smallholder farmers in sub-Saharan Africa, deforestation has become a widespread solution to their needs; but they remain largely uneducated about its effects on the ecosystems on which they rely and the global impact that affects humanity[19, 20,21]. Smart villages help to stem biodiversity loss by mitigating these anthropogenic impacts on forests.

3.1 Deforestation

There are many reasons for deforestation, including large-scale agriculture for international commodities (e.g. soybean, oil palm particularly in S E Asia), logging, and mining. About 130 m hectares of forests rich in biological diversity and home to many terrestrial species of animals, plants, and insects have been lost since 1990, an area almost equivalent in size to South Africa, so that the global intact forest landscape has been reduced by 7.2% since 2000[22]. The threat is likely to continue with further deforestation from illegal logging, forest degradation, fire and pollution, to which is added the challenge of climate change[23]. Effective conservation policies will need to create incentives for efficient resource management and the recycling of water and nutrients[24].

Smart villages recognise the critical importance of forests for sustainable landscape management and for the development of a country's low carbon energy strategy. The UN Framework Convention on Climate Change and its programmes of Reducing Emissions from Deforestation and Forest Degradation (REDD+) have the broad intent to help developing countries to value healthy forests as one of the largest stores of carbon. Through information and communication technologies (ICT, radio, telephony, computers, internet) smart villages will be advised about a country's REDD+ strategy or action plan, the voluntary forest monitoring systems to conserve and restore healthy forests, and results-based payments schemes for reductions in forest emissions[25].

A Payment for Ecosystem Services (PES) used to transfer money to individual farmers has the objective of incentivising biodiversity conservation, sustainable resource management, and the provision of ecological services. In Mexico, a study from 2004 to 2009 showed a 40-51% mitigation of forest cover losses compared to what would have happened in the absence of a PES programme. However, the greatest impacts were observed in the areas with lower risks of deforestation rather than in areas at high-risk, and overall the programme was more effective at achieving environmental goals than benefitting the socioeconomic status of the areas. Similar schemes have been tested with user-financed PES, in which funding comes from the users of the ecosystem service being provided, and government-financed PES where funding comes from a third party. User-financed programmes were found to be better targeted to local conditions and needs, and better monitored than government-financed schemes[26]. Any promising signs of forest conservation are therefore welcome and results over the last five years in Africa show the highest annual increase in the area of forest for conservation while Europe, North and Central America reported the lowest compared to previous reporting periods. The increase reported by Asia for 2010-2015 was lower than that reported for 2000-2010 but higher than the increase reported in the 1990s[24].

For smart villages, confirmation of the critical importance of biodiversity conservation comes from recent studies of forests in 44 countries that show a positive and consistent relationship exists between tree diversity and ecosystem productivity; a 10% loss in biodiversity leads to a 3% loss in productivity[27]. Furthermore, the economic value of maintaining biodiversity for the purpose of forest productivity is fivefold greater than the cost of conservation, with clear implications for the biodiversity-productivity relationships in off-grid villages with their dependence on biomass.

3.2 Biomass

Nearly 40% of the world's population rely on solid biomass as it is the world's fourth largest energy resource for heat, burning, and cooking (138 exajoules of primary energy). In sub-Saharan Africa (excluding S. Africa) over 80% of the total energy supply for heating, cooking, and processing of agricultural produce is derived from biomass such as fuelwood and agricultural residues. In Latin America the figure is somewhat less (40%) but in other cases it is about 60%. Calculations show the vital role of biomass consumption in the economic growth of sub-Saharan countries; a 1% increase in biomass production can lead to an increase in GDP of up to 1.8%; a 1% increase in a country's openness to trade to an increase in GDP of 0.3%; and a 1% increase in population to 0.7% increase in GDP[28].

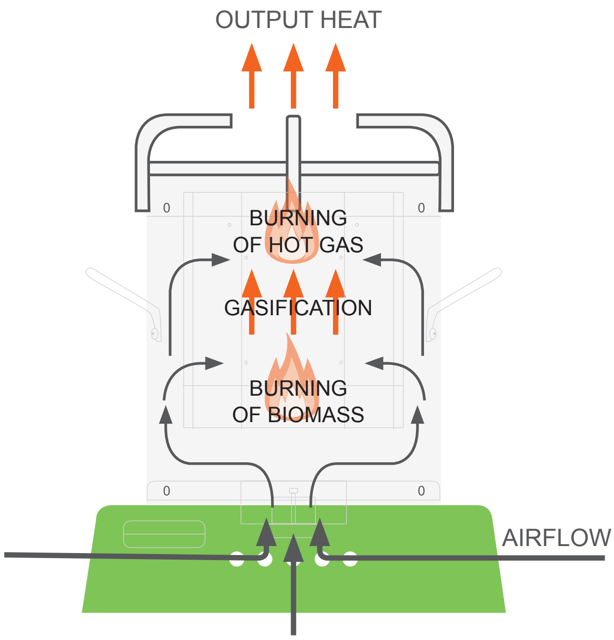
Biodiversity loss affects the production of biomass and essential services such as water, nutrients and light (biodiversity and ecosystem services, BES). The transformation of a diverse plant stand into a monoculture can also influence biodiversity and ecosystem functions (BEF) and reduce plant biomass[29]. Therefore, biomass harvesting and usage in less developed countries (LDCs) are an issue when conducted in unsustainable ways because they affect ecosystem functioning[30,31]. Smart villages seek to produce and use biomass in ways that are sustainable and renewable, that do not deplete resources, and that utilise it efficiently. They also recognise the fundamental importance of gender sensitivity because the transformative power of renewable energy sources brings about fundamental changes for the life of women living in off-grid villages[32].

Different forms of biomass exist, ranging from woody cellulosic biomass (grasses, trees, wastes) for combustion to produce heat and electricity; sugar-rich crops (sugar cane, sugar beet) for fermentation to produce ethanol and the leftover biofuel, bagasse in the case of sugar cane; oil seeds (rape seed, soy, sunflower, palm oil) for pressing and biodiesel production; sorghum and cassava for ethanol production; to Jatropha, peanuts and palm oil for biodiesel. Biomass also originates from the food supply chain, such as animal wastes, crop and forest residues[30,31]. India, with its over 600,000 villages and a substantial biomass energy sector, has the potential to produce about 17,000 MW of electricity from surplus agro-residues and a further 5,000 MW if the sugar mills switch over to modern techniques of co-generation. This projection is part of India's ambitious programme to source nearly 60% of its electricity capacity from non-fossil fuels by 2017.

Biomass usage in LDCs includes the provision of direct energy in households. It can be in the form of energy carriers such as briquettes that use agricultural waste like sugarcane, which saves cutting down trees. Briquettes can be sold as eco-fuel for community heating, for anaerobic digestion at combined heat and power plants, or sold in greater volumes to supply larger commercial liquid biofuel production plants. The non-governmental organisation Energy4Impact[33] identifies the importance of biomass along with other multiple generation technologies such as solar PV, hydro, and renewable-diesel hybrids for developing mini-grids in rural communities. Energy4Impact supports developers to overcome financial obstacles and facilitate site selections, equity provision and market analysis to ensure that the new energy supply has the most powerful impact possible. Working with rural communities the aim is to develop mini-grids, though few have been economically successful in Africa to date. African countries and Brazil are frequently identified as the two regions with the greatest capacity for biomass production. Smart villages adopt novel crop and forestry systems that are sustainable, reduce unsustainable deforestation[31] and make more efficient use of innovations in renewable energy technologies.

3.3 Cookstoves

About two-thirds of households in LDCs depend on biomass and charcoal for cooking purposes, which is responsible for causing respiratory illness and the death of 4.3 million per year, primarily among women and children. A Smart Villages Initiative workshop held in Myanmar, with inputs from Indonesia, Laos, Cambodia, and the Philippines, focused on the design and dissemination of improved cookstoves in S E Asia. The annual consumption rate of fuelwood in Myanmar is about 2.5 tonnes per household, and increasing fuelwood requirements present a significant challenge to the sustainability of forest resources. The Ministry of Environmental Conservation and Forestry aims to reduce the total biomass energy consumption from its current 76% of total annual energy consumption to 58% by 2020 and to 46% by 2030. It also aims to supply 25% of fuelwood needs through forest plantations and reforestation, and to distribute new designs of cookstoves which are up to 40% more efficient than traditional open-fire cooking or self-made stoves. This can result in up to one tonne of fuelwood being saved per rural household per year, while the use of novel forestry systems reduces soil degradation and combats pests and diseases. A similar initiative has been launched in Indonesia with the support of the World Bank with the aim to ensure universal access to clean cookstoves by 2030[34].



Efficient cooking stoves save fuel and biomass as well as reducing smoke inhalation[35, 36]

In the Indawgyi Lake area of Kachin State in Myanmar, where biomass dependence is extremely high, the majority of the firewood comes from the felling of mature Dipterocarp trees, thus threatening local forest biodiversity. Unlike in most other areas, men collect the firewood and women are responsible for cooking. Focus groups were organised to understand local requirements for improved cookstoves, which led to the development of the Indawgyi Stove. The stove has a constant flow of air and uses less fuel than traditional cookstoves. It can be constructed from locally available materials and the design can be modified to meet the requirements of different households. The Smart Villages Initiative was welcomed by George Dura of the European Union Delegation at Myanmar, as reduced deforestation helps to combat climate change in a country that ranks as the second most vulnerable in the world to climate change and where communities are often poorly equipped to deal with extreme climate events[34]. Envirofit, a producer of modern cookstoves, claims to have saved over the past decade US$179 million in fuel costs from 1.3 million stoves, created 2500 direct and indirect jobs, conserved 52 million trees and prevented 22 million tons of carbon dioxide emissions. African Clean Energy (ACE) is the producer of the ACE 1 solar biomass energy system that reduces smoke emissions to negligible levels and provides clean cooking with a range of biomass fuels, as well as offering solar electricity for mobile phone charging and LED lighting[35].

3.4 The biomass dilemma

Over 20 million tonnes of charcoal is consumed annually in Africa and this is expected to increase to 46 million tonnes by 2030, driven by sustained population growth, rapid urbanisation, and lack of practical and affordable alternatives. When comparing price and energy content against other alternatives, charcoal out-competes most on several fronts, though the rationale for choosing energy sources at the household level is influenced by price, energy content, ash content, smoke and fumes, available cooking appliance, type of food to be prepared, and time of preparation.

Experience in Kenya shows that advising a village against charcoal production in the interest of stemming biodiversity loss will probably fail[37]. Charcoal is one of the most important energy sources on the African continent and its production provides employment in rural communities, with more than 65% of all households in urban areas of East Africa using it as part of their energy mix. Any alternative to charcoal comes up against a societal structure that involves traditional forms of household energy provision for cooking and living, embedded patterns of rural employment for charcoal production, and a livelihood influenced by shadowy interests along the value-chain of charcoal for the urban market.

No one aspires to be a charcoal producer as it is a low-paid, physically intense and health-threatening undertaking, often done as a last-resort coping mechanism. But, as Barasa[37] says, 'a 'top-down' techno-utopian solution could advance modern and alternative sources to charcoal....but (it) has to be matched by a 'bottom-up' social transformation that generates employment and viable income alternatives for (charcoal) producers'. The message is that replacing charcoal as a productive enterprise will require a smart village to produce a real livelihood alternative and economic development to divert people from practices that are deeply embedded in rural structures even if they harm biodiversity and the environment.

4. Stemming losses arising from agricultural practices

Biodiversity in agriculture means not only the supply of a variety of foods for consumers but also the creation of environments that support healthy populations of microbes, insects and small animals[38]. During the past 50 years, while land has been lost to urbanisation, agriculture has led to loss through soil degradation, desertification, erosion, overgrazing, salt accumulation, and pollution. Managed as opposed to natural habitats, with little human intervention, have often resulted in agricultural practices that produced major biodiversity loss, with the ever-increasing demand for food, feed, and fibre products. However, the picture is complex since in some instances (e.g. adult hoverflies, farmland bird diversity) conventional agriculture can generate more biodiversity than organic farming depending on the scale of the landscape[39]. Smart villages take advantage of the many advances in agronomy to produce food in a sustainable manner, create productive enterprises that are linked to market opportunities, and appropriate responsible policies that internalise externalities and reward the stemming of biodiversity loss in managed habitats[40,41].

4.1 Reducing the impacts of agricultural practices

Agricultural expansion in developing countries has seen an 8% decline in the world's natural forest cover, and habitat loss in tropical regions with their high biological diversity is a particular concern[40]. More needs to be learned about the dynamics of loss of habitats in relation to individual species as more diverse communities are more productive when they contain key species that have a large influence on productivity. A 21–40% loss of species can reduce plant production by 5–10%, similar to the effects of climate warming. When higher levels of extinction occur (41–60%) the effects rival those of acidification and nutrient pollution[43,44]. Such extinctions alter key services important to the productivity and sustainability of Earth's ecosystems, and it has been estimated that an increase of species extinction rates by 1000 times could have occurred in the last 300 years, comparable in magnitude to one of the five big extinction events[45]. At last, steps are being taken by multinational organisations that recognise these risks and a coherent set of principles will be launched in order to safeguard commitments to areas of 'no deforestation'[46].

Smart villages address the challenge of agriculture's impact on biodiversity by a holistic approach similar to that advocated by WWF[42] involving renewable (clean) energy, technologies that monitor environmental indicators such as water quality, soil conditions, and landscape changes, and sustainable productive enterprises that create an income stream and facilitate sustainable development. Productive enterprises in smart villages are essential, particularly where distributed energy generation and transmission systems are economically more viable than costly grid extensions. In locations in India, farmers, fishermen and food processing businesses can kick-start cooperative ventures using the energy sources of biomass, solar and wind power, and hydropower, and they adopt the use of non-lead batteries to facilitate energy storage. Agro-businesses expand through improved solar energy-based irrigation systems, agro-processing and refrigeration, and biogas systems and mini-grid power for milling rice and maize. Harvest losses are reduced and post-harvesting processing facilitated. Where heating and cooling systems can be provided, added-value from agricultural products can be gained through food preparation, processing, extraction, refining and preserving. Access to technology through ICT informs farmers about best practices and market opportunities for the sale of products.

A prototype of the smart villages concept is found at Chhotkei, Odisha, a small remote village 160km from the state capital, Bhubaneswar, and situated amidst rich natural resources but previously without electricity. The primary livelihood is rain-fed paddy cultivation once a year, but the village has now been supplied with a 30 kW solar-powered Smart Nanogrid™ to meet the energy demands of 140 households, 20 streetlights, a temple, and three community centres. The renewable energy supplies microenterprises such as poultry, stitching, puffed-rice machines, provision stores, refrigerators, oil mill, welding machines, and irrigation, and enables value-addition to agriculture. Power is supplied throughout the village by underground electrical cables to minimise losses. Fibre optic cables are used for communication purposes and a Smart Nanogrid™ controls metering, billing, payment, and alerts to 'cut off' if unpaid. Smart Nanogrid™ ICT supports tele-medicine, tele-education, smart agriculture and water management[47].

A solar-powered village at Chhotkei. Odisha, India[47]

4.2 Sustainable intensification

'Growing more from less' is the rallying cry for increased food production[48,49] whereby each hectare of land will need ideally to feed five people by 2050, compared to just two people in 1960, using less water and with reduced biodiversity loss. Whereas in the past the primary solution has been to bring more land into production or to take a greater supply of fish, such options are no longer straightforward as little additional land suitable for agriculture remains in many regions and several fisheries have been diminished. Increased cropping intensity by growing a greater number of crops each year on the same land and sustainable expansion of irrigated areas will be necessary.

A different approach would be to close the yield gap, since the best yields from cereal crops grown under optimal conditions are far greater than those typically obtained by farmers. Wheat yields in the UK were 2.8t/ha in 1948 and 8t/ha in 2016 with best yields of 10-12 t/ha limited only by water availability. The yield gap measured locally or by crop simulation models can be as great as 50-60% in some countries in Africa and ca. 20-25% in Asia and South America, while yields for maize, rice, wheat and soybean in a third of areas studied have either not improved or stagnated[50]. (A yield gap of about 20% also occurs between conventional compared to organic crop yields[51]). Questions remain, however, about closing the yield gap of crops in sub-Saharan Africa and whether it can be done sustainably without the negative externalities frequently associated with the conventional methods of increased production—land erosion, eutrophication of water courses and soil degradation[52,53].

Investment in agricultural R&D in the developing countries is problematic as it has relied almost entirely on publicly funded research and global partnerships, such as the Consultative Group for International Agricultural Research (CGIAR), unlike the situation in high-income countries which are relatively well supported by the private sector. Investment strategies to close the yield gap do exist as they provide important opportunities for crop breeders and practitioners familiar with modern agronomic and managerial improvements, and for the conservation of genetic resources in genebanks such as the Crop Genebank Knowledge Base.

A key development for smart villages will be local solutions. For example, *Brachiaria,* a high-quality, drought-resistant native forage grass grown in East Africa, has a high crude protein and a low

Tatu Rajabu of Mitonto village, Kijota ward, Kenya harvested 15 kg of pearl millet grain from a 50 g small pack of seed[56].

fibre content which leads to less methane gas produced for each unit of livestock product such as milk or meat. It withstands dry seasons of three to six months, and when fed to cattle increases milk production by 40%[54]. Smart villages also use better managerial measures, such as the extension service provided by the Science and Technology Backyard platform (STB) developed in China that empowers smallholder farmers by agricultural scientists living among them and alerting them to relevant research findings. The increases in the five-year average yield of wheat and maize have been from 67.9% to 97.0% of attainable levels locally, and from 62.8% to 79.6% of attainable yields countywide[55].

Pioneering work by FIPS-Africa, a not-for-profit company working in Kenya, Tanzania, and Mozambique, also demonstrates how simple local solutions can improve the status and performance of large numbers of poor smallholder farmers who live off-grid and below the poverty line. Self-employed Village-based Advisors (VBAs) selected by the villagers themselves teach good agricultural practice and business skills to generate enough income to sustain their advisory role. The 'Small Pack/Whole Village' method provides a seed pack of 25 -100 g of an improved crop variety and fertiliser for every farmer. Farmers invariably return to the VBA to purchase larger quantities of seed, and maize crop productivity increases from one to four tonnes/ha within one year. Other offers include improved seeds for the most important cereal, legume, root and tuber, banana (vegetative propagation), vegetable and fruit tree crops, and dietary protein obtained from improved livestock breeds and indigenous chickens protected against Newcastle disease by a thermostable vaccine. Future partnerships with seed and fertilizer companies plan to improve the livelihoods of 350,000 smallholder farmer families. The FIPS model enables smallholder farmers in Africa to quickly and sustainably become food secure on existing land through simple methodologies of sustainable intensification [56].

Alternatively, hi-tech approaches to sustainable intensification can raise crop productivity and nutritional quality by the application of accelerated plant breeding gained from knowledge of plant genomes and the use of key marker genes to aid selection by local farmers. Future technologies may pave the way by the transfer of the high-productivity C4 photosynthetic pathway found in maize and putting it into rice, or by photoprotection from specific gene transfer that gives greater yields of leaves, stems, and roots by up to 20%[57]. These options are still at an early stage of development and beyond the reach of poor off-grid smallholder farmers, who are among the most disadvantaged in the world, but they reflect the aggressive intent of plant breeders and companies to tackle the challenges that lie ahead to improve the sustainable intensification of food production. Doubts remain about whether closing the yield gap alone will suffice to meet the demands of food security in sub-Saharan Africa[52,53], and they provide a stark warning that if this cannot be done the tensions between increased agricultural productivity, sustainable intensification and biodiversity losses could be aggravated by a massive expansion of cropland and expensive cereal importations[53,58,59].

4.3 Energy for agriculture

Affordable energy from renewable sources and access to ICT through radio, telephony, tablets, and the internet have the potential to make villages smart and help develop a much-needed second green revolution among smallholder farmers. New solar pumps[60] that make irrigation easier and more efficient align with government policies in countries such as India and Ethiopia to improve small-scale irrigation. They emit no carbon, contribute to more sustainable agricultural practices, and with appropriate business models can boost small-scale irrigation development by saving water, reducing costs, and by managing natural resources more sustainably. Solar pumps can be used for drip irrigation, household micro-irrigation and domestic use, and solar drying of crops enables threshing, milling, sorting, and grading. These solar technologies do not require high investment, gain better price returns and, crucially, lead to youth employment. The overall caveat is that solar-sourced equipment must be serviced and maintained, the lack of training being a common source of setback in the use of renewable energy technologies. Smart villages also use biosensors for soil fertility monitoring to reduce fertiliser usage and decrease not only energy inputs but environmental impacts. They also adopt precision farming methods that become feasible with drones, satellites, and on-farm computer-aided technologies, providing greater accuracy and timing of applications of seeds or fertilizers.

Integrated food-energy systems (IFES) make more efficient use of cropping and agro-forestry systems through links with livestock and fish production[61,62]. On-farm synergies arise from the use of by-products such as crop residues, animal wastes and food waste that help to generate energy with little effect on BES. IFES in smart villages lend themselves to scale-up so that anaerobic digesters for biogas production and neighbouring farms form clusters that invest in the construction of mini-grids. However, specific case studies are scarce and the idea of integrating different farming practices has not gained wide appeal; the more crops and procedures have to be managed and for which farmers require a greater range of management skills, the greater the losses of economies of scale[63]. Looking ahead, however, the agricultural engineering company New Holland has developed the concept of the 'Energy Independent Farm' that would use renewable electricity generated on-site to produce hydrogen fuel for tractors, trucks and transportation[64,65].

Rimbunan Kaseh, located to the North-East of Kuala Lumpur, Malaysia, is one of numerous village communities in S E Asia that exemplify many of the features of IFES. Its integrated production system of agricultural crops, aquaculture, and livestock production uses water in aquaculture where highly valued species of fish are reared. It is then recycled to irrigate crops through an energy efficient hydroponic system that ensures plants receive precisely the level of water and nourishment required. Agricultural waste is mulched to use as poultry feed and to create fish food for aquaculture. Villagers experienced significant improvements in their quality of life, with household income supplemented by up to US$ 500 per month, largely due to the production of high value crops such as golden melon and jade perch fish. ICT-enabled integration of the village into global value chains means that these high value products reach Singaporean supermarket shelves[66].

4.4 Biofuels

Unsurprisingly, much attention has been given to crop production for biofuels and its effect on biodiversity. Currently biofuels provide about 3% of the world's transportation fuels, a figure that could possibly increase to about 30% by 2050. Biofuel blending for transportation fuels ranges from targets of 5-27% in different countries, with Brazil having already attained the higher figure[31]. Biogas is another energy source of growing importance, being a mixture of methane and carbon dioxide produced by the anaerobic digestion of organic waste including manure, landfill organics, or dried and ensiled grass. Expanding energy biomass plantations into the natural landscape obviously brings the risk of direct biodiversity loss due to habitat destruction and fragmentation, or agricultural practices that lead to environmental damage[67,68]. An additional caveat concerns the unregulated production of biofuels without full life-cycle analyses of the threats to biodiversity and food security.

Land taken up for non-food use means that crops and farmland will be removed from food production, and land used outside a feedstock's production area will need to be replaced by the supply of the original commodity, creating an indirect land use change (iLUC). Rebound effects will occur where the replacement of fossil fuels reduces demand, lowers their prices and leads to higher fuel consumption and a spike in greenhouse gases (GHG). Soil nutrient depletion may also occur if carbon is not returned to the soil[30]. Notwithstanding these perceived drawbacks, steps can be taken to use perennial grassy crops as a second-generation feedstock compared with annual crops because they result in a reduced pesticide and net fertilizer use, and a greater animal biodiversity as habitats are improved and natural ecosystems functions restored. Biofuel facilities can also be designated to absorb surpluses if 'flex crops' are grown that serve food, feed and fuel markets. They absorb surpluses according to the circumstances of supply and demand, thereby helping to dampen commodity volatility[24].

A form of distributed energy for smart villages comes from biofuels produced from second-generation feedstocks, such as purposely-grown and renewable energy plantations, pooling sorghum crops from groups of smallholder farmers, and greater use of agricultural residues[31]. The benefits need to flow to the village rather than a distant corporation in order to raise rural incomes and offset rising food prices. Terrat, a Maasai village located in the Manyara region of Tanzania[69], produces biodiesel from Jatropha and croton. The village was at a crossroads with residents increasingly vulnerable to the pressures of globalisation. Terrat inhabitants, including village elders such as Martin Saning'o, developed the Institute for Orkonerei Pastoralists Advancement (IOPA) to create opportunities initially through a local radio station for community-driven economic empowerment. Processing surplus milk to make higher-value dairy products such as cheese, yoghurt, butter, and ghee was discussed and, with the help of a Dutch family foundation, a company was founded and milk processing units purchased. IOPA obtained three generators of 300 kW total capacity to run on locally produced biofuel. Milk processing has become a successful economic activity with daily production of up to 2,000 litres per day, export of processed dairy products to niche national and regional markets, and—although the initiative has not been without its tensions with the Tanzanian government—training opportunities for women, employment opportunities for young people, and distributed biofuel production from locally managed feedstocks have been achieved.

4.5 Education

Energy access in smart villages makes ICT into a realistic vehicle for the expansion of education in rural communities, depending on the distance from urban centres. Mobile phones and the internet become key linkages between researchers, extension agents and farmers (mostly women) raising awareness of best practices, environmental issues, and market prospects. They reduce the information asymmetries faced by small and marginal farmers, help to deal with some of the weaknesses of traditional agricultural extension services, and provide weather forecasts, local language training and advice about sustainable self-financing business models. In India, ICRISAT's GreenPHABLET[70] empowers women by providing farm education and market intelligence, and routes to conventional modes of learning about child health, women's health, nutrition, prevention and cure of common ailments, and employment opportunities. Therefore, the provision of material for smallholder farmers through ICT about the benefits of BES and the impact of their farming systems underpin strategies to stem biodiversity losses[71].

Tariq Zaman of the University of Sarawak, Malaysia, speaks of indigenous communities who transmit knowledge from one generation to another. 'There is so much to learn from indigenous communities' he says 'especially in matters pertaining to stewardship of the earth and community empowerment'. Long Lamai where he works is a Penan village in the Malaysian Borneo, eight hours on rough logging roads and an hour of hiking through the dense rainforest from the nearest town. It is a very lively, gender and generation balanced village of approximately 598 individuals and 116 households situated next to the river and consisting of individual (long) houses on poles, surrounded by the rainforest. People live a subsistence agrarian lifestyle with everyone depending on the jungle as a source of food. Electricity generated through hydro-power and solar power makes it one of the most advanced Penan communities, having adopted ICT into economic, social, institutional, and environmental activities. Its telecentre provides full internet connection and Wi-Fi within the village, and its mobile tower gives access to the outside world and, with external partners for educational purposes, marketing of touristic activities and the preservation of indigenous knowledge. Zaman writes of the need for support from the public and private sectors—'a smart village can only be created and maintained if the villagers make smart decisions…. residents have worked hard to carve out a village and preserve (its) intimate relationship with the environment and jungle… they seek to gain sovereignty of resources (energy, income, and information) in a way that supports long-term community resilience'.

ICT training in Long Lamai, N. Sarawak, Borneo, Malaysia

4.6 Livestock

Burgeoning livestock production with its contributions to pollution and GHG emissions provides a major challenge to BES. Livestock farming is the world's largest land use sector, utilising around 60% of the global biomass harvest. It is one of the fastest-growing sectors in the agricultural industry and it will be driven in future by the projected increase in the human population and an expansion of a middle class that demand dietary upgrading and can afford a meat-based diet. Feed for poultry can account for 60 to 80% of the total cost of inputs, together with increasing demands on land availability and water resources[72,73,74]. Public health consequences also exist because livestock are the source of approximately 75% of newly emerging infectious diseases[75]. The spread of infectious zoonotic and non-zoonotic diseases, such as H5N1 avian influenza panzootic and the pandemic (H1N1) influenza A crisis, demonstrate the magnitude of the problem.

Smart villages take advantage of livestock vaccination schemes because they bring benefits to livestock health, productivity and available household expenditure on childhood education and food purchase[76]. They also facilitate business opportunities for more than half of the bottom billion farmers who keep livestock in rural areas, but these are the people who risk being squeezed out of the sector if land-grabs for large-scale production systems become dominant.

Other opportunities come from aquaculture, because almost one sixth of all animal protein consumed on the planet comes from fish. With the increase in demand for animal protein, aquaculture represents a significant source of improved livelihoods. But the same stresses of densification and yield improvement will occur with fish as with livestock, and therefore efforts to improve the genetic stock of fish and to preserve biodiversity will necessarily have to be strengthened. To date only 18 out of the 400 species of cultured fish have been subject to significant genetic improvement programmes[77].

Several elements discussed in this section on stemming biodiversity losses from agricultural practices are being addressed in entrepreneurial prototypes of smart villages that are being developed in India. GramOorja[78], not unlike Chhotkia, Odisha mentioned previously, consists of a comprehensive enterprise established by four young entrepreneurs who realised that renewable energy could have a significant role in enhancing rural livelihoods. The aim was to establish smart villages that fulfil the electricity, cooking fuel and water needs of tribal communities in remote off-grid regions using solar PV micro-grids, biogas-based cooking grids, and solar pumps. Operational and financial stability is achieved through an effective metering and tariff mechanism. Micro-grids support productive enterprises such as a flour mill, rice huller, water pumps, and education and health institutions. Biogas cooking stoves reduce the burden on women for firewood collection, and increase time for the family, produce cottage industries and reduce the burden on forests. Where cattle are present in villages the availability of cow dung enables biogas production.

5. Improving biodiversity

Over-exploitation of genetic resources is perceived as a continuing threat to biodiversity, though a meta-analysis of 44 published papers demonstrated that no substantial reduction in the regional diversity of crop varieties released by plant breeders has taken place in more developed countries. A significant reduction of 6% in diversity in the 1960s as compared with the diversity in the 1950s was observed, but after the 1960s and 1970s breeders have been able to again increase the diversity in released varieties[77]. Similarly, growers of garden beans, garlic, lettuce, peppers, squash, and tomatoes had many more choices in 2004 than they did in 1903, though growers of beets, cabbage, radishes, and turnips had vastly fewer choices[79].

5.1 Agroecology

Employing methods close to nature has many attractions and smart villages have options to improve BES by the adoption of conservation agriculture with minimum disturbance of the soil, using crop remains to protect the soil and planting a variety of crops to achieve biodiversity rather than mono-culture production systems. It makes greater use of natural fertilisers in view of the paucity of nitrogen fertilisers in several LDCs, though many African countries have been slow adopters suggesting smallholder farming is undergoing a slow evolution rather than a revolution. Research into 'push–pull' or 'stimulo-deterrent diversionary' strategies exploits natural semiochemicals that repel insect pests from the crop ('push') and attract them into trap crops like Desmodium spp. which in turn produce a nitrogen fertilizer through their nodular activity. The strategy increases yields of maize substantially in areas of Kenya where stem borer and parasitic Striga are prevalent pests. It improves soil fertility through nitrogen fixation, gives natural mulching, better biomass and erosion control, and provides high-value animal fodder for improved milk production, all achieved without any chemical burden[81,82].

'Push-pull' intercropping where natural chemicals from Napier grass pull in moths to lay eggs; natural chemicals from *desmodium* repel moths (push)[81]

Agroecology is less well authenticated or developed as an agriculture production system and technologies such as 'push-pull' may have limited geographical spread, but advantages accrue from multiple applications such as rhizobia nitrogen-fixing bacteria and mycorrhizal fungi that greatly enhance the ability of roots to extract various nutrients from the soil. Neither the bacteria nor the fungi can survive without the host plant that in return supplies oxygen and products of photosynthesis in the form of proteins and carbohydrates, illustrating biodiversity in action. Similarly, a mixture of earthworms and arbuscular mycorrhizal fungi improve biomass above ground and nitrogen uptake of clover plants[83,84,85]. Biopesticides reduce chemical usage, but so far they are not competitive economically. Biocontrol agents, the natural resistance of crops to infection, the biodiversity of the soil microbiome particularly in sub-Saharan Africa, and how certain plants exhibit a systemic acquired disease resistance are topics of incomplete knowledge[86,87,88] and future results are awaited with great interest[89,90].

Smart villages may use agroecology to produce biologically-diverse landscapes, minimise pollution of natural habitats by reducing toxic run-off into aquatic systems, modify farming systems to mimic natural ecosystems using mosaics of new and improved perennial crops and agroforests, and use remote sensing for landscape planning and monitoring[91,92]. Markets and reward mechanisms for producers of certified sustainable products will need to be developed to provide a supportive framework for smart villages to follow this approach. The landscapes will appeal to Pope Francis, who in the landmark encyclical *Laudato Si* expressed his preference for the practice of 'agroecology' rather than 'sustainable intensification', though he recognised that neither could claim legitimately to ignore the utility of genetic engineering[93], a topic that was explored in depth in an earlier conference at the Pontifical Academy of Science[94,95]. 'It follows', he said, 'that certain scientists, lacking any ethical point of reference, are in danger of putting at the centre of their concerns something other than the human person and the entirety of the person's life. Further still, some of these, sensing the opportunities of technological progress, seem to succumb not only to a market-based logic, but also to the temptation of a quasi-divine power over nature and even over the human being'[93].

Clearly, we do not see the aim of smart villages as being to exercise power over nature or fellow human beings, but rather the care of the local environment, aided by technologies including those that inform, educate and remotely monitor indicators, such as forest diagnostics, soil conditions, water quality, and landscape changes. These indicators can help to safeguard BEF and BES that maintain the earth's life-support systems, and at the same time take into account the traditional skills and livelihoods when new productive enterprises provide different forms of employment[96].

5.2 Orphan crops

Smart villages need smart foods[97], yet most of the world's food needs are provided by some 30 species of plants whereas at least 12,000 species have been named as edible. Only three crops—maize, wheat, and rice—account for about 50% of the world's consumption of calories and protein, and they attract the biggest amount of research, development, policy support, and investment. Understandable concerns have emerged about the possible risks posed by selection that leads to a narrowing of the genetic base from which crops are selected, to a genetic erosion of the crop gene pools, and to a loss of BEF.

Sustainable nutrition has become a United Nations (UN) priority to counter malnutrition which is influenced by environmental degradation, water scarcity, and migration of the labour force, amongst other issues. The African Orphan Crops Consortium (AOCC)[98] is a partnership that works to make high-nutritional value crops grown by African farmers available to rural and urban consumers. The plan is to undertake genome and transcriptome sequencing, develop tools to assess genetic diversity in crops, and support new breeding programmes. Pigeon pea, an important crop in Asia, Africa, and Central and South America which is grown on nearly five million hectares worldwide, is the first orphan crop to have a completed genome analysis[99]. Alongside their commercial potential, many of the underused crops provide important BEF as they are adapted to marginal soil and climate conditions.

Smart villages take advantage of the nutritional advantages of crops such as millets because they are high in micro-nutrients and antioxidants; they are gluten free and can provide the full daily allowance of iron and zinc[97]. Millets require 30% less water than maize, grow faster (maturing in half the time of wheat), put less stress on the environment, and grow on minimal pesticides/fertilizer. In times of drought they are often the last crop standing, making them potentially critical for addressing the challenges of climate change. Whilst the breeding of millets has received a lot less investment, they have the potential to increase yields by up to three-fold and produce biomass for alternative use (for example, fodder, biofuels, and brewing).

Biofortification of plants helps to overcome human deficiencies in dietary micronutrients through the production of nutrient-dense food fortified with iron, zinc, and vitamin A. The process has already been developed in rice, cassava, banana, maize, sweet potato (provitamin A), beans, pearl millet, rice and wheat (iron and zinc). The best known example of the transgenic approach is 'Golden Rice' fortified with provitamin A, which smart villages will adopt once tendentious regulatory processes have been resolved[100]. Nonetheless, a diversity in food supplies achieved with orphan crops would complement the need of fortification since a varied diet can be more nutritious.

5.3 Organic procedures

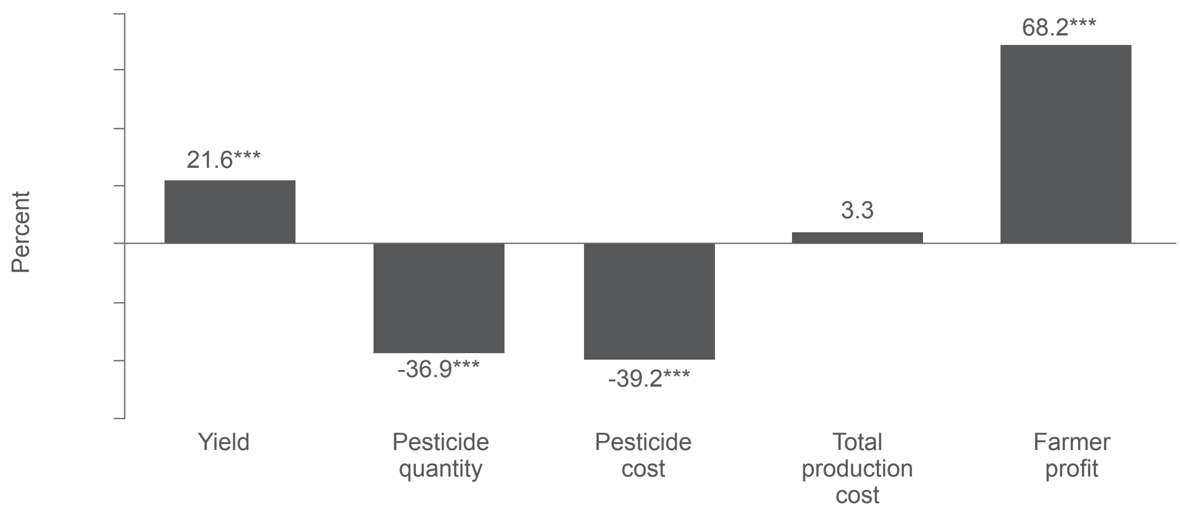
Organic farming continues to be hotly debated because of its claims about the exclusion of the use of most synthetic pesticides and fertilisers, and the benefits for biodiversity compared with the high yielding methods that rely on genetic engineering and pesticides. Organic yields are typically 19-25% less than conventional ones[101,102]. A meta-analysis shows that on average organic farming increased species richness by about 30% (optimal soils, 5%; bad soils, up to 60%)[103]. Plants benefit the most, as do arthropods, birds and microbes, though the effect on soil organisms was less marked. Three-quarters of the studies were carried out in Europe, while three-quarters of the land under organic production is outside Europe. This means that the biodiversity benefits of growing bananas, cassava or cacao beans organically remain to be assessed. Organic methods, therefore, could help smart villages to stem the loss of biodiversity but at the price of lower yields.

5.4 Genetic engineering

Where they choose to do so, smart villages can gain access to genetically modified (GM) planting materials that take advantage of the knowledge by which we understand in a more systematic way the controls of a world whose mechanisms are complex and delicately balanced. The first-generation techniques successfully modified a few simple input traits in a small number of commercial commodity crops leading to a reduction of chemical usage to control destructive pests and diseases and combat weeds. Second-generation technologies improved consumer benefits through increased food production, better nutritional quality in terms of dietary micronutrients, and greater economic benefits. Third-generation technologies promise new opportunities as genes can be transferred from the same or related species (cisgenesis) instead of different sources (transgenesis), the specific coding region of a gene from the same species inserted, and gene editing systems used to edit and silence genes by simple 'cut-and-paste' techniques at low cost with great precision—all part of an ever-expanding GM toolbox[104-108].

Insect-resistant and herbicide-tolerant GM crops stem the loss of biodiversity by decreasing the environmental impact of chemical herbicides and insecticides in the environment. In a meta-analysis of 147 studies, the use of GM soybean, maize, and cotton decreased chemical pesticide use by 37% and increased crop yields and farmer profits by 22% and 68%, respectively. The release of greenhouse gas emissions declined through less fuel use, and if 'no tillage' production systems were used more carbon was stored in the soil. Thus there were very significant net global economic benefits at the farm level amounting to $98.2 billion in the period 1996-2012[109].

A meta-analysis of the impact of GM crops
Klümper and Qaim, PLoS ONE 8 (11) 2014



Av % differences between GM and non-GM crops (herbicide tolerant and insect resistant); yield, n=451; pesticide quantity, 121; pesticide cost, 193; total production cost, 115; profit 136. *** P<0.001

Insect-resistant and herbicide-resistant genetically modified (GM) crops stem the loss of biodiversity by decreasing the impact of chemicals on the environment; columns show the percentage difference between GM and non-GM crops[109]

Moreover, herbicide-tolerant GM crops that deal with weeds had beneficial effects on soil fertility because conservation tillage meant that there were fewer tractor passes in the field[108]. Insect-resistant GM maize did not affect insect biodiversity, and non-target insects including a whole range of butterflies had a better chance of survival than in conventional crop fields. Similar messages came from studies in wheat transformed with different inserts[111-114].

The uptake of GM crops as an agricultural innovation has been one of the fastest in history, with LDCs now growing more of them by area than industrial countries[16,94,95]. About 80% of farmers who have adopted GM crops are smallholder farmers because the attraction of higher yields and the use of more environmentally benign herbicides reduce the pressure to convert additional land into agricultural use, which is good for BES. Smart villages that find biotic constraints such as pests, diseases or drought are not easily addressed through conventional means may be faced with the prospect of turning to other alternatives such as GM crops. As a food market it is expected to grow from the present value of about 112m to 130m tonnes by 2021.

No evidence of hazards from GM crops has been recorded in terms of human health, environment, or food in over 2000 reports[116, 117,118]. However, a rigorous monitoring regime will be important to ensure that no deleterious effects arise in the longer term through new traits being passed to wild relatives (out-crossing), or a reduced number of preferred varieties that results in greater risks of disease incidence and spread. Some GM technologies that work well today will become less effective as certain insects evolve resistance. Insects that feed on GM crops can, in some cases, start to develop a resistance to the protein that usually kills them, so this is something to keep an eye on in the future. An intriguing option is to merge GM plants with organic agriculture, a synergy that would take advantage of an environment with diminished chemical applications and soil enriched with organic material, respectively[119,120].

5.5 The continuing tension between Europe and Africa

In the African continent agriculture contributes to over 25% of GDP and employs about 60% of the labour force. The attitude to GM crops is greatly influenced by the European perspective so that only three out of 52 African countries (South Africa, Sudan, and Burkina Faso) have enacted the obligatory National Biosafety legislative and regulatory procedures and developed GM crops commercially. Forty-five African countries have ratified the *Cartagena Protocol on Biosafety to the Convention on Biological Diversity* in 2009, a risk-based procedure that ignores benefits, and a prerequisite before GM crops can be considered for commercial production[121].

The negativity in many European countries towards GM crops has been interpreted as indicating that there is something to fear about the technology. Recent reports from Spain suggest that perceptions may be changing as the benefits from the adoption of GM maize become increasingly apparent. Insect-resistant maize increased yields of 7-10% compared with conventional maize, depending on the geographical area and the pest incidence. Environmental benefits included water savings equivalent to the provision of water for 0.75m people per year, a reduced hydrological footprint, fewer sprayings with pesticides, less pressure on land use, and a net fixation of additional carbon[122,123].

5.6 Other tools for engineering biodiversity

Looking to the future, synthetic biology, nanotechnology, and genetic engineering offer new solutions to the challenges of biodiversity loss. Applications of GM typically concern the transfer of individual genes between cells, while synthetic biology involves the assembly of new sequences of DNA and even new genomes, and nanotechnology reduces quantitatively the application of crop protection products, nutrient losses in fertilizer applications, and gives better plant yields through integrated soil fertility management. Some of these technologies build on classical genetic engineering, but many elements are entirely novel. Cells can be equipped with new functions and entire biological systems can be designed so that synthetic organisms have much larger-scale interventions than classical genetic engineering. Current trends show that these technologies can be used to create organisms that could help ecological restoration, combat reservoirs of human viruses, and prevent infectious diseases like white nose syndrome (a fungal disease that affects hibernating bats).

Tools can be provided to better understand biological systems and produce valuable products such as drugs, fuels, or raw materials for industrial processes as well as food. For these reasons synthetic biology has been linked to future economic growth and job creation worth billions of dollars[124]. Gene drive systems that change the genomes of populations of mosquitoes and make them less able to cause malaria[125] could facilitate the rapid spread of genes through wild species, or lessen the threat from invasive species or from other insect vectors of diseases that pose significant threats to BEF[126]. This world of research has been described as rewriting 'the code of life in the wild', but great care is needed as little is known about how synthetic organisms introduced into the environment will evolve or be degraded, or interact with natural organisms and transfer genetic material to wild populations through horizontal or vertical transfer with adverse effects on native species, habitats or food webs[127].

The research pipeline contains a raft of other initiatives relevant to the challenge of stemming biodiversity loss—bees genetically modified to resist pesticides or mites, microorganisms engineered to convert sugars in biomass into biofuels or pharmaceuticals, slow release fertilisers that enhance plant growth rates, benign life forms that facilitate the provision of clean water and reduce the stress on BES, and genomic coefficients based on single-nucleotide polymorphisms that give the exact proportion of the genome that is homozygous or shared by two individuals—information that helps to maintain genetic diversity and overcome inbreeding depression[128,129].

New technologies of the present, and promising solutions of the future, can play a pivotal and positive role in stemming biodiversity loss—but they are not enough. Opposition to technological advances has a long history and can impede application. Belgian philosophers and scientists have turned to cognitive science to try to understand why the opposition to GM crops, for instance, has become widespread despite the positive contributions they can make[130]. Typical responses are those of essentialism because technology portrays DNA as the essence of an organism, teleological thinking that portrays GM technology as unnatural and playing God, and romanticism that sees technologies as contamination and interventionist of nature. For smart villages, therefore, technological advances need to be set in the context of a wide range of normative considerations and different ethical demands[71,130].

6. Comment

Biodiversity has been described as a natural insurance policy against sudden environmental change because it underpins a wealth of beneficial ecosystem services, such as water, soil fertility, and pollination, on which all depend. A worldview in the global South is that nature constitutes an integral part of people's livelihoods and material wellbeing, so that biodiversity with its ecosystem services and functions is central to their culture, religion, and identity, and therefore to be rightly conserved[131]. For some, it is a strong utilitarian argument that matters—the good of the many; for others there is an overriding moral obligation of fairness and technology justice, concerns that people have access to the use of technology. From an environmental point of view, it is how technology can be used in a way that avoids negative effects; the voice of the rural poor who live off-the-grid has the right to be heard in relation to biodiversity and its services on which they depend.

Georgina Mace[132] writes of the changing relationship between nature and people as it has emerged over the past 50 years. Originally, the emphasis was on 'nature for itself' and species, wilderness, and protection. It was followed by 'nature despite people' when there was exploitation, habitat loss, and extinction that demanded natural resource management. Then 'nature for people' emerged when ecosystem services and functions were seen as commodities that provide food or clean water for growing populations. Today, it is a two-way interaction of 'people and nature', recognising socio-ecology, adaptability, resilience, and value systems. It is in this latter frame that we place smart villages, since they can act as significant agents instead of patients in helping to stem biodiversity loss.

Early insights have emerged from our Smart Villages Initiative and how they could help the process of development through energy access but also stem biodiversity losses, and we summarise a few of these interim findings[133].

First, smart villages are attracting international interest and proto-smart villages are under construction in several countries. Not all elements of our smart villages concept have been incorporated into a single prototype, but we see the potential of energy access from renewable sources combined with ICT in helping to stem biodiversity losses and the mitigation of fossil fuel usage. The media have a particular role to play in raising awareness of the potential. Journalists at our S E Asia workshop in Sri Lanka expressed their goals in terms of 'learning about sustainability and energy, contributing to a better quality of life in their countries, improving environmental coverage, gaining skills to write in-depth stories and even books, improving business coverage, and learning from peers about story opportunities and challenges'[134].

Second, smart villages and access to energy do not automatically or rapidly solve the challenges of biodiversity loss or rural poverty[135,136]. Neither happens in isolation but as part of a broader process of incremental structural transformation, with rising agricultural productivity and productive enterprises in the agricultural and rural non-farm economy to meet urban growth and transformation. Social impacts in greater life expectancy, improved education, and better healthcare arise from the conditions that help to foster entrepreneurship and the empowerment of women and youth, leading to changes in lifestyle and income generation.

Third, symbiotic private and public sector investment with enterprise growth capital funds are needed to de-risk and bridge the financial 'valley of death' if smart villages are to become sustainable and replicable. At the company level there is difficulty in accessing affordable working capital because of the lack of a successful track record. This results in high perceived risk in the finance community and consequently high interest rates, exacerbated by the banking sector's lack of familiarity with off-grid energy. At the domestic level, investment is required for appliances such as sewing machines, food mixers, and bread bakers. At the village cooperative level, investment is needed for grinding equipment, welding tools, refrigerators, and water pumps.

Simon Trace remarks[137] 'it is an immense injustice that humanity has not managed to ensure universal access to technologies critical to achieving a minimum reasonable standard of living, technologies that have generally been in existence and use for decades and, in some cases, centuries. Technology Justice, in this respect, must mean establishing a global governance process that ensures these gaps in technology access are addressed and closed, something it has long been in our power to do'. Our society chooses to subsidise the coal, gas, and oil industries that cause harm to local populations by air pollution and the effects of floods, droughts, and storms. Such harmful effects are estimated to cost US$5.5tr each year, in comparison with a woefully low investment in renewable energy of $120bn.

Fourth, sustainable education and training in smart villages will be needed at all levels to enable rural communities to climb the energy escalator, and to understand the benefits of biodiversity and ecosystem services. These levels range from local technicians to engineers, product designers to university researchers, and local entrepreneurs trained to run a productive enterprise. The financial community needs to familiarise itself with the issues associated with off-grid energy schemes, and government institutions need to build capacity in policymaking and regulation. The mobile telephony industry has a key role as opportunities and responsibilities in LDCs grow exponentially and smart villages become scaleable.

Fifth, governments will need to provide supportive policy and regulatory environments to attract private sector capital into smart villages, simplify licensing frameworks, cut red tape, and allow sufficient breathing space in respect of taxation regimes for businesses to get off the ground. The Government of India has decreed that any high-value companies have to spend at least two per cent of the previous three years' average net profits on Corporate Social Responsibility (CSR) initiatives. Currently, US$5.2bn is available for organisations concerned not only with maximising shareholder value but also with taking steps to improve the quality of life of rural communities and people. As part of CSR, a business can set up renewable energy technologies like solar PV and biogas to serve energy needs, which has significance for smart villages by potentially linking with small-scale farming communities in over 600,000 villages.

The concept of smart villages as a path of rural development is multi-faceted and we have focused in this paper on potential contributions to stemming biodiversity losses. 'Smart' in this context means using modern renewable energy to replace fossil fuel in rural communities to reduce biodiversity loss and mitigate climate change, improve the efficiency of biomass usage, develop sustainable intensification of food production with high-quality seed and best-practices of agronomy, and the protection of genetic resources by the preservation of new and existing stocks aided by a raft of new technologies. Smart villages are sensitive to the socioeconomic realities of smallholder farmers who will have lived hitherto off-the-grid, because indigenous knowledge holds deep value[138]. A full awareness of the benefits of biodiversity is an ethical imperative, particularly with the worrying consumption of the world's cultivatable areas by urban expansion estimated to be at the rate of 1Mha annually[138,139], and because of the lack of a directed and integrated international programme devoted to the rural environment and its communities on account of a persistent urban predilection.

Acknowledgements

We are deeply indebted to Professor Klaus Ammann, who gave us access to his comprehensive and unique bibliography on biodiversity, Professor Georgina Mace for her expert advice, and Drs Claudia Canales, Terry van Gevelt, and all colleagues engaged in the Smart Villages Initiative.

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Morning mist in rain-forest at Danum Valley, Borneo, Malaysia

SMART VILLAGES

New thinking for off-grid communities worldwide

The Smart Villages initiative is being funded by the Cambridge Malaysian Education and Development Trust (CMEDT) and the Malaysian Commonwealth Studies Centre (MCSC) and through a grant from the Templeton World Charity Foundation (TWCF). The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the Cambridge Malaysian Education and Development Trust or the Templeton World Charity Foundation.