Modeling and Optimization in Science and Technologies

Srikanta Patnaik
Siddhartha Sen
Magdi S. Mahmoud *Editors*

Smart Village Technology

Concepts and Developments

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Srikanta Patnaik · Siddhartha Sen ·
Magdi S. Mahmoud
Editors

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Editors
Srikanta Patnaik
Department of Computer Science
and Engineering, Faculty of Engineering
and Technology
SOA University
Bhubaneswar, Odisha, India

Siddhartha Sen
School of Architecture and Planning
Morgan State University
Baltimore, MD, USA

Magdi S. Mahmoud
Systems Engineering Department
King Fahd University for Petroleum
and Minerals
Dhahran, Saudi Arabia

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Prof. Srikanta Patnaik
Prof. Siddhartha Sen
Prof. Magdi S. Mahmoud

Introduction

Smart village initiatives are being undertaken in rural communities all over the world to improve the lives of the people living in villages. The objective of such initiatives is to provide the benefits of an urban lifestyle to the villagers while retaining several valuable aspects of rural communities. These initiatives enable inhabitants of rural communities to attain complete potential for the development by connecting to the world and earning a viable livelihood while leading a healthy lifestyle. Such initiatives also attempt to prevent the migration of villagers to cities by providing immense opportunities in smart villages. They also bridge the digital divide between urban and rural areas. The digital divide consists of a gap in access to the Internet and other services that are available in urban areas due to the advancement of Information and Communication Technology (ICT) (Prieger 2013; Landers 2017). Many cities across the world, especially in the Global North, are using data to understand their strengths and weaknesses and capitalizing on opportunities while eliminating threats. The divide in smart principles and applications allows urban areas to prosper at the expense of rural areas that have not adapted or prepared for changes due to the progress in ITC.

Some of the basic aspects of smart village initiatives focus on sustainable environment, renewable energy, health and sanitation, food and clean water, eco-friendly production-oriented enterprises, education and awareness, and, lastly, democratic involvement of the villagers in various issues. The production of and access to renewable energy also form the backbone of the entire developmental process as energy access must be integrated into other initiatives for the development of smart villages. For instance, the development of productive enterprises by harnessing local suppliers and employing sustainable energy can result in great transformative changes.

For the successful development of smart villages, ICT plays a significant role by connecting the smart villages to towns and cities. To begin with, these technologies along with the Internet will link the smart village schools and people to the entire world's knowledge base through distance learning, thus enhancing education. Further, smart village initiatives attempt to offer students ample time to study by addressing several negative factors that impact their ability to learn. For example, through Internet connectivity in schools, educational materials and resources from all over the world are available. This will generate new opportunities for distance learning for students, thus minimizing the need to migrate to cities for quality education. Another important factor that has been addressed in the development of smart villages is improving the quality of the lighting system so that students can study in a safer, pollution-free environment.

Similarly, in smart villages, households can consume clean and safe water along with nutritious food while minimizing the cost of boiling water for drinking. Replacing traditional biomass-based cooking stoves in the villages of the Global South with cleaner fuel-based advanced stoves will reduce indoor pollution. Likewise, health services in smart villages in the Global South can be enriched by the support of telemedicine and mobile health services. Mobile health services can provide mobile health diagnoses and corresponding healthcare solutions in villages at a reduced cost. Again, collection and analysis of epidemiological data will generate early warnings to prevent the spread of contagious diseases in smart villages.

Next, in the Global South, providing sufficient food to the citizens to lead a healthy life is a major concern. Sustainable energy along with ICT in smart villages can contribute to a great extent in this context by providing smart irrigation systems to monitor the water requirements of crops; advanced weather forecasting systems for supporting farmers in the planting of crops at the right time; cold storage infrastructures to reduce the wastage of harvested perishable crops; and agronomic and market information awareness among villagers, thus helping in capturing the value chain by adapting to modernization. Furthermore, the development of small and medium enterprises in rural areas such as textiles, agro-product processing, handicraft developing units, and machinery providing enterprises will support the overall economic growth of smart villages, since such development mainly depends on the energy access scale in off-grid villages. However, an increase in the availability of energy access at local sources promises more participation of both formal and informal businesses and transforms them into productive enterprises, increasing opportunities and employment. Smart villages will strengthen the rural industry through multiple channels such as delivering a highly skilled workforce through ICT-enabled education, developing renewable energy sources, and extending work hours as per requirement with high-quality lighting. Moreover, incorporating ICT will enable access to updated market information with several mobile financial services, which in turn will support reaching international markets with a larger customer base and competitive advantages.

In addition to the above, smart villages in the Global South will also protect the environment through modern technologies. These technologies can be employed to monitor several indicators to measure environmental qualities. Some of these indicators include water quality, forest health and density, soil conditions, and landscape-based changes. Also, as charcoal and wood serve as a major source of biomass energy, the use of modern cooking stoves reduces deforestation. Again, recycling of organic and water waste using next-generation technologies can reduce pollution from agro-processing. Next, ICT can also improve rural wealth by transforming smart villages into local ecotourism hubs depending on geographic attractions. Smart villages empowered through ICT will also increase the social and political awareness of people living in such village communities while engaging them in governance processes and policy making at all levels. Thus, smart village initiatives will improve the quality of life with modern energy, public lighting, and increased education and awareness, accompanied by the capability of self-sustenance by adopting renewable energy systems while reducing the cost of living. Above all, the smart villages are expected to complement the overall economic growth of the rural communities in the Global South by delivering agricultural as well as rural industry-based products not only to local rural markets but also to national and international markets.

The benefits of smart villages are not only limited to the Global South. In the Global North, many parts of rural Europe are facing population decline. Measures to promote the development of intelligent and competitive rural areas can stem such population decline. In addition, the development of smart villages can improve services such as health, social, education, energy, transport, and retail in rural areas. Even in the United States (USA), many rural areas have poor cell phone service and lack high-speed Internet. Both in Europe and the USA, digitalization in rural areas can enhance public transportation and carpooling, improve caregiving, and create new value chains for rural entrepreneurs. In rural areas in the USA, various types of green infrastructure can be used for an eco-friendly solution for storm water management. In addition, vertical farming can add to the economic productivity of peri-urban areas in the USA. Like their counterparts in the Global South, empowerment and citizen participation are important aspects in developing smart villages in the Global North.

This transdisciplinary book brings together scholars from various fields such as engineering, public health, architecture, urban planning, and social and behavioral sciences to discuss some of the technological needs and managerial issues that are essential for the development of successful smart villages. The book's unique contribution lies in the fact that most of the scholarly books are on smart cities (McLaren and Agyeman 2015; Townsend 2015; Kar et. al. 2017; Manika 2018; Green 2019; Karvonen et al. 2019), while very little exists on smart villages (for exceptions, see for example Heap 2015; Visvizi 2019). Yet, smart cities cannot exist without smart villages (Fennell et. al. 2018; Visvizi and Lytras 2018). The topics covered in the book are crucial for all the project developers, engineers, academicians, policy makers, researchers, and younger generation to understand, empathize, and undertake measures to enhance the life of the rural population. The book takes a very broad definition of smart villages that incudes urban villages and peri-urban areas. Urban village is a term that is generally employed in India to refer to rural or semirural areas on the fringes of large metropolitan cities. Such areas are also referred to as peri-urban areas in India as well as in other parts of the Global South. They have been consistently under the pressures of rapid urbanization in the Global South, which brings about changes in population, land uses, and livelihoods of the inhabitants of such areas. The term also used to refer to the fringes of cities in the Global North that may have semiurban or semirural characteristics (Geneletti et. al. 2017; Dadashpoor and Ahani 2019; de Falco et. al. 2019).

Organization of the Book

The book has twenty chapters organized in four parts, namely smart village policy and technology, smart agriculture and water management, smart renewable energy management, and IOT and smart application. Seven chapters are presented in the first part. Chapter 1, entitled "Smart Village Initiatives: An Overview" by Sroojani Mohanty, Bhagyashree Mohanta, Pragyan Nanda, Siddhartha Sen, and Srikanta Patnaik, sets the tone for the book by discussing the technological, managerial, and human needs for the development of smart villages. The chapter also argues that a smart village is built on the philosophy of a self-sustaining ecosystem, one that is capable of adapting to changing governance regimes and generating resources in order to augment human development. The chapter postulates that education, health, sanitation, information connectivity, electrification, and establishment of cottage industries are the critical dimensions of a smart village.

Chapter 2 by Amanda Davies, entitled "IOT, Smart Technologies, Smart Policing: The Impact for Rural Communities," discusses the relationship between the use of the IOT for policing and security as well as the potential of IOT-based systems and processes for enhancing safety and security in rural India. Various types of IOT-oriented policing strategies are presented. These include reactive policing (RP), predictive policing (PP), problem-orientated policing (POP), community-oriented policing (COP), intelligence-led policing (ILP), and evidence-based policing (EBP). The discussion is contextualized through an examination of critical factors: the concept of "smart"; urban vs. rural population statistics in India; prioritization of needs for communities living in rural Indian villages; the accessibility of IOT in rural India; and the limited accurate and comprehensive reporting of crime typologies and rates for Indian villages.

Chapter 3, by Alejandro Barragán-Ocaña, Gerardo Reyes-Ruiz and Humberto Merritt, entitled "Scientific, Technological, and Innovation Dynamics in Nanotechnology for Smart Cities and Villages: The OECD Case and Its Implications for Latin America," identifies dynamics associated with the generation of patents among The Organization for Economic Co-operation and Development (OECD) member countries. Member countries have at least one application in one of the world's five most important intellectual property offices. There are two main objectives for the chapter. The first is to determine whether the (average) production of an IP5 (Patent Families) nanotechnology patent had a first-order relationship with the applicant's place of residence (priority date) and inventor's place of residence (priority date) during the same period in member countries. The second is to determine whether the formation of this type of patent family by place of residence of applicant (priority date) is associated with five variables. Despite the technical nature of the chapter, it has policy implications. As the authors conclude, advanced economies as well as developing countries, especially those in Latin America, must keep on strengthening nanotechnology progress, taking advantage of their opportunity areas by encouraging the development of more robust indicators in order to support the advancement of these activities. This, in turn, will help to stimulate the construction of smart cities. Although technological advances are usually within the context of a large metropolis, technical progress on nanotechnology can be extrapolated to rural areas with the intention of solving everyday problems that call for new technological solutions such as the generation of new materials, applications, and processes, which could contribute to the strengthening of these initiatives.

Chapter 4, by Reto Bürgin and Heike Mayer, entitled "Digital Periphery? A Community Case Study of Digitalization Efforts in Swiss Mountain Regions," analyzes how technological changes are changing rural economies in the mountain regions of Switzerland. The chapter describes the challenges faced by rural mountainous regions of Switzerland with the advancement of digitization. The chapter also covers the urban–rural digital divide. The chapter argues that rural areas run a risk of falling behind urban areas in the digital advancement due to a lack of digital connectivity as well as speed and reliability of the Internet, thereby creating this divide. This is true for even advanced economies such as Switzerland, which has one of the highest national coverage of broadband in the world. Using a case study, the chapter illustrates that despite overall advancement, not all actors can participate in the digital revolution that is taking place in the mountainous regions of Switzerland. While larger businesses, larger hotels, schools, and health service providers have benefited from digitization, smaller businesses have suffered from its high cost. So, there is a digital divide even within rural areas.

Chapter 5, by Mareike Meyn, entitled "Digitalization and Its Impact on Life in Rural Areas: Exploring the Two Sides of the Atlantic: USA and Germany," explores the possibilities of using digitalization as a means to empower people in rural areas in the USA and Germany. As pointed out by the author, digitalization implies not only the technical way of converting information, but also the opportunities digital technologies can create. It consists of broadband access and high-speed Internet; adaptation of digital technologies; and combination of the data that is produced to create smart solutions. The author recognizes that the USA and Germany are very different from each other and set the context through a discussion on rural areas, their transformation into the digital age, and the political framework at the federal level to enhance digitalization in the two nations. Using examples of best practices from both countries, the author shows that despite differences, digitalization offers tremendous potential for rural communities. The chapter identifies the recognition of rural communities' needs and ways of distributing knowledge, as well as a mind-set to embrace digital possibilities as key factors for developing smart rural communities. The chapter postulates that digitalization in rural areas can enhance public transportation and carpooling, thereby minimizing the commute between rural and urban areas, resolve issues around caregiving, enhance volunteering and participation in the policy-making process, and create new value chains for rural entrepreneurs.

Chapter 6, by Tej Karki, entitled "Government Versus Private Sector-Led Smart Village Development Policies and Programs in India," alludes to Mahatma Gandhi's vision of a village which is very similar to today's concepts of a smart village. The chapter begins with a discussion of recent policies for developing smart villages in India. These include Provision for Urban Amenities in Rural Areas

(PURA) and Member of Parliament Model Village Plan (MPMVP). The first was a brainchild of the former president of India A. P. J. Abdul Kalam and initiated in 2003 by the central government. The objective of the program was to inject urban amenities and employment opportunities in villages to retain population and reduce rural to urban migration. Prime Minister Narendra Modi launched MPMVP at the beginning of his first term in 2014 to improve the well-being of the villages in India. Every Member of Parliament (MP) is mandated to select and develop one model village in their constituency under this policy. After a review of the general achievement and requirements of the MPMVP, the author presents four case studies of smart villages—two from Gujarat, one from Bihar, and one from Puducherry. As pointed out by the author, these villages have met some of the expectations that many smart city scholars have argued for. The recommendations provided in the chapter are useful for improving the MPMVP in India.

Chapter 7, by Sweta Byahut, and Jay Mittal, entitled "Can Haphazard Growth in Urban Villages Be Prevented? Experience from the Ahmedabad-Gandhinagar Region," explores planning growth challenges associated with haphazard growth in urban villages in the Ahmedabad–Gandhinagar region in Gujarat, India, also known as the Gandhinagar Notified Area (GNA). The chapter discusses how the well-known land readjustment (LR) planning tool was applied innovatively in the region to ensure planned development in high-growth villages. It also presents the process and challenges of introducing a market-based land development mechanism to re-plan a mid-twentieth-century new town built on an outdated top-down planning model. The chapter finally highlights the opportunities that smart technologies can offer for enhancing urban design scenarios to improve the outcomes for formulating place-based building regulations.

The second part of the book begins with Chap. 8, by Shahriar Shams, Shah Newaz, and Rama Rao Karri, entitled "Information and Communication Technology for Small-Scale Farmers: Challenges and Opportunities." The chapter focuses on the need for ICT to provide the best sustainable practices and optimized water management to improve farming technology. The authors first discuss the challenges faced by small-scale farmers. These include poor water management and water shortage; high value of agricultural products; vulnerability to climate changes; lack of institutional innovations for increased productivity; and affordability of technology. As demonstrated by the chapter, ICT can play an important role in disseminating information to small-scale farmers on weather forecasts, selection of production technologies, and potential agricultural input and output prices. The authors assess various technologies available for small-scale farmers, in terms of their user-friendliness and affordability. These include sensors and actuators and wireless communication technologies. This is followed by a discussion on various techniques as well as instruments that can be used for data aggregation, which includes drones and agricultural vehicles and sensor platforms such as SmartFarmNet Sensor Cloud and IBM Bluemix. The authors also discuss the role of cloud computing in agriculture in areas such as farming automation, experience sharing, and computational and storage support. In discussing the role of ICT in automated agriculture, the authors focus on automatic irrigation, automatic fertilization, and precision agriculture. The chapter concludes by pointing out the challenges of ICT-based precision farming.

Chapter 9 in this part, entitled "Big Data for Smart Agriculture" by Nidhi Sinha, explores the role of big data in developing smart agriculture. As pointed out in this chapter, the aim of big data in agriculture is to procure the best possible raw material for farming to get the best possible output. As the chapter posits, big data in agriculture encompasses maps and data on physical and chemical properties of soils; records on past management practices; weather vagaries; yield-related information; and so on. By using such data, it has become easy to assess the impact of real-time events like sudden changes in operational conditions or other circumstances such as weather or disease. Using big data, farmers are able to make informed decisions regarding fuel, labor, fertilizers, pesticides, and soil and water conservation to achieve sustainable yields and quality of crops. As further pointed out in the chapter, the application of big data in agriculture is not only about production, but it also plays a significant role in improving the efficiency of the entire supply chain. As the chapter further notes, turning big data into compact, structured, manageable, and ready for use information in a specific decision-making context poses a great challenge. Since end users need robustness of the data in terms of the authenticity of sources, rigorous processing, and interoperability, a vast responsibility rests on ICT experts, data scientists, and domain experts. It also requires collaboration between different stakeholders having different roles in the data value chain, which is defined in the chapter.

Chapter 10 in this part, by Ahmad Latif Virk, Mehmood Ali Noor, Sajid Fiaz, Hafiz Athar Hussain, Muzammal Rehman, Muhammad Ahsan, and Wei Ma, entitled "Smart Farming: An Overview," discusses various aspects of the topic. As pointed out by the authors, smart farming mandates the integration of information and communication technology for better utilization of resources for sowing, irrigation, fertilizer, pesticide and herbicide application, and harvesting. The authors address all these aspects in the chapter. They begin with a discussion of replacing labor with automation, robotics, artificial intelligence, and machine learning. As discussed in the chapter, smart farming involves autonomous vehicles and robots operated through Global Positioning System (GPS) and connected through smart applications. The precise application of this technology along with Internet of Things (IoT) is likely to uplift farmers' living standards. Topics discussed include the use of such technology for driverless tractors; automatic watering and irrigation; crop health, weeding, and spraying; planting and sowing; seedbed preparation to reseeding; planting from the air; harvesting from the field; drones for fields; and yield analysis and mapping. The chapter concludes with a discussion on future challenges, opportunities, and prospects for smart farming. As pointed out by the authors, some of the impediments to smart farming include high cost, non-availability of Internet, and lack of knowledge about the technology among farmers. Furthermore, knowledge gaps regarding the application, efficiency, and workload of autonomous vehicles and drones are obstacles to smart farming.

Chapter 11 in this part, by Kheir Al-Kodmany, entitled "The Vertical Farm: Exploring Applications for Peri-urban Areas," reviews recent advances in greenhouse technologies, including hydroponics, aeroponics, and aquaponics and explains how they have provided a promising future for the vertical farm concept. The chapter argues that compact high-tech agriculture is not only applicable in dense urban areas but also in peri-urban areas. In order to demonstrate the applicability of vertical farms in a peri-urban area, the author presents examples that can be "inspirational" to peri-urban areas. As the author argues, pioneering projects in urban areas embrace advanced technologies and methods that are easily transferrable to peri-urban areas. The chapter argues that justifications of introducing the vertical farm to smart villages include responding to food security and climate change threat, reducing vehicle miles traveled (VMT), and improving health, economic, environmental, and ecological conditions. The lack of required technologies and technical expertise to implement the vertical farm remains an obstacle to such farming in the Global South. Finally, as pointed out by the author, the success of the vertical farm depends not only on innovation in technologies but also on local conditions including demand for certain types produce by population, availability of labor, farming conditions, and an effective organizational structure and sound leadership.

Chapter 12 in this part, by Antonio Santos Sánchez, Karla Patricia Oliveira-Esquerre, Idelfonso Bessa dos Reis Nogueira, Pieter deJong, and Adelmo Aguiar Filho, entitled "Water Loss Management Through Smart Water Systems," discusses various aspects of water loss management through smart water systems. The chapter first explains the various types of water loss in distribution systems and methods of managing such loss. These include sectorization, water audits, pressure management, and proactive leak detection programs. Ways to transition smart water systems are then discussed. The architecture and functionalities of a smart water network are then described with the aim of explaining how available technologies can increase resilience against extreme climate events, improve the asset management of water infrastructure, and operate the network efficiently to reduce leakages, pipe bursts, and energy waste. The authors finally review statistical tools and algorithms that allow efficient processing of data as smart water systems generate an incredible amount of data. As pointed out by the authors, rural areas can also implement smart water infrastructure, which is not likely to be more expensive than a traditional one. Although the initial costs of installing such systems can be higher, such costs could be recovered within a few months as a result of the reduction in leakages, pipe bursts, and energy waste.

Chapter 13 in this part, by Aziaz Faissal, Mourner El Achaby, Naaila Ouazzani, Jauad El Kharraz, and Laila Mandi, entitled "Rainwater Harvesting: A Challenging Strategy to Relieve Water Scarcity in Rural Areas", discusses various aspects of rainwater harvesting. The chapter discusses different types of storage systems, and the various aspects of tank design required for such systems are presented. The chapter then presents obstacles to developing such systems mainly using examples from Morocco. Technical aspects such as chemical or microbial contamination of reservoirs, factors leading to the revival of bacteria in a water reservoir, risks related to reservoir sediments, impact of reservoir conditions on the quality of stored water, and organoleptic quality of water are discussed. The chapter also discusses diseases related to stored water, measures to protect the quality of stored water, and use and maintenance of water storage systems.

The next chapter in this part, Chap. 14, by Asavari Devadiga entitled “Building Smart Water Communities: Technology and Institutions Toward Better Water,” focuses on water service for small communities located in the southern states of Karnataka and Telangana in India. The chapter demonstrates how a combination of technological and institutional aspects can bring reliable service for a better quality of living that is sustainable. The chapter begins with a discussion on the Indian context by presenting “100 Smart Cities Mission” in 2016 in India, which was followed by the announcement of the Shyama Prasad Mukherji Rurban Mission (SPMRM). SPMEM aimed at making villages smart and the future growth center of the nation and proposed 2500 Smart Villages by 2019. The chapter also presents goals of the *Saansad Adarsh Gram Yojna*, also referred to as the MPMVP. As argued by the author, creating a reliable water supply would involve more than a one-time deployment of a technological solution. Regular training and management of the individuals involved along with monitoring of the overall performance are critical for ensuring that the mechanism used continues to achieve reliable water. The chapter shows how a combination of technology and institutional aspects can create what the author defines as “smart water communities.”

The last chapter in this part, Chap. 15, by Monica Aspacher and BhuiyanAlam, entitled “Stormwater Best Management Practices: Green Infra-structure in Rural Communities,” synthesizes the extensive literature regarding storm water management in the USA, with an emphasis on green infrastructure and rural storm water management. After discussing the general history of storm water issues and management in the USA, the authors present various types of green infrastructure that are available for an eco-friendly solution to these issues. A case study of communities in rural Ohio provides useful insights into how green infrastructure is an effective and best method to manage storm water. The authors discuss various aspects of policy and planning for moving forward with implementing such infrastructure. They argue that the widespread character of storm water issues demands a collective, holistic effort from all levels of government. As pointed out by the authors, in rural USA, pollution from agricultural practices is perhaps the most significant source of water quality degradation. Green infrastructure can be an innovative and promising alternative to traditional storm water management methods, for managing such pollution. Although not explicitly discussed in the chapter, ICT plays an important role in operating green infrastructure for storm water management.

The next part of the book begins with Chap. 16 by Muhammad Mujahid Rafique and Shafiqur Rehman, entitled “Solar Electrification and Zero Energy Rural Communities”. The chapter focuses on encouraging people and governmental institutions to develop zero energy communities. After discussing Pakistan’s energy profile and solar energy potential, the authors present a simplified design procedure to size an off-grid photovoltaic system to fulfill the load demands of a household in particular and a group of houses in general. The basic off-grid PV system consists of PV modules, inverter, power backup storage system, and a charge controller.

As noted by the authors, the correct sizing and configuration of a PV system for household electrification are very important for a predefined load demand. The authors also estimate the lifecycle cost analysis of the PV system for single household application based on the available market prices in Pakistan and the inflation rate. Although the chapter uses Pakistan as a case study, the findings are applicable to other developing countries.

Chapter 17, by Anas Tallou, Ayoub Haouas, Mohammed Yasser Jamali, Khadija Atif, Faissal Aziz and Soumia Amir, entitled “Review on Cow Manure as Renewable Energy,” presents an overview on uses of cow manure and its importance in anaerobic digestion as a method of biological treatment of different organic waste in order to obtain biogas and biofertilizers. As pointed out by the authors, biogas plants are rising all over the world and can be a sustainable solution to protect our natural resources and afford renewable, clean, and cheap energy. As further pointed out by the authors, as the anaerobic digestion process is complicated, there is a need to be aware of the major environmental problems and seek new technologies to reach an environmental, industrial, and health balance. Although not explicitly discussed in the chapter, such technology has tremendous potential for the development of smart villages. This is especially true for rural India, where cow manure is abundant.

Chapter 18, the last chapter in this part, by Ahmad Farhad Talebi, Meisam Tabatabaei, Mortaza Aghbashlo, Soha Movahed, Masoumeh Hajjari, and Mahmoud Golabchi, entitled “Algae-Powered Buildings: A Strategy to Mitigate Climate Change and Move Toward Circular Economy,” reviews the current state of the microalgae-based bioinspired designs in the development of green architecture. The chapter provides insights into the current algae production technologies while looking into the possibilities of using algal cultivation systems in architectural designs. After reviewing green building regulations, especially in USA, the authors delve into a detailed discussion on algae-powered buildings. The authors then discuss the effects of various parameters such as light intensity, temperature, wind velocity, and nutrient concentrations on algae growth and yield. This is followed by a discussion on the cost and long-term benefits of green buildings. The authors then present smart bioenergy solutions for green buildings. As aptly pointed out by the authors, algae-powered buildings could serve as a multifunctional key to integrate smart villages with modern eco-friendly technologies and concepts such as renewable energy production, waste valorization, circular economy, zero discharge, and so on. Off-grid algal power stations could be specially designed to produce smart villages with electricity while supplying livestock with a quality feed.

Chapter 19, by Nilima R. Das, S. C. Ra, and Ajit K. Nayak, entitled “Scheduling Operations of Smart Appliances Using Demand Response,” is the first chapter in the last part. The chapter focuses on optimal load scheduling for energy cost minimization and peak load reduction. The authors propose a model that uses time-of-use (TOU) pricing tariffs in the optimization process. The chapter solves optimization with multiple optimization techniques including genetic algorithm (GA), particle swarm optimization (PSO), and a hybrid algorithm formed by combining GA and PSO. As pointed out by the authors, microgrids, powered by renewable energy resources, are considered to be an ideal technological solution to supply energy to rural areas. One of the main challenges facing distributed energy microgrid (DEM) designers is the intermittent nature and characteristic unpredictability of renewable sources. The unpredictability of demand in rural areas intensifies the problem. Various energy management techniques involving computational intelligence can be used to optimize demand and supply. Most rural energy consumers also have a very volatile day-to-day energy budget, thereby requiring careful consideration during the project planning to ensure that the consumers have the ability to stay within their daily budget. As there is a lack of advanced communication systems in rural areas of the Global South, the energy management programs may not use centralized controllers. Instead, machine learning techniques can be used in a distributed fashion to make demand forecasts of the household energy expenditure for the next day. Such forecasts can then be optimized to avoid overload situations and maintain a balance between user demands and the financial condition of the family.

The last chapter in the book, Chap. 20, by Angel Paniagua, entitled "Smart Villages in Depopulated Areas," discusses the policies and politics of smart villages in Europe. As pointed out by the author, the European rural development program (2014–2020) includes various measures to promote the development of intelligent and competitive rural areas. As discussed in the chapter, the development of smart villages in the European Union (EU) combines initiatives of several policies around rural revitalization through digital and social innovation. The goal is to improve services—such as health, social services, education, energy, transport, and retail—through ICT tools and community-led actions and projects. National strategies respond to three major processes of rural change taking place in Europe, namely rural depopulation, rural–urban divide, and digital transformation of rural areas. The chapter then focuses on strategies for the development of smart villages in depopulated Spain. As the author concludes, rural Europe has multiple disparities in spatial and social terms. Smart villages aim to overcome the urban–urban rural gap that is different in each country. It is important to design an adequate smart village that is place-specific based on the potential and enjoyment pattern of each region. The chapter raises an important issue in developing smart villages, namely the digital divide between urban and rural areas. As pointed out by the author, the digital divide consists of elements of social inequality between rural and urban communities and between peripheral areas and urban core on account of the differences in Internet access.

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Contents

Contributors

Mortaza Aghbashlo Department of Mechanical Engineering of Agricultural Machinery, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran

Muhammad Ahsan School of Computer Science and Technology, Beijing Institute of Technology, Beijing, People's Republic of China

Bhuiyan Alam University of Toledo, Toledo, USA

Kheir Al-Kodmany Department of Urban Planning and Policy, College of Urban Planning and Public Affairs, University of Illinois at Chicago, Chicago, IL, USA

Soumia Amir Interdisciplinary Laboratory of Research and Development, Sultan Moulay Slimane University of Beni Mellal, Beni-Mellal, Morocco

Monica Aspacher University of Toledo, Toledo, USA

Khadija Atif Interdisciplinary Laboratory of Research and Development, Sultan Moulay Slimane University of Beni Mellal, Beni-Mellal, Morocco

Faissal Aziz Laboratory of Hydrobiology, Ecotoxicology, Sanitation and Global Change (LHEAGC, URAC 33), Semlalia Faculty of Sciences, Marrakech, Morocco;
National Centre for Research and Study on Water and Energy (CNEREE), Cadi Ayyad University, Marrakech, Morocco

Alejandro Barragán-Ocaña Centro de Investigaciones Económicas, Administrativas y Sociales, Instituto Politécnico Nacional, Mexico City, Mexico

Reto Bürgin Institute of Geography and Center for Regional Economic Development, University of Bern, Bern, Switzerland

Sweta Byahut Auburn University, Auburn, USA

Nilima R. Das Faculty of Engineering and Technology, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar, India

Amanda Davies Rabdan Academy, Abu Dhabi, UAE

Asavari Devadiga University of California, Berkeley, USA

Mounir El Achaby Materials Science and Nanoengineering (MSN) Department, Mohammed 6 Polytechnic University (UM6P), Benguerir, Morocco

Jauad El-Kharraz Middle East Desalination Research Center (MEDRC) Water Research, Al Khuwair, Oman

Sajid Fiaz Department of Biochemistry, University of Okara, Okara, Pakistan

Adelmo Aguiar Filho Escola de Minas, Federal University of Ouro Preto, Ouro Preto, Brazil

Mahmoud Golabchi School of Architecture, University of Tehran, Tehran, Iran

Masoumeh Hajjari Biofuel Research Team (BRTeam), Karaj, Iran

Ayoub Haouas Interdisciplinary Laboratory of Research and Development, Sultan Moulay Slimane University of Beni Mellal, Beni-Mellal, Morocco

Hafiz Athar Hussain Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing, People's Republic of China

Saddam Hussain Department of Agronomy, University of Agriculture, Faisalabad, Pakistan

Mohammed Yasser Jamali Interdisciplinary Laboratory of Research and Development, Sultan Moulay Slimane University of Beni Mellal, Beni-Mellal, Morocco

Pieter de Jong Escola de Minas, Federal University of Ouro Preto, Ouro Preto, Brazil

Tej Karki Lovely Professional University, Jalandhar, Punjab, India;
Northeastern University, Boston, USA

Rama Rao Karri Petroleum and Chemical Engineering, Universiti Teknologi Brunei (UTB), Gadong, Brunei Darussalam

Wei Ma Institute of Crop Sciences, Chinese Academy of Agricultural Sciences, Key Laboratory of Crop Physiology and Ecology, Ministry of Agriculture, Beijing, People's Republic of China

Laila Mandi Laboratory of Hydrobiology, Ecotoxicology, Sanitation and Global Change (LHEAGC, URAC 33), Semlalia Faculty of Sciences, Marrakech, Morocco;
National Centre for Research and Study on Water and Energy (CNEREE), Cadi Ayyad University, Marrakech, Morocco

Heike Mayer Institute of Geography and Center for Regional Economic Development, University of Bern, Bern, Switzerland

Humberto Merritt Centro de Investigaciones Económicas, Administrativas y Sociales, Instituto Politécnico Nacional, Mexico City, Mexico

Mareike Meyn Andreas Hermes Akademie, Bonn, Germany

Jay Mittal Auburn University, Auburn, USA

Bhagyashree Mohanta Department of Computer Science and Engineering, Faculty of Engineering and Technology, SOA University, Bhubaneswar, Odisha, India

Sroojani Mohanty Department of Information Technology, IIMT, Bhubaneswar, Odisha, India

Soha Movahed Pars Art and Architecture University, Tehran, Iran

Pragyan Nanda Department of Information Technology, IIMT, Bhubaneswar, Odisha, India

Ajit K. Nayak Faculty of Engineering and Technology, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar, India

S. H. Shah Newaz School of Computing and Informatics, Universiti Teknologi Brunei (UTB), Gadong, Brunei Darussalam;
KAIST Institute for Information Technology Convergence, Yuseong-gu, Daejeon, South Korea

Nidhi Department of SMCA, FBS&H, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India

Mehmood Ali Noor Institute of Crop Sciences, Chinese Academy of Agricultural Sciences, Key Laboratory of Crop Physiology and Ecology, Ministry of Agriculture, Beijing, People's Republic of China

Karla Patricia Oliveira-Esquerre Escola de Minas, Federal University of Ouro Preto, Ouro Preto, Brazil

Naaila Ouazzani Laboratory of Hydrobiology, Ecotoxicology, Sanitation and Global Change (LHEAGC, URAC 33), Semlalia Faculty of Sciences, Marrakech, Morocco;
National Centre for Research and Study on Water and Energy (CNEREE), Cadi Ayyad University, Marrakech, Morocco

Angel Paniagua Csic, Instituto de Políticas Y Bienes Públicos, Departamento de Economía y Política, Group: Geografía Rural (GGR), Madrid, Spain

Srikanta Patnaik Department of Computer Science and Engineering, Faculty of Engineering and Technology, SOA University, Bhubaneswar, Odisha, India

Muhammad Mujahid Rafique King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

S. C. Rai Department of IT, Silicon Institute of Technology, Bhubaneswar, India

Muzammal Rehman School of Agriculture, Yunnan University, Kunming, People's Republic of China

Shafiqur Rehman Center for Engineering Research, Research Institute, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

Idelfonso Bessa dos Reis Nogueira Escola de Minas, Federal University of Ouro Preto, Ouro Preto, Brazil

Gerardo Reyes-Ruiz Centro de Investigaciones Económicas, Administrativas y Sociales, Instituto Politécnico Nacional, Mexico City, Mexico

Antonio Santos Sánchez Escola de Minas, Federal University of Ouro Preto, Ouro Preto, Brazil

Siddhartha Sen School of Architecture and Planning, Morgan State University, Baltimore, USA

Shahriar Shams Civil Engineering Programme Area, Universiti Teknologi Brunei (UTB), Gadong, Brunei Darussalam

Meisam Tabatabaei Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia;
Biofuel Research Team (BRTeam), Karaj, Iran;
Microbial Biotechnology Department, Agricultural Biotechnology Research Institute of Iran (ABRII), Agricultural Research, Extension, and Education Organization (AREEO), Karaj, Iran

Ahmad Farhad Talebi Genetic Department, Faculty of Biotechnology, Semnan University, Semnan, Iran

Anas Tallou Interdisciplinary Laboratory of Research and Development, Sultan Moulay Slimane University of Beni Mellal, Beni-Mellal, Morocco

Ahmad Latif Virk College of Agronomy and Biotechnology, China Agricultural University, Beijing, People's Republic of China

Part I
Smart Village Policy and Technology

Chapter 1
Smart Village Initiatives: An Overview

Sroojani Mohanty, Bhagyashree Mohanta, Pragyan Nanda, Siddhartha Sen and Srikanta Patnaik

Abstract This chapter postulates that a smart village is built on the philosophy of a self-sustaining ecosystem, one that is capable of adapting to changing governance regimes and generating resources in order to augment human development. Education, health, sanitation, information connectivity, electrification, establishment of cottage and small-scale industries, etc. are the critical dimensions of a 'smart village'. The entire globe today strives for a 'Sustainable Development' agenda that would include smart villages. As the chapter posits, rural-urban migration, and economic vulnerability stemming from unemployment could be prevented by rejuvenating rural infrastructure. The goal of this chapter is to discuss various smart village initiatives and technologies to improve the lives of people in the rural areas while respecting their local environment, beginning with the basic or first phase of development in which small technological initiatives can lead to healthier living.

Keywords Smart agriculture · Rural development · Migration · Employment · Food and water security · Renewable energy and sustainability

S. Mohanty · P. Nanda (✉)
Department of Information Technology, IIMT, Bhubaneswar, Odisha, India
e-mail: n.pragyan@gmail.com

B. Mohanta · S. Patnaik
Department of Computer Science and Engineering, Faculty of Engineering and Technology, SOA University, Bhubaneswar, Odisha, India
e-mail: patnaik_srikanta@yahoo.co.in

S. Sen
School of Architecture and Planning, Morgan State University, Baltimore, USA
e-mail: siddhartha.sen@morgan.edu

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1.1 Introduction

Smart village is the concept of developing a village to such an extent that it is self-dependent and self-sufficient to provide services. While talking about smart villages we not only focus on developing or maintaining the village environment for substantial use but we also tend to design such a scenario wherein the village starts to earn for itself. Today across the globe non-profit and developmental agencies like FASAF (Family and Schooling in Africa), UAPS (Union for African Population Study), UNESCO (United Nations Educational, Scientific Cultural Organisation), UNICEF (United Nations Children's Fund), USAID (United States Agency for International Development) and many others are striving hard to strengthen the living standards in the rural areas, and smart villages may be a solution.

People want to have a comfortable life with ample opportunities, and many factors force them to migrate to urban areas. Urban areas tend to have amenities that rural areas lack such as better social and cultural facilities, greater employment opportunities, and educational and other human services. The reasons behind mass migration from rural to urban are due to some of the following factors:

- Search for jobs in urban areas where opportunities of employment are high due to high industrialization in these areas.
- Low prices for agricultural products that lower the income for people living in rural areas since agriculture is their major source of income.
- Nature of the education system, i.e., institutions of higher learning are located in cities, forcing many of the youth to migrate to cities.
- Lack of security in some rural areas since mechanisms and institutions for security are concentrated in cities.
- Better healthcare facilities in urban areas.
- Wage gap between rural and urban areas; since many jobs in urban areas pay more than the same jobs in rural areas, people move to urban areas in search of higher wages.
- Less opportunity for banking and (Automated Teller Machines) ATMs.

While migration to urban areas may be a sign of development, modernisation and globalization, the question that arises is, if a large segment of the population moves away from the villages, then what will be left out there? Rural areas are full of natural resources and skills that need to be upgraded with technological support. These are the underlying assets of nature which are still underutilized. Technological interventions for rural development would create a sustainable livelihood. Technology is important as are investments in infrastructure, business development, human capital, capacity, and community building. A smart village normally aims to develop e-literacy skills, access to e-health and other basic services, innovative solutions for environmental concerns, circular economy application to agricultural waste, promotion of local products supported by technology and Information and Communication Technology (ICT), implementing and taking full benefit of smart specialisation agro-food projects, tourism and cultural activities, etc. This chapter attempts to provide an overview of smart village initiatives from a technical standpoint as well as implementation aspects along with various potential application areas such as agriculture, health, infrastructure planning, and lifestyle. This chapter also discusses some of the technological needs and managerial issues that are essential for the development of successful smart villages. Although a plethora of literature is available on smart cities [14, 21, 22, 27, 28, 37] not much exists on the overall idea of the smart village initiatives and current trends (for exceptions, see for example [15, 39, 41]). This chapter will provide a strong foundation for researchers who are beginning their research. It will also serve as a quick reference for recent trends and progress in the field for project developers, academicians, and policy makers working on various smart village initiatives for the betterment of rural people. The chapter is organized as follows: Section 1.2 discusses the technological adoptions in different application areas, Sect. 1.3 discusses managerial implications of various recent initiatives, Sect. 1.4 presents various technological requirements and technologies, Sect. 1.5 gives an overview of the application sectors and Sect. 1.6 concludes the chapter.

1.2 Technologies to be Adopted in Various Application Areas

- Smart Agriculture
  - IoT (Internet of Things)—smart cameras, web-based sensors, actuators, drones, robots and other advanced agro devices can be used to automate the decision-making mechanism.
  - Big Data Technology—It can be used for raw material production. Such technology aims at procuring the best possible raw materials in farming which will thereby give the best possible results.
- Electrification through Sustainable Development (Solar Panels or Grids)
  - Solar panels can be built on roofs with suitable storage spaces for preserving solar power in order to generate electricity.
  - Solar-powered street lights can be employed to illuminate village roads.
- Smart Transportation System
  - Availing smart and quick mobility.
  - Improvised transportation and logistics infrastructures connect the rural areas with urban areas.
- Smart Health and Education
  - Embedding digitally equipped classes.
  - Smart educational services focusing on secondary or higher education.

- Spreading awareness through smart health education, accessibility to e-health services focusing more on infants and maternity care hygiene.

- Growing Information and Communication Network
  - Extended implementation of broadband systems.
  - Focusing on digital education of rural masses.
- Renewable Energy
  - Generating renewable energy through biogas technology.
  - Cow manure can be used as a source for extracting fuel and energy.

1.3 Managerial Implication

- Proper Social Education and Empowerment
  - Employment of local self-governance can assure basic amenities and responsible individuals and community to build a happy society.
  - Empowering the village population through participation.
- Encouraging Entrepreneurial Activities
  - Defining novel business models and imparting knowledge to strengthen the potential for development.
  - Encouragement of small-scale developmental activities to be done in-house.
  - Adaption of web-based service providing for developmental activities.
  - Evolution of new agricultural value chains.
  - Promotion of new cottage and small-scale business frameworks.
- Encouraging Tourism and Cultural Activities
  - Stimulating employment and investments in the tourism sector.
- Water Management
  - Providing safe drinking water facilities through reverse osmosis-based water plants.
  - Conserving water through rain water harvesting systems.
- Enhancement of Sanitation Conditions
  - Smart waste management systems.
  - Adopting advanced toiletry systems for hygiene.
  - Spreading awareness of hygiene, basic toiletry items and their usage.

Although there is a lack of technological advancement in the rural areas, immense amounts of other natural resources are available that can be utilized by the intervention of technology to become assets. This includes green fields, plenty of water resources (rivers, channels, lakes, and ponds), livestock, nature's abundant meadows and a variety of species of flora and fauna which together can make life soothing. What is needed is some planning coordinated by minimal technological advancement. Rural areas have large abundant fields that can be used for agricultural development. Growing more crops through technological intervention would definitely create a difference in the village lives. Free land cannot be used for agriculture unless it is equipped with proper irrigation. So using different agricultural machineries and technology can help make the land fertile and ready for different types of crops. Including artificial intelligence techniques to help agricultural activities would further strengthen agricultural production. As is well known, the backbone of every country is its food inventory. Hence, technology and science should and must be infused into food production for efficient utilization of agricultural resources. IoT—i.e. using a smart web of sensors, actuators, cameras, drones, and other agro devices to have an automated decision making mechanism—are likely to increase food production [36].

Using the benefits of big data technologies in raw material production is another means of improving agricultural production. The aim of big data technology in agriculture is to procure the best possible raw material in farming which will thereby give the best possible output. Including GPS (Global Positioning System) in farming can boost harvesting by maximizing yield. For example, it is vital to measure the exact spacing of the seed in the soil for suitable growth. GPS can be used in multiple agricultural activities such as identifying agro-machinery direction, distinguishing suitable areas for cultivation, identifying machine location, soil property mapping, yield mapping, finding proper availability of water resources, meteorological mapping, tractor guidance, field mapping, etc. Implementation of ICTs in educating the rural masses by using a diversified set of technologies and other various resourceful tools can create massive diversification in rural areas. Learning is something that should be a steady and continuous process. The development of a smart village is not possible without proper guidance and knowledge of how and where to use advanced technical tools. We can only say that the village has turned into a smart one when the people living there have the knowledge and skills to utilize the digital tools provided. A knowledgeable society enables developing a smart ambiance.

The continuous use of fossil fuels is destroying the ozone layer and also depleting it on a large scale. Villages are blessed with an abundance of livestock that secretes huge quantities of organic waste. Many scientific and technological aspects are available to turn these organic wastes into renewable energy and fertilizers. Bio-gas utilization is a familiar concept taught in school, but to what extent is it actually used? These techniques used to extract energy and bio-fertilizers not only help reduce resource depletion, but they are also environmentally friendly and less expensive means of energy production. While discussing sustainable development we should focus on smart rural electrification. Generating electricity from solar energy with the help of solar panels adds to the formation of smart electricity systems for the rural life. Electrifying the spaces with solar energy with the help of solar panels will boost the livelihood of rural areas. Furthermore solar street lights can be embedded with sensors that detect the sunrise, sunset and temperature change while functioning automatically. The high hills, mountains, and other geographical advantages can be utilized to extract energy from the wind with the technological intervention.

The demand for water has always been rising due to the scarcity of drinking water reservoirs. Many areas throughout the world face difficulties in gathering safe drinking water due to drought and pollution. This has subsequently raised the demand for reserving rain water in safe traditional reservoirs, which is called rain water harvesting. A popular water purifying technology called RO (Reverse Osmosis) is used to refine water by removing ions and other hazardous particles from it, thereby converting it to a pure, drinkable state. Studies have stated that about 60% of the diseases in rural areas are water borne [20]. Many more concepts related to smart water management like sectorization, water audits, pressure management, and leakage detection using IoT and artificial intelligence are further discussed in this chapter.

Health and Education are the most imperative factions of society to be addressed. Technological advancement in these areas should be vigorous and consistent, starting from smart or digitally equipped classes to focusing on higher standards of education. E-learning techniques for farmers can help solve their online queries while in the fields. We have educated masses living together, who can by themselves contribute to the development of smart villages. Proper systematic education along with practical exposure will help enhance the skill sets of the people, thereby reducing the need to migrate towards urban areas. New technologies like m-health, telemedicine/tele-health, e-health services, smart health education and prioritizing infants and maternity care hygiene are an integral part of a smart village.

Humans tend to stay and build livelihoods where they feel secure to live and construct a life. When discussing other developmental aspects like health, education, agriculture, energy and sustainable development, we also have to include a secure and safe society. Inhabitants need to be free from worries about crime, such as theft, burglaries, etc. Building banks (financial security), police stations, e-governance bodies, and deploying CCTV cameras would help with smooth functioning of the day to day lives of the people by safeguarding their lives. Embedding smart sensors in various infrastructures can alert the villagers about the lifespan of the houses and bridges to prevent the occurrence of any disaster and keep the villagers safe [23].

Generating services or creating jobs in the rural areas of the Global South would help improve the economic lives of people. When people living in rural areas are economically better off, they may not seek help from urban sources. In developing a smart village we need to focus on varied areas like education, health, building financial institution, etc. However, the most vital source of income lies in agriculture, poultry, fisheries, and dairy farming and nursery houses. Apart from these the beautiful landscape—that includes meadows, valleys, waterfalls, tall hills and mountains, lustrous green fields and the varied natural species of birds and animals —can encourage tourism and act as a cultural platform to attract outsiders for recreation. The other way of getting economic stability is through entrepreneurial activities. Small-scale industries and handmade products like food products and handicrafts should be encouraged. There are ample amounts of small- and medium-scale industrial schemes and benefits from most governments that should be taken into account. Service industries like web-based or online ordering services, travel services, new cottage industries, and small-scale businesses can improve the economic standards of the rural masses.

Smart villages today must be a priority as human lives are becoming more sophisticated and transformed. Mere discussion and studies will not make any difference until policies are deployed, monitored, and executed. The majority of the world's population still lives in villages. In many countries in the Global South more than 70% of the population resides in villages: Sri Lanka (82%), Nepal (80%), Burundi (87%), Kenya (73%), Malawi (83%), Rwanda (83%), Samoa (82%), Micronesia (77%), Cambodia (77%), Chad (77%), Papua New Guinea (87%), Tonga (77%), Tajikistan (73%), Solomon Islands (76%), Uganda (76%), Ethiopia (79%), Eswatini (76%), Afghanistan (75%), Vanuatu (75%) and St. Lucia (81%) [34]. Development of smart villages in such countries can boost their economy and stem migration. Similarly development of smart villages in the Global North can resolve the issue of depopulation that is taking place in such areas.

1.4 Technological Requirements

Development of rural areas has now become important for improving overall economic growth. Although villages have their own lifestyle and cultures, they still have their day-to-day basic needs and pose many risks related to health and hygiene. These risks are supposed to be addressed for the realization of the smart village concept. As previously discussed, smart villages will be providing long-term welfare activities for social and environmental as well as economic aspects of village communities. Moreover, the focus will be on building resilient communities by enhancing local governance and empowerment, as well as promoting entrepreneurship. Again the smart village concept must ensure development of better infrastructures to avail other facilities such as clean drinking water, hygiene in sanitation facilities, good health and education, efficient resource utilization, environmental protection, waste management and renewable energy management systems along with economic growth. However, to attain this state of developing smart villages, initiatives are being taken worldwide by applying various integrated approaches to connect the villages to the outside world as well as to the government and private sectors. Now, in order to realize this concept of sustainable smart villages, many challenges are being addressed while installing decentralized infrastructures.

Thus, traditional villages must be transformed into smart villages to address the aforementioned risks and challenges. This transformation should take place in terms of physical appearance, solving environmental issues, availing social life facilities and connecting villagers to governance for smart administration along with economic growth while retaining some traditional features required for a healthy and happy life. During this transformation process, solution building, planning and awareness among villagers must be considered. The transformation of existing villages into smart villages revolves around adaption of technologies such IoT, ICT), Geographic Information Systems (GIS), Cloud Technology and Big Data. These technologies form different layers in the base structure of the smart solutions for the smart village, which are further integrated through secured interfaces to worldwide applications such as smart agriculture, smart transportation, smart governance, smart health, and smart education. The underlying technologies forming the foundation of these solutions are discussed below.

1.4.1 Internet of Things (IoT)

IoT comprises a worldwide dynamic network with billions of objects with self-configuring capabilities, connected through the internet and interacting with end-users in the physical environment. End-users interact with these objects (also known as smart objects) through various application-based services. These interactions are responsible for controlling the actions of the objects by exchange of states and associated information between the end-user and the smart objects. This exchange of information is attained through integration of both physical and virtual things into smart interfaces with interoperable communication protocols. Unlike the physical things, the virtual things possess attributes and identities which make them distinguishable over the network. These objects or things can be of any form from garbage bins to soil and water tanks. These objects are embedded with intelligent sensors and smart mechanisms that can help in timely decision making [45].

For example, in smart villages, the irrigation management system can measure the humidity in the climate and moisture in the soil to interact with the water reservoir and request to initiate an irrigation process in a timely manner. Another example involves the waste management system installed in smart villages. The trash bins can be embedded with sensors that can measure and compare the current weight of the bin with the pre-defined weight and interact with trucks once the predefined level of load is reached for clearance. This will reduce the time and cost of the management system and improve efficiency. In the above discussed examples, the underlying framework is that of IoT, connected to the end objects as well as the control interface-based software responsible for the interactions. Thus, IoT can form the building block of smart villages that can integrate various devices into Cyber Physical Systems [9, 19].

1.4.2 Information and Communication Technology (ICT)

ICT is the underlying technology that supports the activities and interactions discussed above through certain processes defined for all objects. These processes involve gathering of data, storing, and processing of the data into information. Further, it involves communication of information among the physical and virtual objects in a collaborative manner. ICT is considered as the driving force behind the fulfilment of smart villages. Use of ICT is essential to involve local villagers in management processes by enhancing their awareness to increase employment and implement an e-governance-based administration which will upgrade the standard of living of villagers while maintaining transparency in the system.

1.4.3 Radio Frequency Identification (RFID)

The next technology adopted by the smart village system is the Radio Frequency Identification (RFID) technique that assigns tags to the objects and devices for identification. These tags use radio frequencies to identify different entities by transmitting information. Then the RFID reader is used to read the information which can be further utilized by the system. The use of RFID tags on physical entities over a distributed network can take the form of an IoT-based ecosystem with the tag and reader communicating with other tags and readers over the network at certain radio frequencies. In the previously discussed instances, RFID tags can be attached to the water tanks, trash bins and trucks that can transmit information about their current status and location.

1.4.4 Geography Information System (GIS)

GIS comprises a collection of hardware and software that captures geographic data efficiently, stores it for analysis and displays as per requirement. GIS plays a significant role in the creation of smart villages by utilizing geo-spatial data generated by various techniques. Geo-spatial data helps in distinguishing villages by defining their boundaries in digitized maps. GIS detects settlement locations and digitally maps the physical coordinates into virtual settings at fine scale. Again, GIS-based maps provide additional dimensions in analysing the satellite data at the micro-level to visualize real-time planning to identify villages that lack basic infrastructures, unused lands, availability of resources, and so on. Further, micro-level digitized mapping focuses on other utility facilities such as road construction, drinking water facilities, drainage and sewage systems, electricity distribution and construction of residential sectors. GIS-based planning of smart villages can help in identifying alternative options and their potential impacts when required. Also, once the objects, resources and utility facilities are mapped, social indicators can be monitored by change analysis support. Then, next action plan maps can be prepared to support sustainability. Since, the smart village-related information available in GIS-based web services is in the form of maps and statistics, planners and decision makers can easily handle it and act accordingly.

1.4.5 Global Positioning System (GPS)

GPS is a radio navigation system spread worldwide which has been formed from a constellation of satellites and their ground stations. It determines the accurate geodetic position and altitude on the earth's surface. This technology can help in collecting comprehensive information about cattle as well as other objects and keep track of those cattle [6].

1.4.6 Remote Sensing (RS)

The Remote Sensing method involves extracting information about various objects on earth without being in direct contact with the object, i.e., collecting geo-spatial data from sensors and other remote devices to be used for analysis. Some of the commonly involved processes are data acquisition, satellite image interpretations, classification, cage detection, visualization, simulation and terrain analysis and, finally, map generation. Remote sensing is beneficial in many smart village applications such as sensing moisture of soil, condition assessment of farms, classification of farms, monitoring compliance of agricultural lands and so on.

1.4.7 Wireless Sensor Network (WSN)

A Wireless Sensor Network (WSN) consists of a network with sensors which act as a storage cum transmitter for acquisition of data and further transmission [33]. Sensors are comprised of wireless transceivers, CPU, memory and battery integrated together. Individually, each sensor has limited bandwidth, energy, computation capability, storage and bandwidth. However, collectively numerous sensor nodes form a WSN from which the sensors collect data from the environment and transmit it to a sink node. This sink node receives the collected data and transmits it further to end-users or applications as designed. WSNs are useful in many applications such as environmental, climate, structural and agricultural monitoring; waste management applications; health monitoring; and security-based operations that are essential for the development of smart villages [5, 8, 17, 18, 31, 42].

1.4.8 Cloud Computing

Cloud Computing is a type of computational method based on the internet that enables on-demand sharing of hardware and software. The end-users are not required to know about the underlying technique; they only use it dynamically.

Cloud computing provides various IT services and software as well as storage places to end users. Cloud storage dynamically allots storage over the internet to end-users, on-demand whenever required. Again, cloud storage can be accessed from anywhere in the world. The data collected via WSNs using sensors, RFID tags, surveillance cameras and other remote devices can be directly stored in cloud storage systems. It can then be accessed and processed from any place all over the world using various Big Data analytics tools. In other words, it provides rapid elastic on-demand storage as well as computational services to the user by enabling new ways of exchanging and using dynamic IT services. Also, cloud computing-based databases will allow monitoring and managing of information regarding specific processes to measure plant productivity through tracing farm production and automatic analysis of performance of plants, problems and defects. They can also enhance security of the farm products by regular monitoring [2, 26, 46].

1.5 Applications in Smart Village Technology

1.5.1 Smart Agriculture System

To have a robust agriculture or cultivation, a few parameters need to be considered. These include proper irrigation systems, high-quality fertilizers and manure for the growth of crops, and protection of crops from insects and pests through the use of pesticides. These are some of the parameters upon which agriculture is dependent. Most importantly the fertility of the soil needs to be calculated for any type of crop that is being planted. So, to understand these parameters IoT is a new emerging technology which is helping in governing or determining the exact value or impact of these parameters on a particular land for healthy production [1].

The agricultural productivity mostly depends on smart and efficient irrigation systems. Advanced interactive irrigation systems comprise smart irrigation scheduling which will prevent the wastage of water. These systems control and monitor various parameters that are derived or extracted from the agricultural land such as humidity, water level in soil, temperature, etc. without human intervention. According to the value of each parameter that is generated automatically by sensing the soil moisture and weather condition, the irrigation of the roots of various plants is done either by scheduling the water supply directly onto the root zone or indirectly onto the soil surface. The entire process is done through a composite network of valves combined with pipes, tubes and emitters through which water wastage is minimized and water resources are optimized. Smart drip irrigation systems are useful for farmers because they facilitate resource optimization and minimization of water wastage [10, 12, 13, 30, 38].

Similarly, smart agriculture systems based on IoT concepts comprise different sensors such as a temperature sensor, moisture sensor, water level sensor, DC motor and GPRS module. When the system starts, different sensors monitor the value of different parameters by sensing automatically and send the recorded value with an alert message to the remote controller system like mobile device etc. When these values deviate, the actuators automatically start their process. For example, if the water level goes down the drip irrigation process will automatically start. If the temperature level goes high, the fan starts and so on. Through this system farmers can schedule the application of fertilizers and pesticides according to the requirement of the crop that is going to yield. One can remotely set the temperature value and forcefully stop the water supply based on the type of crop cultivated [29].

Similar to crop monitoring, cattle monitoring and management can be achieved by IoT-based agricultural sensors embedded in collar tags which can deliver body temperature, health conditions, activity data, and nutrition insights for each individual cow as well as collective information about the health status of the entire herd [32] (Fig. 1.1).

1.5.2 Smart Waste Management System

Waste management is a primary and necessary concept in smart and healthy village planning. If the surroundings of human beings can be kept clean, then it can be easier to develop a healthier society. Figure 1.2 is a basic block diagram of an IoT-based smart waste management system. In this concept smart bins fitted with ultrasonic sensors are located in different places of the locality. These wireless sensors sense and monitor the bin status, collect data at every instant, and then signal the control centre through the cloud platform. These sensors are powered by the solar powered systems. The waste management web portal is responsible for monitoring and controlling the wastes in the bin through a centralized main controller [25, 43, 44].

If not properly managed or handled, the waste management techniques can lead to serious environmental problems, and operating costs may increase. An optimized route schedules waste collections from bins to reduce fuel costs. The bin truck collects the wastes from the bins whose waste level status exceeds 80% and the GPS systems directs the bin truck to reach the destination with the shortest route coverage, saving time and money (Fig. 1.3).

1.5.3 Smart Water Management System

Water is essential for daily household activities. Figure 1.4 depicts how to manage and plan the usage of water using an IoT concept. The “Water Scarcity” can efficiently be managed by this concept to solve the life-threatening problems in various aspects of daily life through smart, automated and predictable management services. In this concept, sensors are fitted in different water sources and storage reservoirs such as lakes, dams, canals, water tanks at houses, etc. Sensors fitted at different water sources send data about the water level in the tank at intervals;

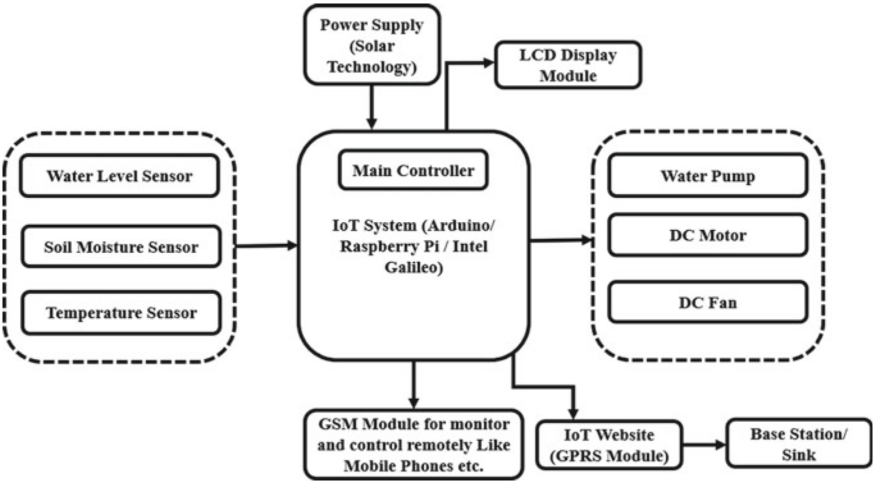

Fig. 1.1 Block diagram of IoT-based smart agriculture system

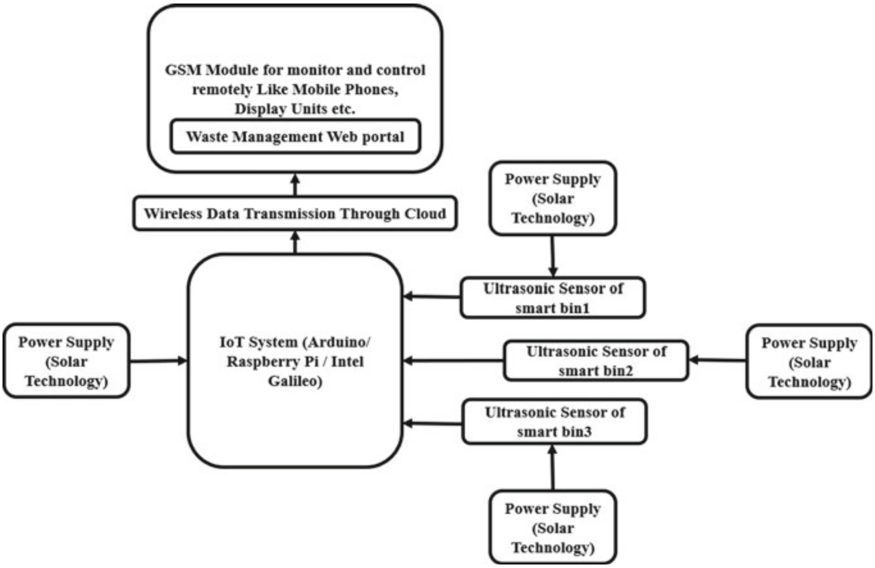

Fig. 1.2 Block diagram of IoT-based smart waste management system

according to that data the motor can be controlled remotely to manage wastage and lack of water in daily needs.

The sensors placed in the water reservoir can help predict the future water requirement. The sensed data is then uploaded and updated in the cloud platform. Based on the data, water is supplied from the reservoir to the water storage tank of

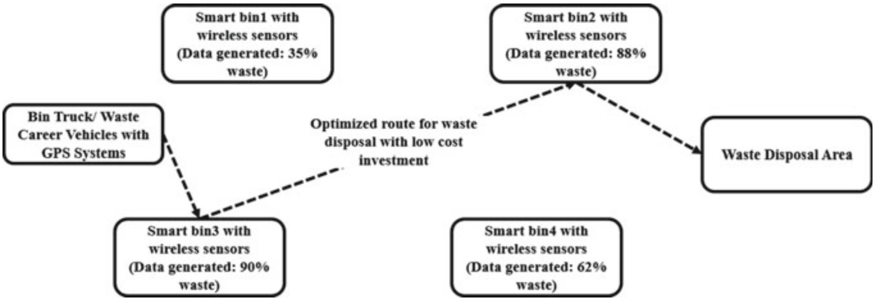

Fig. 1.3 Smart optimized waste collection technique

the locality. From that storage tank water is supplied to each household during scheduled time intervals per day. The timely water supply to each household and emergency supply of water can be achieved with this technology to avoid any unfavourable weather conditions [26, 35].

1.5.4 Smart Health Monitoring System

A change in lifestyle and food habits leads to different diseases. An increase in population and their immediate medical requirements generates gaps in medical science. So, introduction of IoT concepts in medical science eases the healthcare complexity with the least effort. The introduction of highly advanced wireless sensor networks and embedded systems reveals a new platform for health monitoring systems. The IoT sensor can sense a sudden decline in a patient's health through a wearable interface and immediately transmit that sensed data to the respective health centre and to the ambulance for immediate action. When that ambulance is on its way to pick up the patient, the person's medical records are available at the same time to the doctors and nurses. Thus, the medical records are ready before the patient reaches the hospital. When the patient arrives, treatment can be started, thereby saving time and lives [7, 11, 24].

In this concept, RFID (radio frequency identification) technology is used for data storage and transfer using radio frequency wave and EMR (Electronic Medical Record). This is a digital form of the medical record, by which a registered user is able to access the patient's health care information and so that his/her assigned doctor is able to monitor the reports remotely, anytime and anyplace. The cloud computing for efficient data storage and retrieval, wearable devices for health data generation and wireless sensors responsible for data generation and transfer to the nearby base station influence the medical services in a better and more accurate way.

The data collected by the wearable sensors like pulse rate, oxygen level, body temperature, etc. are stored in the cloud and used by the doctors and the patient

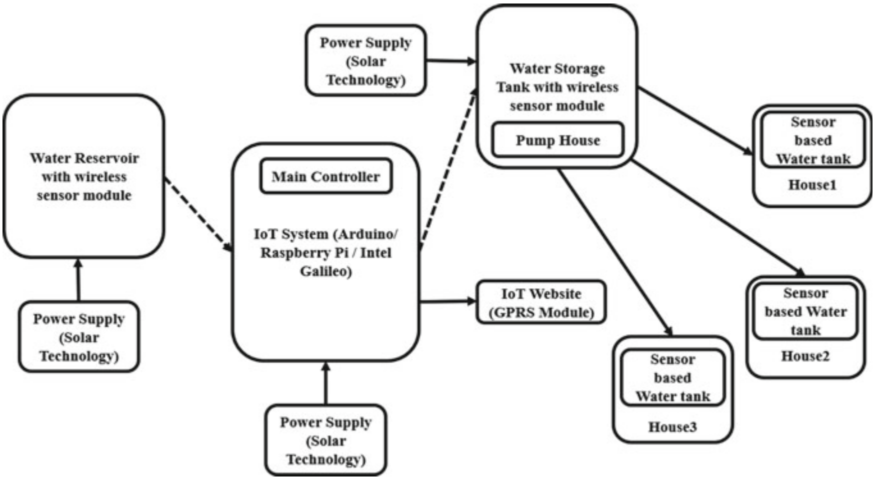

Fig. 1.4 Block diagram of smart water management system

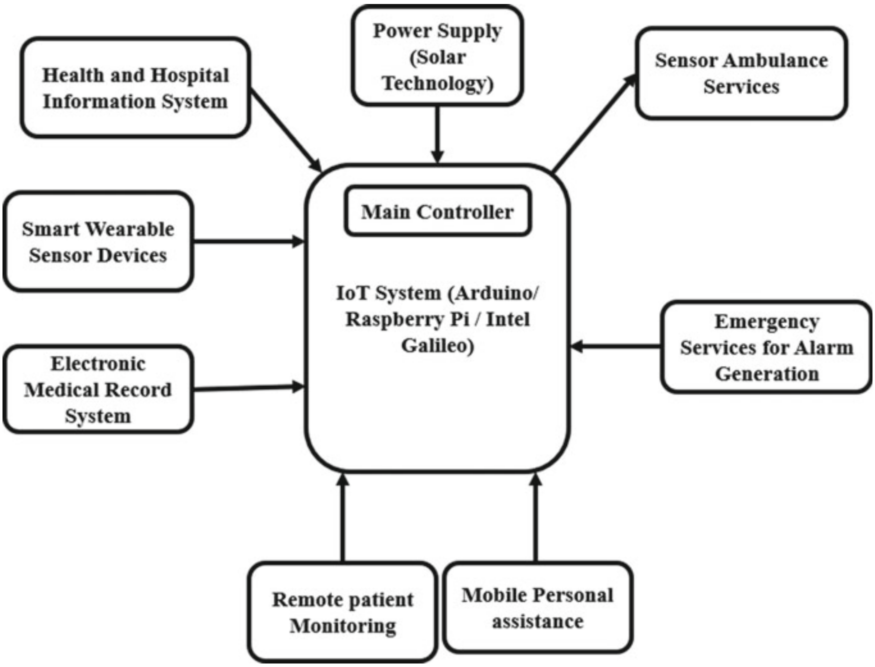

Fig. 1.5 Block diagram of smart health monitoring system

whenever needed. At the time of the emergency the sensors sent the alarm to the hospital and the ambulance so that immediate procedures can be initiated [4, 16] (Fig. 1.5).

1.5.5 Smart Energy Management System

Energy management is the process of controlling wastage of electricity or energy, monitoring the efficient use of energy, and energy conservation by the use of green energy system like solar power. The strategy of efficient usage and optimization of energy by using wireless sensors, IoT devices, solar panels, energy storage grid house, etc. are the key parameters of smart energy management systems.

The encouragement of the installation of solar panels in individual houses can be beneficial for both the users and the government. Solar panels store solar energy and one can utilize it for daily use and also sell the unused or extra energy to the government. Sensors placed in the solar panels can sense the weather condition and according to that control the usage of electricity so as to prevent unnecessary loss of energy. The smart street lights can also be controlled by the above concept remotely and without human intervention which can reduce the crime rate in smart villages [40] (Fig. 1.6).

1.5.6 Smart Education System

Education is essential for the growth of a smart, healthy, secure and developing society. In the tech-friendly world people need to be educated technically. So, smart education is must in every educational medium. An IoT-based education system is focused on an interactive and interesting education medium. Education presented in an interesting way like video games and lectures attracts students to learn in an interactive manner rather than traditional classroom teaching from textbooks. Video-conferencing and video-gaming are two examples of smart education in villages. The introduction of learning tablets in *Aanganwadi Shiksha Kendra*[1] and in primary schools in India to teach students is essential for developing smart villages. Providing internet and projector teaching facilities to high school students and arranging lessons or classes from highly qualified and renowned personnel through video conferencing will encourage the village children to go to school and pursue their education.

In Fig. 1.7, the recorder station depicts the module where the video lectures are recorded and stored in the cloud. When the schedule for the video lecture arrives, then the data is transmitted automatically from the cloud to the destination or educational institution and delivered via projector in the classrooms. The broadcasting of the lecture can be monitored and remotely controlled through GSM modules like mobile devices, tablets, laptops, PCs, etc.

[1]These are rural child care centers in India. They were introduced by the Indian Central Government in 1975 as a part of the Integrated Child Development Services Program initiated to eradicate malnutrition and hunger among children.

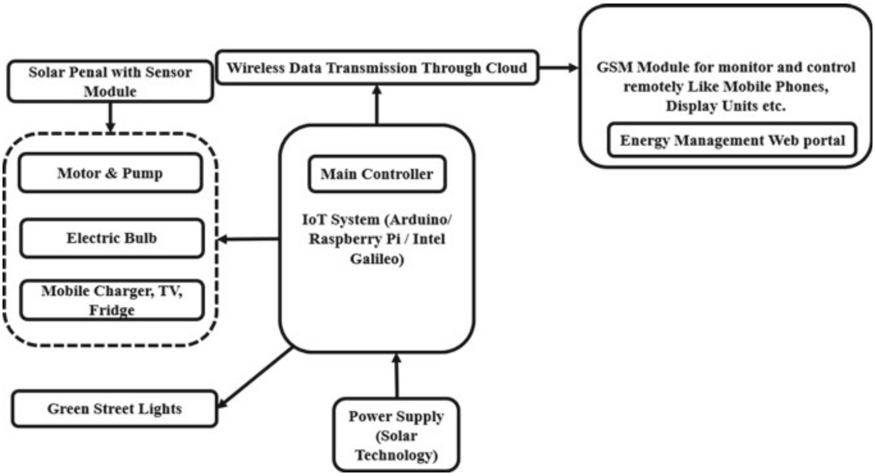

Fig. 1.6 Block diagram of smart energy management system

1.5.7 Smart Safety System

Being smart in every field is desirable but safety in each field is a necessity. Traffic signal and surveillance system analysis and emergency police protection system analysis are the two crucial categories of a smart safety system. A smart safety system might implement surveillance cameras at traffic signals/posts and wide-ranging surveillance cameras to cover maximum geographical areas to monitor any illegal activities. These monitored data are stored in the cloud and transmitted to the nearest police hub or base station, special juvenile police units, Police Control Room (PCR) vans, etc., where these data are examined thoroughly to detect suspicious activities. This data helps trigger the investigation and protection process. Figure 1.8 depicts the overall process flow of a smart safety system in the smart village context.

1.5.8 Smart Environment and Climate System

The impact of climate change on agriculture, associated landscapes and natural resources in general is crucial for the developmental aspects that increase the adaptability against climate change. The climate smart village concept involves implementation of various technologies and practices to target different aspects of livelihood security, adaptation, and sustainable development. Weather wireless sensors monitor barometric pressure, solar radiation, wind speed, wind direction, humidity, and temperature data. These data are stored in the cloud and transmitted to the base station or weather stations for further analysis, which are useful to alert villagers before any critical unfavourable adverse situation or any disasters occur [3] (Fig. 1.9).

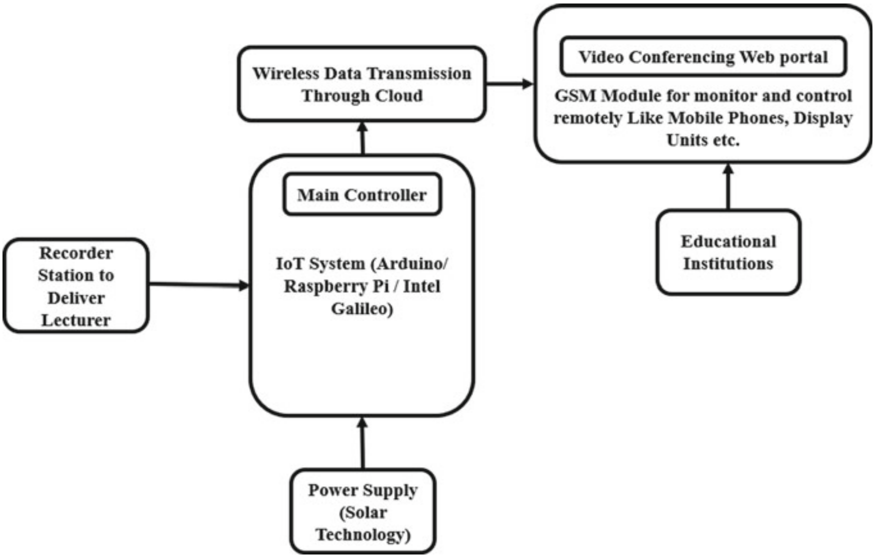

Fig. 1.7 Block diagram of smart education system

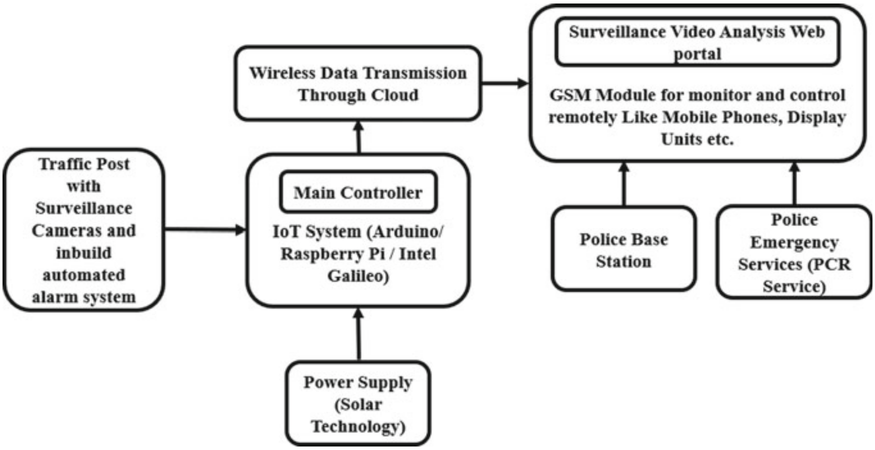

Fig. 1.8 Block diagram of smart safety system

1.5.9 Smart E-governance System

A good governance system comprises better administration, better interaction, less corruption and more transparency in the government. It gives the facility to the citizens to benefit from the services provided by the government. Establishment of

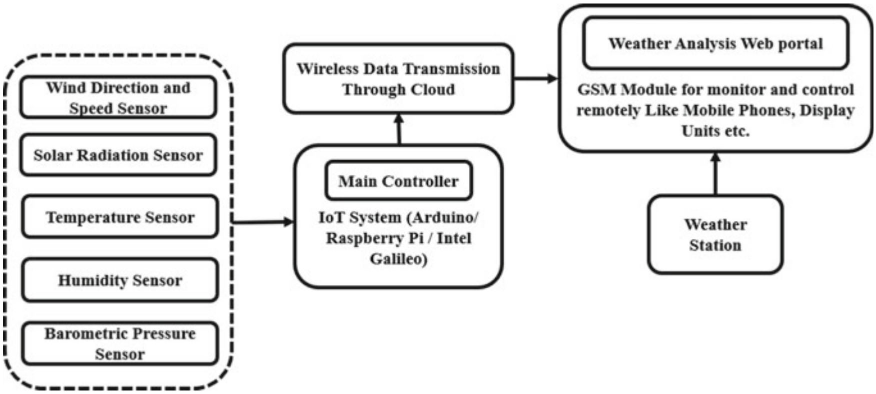

Fig. 1.9 Block diagram of smart environment and climate system

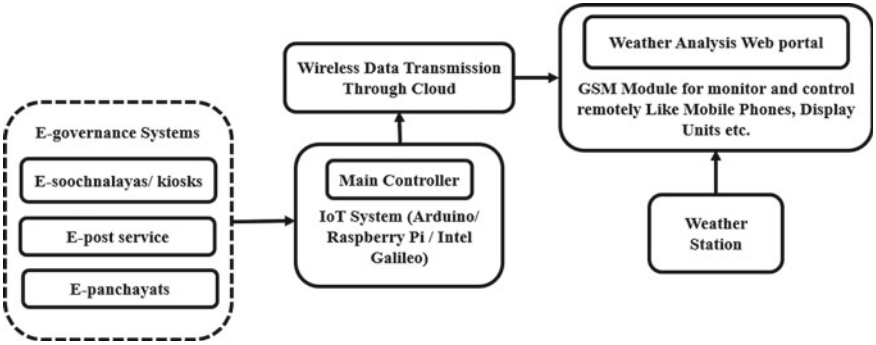

Fig. 1.10 Block diagram of smart E-governance system

different *soochnalayas*,[2] e-posts, e-*panchayats*, etc. in the villages help the villagers to get information about their farming lands and about any schemes that the government launches for the farmers through e- *soochnalayas*/kiosks; E-post service was launched by the secretary of the Department of Posts. The service facilitates the citizens sending messages anywhere in India. *Panchayats* are a local village-based elected self-government in India. The *e-panchayat* was initiated to collect all the information about the village and save it for future reference (Fig. 1.10).

[2]These are rural information kiosks that provide ICT services.

1.6 Conclusion

Recently smart village initiatives are being considered by countries all over the world. The main objective of developing smart villages is establishing a smart and sustainable environment in the villages to contribute towards global economic growth. Various sectors in villages receiving attention to accomplish this include education, agriculture, healthcare, food and clean drinking water, sanitation, transportation and e-governance. Some critical obstacles and challenges faced during the implementation phases are the absence of high-end technologies in villages, access to high speed internet, lack of proper administration, lack of infrastructures, lack of awareness among villagers, and so on. In such a scenario IoT and ICT can form the backbone of the entire system and the rest of the layers can be developed over this framework. More initiatives should be undertaken by the government as well as private sectors for faster realization of the smart villages. However, empowerment and citizen participation are important aspects in the development of smart villages. Technology alone cannot lead to development of smart villages. We need to come together and focus on the various human and technical attributes that aid towards the development of a village into a smart village. This chapter is crucial for all the project developers, engineers, academicians, policy makers, researchers and younger generation to understand, empathise and undertake measures in order to enhance the life of the rural population.

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Chapter 2
IOT, Smart Technologies, Smart Policing: The Impact for Rural Communities

Amanda Davies

Abstract Globally policing agencies are scaffolding on the capabilities of the IOT to enhance predictive and responsive approaches to criminal activity in the pursuit of establishing and maintaining safe communities. The availability of a variety of technologies ranging from sophisticated drones, global positioning systems and artificial intelligence programs to more publicly overt systems as body worn cameras and CCTV is increasing the impact of policing initiatives. Whilst the IOT is enabling the collection of 'big data' and realising improved policing response to crime through application of a predictive policing model approach—this is only the beginning of the journey in understanding the potential of the IOT to enable smarter policing directions. The following chapter offers insight into the potential application of the IOT and smart technologies to build safe communities. The connectivity between smart technologies, the IOT and smart policing strategies on the future 'liveability' quality for rural populations isdiscussed. The chapter offers areas of consideration for the built environment, community safety and the challenge of connecting rural populations as global citizens.

Keywords Community · Safety · Smart policing · IOT · Big data · Policing and security strategies

2.1 Introduction

The capabilities of the Internet of Things (IOT) is seemingly limitless with possibilities. Whilst this state of affairs continues to identify previously unimaginable advances for human kind, a drawback is the virtual impossibility of placing a perimeter around a singular area of our lives and provide a status report of the impact of the IOT on that isolated factor. The current and future impact of the IOT on the safety and security through policing initiatives for rural villages in India is no

A. Davies (✉)
Rabdan Academy, Abu Dhabi, UAE
e-mail: ADavies@ra.ac.ae

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exception. It is not unreasonable to suggest Smart Policing strategies, IOT dependent, which have been deployed to varying degrees and configurations across the globe are equally applicable to advancing community safety in rural India. The IOT is affecting the types of crimes being committed with the emergence of online/cybercrime for example. Importantly, in relation to community safety, the IOT is influencing policing and security strategies in combination with city and village design.

It is important to place the discussion of IOT and connectivity to policing and security for the future of rural Indian villages by briefly examining the following critical factors.

The concept of 'smart';

1. The urban versus rural population India statistics
2. The prioritization of needs for communities living in rural Indian villages
3. The accessibility of IOT in rural India
4. The limited accurate and comprehensive reporting of crime typologies and rates for rural Indian villages.

The work of Velagaleti and Kumar [37] in discussing the rural smart village and the influence of the IOT, which reports the experience in the Gudlavalleru Smart Village project (a proof-of-concept deployment of an IOT in the village of Gudlavalleru (Andhra Pradesh) identifies widely acknowledged areas of potential IOT influence. As Velagaleti and Kumar (2017, p. 2347) suggest, the goal for IOTs in rural environs is to harness the IOT and ICT developments to enhance the many and varied services required for efficient and effective administration of the community/village for which it is responsible. The 21st Century emergence of the Smart City and by association Smart Village concept draws its label of Smart from the idea that the IOT is the key ingredient required to build smart infrastructure and systems. In the context of smart villages, this spreads to include both old structures and activities re-engineered and new systems and technology to enhance livability in a smart environment [30]. Velagaleti and Kumar [37] offer a summary of this new world phenomenon:

> A smart sustainable village is an innovative village that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of rural operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects (p. 2).

The transition to ICT as a 'way of life' is clearly expressed in Elfrink's [10] discussion of the smart city concept and offers early indication of the reality of the rapid race of the IOT in impacting lives globally:

> Today in India people often have access to ICT before they have water or electricity. One of the most used apps in rural areas there is to make your cell phone a lamp, because there's no electricity. During the day you can recharge it via a solar panel in the village. And that is, in turn, leapfrogging access to health care, education, and eventually work. Technology will empower diverse demographics across continents. Right now, there are illiterate people in rural India doing video surveillance for retail stores in the United States. They can observe and press a button if they see strange behaviour.

Chaturvedi [5] in 2018, offers an update on the Indian Government plans relative to transforming the country into a techno-knowledge based India. The program, Chaturvedi explains, will be responsible for uplifting areas of rural India through connecting rural India with high-speed internet.

Whilst continual rapid global urbanization is widely accepted as inevitable, Ahvenniemi, Huovila, Pinto-Seppa and Airksinen [1] refer to the United Nations 2015 report, which indicates 66% of the world's population will live in cities by 2050. The United Nation's report of 2018 [32, 35] identifies that currently 55% of the world's population resides in urban areas. However, the rural population in India was reported at 66.46% in 2017, according to the World Bank collection of development indicators [2]. Bhattacharyya et al. [3] provide a powerful illustration of India's population dispersion in referring to the more than 600,000 Indian villages. As the Father of the Nation Mahatma Gandhi stated, 'India lives in its villages' (p. 513). Bhattacharyya et al. [3] further suggest the Ministry of the Rural Development in India has a vision and mission of sustainable and inclusive growth for rural India to increase amongst other factors, social safety.

Of the 650,000 villages in India, most of them have inadequate and rudimentary infrastructure, which fails to fulfil the primary need of villagers. Villages and other remote locations have poor educational facilities, irregular water supply, electricity supply, improper sanitation, transport, road connectivity and infrastructure [20, 33]. India being a billion-strong nation has 68.84% of villagers less than 30 years old. All these factors push villagers to migrate to towns and cities in search of better employment opportunities and quality of life [33].

There is a growing body of literature that is focused on research projects involved with investigating, developing and evaluating Smart City concepts [34, 39]. Work is progressing in understanding and developing solutions through adoption of Smart Cities concepts to village design and or redesign [21, 34, 38]. The goals of such work include(a) reducing the migration of villagers to cities and (b) responding to the needs of villages and villagers to build sustainable, livable communities [27].

Universally, the focus of efforts related to smart concepts is more advanced for cities. In the meantime, India is demonstrating a commitment to turning the lessons learnt from across the globe about building smart environments. Developments such as Lavasa and Gudlavalleru are providing a valuable contribution to the challenge of using technology and the IOT in the most efficient and effective approach for India's needs. In addition, individual projects addressing specific needs and solutions in the Indian context are also contributing to finding solutions for the Indian context. Joshi's [17] work discusses the trialing of solar energy for 60 villages in the districts of Madhya Pradesh namely Rajgarh, Sehore and Satna which is informing the way forward for application on a wider country based scale. Anvi Jain in 2018 [16] reported, through a literature review, on the various projects and advances in the mission to digitalize India. Jain's [16] report demonstrates the limited attention focused on issues of safety and security and the initial divide between the rural and urban India for access to digital technology:

> The initial survey in ICTs created a technology divide between the rural and the urban India, as these were not available, accessible or affordable by the rural poor. But with the fast development of the rural India and initiatives taken by the government and private sector … this divide seems to be diminishing with more and more digital services penetrating in rural India, providing employment opportunities as well as increasing the standard of living of the rural poor (p. 252).

Fennel et al. [12] reflect the current status of limited literature which focuses on the rural villages of India and their relationship with Smart City concepts:

> The literature on Smart Cities has not as yet paid adequate attention to the rural sector, and the potential in villages for creating smart and sustainable solutions for the 21st century.

The key point of the above discussion is the relative focus of Smart City concepts and specifically the affordances of the IOT globally, including rural India have been centred on immediate and urgent infrastructure—public health, education, water, electricity. As Rathore and Sharma [24] identify enforcement of law and order is among other areas that require urgent attention for rural development in India. Attention on the role of the IOT, an integral part of Smart City concepts and the potential for addressing crime and criminal activity in combination with built design deliberations to progress safety and security is limited.

The real world reality is that safety and security is critical for establishing sustainable livable cities and villages. Understanding how the IOT can assist policing strategies and by association the safety and security of communities is a key consideration for future city and village design.

2.2 The IOT Contribution to Policing Strategies

In the context of law enforcement and crime management, as discussed by Ferguson [13] the IOT has the capacity to collect big data [42]. The application of algorithms to such big data identifies crime trends. Understanding the why, what and how of the crime trends has the capacity to offer insight for future policing strategies and contribute to the design of city and village infrastructure. An explanation of the key policing models and the influence of the IOT on the application of their fundamental strategies is helpful here.

The definition offered in the work of Minerva et al. [22] in referring to the CERP-IOT Vision and Challenges Report for the European Commission provides a very clear example of the IOT contribution to policing strategies. Minerva et al. [22] state:

> In the IOT, "things" are expected to become active participants in business, information and social processes where they are enabled to interact and communicate among themselves and with the environment by exchanging data and information "sensed" about the environment, while reacting autonomously to the "real/physical world" events and influencing it by running processes that trigger actions and create services with or without direct human intervention (p. 27).

2.2.1 Reactive Policing (RP)

Reactive Policing, the historical origins of policing, involved officers responding to a call for assistance, managing the situation, reporting and handing over the follow up to other branches. The model allowed for officers to continue on patrol. This approach to policing is based on "supply and demand". Cordner and Sheehan [7] suggest reactive policing includes three main patrol functions i.e. routine patrol, immediate response to calls and follow-up investigations.

The historical nature of Reactive Policing is not reported as being conducive to allocating human and fiscal financial resources to analysis of crime at a less than surface level. The challenge here is that the capacity of the IOT would offer significant advantages for the patrol officer, the deployment of patrol resources, the prediction of crime 'hot spots' and move from reactive policing to predictive policing.

The impact on policing criminal activity resulting from the application of the IOT and its mass of options to the Reactive Policing approach is being acknowledge and progressed. The reality of this impact is powerfully illustrated by the following case described by Lieutenant Brian Ellis [11] Sacramento Police Department.

> It's a Saturday night on the outskirts of the city limits when police receive a call from a distraught convenience store clerk reporting a violent robbery occurred and he's been shot. As police units respond to the emergency call, they are aided by connected vehicle technologies to control traffic lights to safely help officers get to the scene as quickly as possible, minimizing the possibility of a traffic accident en- route. Concurrently, data is relayed to the responding officer's mobile computer without the need to search for it. This data pertains to the call the officers are being dispatched to, the persons involved, and the information about the environment. Information from nearby police observation devices also capture a license plate fitting the description of the getaway vehicle and broadcast it to responding patrol units.
>
> Just prior to arrival at the original scene, another unit engages in a short vehicle pursuit with the getaway vehicle, ending in a nearby residential area. The suspect barricades himself inside a residence; the police are now in a standoff with an armed barricaded suspect and are searching for his nexus to the house he is now inside. As the incident commander responds, he is monitoring the event through real-time information monitoring, a program that encapsulates everything from bodycam video of the officer, pulse rate of the officer, and any other sensor-able connectivity into which the platform is connected. Before tactical assets are even on-scene, computer information has the suspect's identity via facial recognition taken from surveillance video uploaded into the police cloud; it links him to five other similar robberies in the last two months.

Following such incidents, officers are able to utilize all of the detailed data to investigate beyond the incident to search for connection with other crime or criminals.

The above illustration indicates the many points at which the enabling attributes of the IOT aids in resolving immediate threats to security and contributing more widely to law enforcement strategies.

2.2.2 Predictive Policing (PP)

Predictive Policing refers to the use of predictive and analytical techniques in law enforcement to identify potential areas of crime and offenders [1, 3–5].

Predictive policing seeks to use the power of information, geospatial technologies and evidence-based intervention models to reduce crime and improve public safety. The key feature of this approach is to interrogate data sets through application of advanced analytics to identify patterns associated with the committing of crimes. A key feature of this approach is to enable appropriate deployment of human, fiscal and physical resources to address potential crime. Further this approach complements the application of additional strategic policing approaches such as problem-oriented policing, community policing, intelligence-led policing and hot spot policing.

An illustration of the application of predictive policing strategies is reported in Pearsall's [23] National Institute of Justice article entitled Predictive Policing: The Future of Law Enforcement. Pearsall discusses [23, p. 17] the example of random gunfire in the Richmond (Virginia, USA) area. A reduction of 47% in random gunfire and seizure of 246 weapons was achieved through analysing patterns of occurrence of time and location of crimes across several years in Richmond.

Similarly, the work of Coelho et al. [6] reports the work of the City of Natal, Brazil in building on the capabilities of technology to tackle their high crime rate. Employing a combination of IOT dependent programs and software has provided 'a technological tool in the hands of patrol supervisors, providing precise and critical information that helps them in their duties' (p. 787).

The IOT and its capabilities is rapidly becoming a central ingredient for predictive policing strategies [36]. It is the inherent nature of predictive policing to look forward, to anticipate based on analysis of historical data and analysis of emerging societal trends. The availability of an ever increasing range of technological applications—drones, body worn cameras, CCTV, sensors, facial recognition (this is by no means an exhaustive list) accompanied by increasingly sophisticated algorithms, through Artificial Intelligence applications, is offering police and law enforcement avenues to predict and mitigate future crime. As reported by the British Broadcasting Corporation in a news item on 4 February 2019,14 policing agencies in the United Kingdom are reported to be adopting crime prediction software as a predictive policing tool in 2019 [18].

2.2.3 Problem-Orientated Policing (POP)

Problem-Orientated Policing has as the central focus proactive strategies to stop crime before it occurs. Operationalising this model requires dedication to analyzing crimes and the environment in which they occur in order to identify trends and patterns of crimes and crime typologies. Weisburd et al. [40] suggest the POP approach was first proffered by Herman Goldstein (1979). Weisburd et al. [41] identify Goldstein as suggesting the more common reactive approach to policing could be more effective through a proactive approach.

The IOT has the capacity to be at the centre of the Problem Oriented Policing approach. The analysis of crime data, and crime commission patterns offers opportunity to inform on potential catalysts for specific crimes.

In a similar trend to that discussed for Predictive Policing the many and varied data capture and analysis tools offered by the IOT and software technology have the potential to advance POP strategies and outcomes. At the heart of POP is developing an understanding of underlying issues which may manifest into criminal activity. The potential connectivity IOT offers between health, education, and crime hot spots within a community may aid in developing policing strategies for the future security health of the community.

2.2.4 Community-Oriented Policing (COP)

At the centre of the Community-Orientated Policing model is building a relationship between police and the community they serve. This approach is designed to build confidence in the police and engage the community in reporting activity which is or may be linked to criminal activity. It is not only individuals with whom police seek to build confidence and relationships in the application of the COP model. Organisations, in particular, social and welfare focused organisations established within the community are valuable avenues through which police can build relations with the community. Weisburd et al. [41] in 2010 suggested this was the most widely adopted policing model at that time.

There are real world examples of the role the IOT has taken in progressing, in part, Community Oriented Policing. For example, the establishment of Smart Policing Booths, safe and secure booths accessible to the public which contain electronic dashboards. Such dashboards enabling the anonymous reporting of crime, suspicious behaviour, witness information, victim information. Abu Dhabi and Dubai Police in the United Arab Emirates have developed Smart Policing Booths enabling efficient and timely connection between the community and the police service.

On16 February 2019, the Khaleej Time, Dubai reported Pinarayi Vijayan, Chief Minister of the south India State of Kerala announced plans to develop police services which are ICT based. Similar initiatives to develop ICT based services to support re-balancing the focus of police work are evidenced around the globe. For example in Australia, the New South Wales Police Force has established an online portal for reporting minor property loss or damage (https://www.police.nsw.gov.au/community_portal/online_reports).

2.2.5 Intelligence-Led Policing (ILP)

The Intelligence-led Policing strategy utilizes identifying and managing risk. ILP is a policing framework that builds on earlier models of policing. The methodologies include community policing, problem-oriented policing, and a focus on surveillance to address repeat offenders and future crime.

A major strategy of ILP is its use as a management decision making tool for prevention, disruption and enforcement in the fight against crime and building safe communities. Ratcliffe [25] offers the following definition:

> … Intelligence-led policing is a policing business model that incorporates data analysis and criminal intelligence into a strategy that coordinates strategic risk management of threats with a focus on serious, recidivist offenders. It originated in the UK but has been increasingly adopted around the world.

Surveillance is a pivotal element of ILP, not limited only to physical surveillance achieved through the range of technological products police employ, e.g. body worn cameras, mobile surveillance devices, CCTV, here it is important to also consider cyber surveillance.

As the world has adopted the IOT, the role of ILP has similarly expanded to address the needs of surveillance by law enforcement and security agencies of online activity. For example, monitoring of activities within the online banking, financial institutions and monetary exchange arena for intelligence on illegal activities. Similarly, law enforcement and other governing agencies have turned to monitoring and analyzing online activities in their fight against human trafficking, drug, arms and terrorism activities.

2.2.6 Evidence Based Policing (EBP)

Sherman [29] is widely acknowledged as the lead in the concept of EBP. Sherman explains evidence based policing combines policing and police strategies with scientific evidence to determine the most effective approach (p. 2). Sherman [29] explains

> …Evidence-based policing is the use of the best available research on the outcomes of police work to implement guidelines and evaluate agencies, units, and officers. It suggests that just doing research is not enough and that proactive efforts are required to push accumulated research evidence into practice through national and community guidelines. These guidelines can then focus in-house evaluations on what works best across agencies, units, victims, and officers (p. 1).

Lum and Koper [19] offer a pragmatic explanation of EBP in suggesting the evidenced-based policing philosophy stresses regular institutionalized and consistent use of research, analysis and science to inform a broad range of [policing] activities (p. 4). Further, Lum and Koper [19] explain an important consideration in regards to the concept of evidence-based policing. The idea is the concept does not replace other models of policing, including the foundational or traditional model, rather that the decision to apply a particular model at any given circumstance should be based on research, analysis, evaluation evidence, and empirical information (p. 13).

It is with the core goals of evidence-based policing that the IOT has an increasingly central role. In all stages i.e. research, analysis, evaluation, and empirical information gathering that artificial intelligence (machine learning) and the IOT including sensors, body worn cameras, drones, facial recognition and other technological applications are becoming pivotal.

The value in presenting the relationship between policing strategies and the IOT, which is being experienced by policing agencies across the globe, is to highlight the value of the IOT for fighting crime, also for building safer communities.

2.3 Concepts for Consideration: IOT, Big Data and Village Safety

The growing body of literature suggests an increasing trend by policing and law enforcement agencies to build and analyse *big data* to inform operational decision making. *Big data* in the policing domain is developed in part from the sources of surveillance deployed e.g. CCTV cameras, drones, body worn cameras, mobile phones and in part from statistical data e.g. crime reports, rates of specific crimes, locations and timeframes of crimes.

The application of artificial intelligence tools—machine learning/data mining to *big data* contributes to policing decision making and strategies. Importantly, this process offers intelligence to infrastructure design. Traffic management provides a powerful illustration of the multipurpose impact of *big data.* Globally the employment of IOT technology to map traffic is gaining momentum. The cities of Abu Dhabi, Los Angeles, Tokyo for example are leveraging on the capabilities of a combination of the IOT, artificial intelligence and human intervention to understand traffic behaviour and increase quality traffic management outcomes. By extension, review of these projects has the capacity to inform on future design of traffic infrastructure and systems for new and re-engineered cities, towns and villages.

One of the major barriers in India to advancing reduction of crime strategies and by association develop design considerations for village infrastructure is the acknowledged underreporting of crime [8, 9, 15, 28]. Under reporting of crime influences the development of a transparent and accurate picture of the reality of criminal activity and importantly the root causes of such activity. It is in this space that the attributes of the IOT have a valuable role. As discussed earlier, the two core areas of information, which combine to provide a more accurate picture of the state of crime, are: (1) the IOT connected applications and systems and (2) the crime metrics data. In these circumstances, deployment of IOT connected monitoring devices has the potential to (1) increase recording of criminal activity and (2) through analysis of the characteristics of the criminal activity inform on future design of monitoring infrastructure for increased public safety. The work of Glass [14] in investigating the relationship between the built environment and criminal activity associated with rail transport, offers insight into the value of analyzing crime trends to inform community infrastructure and policing strategies.

A compelling illustration of the influence of deploying and combining the outcomes of IOT based systems with metrics is presented in the Akodara Village, India project. Singh and Patel [31] report Akodara Village CCTV cameras have reduced the crime rate. The authors refer to a theft case, which was detected and solved with the help of surveillance cameras. Further, Singh and Patel [31] advise this has improved the villagers' sense of security (p. 42). Similarly, Singh and Patel [31] in reporting the findings from Punsari Village (dubbed a model Indian Village, a Smart Village) located in Sabarkantha district in Gujarat state:

> … the last six years has been without any crime (p. 40).

Of note, in Punari village the entire village has been supplied with Wi-fi connection. Further, in this village, apart from at schools, CCTV cameras are installed at public places to keep surveillance (p. 40). Ferguson [13] summarizes the powerful influence of combining the IOT with technology on policing.

> …Behind the data is technology: algorithms, network analysis, data mining, machine learning, and a host of computer technologies being refined and improved every day. Police can identify the street corner most likely to see the next car theft or the people most likely to be shot. Prosecutors can target the crime networks most likely to destabilize communities.

Figure 2.1 offers a representation of the process offered by combining the policing strategies the IOT, *big data* and artificial intelligence. The combination offers a model for increasing safety and security efforts for cities, villages, communities and individuals.

2.4 Conclusion

The evidence emerging from application of the IOT by governing organizations—public authorities, policing and law enforcement organisations whose mandate is to improve the sustainability and livability of citizens is optimistic. Further, as the race continues to find more applications to which to deploy the IOT, the bank of knowledge and subsequent deployment of lessons learnt has the potential to have both positive and negative consequences for current and future citizens in rural Indian villages. The aspects associated with potential loss of privacy through, for example, the deployment of public CCTV cameras is an area for consideration by governing bodies and appreciatively may vary across states and countries.

This chapter has presented a discussion of examples of the current connection between the use of the IOT for policing and security. Further, the discussion

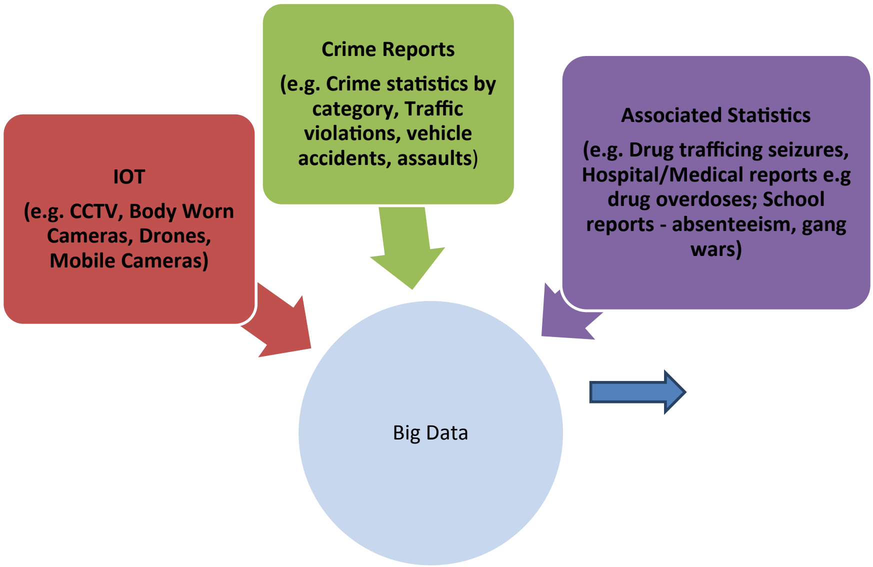

Fig. 2.1 Connectivity of IOT, big data and village design

indicates the potential for the outcomes of such connection to inform on future applications of IOT based systems and processes to enhance the standard of safety, security and living in rural India. Understanding key policing models and methodology provides a valuable contribution to the wide range of built design considerations required to influence the safety and security standard of living in rural villages.

It is important in the race to develop increasingly sophisticated technology capable of gathering increasingly sophisticated *big data* that society does not lose site that underneath the data and technology are people—individuals living their lives [12].

The connectivity between smart technologies, the IOT and smart policing strategies has the potential to influence the safety and security of current and future living environments through design of its systems, buildings and infrastructures.

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Chapter 3
Scientific, Technological, and Innovation Dynamics in Nanotechnology for Smart Cities and Villages: The OECD Case and Its Implications for Latin America

Alejandro Barragán-Ocaña, Gerardo Reyes-Ruiz and Humberto Merritt

Abstract The rise of emerging technologies is a priority for generating innovative products and processes aimed at contributing to the solution of cutting edge problems for smart cities and villages. The progress and development of nanotechnology make possible to market leading technological applications in fields as diverse as medical science, new materials development, and electronics, among others. The present study has two main aims. First, to determine whether the (average) production of IP5 nanotechnology patent families from 1999 to 2013 had a first-order relationship with the applicant's place of residence (priority date) and inventor's place of residence (priority date) during the same period in The Organisation for Economic Co-operation and Development (OECD) (The OECD is an international organism whose main mission is generating policies focused on the advancement and well-being of the countries that integrate it, promoting actions oriented toward the attention of environmental, economic and social problems (OECD in Who we are, 2019 [34].) member countries, and second, to determine whether the formation of this type of patent families by place of residence of applicant (priority date) in 2013 is associated with five variables. Results show that a relationship exists between variables in both cases, especially in the second, in which the weight of the participation of research scientists and the industry's value-added is quite significant. This approach allows for conclusions concerning OECD member countries and also has implications for the development of nanotechnology in Latin America to consolidate as smart cities and villages.

Keywords Patents · Nanotechnology · IP5 patent families · Indicators · Smart cities and villages · Spearman

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A. Barragán-Ocaña (✉) · G. Reyes-Ruiz · H. Merritt
Centro de Investigaciones Económicas, Administrativas y Sociales, Instituto Politécnico Nacional, Lauro Aguirre 120. Col. Agricultura. Alcaldía. Miguel Hidalgo. C. P., 11360 Mexico City, Mexico
e-mail: abarragano@ipn.mx

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3.1 Challenges and Opportunities in Nanotechnology Research, Development, and Innovation

Nanotechnology has been conceptualized as an emerging discipline which is in its first formation stages and demands the integration of ethical and social issues to address. It is also a field in which different areas of knowledge have converged to promote its development, especially through academia and firms that support research and development (R&D). This approach is aimed at opening areas of opportunity for innovation and markets via collaboration networks and National Innovation Systems (NIS), as well as policies focusing on the international arena because the management of an innovation system in the field faces complex and difficult to tackle issues [19, 24, 35, 36, 40]. Although emerging scientific disciplines, by definition, entail opportunities for innovation, the uncertainty associated with these disciplines is proportional to these opportunities [37].

Thus, as innovation and change in science and technology lean toward nanotechnology, biological sciences, and energy research, the development of capabilities to seize opportunities establishes new mandatory research work agendas [6]. Nanotechnology applications play critical roles in diverse scenarios as, for instance, in advanced materials development and manufacturing techniques, all of which call for the necessary skills to support the survival of national industrial systems in the global framework, even though the learning dynamics, R&D strategies, and innovation schemes in firms, academia, and the government vary from one region to another as, for example, in the United States and Japan in comparison with the European Union [33].

Therefore, to address nanotechnology's progress and future challenges the discussion must consider different elements, such as knowledge pools managed by the industrial sector, relevant actors, and other agents involved in the further development of this field [7]. Although private companies can benefit from academic studies (and these from the private sector's achievements), one must consider the type of industry and the knowledge base supporting them to build a genuinely functional innovation framework. Other factors at play are industry-academia knowledge transfer mechanisms, the role of public financing and the innovation cycle, the rhythm of scientific development, and the co-participation of industry and market. Additionally, an innovation framework should involve critical aspects such as new product design, the enabling of technological capabilities, and the clients' needs [3, 4]. In short, nanotechnology development relies heavily on the demand side.

In comparison with other scientific and engineering fields, nanotechnology is growing at an increasing pace. For example, China has been rapidly moving forward both by relying on its own capabilities and by collaborating with the United States. Although the involvement of the scientific community has been essential for patent production, it has been observed that scientific collaboration between academia and firms fosters a positive relationship between scientists, who are simultaneously authors of scientific papers and inventors of patents associated with corporate research [5, 42]. Moreover, there are specialized fields in nanotechnology whose development has been supported by research capabilities generated in a country. In the United States, the most remarkable skills are associated with nanobiotechnology, whereas Japan, China, South Korea, India, and the European Union have focused on the areas of nanomaterials, nanoelectronics, and different aspects of manufacturing [20].

Interestingly, the relationship between academia, firms, and the government has firstly reinforced the science-technology link because firms need to resort to alternative sources of knowledge to improve their innovation and competitiveness processes, and secondly because the university has become an entity that generates knowledge that can be applied and commercialized. Thus, the cooperation scheme between corporate activity and high-impact scientific production is generally viewed as a positive phenomenon [31]. Research work and technological development in nanotechnology require the convergence of multiple disciplines interacting with one another, although not necessarily as integrated entities, asking for the association of a wide range of actors and conditions to effectively achieve the field's goals [32, 38].

Nanoscience and nanotechnology are two important sources of high-profile results for the industrial sector to apply, although the high overhead costs and technical and operating problems associated with these advances demand ample cooperation. In this context, analyzing citations in patents is an interesting indicator of the links between these two areas. For instance, the interaction between nanoscience and nanotechnology has been observed to be inconsistent in the degree that references to scientific articles within patents are scarce, all of which suggests a weak relationship between research and technical activities. However, in comparison with other disciplines, the result is positive because the number of such citations in patents submitted by universities is remarkably higher [27, 30]. However, further analyzes on the topic are still essential, especially in developing countries.

A patent analysis focused on the world's most important intellectual property offices (i.e., the United States, Europe, and Japan) over the past three decades confirms that academic institutions and firms in these economies lead the nanotechnology business worldwide [8]. These offices are facing new challenges as the number of patent applications from numerous countries grows, especially in the United States and Europe, and, to a lesser extent, in Japan. In some cases as, for example, the European Patent Office (EPO), a significant increase in the number of patent submissions is expected as a result of considerable investments on these technologies [23, 26, 39].

In the case of Latin America, patent production is generally scant and far behind from that of the leading innovative economies [22]. Although different policies and programs to promote the development of nanotechnology in the region are in place, progress is heterogeneous, and the generation of science and technology is limited to a small number of countries whose achievements are not being systematically crystallized as registered patents. According to Kay and Shapira [21], the most active countries in the region are Brazil, Argentina, Chile, and Uruguay, especially the first two, although none of these have shown a clear intention to commercialize their knowledge, whereas collaboration is dictated by the goals and scope that each country has determined for the scientific disciplines (physics, chemistry, and material science); therefore, establishing new areas for research, together with nurturing existing science systems, and intensifying links between academia and the industry are crucial for the regional development of this field.

Nonetheless, Latin America has achieved important growth milestones in nanotechnology, and countries such as Brazil, Mexico, and Colombia have expressed their interest in developing this area of knowledge or initiated actions in that direction. Yet, science progress is not free of opposing views among political and scientific groups, as in the case of Argentina. Another challenge is that potential and latent risks have not been adequately assessed; so addressing these issues is key to the development of nanoscience and nanotechnology as two areas that can contribute to the economic, environmental, and social progress of the region, which would also tend to increase the welcoming of these technologies by the population [9]. All of these requisites must concur with production development policies aimed at promoting growth, competitiveness, employment, education, R&D, innovation, social well-being, and improving national production capabilities, among other goals [28].

On the other hand, many countries such as Brazil, Mexico, Argentina, Colombia, Costa Rica, Guatemala, Ecuador, El Salvador, Peru, Dominican Republic, Uruguay, and Panama have adopted the development of nanotechnology in their public policy agendas but differentiated levels of financial, scientific, and technological support in each country can deter the successful achievement of such endeavours, which are mostly derived from the existing industry-academia cooperation model in many countries that are used to compete in the international arena. Other factors that impinge upon this effort are the international demands derived from the advancement of a global scientific and technological policy that advocates for the emergence of this field; the need to conduct studies to guarantee the use of these technologies in the benefit of human health and the environment, and the priorities that must have local agendas in relation to the international guidelines issued by the World Bank, the Organisation for Economic Cooperation and Development (OECD), and the Organization of American States (OAS). These goals seek to warrant equal access for both developed and developing economies [10–12, 18].

The purpose of the present study is to identify dynamics associated with the generation of patents among OECD member countries having at least one application in one of the world's five most important intellectual property offices. Our purposes are, firstly, to demonstrate the relationship between IP5 patent families in nanotechnology (date of priority), both by applicant and inventor place of residence, and secondly, to define the relationship between IP5 families in nanotechnology (date of priority) by applicant place of residence and five indicators associated with investment in R&D, human resources, and value-added of industry.

The individual goals of the present study are defined as follows: (1) To carry out an extensive nanotechnology and nanoscience literature review and perform a analysis between OECD member countries and Latin American countries;

(2) To use Spearman's[1] correlation coefficient (r_s) to analyze relationships among the previously mentioned variables among OECD member countries, and (3) To carry out a multiple linear regression analysis to explore the way in which the five predictor variables are associated with the response variable in OECD member countries. These analyses allow for an initial approach to existing nanotechnology-related science, technology, and innovation dynamics in OECD member countries as well as and to evaluate the implications of such dynamics for Latin America to seize opportunities and face future challenges.

The smart villages concept has an important similarity with the smart cities concept which aim is to address different problems related with health, education, nutrition, energy, information and communication technologies, sustainability and democracy within rural environments for its development [16, 17]. As in the case of smart cities, smart villages seek to address aspects oriented to urbanization, planning issues and to the attention of common problems that arise from the promotion of development [44].

For instance, aspects such as electrification become fundamental for the achievement of these objectives, and thus enhancing the connection with the global world. In addition, these goals are oriented toward providing alternatives for supplying drinking water, sanitation actions, and water availability for agriculture and related productive activities, as well as paying attention to climatic problems derived from these actions, which goes hand in hand with the vision of sustainable development of United Nations-UN. All this, requires the active participation of experts, companies, non-governmental organizations, local innovators, leaders and the community itself to generate a change and progress in economic, social and technological issues [1, 2, 25].

By considering this context, the development of technological areas such as nanotechnology can contribute significantly to the advancement of smart cities and villages. Although technological advances initially appear within the context of large metropolis, technical progress can be extrapolated to rural areas with the intention of solving everyday problems that call for new technological solutions such as the generation of new materials, applications, and processes, which could contribute to the strengthening of these initiatives.

[1]Spearman's correlation coefficient is a non-parametric statistic tool but it lacks a probabilistic distribution which can be established as an association measure between two variables. This statistic describes the monotonic relationship between variables and it is used when data distribution is unreliable through the Pearson's linear correlation coefficient. To calculate Spearman's statistic is required that variables must be arranged in an ordinal scale so that each observation can be assigned a rank and placed in its corresponding series in an orderly fashion [15, 41].

3.2 Scientific and Technological Dynamics in Nanotechnology in Latin America and Around the World

With the intention of conducting a deeper analysis, the main statistics of patent applications related with nanotechnology in three languages (English, Spanish and Portuguese) are analyzed, and also with the intention to understand the dynamics generated in the most amount of intellectual property offices, particularly in Latin America. Within this search, some aspects stand out such as the main applications by country, technology sectors, applicants, and total applications. In the case of English applications, the search was done in all intellectual property offices, whereas searches for the Spanish and Portuguese cases were carried out in Latipat database because of its focus on these languages.

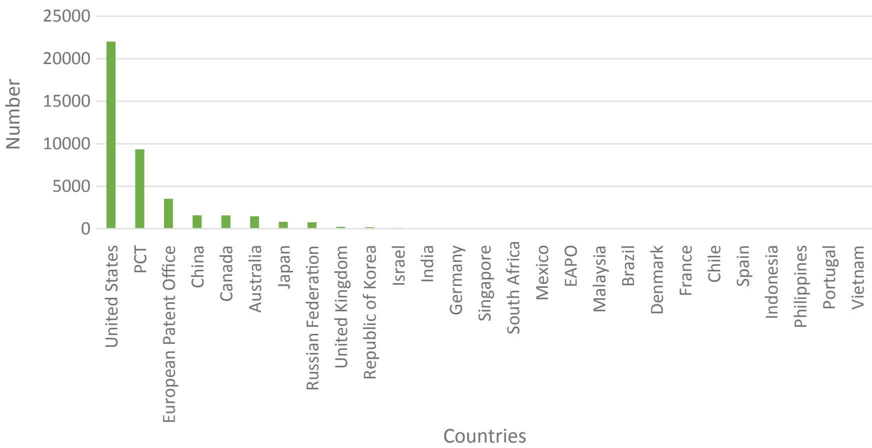
The United States, the Patent Cooperation Treaty (PCT), and the EPO hoard the largest share of nanotechnology-related patent applications. However, China, Canada, Australia, Japan, and Russia have joined the ranks of countries where important nanotechnology activities are also carried out. Although more modestly, other countries are beginning to play relevant roles, as can be appreciated in Graphic 3.1. In general, OECD member countries are high performers, whereas for Latin America only Mexico, Brazil, and Chile show up in the graphic.

At the global level, the technological sectors that concentrate the largest number of patent applications associated with nanotechnology are the medical, dental, toilet, chemical, physical, microbiology, and enzymology sectors, as well as applications in data processing, semiconductor devices, nanostructures, and non-metallic elements. Among these applications stand out those related to preparation of formulations, manufacturing, treatments, property analysis, measurements, and maintenance, processes, among others (see Table 3.1).

Among the most numerous applicants are firms in the information and communications technology (ICT) sector, although a large proportion of applicants are institutions with academic liaisons that specialize in product/process development in which nanotechnology plays a fundamental role (see Table 3.2).

Although the number of patent applications around the world has increased and decreased between 2008 and 2018, total figures are considerably high. For example, in 2008, 2490 applications were registered, whereas in 2017 the figure raised up to 3522, which is a considerable increase in comparison with the first year included in this study. When data were collected (before the end of 2018) 15 more applications had already been registered in comparison with 2008 (see Graphic 3.2).

The participation of Latin America is modest. Yet, three cases stand out: Brazil (which will be specifically discussed in this paper using data on patent applications published in Portuguese), Mexico, and those applications filed via PCT. The remaining countries filed less than ten patent applications from 2008 to 2017 in this field, all of which reflects their limited participation and lack of progress (see Graphic 3.3).



Graphic 3.1 Main patent applications by country, all offices, published in English (2008–2018) (Graphics 3.1 and 3.2 and Tables 3.1 and 3.2 were elaborated using information on nanotechnology-related patents obtained by advanced search in all patent offices registered in PatentScope and published in English from 2008 to 2018. It should be mentioned that this database includes both national and international patent collections, which host millions of documents, especially published PCT international patent applications.). *Source* Authors' elaboration based on data from WIPO [45]. (PatentScope is a WIPO database that integrates millions of patent documents from different intellectual property offices around the world, including PCT applications [45])

Table 3.1 Main patent applications by technological sector, all offices, published in English (2008–2018)

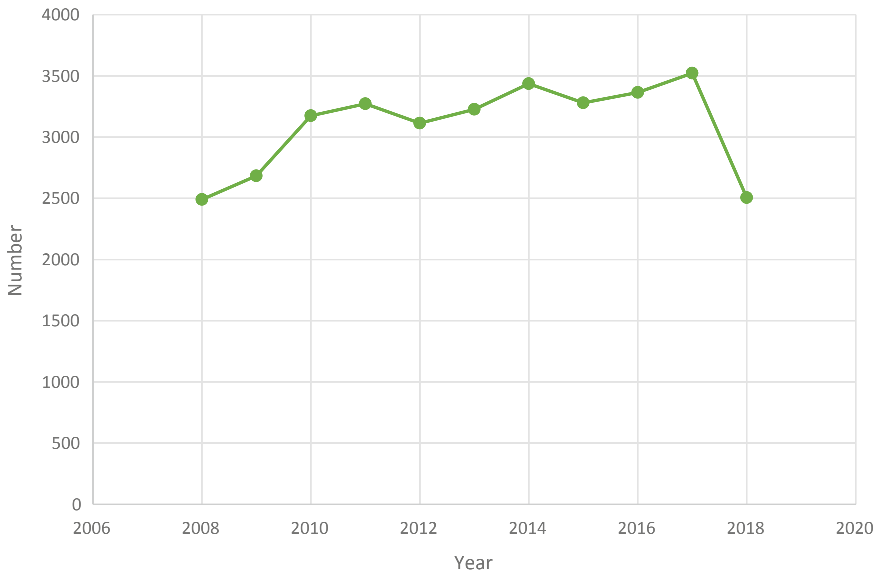
No.	Code	Classification	Number
1	A61K	"Preparations for medical, dental, or toilet purposes"	6628
2	G01N	"Investigating or analysing materials by determining their chemical or physical properties"	5296
3	H01L	"Semiconductor devices; electric solid state devices not otherwise provided for…"	4744
4	G06F	"Electric digital data processing"	3012
5	B82Y	"Specific uses or applications of nanostructures; measurement or analysis of nanostructures; manufacture or treatment of nanostructures"	2617
6	C12N	"Microorganisms or enzymes; compositions thereof.; propagating, preserving, or maintaining microorganisms; mutation or genetic engineering; culture media…"	2415
7	C12Q	"Measuring or testing processes involving enzymes, nucleic acids or microorganisms.; compositions or test papers therefor; processes of preparing such compositions; condition-responsive control in microbiological or enzymological processes"	2324
8	C01B	"Non-metallic elements; compounds thereof"	2003
9	A61P	"Specific therapeutic activity of chemical compounds or medicinal preparations"	1694
10	B01J	"Chemical or physical processes"	1595

Source Authors' elaboration based on data from WIPO [45]

Table 3.2 Main patent applications by applicant in all offices, published in English (2008–2018)

No.	Applicant	Number
1	The regents of the University of California	710
	Massachusetts Institute of Technology	555
2	SII Nanotechnology Inc.	442
3	Microsoft Corporation	342
4	Shanghai National Engineering Research Center for Nanotechnology Co., Ltd.	338
5	International Business Machines Corporation	251
6	Microsoft Technology Licensing, LLC	248
7	Google Inc.	202

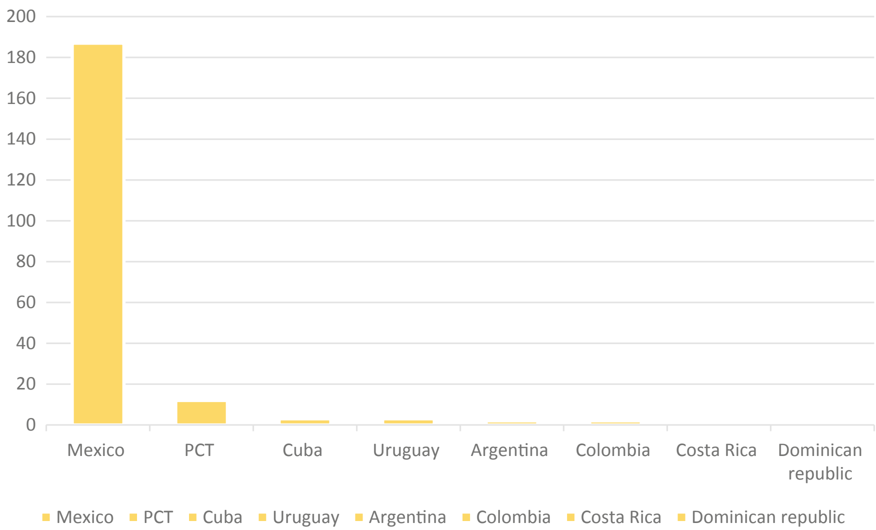
Source Authors' elaboration based on data from WIPO [45]



Graphic 3.2 Main patent applications, all offices, published in English (2008–2018). *Source* Authors' elaboration based on data from WIPO [45]

It is worth mentioning that the pattern of patents applications by technological sector in Latin America is similar to that observed at the global level, although Latin American nations are relevant in other areas such as food, peptide and heterocyclic compounds, as well as diagnostics and surgery. We note that these data must be analyzed in greater detail to explore possible knowledge areas and opportunities to be exploited in the future (see Table 3.3).

Foreign firms show a substantial activity in the region when submitting applications associated with nanotechnology, mainly from the pharmaceutical sector, but also from the electrical and electronics and ICT sectors. As regards domestic



Graphic 3.3 Main applications patents by country—Latipat, published in Spanish (2008–2017) (Graphics 3.3 and 3.4, and Tables 3.3 and 3.4, which correspond to the analysis of Latin America, were elaborated using information obtained in Spanish by advanced search from all offices registered in Latipat from 2008 to 2017. Spanish was selected because it is widely spoken across the Latin American region.). *Source* Authors' elaboration based on data from WIPO [45]

Table 3.3 Main applications patents by technological sector, Latipat, published in Spanish (2008–2017)

No.	Code	Classification	Number
1	A61K	"Preparations for medical, dental, or toilet purposes"	45
2	G06F	"Electric digital data processing"	16
3	G01N	"Investigating or analysing materials by determining their chemical or physical properties"	13
4	C07K	"Peptides"	10
5	C12N	"Microorganisms or enzymes; compositions thereof.; propagating, preserving, or maintaining microorganisms; mutation or genetic engineering; culture media…"	8
6	A61P	"Specific therapeutic activity of chemical compounds or medicinal preparations"	7
7	C01B	"Non-metallic elements; compounds thereof"	7
8	C07D	"Heterocyclic compounds"	7
9	A23L	"Foods, foodstuffs, or non-alcoholic beverages….; their preparation or treatment…; preservation of foods or foodstuffs, in general"	6
10	A61B	"Diagnosis; surgery; identification"	5

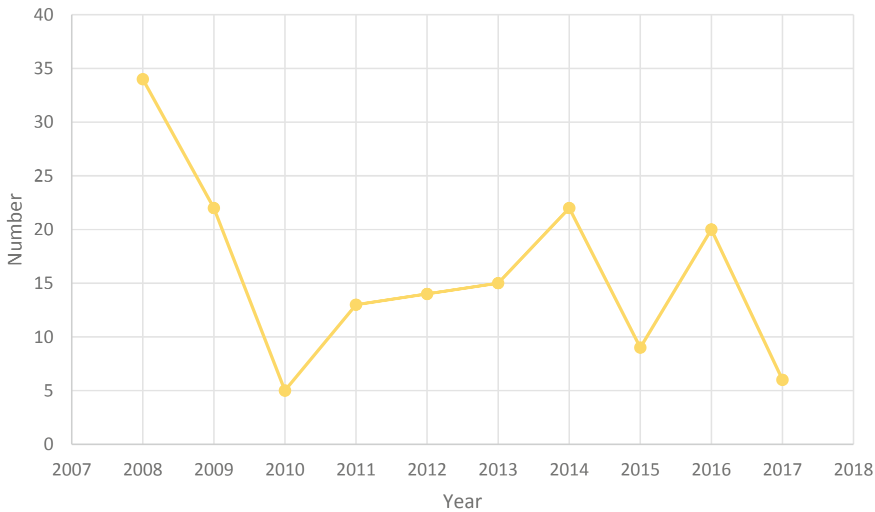
Source Authors' elaboration based on data from WIPO [45] organizations, only two Mexican academic institutions appear in the data, which calls for more local actors making contributions to endogenous technological development (see Table 3.4).

When we searched in all offices for documents in English we found that, contrary to the previous case, patent applications associated with nanotechnology decreased significantly. Thirty-four patents were filed in 2008, 22 in 2009, and only five in 2010. A gradual recovery can be observed from 2011 to 2014, and then there were two falls in 2015 and 2017 (nine and six applications, respectively), separated by a single increase in 2016 (20 applications) (see Graphic 3.4).

Table 3.4 Main applications patents by applicant in Latipat, published in Spanish (2008–2017)

No.	Applicant	Number
1	Microsoft Corporation	11
	General Electric Company	7
2	Elan Pharma International Ltd.	3
3	Universidad Autónoma de Nuevo León (Autonomous University of Nuevo León)	3
4	Activus Pharma Co., Ltd.	2
5	Agüeros Bazo, Maite	2
6	AstraZeneca AB	2
7	Bayer Schering Pharma Aktiengesellschaft	2
8	Board of Regents. The University of Texas System	2
9	Centro de Investigación en Química Aplicada (Research Center for Applied Chemistry)	2

Source Authors' elaboration based on data from WIPO [45]



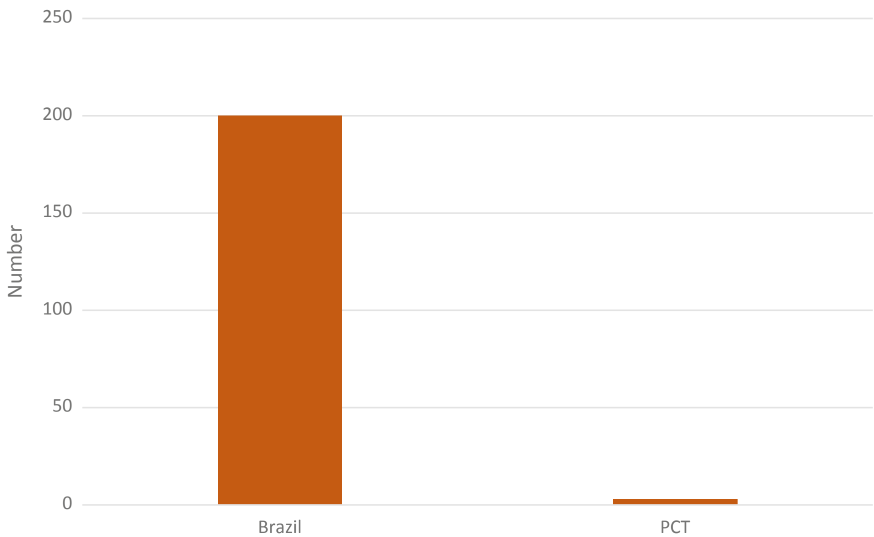
Graphic 3.4 Main applications patents by year in Latipat, published in Spanish (2008–2017). *Source* Authors' elaboration based on data from WIPO [45]

As regards Brazil, all applications published in Portuguese in Latipat were filed via PCT by this country, which filed 200 applications from 2008 to 2018, placing its performance next to Mexico among the most important players in Latin America. Thus, Brazil is a relevant actor in the region and has plenty of potential for R&D in the field of nanotechnology (see Graphic 3.5).

The search for patent applications in Portuguese reveals that prevailing technological sectors are the same in the rest of Latin America and the world, although some associated areas of knowledge varied, such as cosmetology, nanostructures, methods and devices, and metal-containing compounds. According to these findings, different strategies that may consist of nurturing these sectors could be applied to encourage endogenous technological capabilities (see Table 3.5).

Unlike the case of patent applications registered in Spanish by Latipat, a considerable share of applications in Portuguese was filed by academic applicants (see Table 3.6). This is an interesting phenomenon because it highlights the importance of establishing liaison strategies for cooperation among academia, firms, and the government to enable endogenous technological development and to address local problems since academic institutions are ad hoc suppliers of technology and knowledge focused on the Latin American context, especially for publicly funded research organizations.

Finally, no discernible trend could be observed concerning the distribution of the number of patent applications by year. The most relevant data for the period



Graphic 3.5 Main applications patents by country in Latipat, published in Portuguese (2008–2018) (In the specific case of Brazil, the analysis was carried out using the information obtained by advanced search in the Latipat interface for patents published in Portuguese during the period between 2008 and 2018. Search results are presented in Graphics 3.5 and 3.6 and Tables 3.5 and 3.6.). *Source* Authors' elaboration based on data from WIPO [45]

Table 3.5 Main applications patents by technological sector, Latipat, published in Portuguese (2008–2018)

No.	Code	Classification	Number
1	A61K	"Preparations for medical, dental, or toilet purposes"	51
2	A61P	"Specific therapeutic activity of chemical compounds or medicinal preparations"	22
3	B01J	"Chemical or physical processes"	12
4	B82B	"Nanostructures formed by manipulation of individual atoms, molecules, or limited collections of atoms or molecules as discrete units; manufacture or treatment thereof"	12
5	A61L	"Methods or apparatus for sterilising materials or objects in general; disinfection, sterilisation, or deodorisation of air; chemical aspects of bandages, dressings, absorbent pads, or surgical articles; materials for bandages, dressings, absorbent pads, or surgical articles…"	9
6	C01B	"Non-metallic elements; compounds thereof"	9
7	G01N	"Investigating or analysing materials by determining their chemical or physical properties"	9
8	A61Q	"Specific use of cosmetics or similar toilet preparations"	8
9	C01G	"Compounds containing metals…"	8
10	A61B	"Diagnosis; surgery; identification"	6

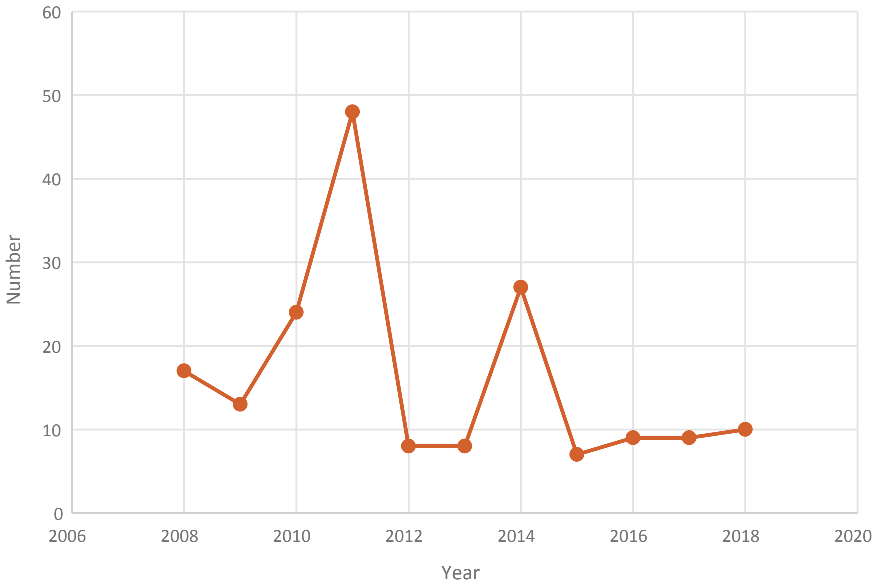
Source Authors' elaboration based on data from WIPO [45]

Table 3.6 Main applications patents by applicant, Latipat, published in Portuguese (2008–2018)

No.	Applicant	Number
1	Universidade de São Paulo—USP (University of São Paulo)	14
	Directa Plus Patent & Technology Limited	5
2	Sonolin Confecção Ltda-Epp	5
3	Microsoft Corp.	4
4	Nanum Nanotecnologia S/A	4
5	Universidade Estadual de Campinas—UNICAMP (Campinas State University)	4
6	Universidade Federal do Rio Grande do Sul (Federal University of Rio Grande do Sul)	4
7	Francisco José Duarte Vieira	3
8	Fundação de Amparo à Pesquisa do Estado de São Paulo—FAPESP (Foundation for Research Support of the State of São Paulo)	3

Source Authors' elaboration based on data from WIPO [45]

2008–2018 indicate that the most significant number of applications were filed in 2011 and 2014, when 48 and 27 applications were filed, respectively. The number of applications decreased to 10 or less per year after 2015, which indicates that countries like Brazil must be consistent in promoting the development of this emerging R&D field within a regulatory framework that can guarantee the introduction of applications into the market, securing the relevant ethical and safety considerations as well (Graphic 3.6).



Graphic 3.6 Main applications patents by year in Latipat, published in Portuguese (2008–2018). *Source* Authors' elaboration based on data from WIPO [45]

3.3 Method

The analysis is based on the 35 OECD member countries, from which a sample of 33 nations was determined as statistically significant with a confidence level of 95% and an error margin of 5%. Mexico and Iceland were excluded from the analysis. After determining the sample size, countries were numbered and sorted alphabetically to generate 33 random numbers. That is, we use a systematic random technique for sampling. As regards the first objective of our study, Spearman's correlation coefficient[2] (r_s) was utilized to establish the relationship between the following two variables [41]: (1) Relationship of IP5 nanotechnology patent families for place of residence of applicant (priority date); and (2) Relationship of

[2]Spearman's correlation coefficient cannot be considered a first-order association measure between two variables. Nevertheless, when assumptions about the frequency distributions of the study variables are unavailable, Spearman's r correlation coefficient can be used to show the setting of an arbitrary monotone function to be used for describing the relationship between variables. Moreover, unlike Pearson's correlation coefficient, Spearman's coefficient can be used without the assumption that the relationship between the variables is of first-order, and variables need not to be expressed using an interval scale. Spearman's coefficient can thus be calculated using an ordinal scale for the variables (see [15]. Therefore, Spearman's correlation coefficient is an excellent non-parametric alternative to Pearson's correlation coefficient when the latter fails to meet the normality assumption.

nanotechnology IP5 patent families for place of residence of inventor (priority date). In other words, the investigation sought to determine whether there is a first-order relationship between the generation of IP5 patent families among applicants (budget) and inventors (inventing activity). Spearman's correlation coefficient is a non-parametric association measure that can prove if a clear relationship between two variables exist, yet a causal relationship cannot be assumed thereof. Undoubtedly there are many (direct and indirect) factors[3] that could be involved in a causal relationship between these two variables, however, our study represents a first approach to the analysis of such relationship (if any), with the purpose of exploring more deeply a potential cause-effect relationships between these two types of IP5 patent families in the short term. It should also be mentioned that the two variables involved in this part of the study were calculated based on the arithmetic mean[4] of the 1999–2003 period, which allowed us to use Spearman's correlation coefficient and it is defined using the following expression[5] (3.1):

$$r_s = 1 - 6\frac{\sum_{i=1}^{i=n} d_i^2}{n^3 - n} \tag{3.1}$$

where $-1 \leq r_s \leq 1$ and d_i is the difference between the rank assigned to variable X and the rank assigned to variable Y in the *i*-th observation.[6]

Once the results relevant to the first aim of this study were obtained, they served to complement the multiple linear regression analysis involved in the second aim of the study [29]. In this analysis, the variable to predict refers to IP5 nanotechnology patent families by applicant's place of residence (date of priority). Thus, the functional relationship for the population model is determined in the next expression (3.2):

$$y = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \beta_4 x_{4i} + \beta_5 x_{5i} \quad i = 1, 2, \ldots, 33 \tag{3.2}$$

where $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ are the unknown constants and the predictor variables are the corresponding x_{1i}: Gross domestic expenditure on R&D (GERD) as a percentage of Gross Domestic Product (GDP); x_{2i}: Total of researchers (full-time or equivalent); x_{3i}: Business-Financed GERD as a percentage of GDP; x_{4i}: Higher

[3]An example of direct factor may well be the economic investment that a country or region allocates to nanotechnology-related research, whereas the number of nanotechnology-related patents is an example of indirect factor.

[4]This arithmetic mean, or first moment, is calculated from direct quantitative data, and it can be converted into positions or ranks.

[5]To carry out hypothesis test H_0: $\rho_S = 0$ versus H_1: $\rho_S \neq 0$ uses statistic $t^* = \frac{r_s}{\sqrt{\frac{1-r_s}{n-2}}}$ which presents a Student's t distribution with $n - 2$ degrees of freedom (where n represents number of observations). The decision rule to contrast this hypothesis is: Do not reject $H_0 : \rho_S = 0$ when $|t^*| > t_{n-2}^{\alpha}$.

[6]When two or more values are equal, the rank for each one will be the average of the ranks that would correspond to such values if they were different.

education expenditure on R&D (HERD) as a percentage of GDP, and; x_{5i}: Value added of industry (current PPP$).

The following assumptions were made in order to enable the model estimation: (1) As regards its parameters, the proposed model is linear; (2) No collinearity between explanatory variables is assumed[7]; (3) The values derived from the proposed variables are considered as constant and non-random; (4) Error ε_i is normally distributed, its mean is zero, and its variance equals $\sigma^2\mathbf{I}$. Thus, the equation used in the estimation of the linear regression model is as follows (3.3):

$$\hat{y}_i = b_0 + b_1x_{1i} + b_2x_{2i} + b_3x_{3i} + b_4x_{4i} + b_5x_{5i} + \varepsilon_i \quad (3.3)$$

where $E(b_i) = \beta_i$ and ε_i is the stochastic term of the estimation.

3.4 Results

Spearman's correlation coefficient (r_s) was determined with the purpose of establishing the (first-order) relationship between the variables termed "average of IP5 patent families (nanotechnology, 1999–2013) by place of residence of inventor", and "average of IP5 patent families (nanotechnology, 1999–2013) by place of residence of applicant" for each of the selected countries. These two variables were expressed on a scatter diagram, which made it possible to attest the degree of relatedness between the two variables (see Graphic 3.7).

Jarque-Bera statistic[8] was used to validate the pertinence of Spearman's correlation coefficient, i.e., to confirm that the two variables involved in this part of the study did not behave as a normal probability function. Results of the Jarque-Bera statistic in Table 3.7 show that *p-value* < 0.05 for both variables, which allows for the rejection of H_o hypothesis. In other words, statistical evidence allows us to claim that neither of these two variables is normally distributed.

As described above, the pertinence of Spearman's correlation coefficient was validated and so was the study which included 33 countries, randomly selected by systematic sampling. Ranks were then sorted for each of the variables under analysis and the values of d_i and d_i^2 were determined for each selected country (see Table 3.8).

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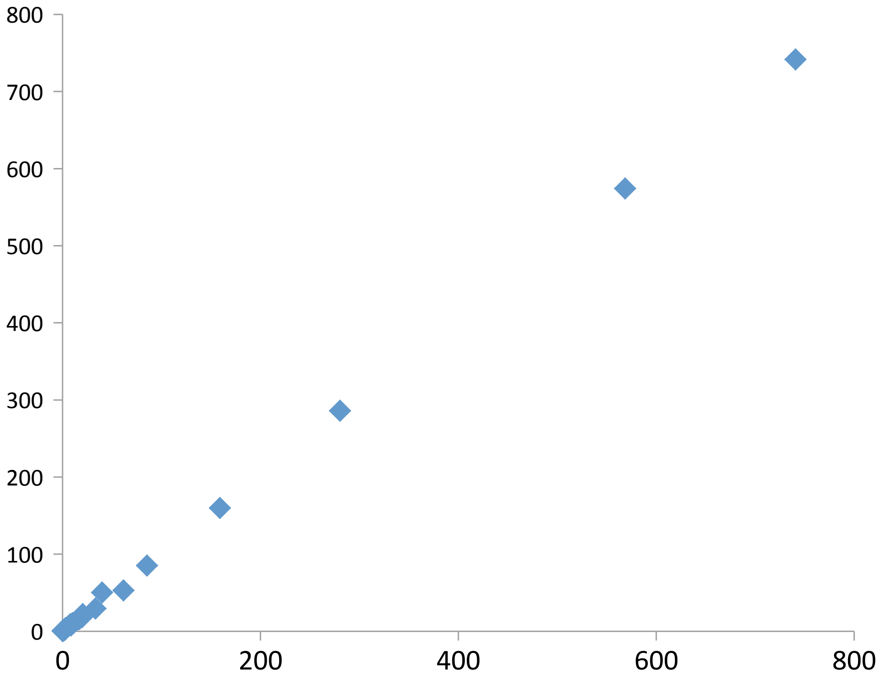
[7]Even though the concept of collinearity refers to a single perfect linear relationship between two explanatory variables, the term multicollinearity refers to more than one relationship of this kind between independent variables. Therefore, the term 'multicollinearity' is used in a more generic sense, with the purpose of including both cases (see [13, 14]).

[8]Jarque-Bera statistic is used for testing data normality. The null hypothesis H_0 assumes data normality through asymmetry coefficient (m_3) and kurtosis coefficient (m_4). The test statistic is $JB = n * \left[\frac{m_3^2}{6} + \left(\frac{m_4-3}{24}\right)^2\right]$, which presents a Chi-squared distribution with two degrees of freedom.



Graphic 3.7 Average of IP5 patent families (nanotechnology, 1999–2013) by place of residence of inventor versus place of residence of applicant. *Source* Authors' elaboration based on data from OECD [43]

Table 3.7 Jarque-Bera normality test results

Series: applicant		Series: inventor	
Sample: 133		Sample: 133	
Observations: 33		Observations: 33	
Mean	64.481210	Mean	64.248790
Median	7.430000	Median	7.750000
Maximum	741.570000	Maximum	740.840000
Minimum	0.060000	Minimum	0.110000
Std. Dev.	164.390800	Std. Dev.	163.506500
Skewness	3.208779	Skewness	3.221485
Kurtosis	12.372930	Kurtosis	12.479810
Jarque-Bera	177.425600	Jarque-Bera	180.645800
Probability	0.000000	Probability	0.000000

Source Authors' elaboration based on data from OECD [43]

Table 3.8 Relation of nanotechnology IP5 patent families by place of residence of applicant and inventor (1999–2013)

No.	Country	Average of IP5 patent families (nanotechnology, 1999–2013) by place of residence of inventor (date of priority) (1)	Average of IP5 patent families (nanotechnology, 1999–2013) by place of residence of applicant (date of priority) (2)	Ranks (1)	Ranks (2)	d_i	d_i^2
1	Germany	158.96	159.78	32	32	0	0
2	Australia	11.11	10.67	22	22	0	0
3	Austria	8.61	7.43	20	19	1	1
4	Belgium	14.51	14.24	23	23	0	0
5	Canada	33.21	29.45	28	28	0	0
6	Chile	0.33	0.31	4	5	−1	1
7	Korea	280.42	285.75	33	33	0	0
8	Denmark	5.55	5.88	18	18	0	0
9	Slovenia	1.04	1.13	8	8	0	0
10	Spain	9.93	10.14	21	21	0	0
11	United States	568.49	574.05	34	34	0	0
12	Estonia	0.30	0.20	3	3	0	0
13	Finland	7.75	8.81	19	20	−1	1
14	France	85.32	85.03	31	31	0	0
15	Greece	0.98	0.84	7	6	1	1
16	Holland	39.93	50.03	29	29	0	0
17	Hungary	1.68	1.50	13	13	0	0
18	Ireland	2.90	3.65	16	16	0	0
19	Israel	17.16	15.92	25	25	0	0
20	Italy	19.66	18.08	26	26	0	0
21	Japan	740.84	741.57	35	35	0	0
22	Latvia	0.11	0.06	1	1	0	0
23	Luxembourg	0.35	0.93	5	7	−2	4
24	Norway	3.12	3.80	17	17	0	0
25	New Zealand	1.34	1.24	10	10	0	0
26	Poland	2.73	2.14	15	15	0	0
27	Portugal	1.55	1.33	12	11	1	1
28	United Kingdom	61.67	52.91	30	30	0	0
29	Czech Republic	1.94	1.78	14	14	0	0
30	Slovak Republic	0.17	0.16	2	2	0	0

(continued)

Table 3.8 (continued)

No.	Country	Average of IP5 patent families (nanotechnology, 1999–2013) by place of residence of inventor (date of priority) (1)	Average of IP5 patent families (nanotechnology, 1999–2013) by place of residence of applicant (date of priority) (2)	Ranks (1)	Ranks (2)	d_i	d_i^2
31	Sweden	16.58	15.69	24	24	0	0
32	Switzerland	20.43	22.03	27	27	0	0
33	Turkey	1.54	1.35	11	12	−1	1

IP5 patent families are formed when patent applications are submitted to two different intellectual property offices, one of which must be submitted to one of the following five: (1) European Patent Office (EPO); (2) Japan Patent Office (JPO); (3) Korean Intellectual Property Office (KIPO); (4) United States Patent and Trademark Office (USPTO); (5) The State Intellectual Property Office of the People Republic of China. Fractional counting was used to compute such families (OECD [43]

Source Authors' elaboration based on data from OECD [43]

Based on the results of these procedures, we calculate that $\sum_{i=1}^{i=33} d_i^2 = 10$, and this result was employed to determine the value of r_s as follows (3.4):

$$r_s = 1 - \frac{6(10)}{(33)^3 - 33} = 0.998 \quad (3.4)$$

The result of Spearman's correlation coefficient shows a strong association between the two variables considered in this part of the study. Testing the hypothesis was conducted to verify whether the correlation coefficient was statistically significant. The Spearman's correlation coefficient[9] test was applied to test the hypotheses underlying these two variables and is expressed as follows:

H_0: There is no (first-order) relationship between the average of IP5 patent families (nanotechnology, 1999–2013) by place of residence of inventor and average of IP5 patent families (nanotechnology, 1999–2013) by place of residence of applicant.
H_1: There is a (first-order) relationship between the average of IP5 patent families (nanotechnology, 1999–2013) by place of residence of inventor and average of IP5 patent families (nanotechnology, 1999–2013) by place of residence of applicant.

The calculated t* value was 87.902, and the value in tables for a Student's t with an α = 5% (two tails) and 31 degrees of freedom was 2.042.[10]

[9]The lack of data normality does not limit the significance of Spearman's correlation coefficient; this statistic verifies that prob $(r_s \geq k|H_0) = \alpha$. Nevertheless, as a consequence of this result, coefficient r_s cannot be considered for establishing a codependence (causality) of first-order between variables X and Y.

[10]In tables, this value corresponded to a Student's t with 30 degrees of freedom and two-tailed α = 0.05.

Therefore, Spearman's correlation coefficient can be considered statistically significant for the two variables. Moreover, for a calculated value of $r_s = 0.998$, the test of hypothesis demonstrates that this value is significant for any value of α (the value in tables for a Student's t when degrees of freedom tend to infinity and two-tailed α = 0.001 is 3.29), thus, the null hypothesis H_0 can be rejected for the selected sample, and the alternative hypothesis H_1 can be accepted. In other words, the direct (first-order) relationship between the two study variables was confirmed.

A multiple linear regression model, which was described in the methods section, was selected to this part of our study. Table 3.9 shows data for the response variable, as for the five predictor variables, and for each of the 33 selected OECD member countries. The regression analysis sought to explain the generation of IP5 nanotechnology patent families as a function of applicant's place of residence through other variables; these families represent applications submitted by the owners of the intellectual property rights, usually firms, producers, or inventors themselves, which provides an insight into market dynamics.

Table 3.10 shows that the values obtained for both determination coefficient (R^2) and adjusted R^2 are close to 1, which represents an initial justification for the representativeness of the proposed model: it will provide an adequate explanation of the phenomenon under study. Nevertheless, these results should not be considered as conclusive because they can only represent the first approach to the relationships between IP5 nanotechnology patent families and the selected variables. Further research must, therefore, be conducted to confirm these results by using more statistical tests, especially if the purpose is to build a predictive model in the short term. It is also important to point out that the value statistic F is significant enough to argue that the explanatory variables are statistically significant when considered jointly. That is, the critical value of statistic F shows a *p-value* < 5%, which represents a low probability of occurrence to accept the null hypothesis. In other words, there are higher probabilities for the establishment of a relationship among all the explanatory variables and the variable to predict than otherwise, therefore, the variables analyzed in the present study can be used jointly to explain the phenomenon under study.

Table 3.11 shows the values of the coefficients estimated for each predictor variable (in this context, Student's t statistic is a parameter employed to determine the individual significance of each independent variable). Significant values (greater than 2 in absolute terms for Student's t) are presented for the variables of total of researchers (full-time or equivalent) and industry's value-added (current PPP$); there are low probabilities for the null hypothesis $H_0 : \beta_i = 0$ to occur. That is, the variable that has a positive influence on the generation of IP5 nanotechnology patent families by applicant's place of residence is total number of researches (full-time or equivalent), whereas the influence of industrial value-added (in current PPP$) is negative. These results are particularly important. They mean, on the one hand, that specialized human resources are the main actors behind the production and implementation of a larger amount of patents with these characteristics, whereas the formation of these patent families is sensitive to the value added of industry in a country or region, on the other hand.

Table 3.9 Response variable to predict and predictor variables (2013)

No.	Country	Response variables to predict	Predictor variables				
		IP5 nanotechnology patent families by applicant's place of residence (2013)	Gross domestic expenditure on R&D (GERD) as a percentage of Gross Domestic Product (GDP)	Total of researchers (full-time or equivalent)	Business-financed GERD as a percentage of GDP	Higher education expenditure on R&D (HERD) as a percentage of GDP	Value added of industry (current PPP $)
1	Germany	41.42	2.82	354,463.39	1.90	0.51	2,306,650.40
2	Australia[a]	7.00	2.10	100,413.90	1.18	0.62	733,784.15
3	Austria	2.00	2.95	40,425.60	2.09	0.72	264,027.04
4	Belgium	8.00	2.33	46,355.00	1.62	0.51	298,685.38
5	Canada	19.50	1.71	163,180.00	0.87	0.67	993,773.30
6	Chile	0.00	0.39	5892.90	0.14	0.15	275,490.02
7	South Korea	217.50	4.15	321,841.85	3.26	0.38	1,133,309.43
8	Denmark	5.00	2.97	39,868.10	1.88	1.01	151,613.51
9	Slovenia	0.00	2.58	8707.00	1.97	0.27	39,422.48
10	Spain	7.83	1.27	123,224.69	0.67	0.36	942,319.05
11	United States	271.42	2.72	1,305,862.36	1.93	0.37	10,577,593.00
12	Estonia	0.00	1.72	4407.00	0.82	0.73	23,951.43
13	Finland	4.00	3.29	39,196.20	2.26	0.71	127,023.90
14	France	43.92	2.24	265,465.81	1.45	0.47	1,497,601.14
15	Greece	0.00	0.81	29,228.24	0.27	0.30	152,656.54
16	Holland	15.00	1.95	76,670.45	1.09	0.63	534,272.35
17	Hungary	5.00	1.39	25,038.00	0.96	0.20	151,586.27
18	Ireland	2.00	1.58	16,844.30	1.12	0.39	154,546.17
19	Israel[b]	14.50	4.15	63,521.27	3.50	0.53	164,060.81
20	Italy	8.00	1.31	116,163.30	0.72	0.37	1,321,820.00

(continued)

Table 3.9 (continued)

No.	Country	Response variables to predict	Predictor variables				
		IP5 nanotechnology patent families by applicant's place of residence (2013)	Gross domestic expenditure on R&D (GERD) as a percentage of Gross Domestic Product (GDP)	Total of researchers (full-time or equivalent)	Business-financed GERD as a percentage of GDP	Higher education expenditure on R&D (HERD) as a percentage of GDP	Value added of industry (current PPP $)
21	Japan	165.75	3.31	660,489.00	2.52	0.45	3,566,122.10
22	Latvia	0.00	0.61	3625.00	0.17	0.26	29,213.53
23	Luxembourg	1.50	1.30	2503.49	0.68	0.24	34,434.09
24	Norway	1.00	1.65	28,312.00	0.87	0.52	221,398.47
25	New Zealand	0.00	1.16	17,900.00	0.54	0.35	104,318.92
26	Poland	3.00	0.87	71,472.30	0.38	0.25	664,765.26
27	Portugal	0.00	1.33	37,813.40	0.63	0.59	169,903.40
28	United Kingdom	44.40	1.65	267,698.50	1.05	0.44	1,528,864.58
29	Czech Republic	1.00	1.90	34,271.10	1.03	0.52	217,781.07
30	Slovak Republic	1.00	0.82	14,727.40	0.38	0.27	105,788.19
31	Sweden	5.17	3.31	64,194.00	2.28	0.90	269,898.03
32	Switzerland[c]	12.25	3.19	35,785.16	2.28	0.83	343,595.05
33	Turkey	3.00	0.82	89,074.86	0.39	0.34	1,154,989.88

[a]Data for the indicator concerning full-time researchers were unavailable for the years 2011, 2012, and 2013; so the value for 2010 was used instead
[b]Because data for the indicator concerning full-time researchers were unavailable for the year 2013 we use the value for 2012 instead
[c]Data for 2013 were unavailable; data for 2012 were used instead in the following cases: (1) Gross domestic expenditure on R&D (GERD) as a percentage of Gross Domestic Product (GDP); (2) Total of researchers (full-time or equivalent); (3) Business-financed GERD as a percentage of GDP; y (4) Higher education expenditure on R&D (HERD) as a percentage of GDP
Source Authors' elaboration based on data from OECD [43]

Table 3.10 Statistics of regression and variance analysis

No.	Statistics	Value
1	Coefficient of determination R^2	0.89
2	Adjusted R^2	0.87
3	F	45
4	Critical value of F	2.92^{-12}

Source Authors' elaboration based on data analysis

Table 3.11 Values of estimated coefficients

No.	Variables	Coefficients	T statistics	Probability
1	Gross domestic expenditure on R&D (GERD) as a percentage of Gross Domestic Product (GDP)	32.32	0.69	0.50
2	Total of researchers (full-time or equivalent)	0.0004	4.23	0.0002
3	Business-financed GERD as a percentage of GDP	−20.49	−0.42	0.67
4	Higher education expenditure on R&D (HERD) as a percentage of GDP	−69.54	−1.58	0.12
5	Value added of industry (current PPP$)	-2.89^{-5}	−2.35	0.03
	Interception	−7.59	−0.47	0.64

Source Authors' elaboration based on data analysis

Based on the results and with the standard error of 22.74 units for the dependent variable, this variable is explained as follows (3.5):

$$\hat{y} = -7.59 + (32.32)x_{1i} + (0.0004)x_{2i} + (-20.49)x_{3i} + (-69.54)x_{4i} + (-2.89^{-5})x_{5i} \quad (3.5)$$

The equation above shows that even though all the variables are interrelated, three of the multipliers explaining IP5 nanotechnology patent families are negative, which suggests that the three independent variables associated with the three multipliers have a negative effect and that only two explanatory variables have a positive effect, at least for 2013. However, as previously indicated, even though two of these independent variables have the highest degrees of significance, in general, the gross domestic expenditure on R&D (GERD) as a percentage of GDP and total of researches (full-time or equivalent) have a positive influence in the production of IP5 nanotechnology patent families by applicant's place of residence. Additionally, the variables of Business-Financed GERD as a percentage of GDP, Higher education expenditure on R&D (HERD) as a percentage of GDP and value-added of industry (current PPP$) have a negative influence.

Finally, it should be stressed that this initial approach is not a predictive model, which would require more data, and since the constant term of the estimated model is not statistically significant, some statistics are not representative (for example the Durbin-Watson statistic, which requires that the model be estimated using the intercept for validation). Nevertheless, this analysis may well be the starting point for the construction of more robust econometric models useful for short-term forecasting.

3.5 Conclusions

Scientific and technological development in nanotechnology faces highly complex challenges. However, the opportunities for innovation and competitiveness derived from this emerging area of knowledge are remarkable. The discussion in this framework refers not only to the discipline per se because ethical and technological aspects, as well as its implications for economic and social development, are also essential points of the debate. Data show that the United States and the European Union lead IP5 patent families' production, whereas few Latin American countries are just beginning to yield results in this area; therefore, the region must stress the necessity of generating specific policies and programs to further the development of emerging scientific disciplines and technologies such as nanotechnology; even though such scientific progress must still meet adequate safety standards.

In general, patent applications in nanotechnology are monopolized by developed countries and large multinational firms, and the related areas of knowledge are medical science, physics, chemistry, and microbiology, among others. For its part, Latin America exhibits a marginal development in comparison with the advanced economies, but it has some areas of opportunity that can be made possible if specific market niches are exploited. Undoubtedly, academia plays one of the central roles in the region concerning the promotion of endogenous technological development and the attention paid to local issues; especially after considering that a growing number of countries have prioritized nanotechnology in their public policy agendas by establishing clear and concrete programs to advance the scientific and technological development of this area of knowledge, which is badly needed in the region.

Results obtained in the first part of this study allow us to posit an important conclusion (among several others): applicants of IP5 nanotechnology patent families in OECD member countries are using local human resources to develop their capabilities in this discipline, as indicated by the averages for the 1999–2013 period. Hence the importance for Latin America of training more M.Sc. and Ph.D. researchers to create groups of specialized scientists and professionals whose main goal would be to provide an adequate support for the development of the necessary skills that can market the nanotechnology products developed in the region. These efforts must harness innovative schemes that involve competitive factors to impact and transcend in world markets.

Another relevant finding is the presence of variables that had both positive and negative impacts on the relevant indicator in 2013. In the first case, OCDE member countries must, of course, establish actions to increase their expenditure in R&D as a percentage of GDP and to promote the presence of researchers who can bring specialized nanotechnology knowledge into the labor market. In the second case, there are obvious asymmetries in the degrees of technological and scientific development among these countries, which can be ascertained from the presence of indicators that have a negative effect. Therefore, it is necessary to establish more aggressive actions aimed at allowing underperforming countries to mitigate their technological gaps. Similarly, all countries—including the Latin American OCDE member countries and those which are not yet members—must prioritize policies and programs with the purpose of increasing the investment of firms and higher education institutions in R&D as a percentage of GDP, as well as nurturing industrial development and innovation, both of them essential elements of the current configuration of the field.

In summary, advanced economies and developing countries alike, especially those in Latin America, must keep on strengthening nanotechnology progress, taking advantage of their opportunity areas by encouraging the development of more robust indicators in order to support the advance of these activities which, in turn, will help to stimulate the construction of smart cities. Yet, the promotion of nanotechnologies to assist smart villages should be based on offering alternatives for solving problems arising from the rural milieu while also providing viable options for their socio-economic development, increased access to technology, and rising welfare for the involved communities.

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Alejandro Barragán-Ocaña is a research professor at IPN-CIECAS and a research fellow at the National Researchers System (SNI, CONACyT). He holds a bachelor's degree in pharmacobiological chemistry from the Metropolitan Autonomous University (UAM), and a second bachelor's degree in management from the Mexican Ministry of Public Education (SEP). He holds a master's degree in systems engineering (quality) is from the National Autonomous University of

Mexico (UNAM), and a Ph.D. in systems engineering (planning) from the School of Engineering at the National Autonomous University of Mexico (UNAM). His research interests include soft systems, planning, technology and innovation management, quality, intellectual capital, sustainability, economic and social development, nanotechnology and biotechnology in agriculture.

Gerardo Reyes Ruiz is a postdoctoral researcher at CIECAS-IPN. He holds a Ph.D. in business studies (actuarial profile) from the Faculty of Economics and Business of the University of Barcelona (UB). Dr. Reyes is part of different scientific councils, was the leader of the academic body called “Complex Systems, Innovation and Sustainability” at the Autonomous University of the State of Mexico (UAEM) and is also a referee for national and international journals. Dr. Reyes is a member of the SNI (researcher candidate), CONACyT. He has published in prestigious journals both nationally and internationally and given presentations at national and international conferences. His academic profile was selected for inclusion in the 2015 edition of “Who is Who in the World.”

Dr. Reyes was a full-time professor at the University Center UAEM Valle de Chalco thanks to the fact that in October 2013 he earned a retention grant from CONACYT; he taught at the undergraduate and master’s level. He also taught at the doctorate of Economic-Administrative Sciences of the Faculty of Economics of the UAEM. He was also a principal investigator and co-author of different proposals for research projects at the national level (UAEM, PRODEP, CONACyT, and SEP). His research areas are academic evaluation and the national system of science and technology.

Humberto Merritt is a full-time professor of science and technology policy at CIECAS-IPN, Mexico, where he was coordinator of the master’s program on technology management. Professor Merritt has focused his research on the economics of innovation and technology management. Previously, he was Assistant Professor of Business Administration at the Metropolitan Autonomous University (UAM) and the Monterrey Institute of Technology (ITESM), both in Mexico City. He holds a Ph.D. degree in science and technology policy from the University of Sussex-SPRU, a master’s degree in economics from El Colegio de Mexico, and a bachelor’s degree from the Metropolitan Autonomous University of Mexico. He has been awarded Level 1 in the SNI. He has been visiting professor in the universities of Antwerp, in Belgium, and Lund, in Sweden.

Chapter 4
Digital Periphery? A Community Case Study of Digitalization Efforts in Swiss Mountain Regions

Reto Bürgin and Heike Mayer

Abstract Rural economies have undergone major changes in recent years as traditional rural economic sectors declined and shifted. At the same time, digital technologies emerged and rural communities experience profound transformations. In this chapter, we analyze how technological change leads to changing rural economies in a Swiss mountain community. Although Switzerland has one of the highest national coverage of broadband in the world, there is a lack of knowledge regarding the transformation of its rural economy due to digitalization. The community case study's 46 qualitative interviews show that digital connectivity in peripheral mountain communities is experienced differently by various actors. On the one hand, digitalization offers new economic opportunities to larger businesses, larger hotels, schools and health service providers. On the other hand, particularly smaller businesses struggle with the high cost of becoming digital and their owners tend to become more cautious and stressed as competition and price transparencies in the digital economy become intensified. In terms of spatial aspects, we argue that digitalization reduces cognitive distance between core and periphery while physical distance between the urban and the rural still exist.

Keywords Digitalization · Broadband · Peripheral community · Switzerland · Urban-rural linkages

R. Bürgin (✉) · H. Mayer
Institute of Geography and Center for Regional Economic Development, University of Bern, Bern, Switzerland
e-mail: reto.buergin@giub.unibe.ch

H. Mayer
e-mail: heike.mayer@giub.unibe.ch

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4.1 Introduction

Digitalization[1] has become a central part of our everyday lives. As a result, permanent and immediate access to information reached new dimensions. Digital devices and online communication tools have become more important for work and leisure [4, 6, 33, 92, 103, 105]. However, not all people and communities have equal access to the Internet and can benefit from using digital technologies. Notably peripheral mountain regions[2] are still lagging behind the urban core in terms of broadband[3] access and use of ICTs[4] for business and private life [57].

In Switzerland, mountain regions also face a number of disadvantages regarding the access to information and services. There is a general fear of being digitally excluded and left behind (see e.g. [84, 85, 107, 108]). The potential of digitalization is widely discussed and there are efforts underway that aim to utilize digital technologies to connect Swiss Alpine communities in the periphery to urban centers (see e.g. [61, 64, 108]). The mountain region of Engiadina Bassa/Val Müstair is particularly interesting, as there exists a local initiative called 'miaEngiadina' (Eng. my Engadine). The goal is to advance digital development through fiberglass implementation and related offerings such as Wifi hot-spots and co-working spaces known as 'mountain hubs'. The initiative aims to transform the region into a so-called 'third place[5]'. In doing so, the aim is to attract teleworkers and digital nomads from cities for co-working in the mountains [58, 62].

[1]We understand the term 'digitalization' as the conversion of analogue technologies (especially information and communication technologies) into digital formats and as a process that combines the rapid development of ICTs and, in particular, the spread and use of the Internet and its infrastructure (see [9]).

[2]Peripheral regions can be understood as areas "outside the main metropolitan growth area" [51, 18]. This is a process-oriented perspective on the subdivision center-periphery (especially rural regions and mountain areas). Swiss mountain regions are part of the European Alps and here we consider them as peripheral regions [51]. Peripheries are also defined as outskirts and in geography, the term is applied to scarce populated rural regions, border regions or suburban fringes of cities [43, 368–369]. In this chapter, we understand Alpine mountain communities as part of the periphery.

[3]The term 'broadband' is used in terms of a high speed Internet connection that differs from traditional telecommunication infrastructure (Czernich et al. 20: 505). Broadband allows high bandwidths for data transfer in very short time (e.g. see [65], 7). It makes part of telecommunication and combines data of multiple channels in a single medium of communication [60].

[4]'ICT' is a collective term for both information and communication technologies as fixed telephone networks, mobile telephony, Internet and broadband access and for devices such as mobile phones, notebooks, desktop PCs, servers and LAN infrastructure (see Böcker and Klein 13: 11–13).

[5]A 'third place' is a social environment or public setting that combines the 'first place' (home) and the 'second place' (work) that is integrated into daily life (see [67, 270]). The term was introduced by the American sociologist Ray Oldenburg and describes informal public places for gathering [66, 6], where people enjoy the company of others and they can benefit from social participation in this arenas. Third places are forums of association for new experiences and relations that are unavailable otherwise [67, 267–270]. Active participation, conversation and the social exchange

Not only due to this local initiative, but also in general, Switzerland is an interesting case to study digital connectivity in mountain peripheries because of the excellent nationwide coverage [26, 30, 41, 99]. This raises the critical question about how the urban-rural digital divide looks like in a country where peripheral regions are relatively well connected to the Internet and how local communities are experiencing digital transformation.

Focusing on local experiences of digitalization connects with a number of research gaps [110]. There is particularly a lack of research regarding the adoption of digital technologies in mountain communities. Also, research on a community level that combines the perspective of connectivity (supply side) and inclusion (demand side) is still lacking. The research presented in this chapter answers the call for more community-based research on rural development in the digital age by Salemink et al. [87, 368]. To analyze adoption of digital technologies in a mountain community, we conducted a community case study in the Swiss mountain context and focus in particular on the region where miaEngiadina is currently being implemented.

Digitalization has become a relevant topic for Swiss mountain communities and their economies are changing as a result. As Woods [111] argues, technological change is one of the key drivers for rural change. Digitalization can bring up new economic opportunities for rural areas and shape rural economies that may become less dependent on resource-based sectors such as agriculture or forestry. In order to reflect these changing rural economies, we conducted empirical fieldwork in order to find answers to the following research questions: In what ways does the community of the peripheral region Engiadina Bassa/Val Müstair experience digital change as illustrated by the case study? In what ways does the case study reflect the realities of changing rural economies?

4.2 Literature Review

Digitalization challenges mountain regions and provokes structural economic changes. These changes may offer new opportunities like teleworking and linking peripheral businesses with firms in the central regions [100]. So far, little attention has been paid to research on digitalization in Swiss mountain communities. Yet, there is some research on digital development in a mountainous context (see e.g. [1, 5, 15, 17, 36, 76, 83, 113]). These studies found that due to affordability or cultural problems, major gaps between urban and mountain regions exist in terms of ICT use and Internet connectivity. The studies highlight that mountain areas need further investments in digital development and infrastructures so that their

are key elements for third spaces, which become embodied in a “spirit of pure sociability” [67, 272]. Examples for third places are diners, coffee shops, public parks or today’s co-working spaces [89, 72].

communities can be connected and not remain isolated. These studies also note the importance of policy interventions for bridging the digital divide. In addition, a larger body of applied literature such as policy reports, political agendas and newspaper articles exists particularly for Switzerland (see e.g. [31, 59, 61, 62, 64, 84, 86, 77, 78, 108]). At the EU level, the 'Agenda digitale delle Alpi' is also an example of such applied work (see [57]). Common to these reports is the positivist perspective on the potential of digitalization. This is understandable as policy-makers across the board are quite optimistic about digitalization.

Switzerland is an economically, socially and culturally advanced (western) country. Around 85% of its inhabitants live in cities, towns or in the surrounding suburban areas [28]. While the Alpine mountain region accounts for approximately two thirds of the country's total area, only around one fourth of all Swiss residents lives there and this region hosts one fifth of all workplaces [86]. However, rural regions in general, but more specifically Alpine mountain regions are still lacking behind urban economic development [91, 40]. In recent years, the typical rural economy in the Alps that is primarily based on resources has changed through e.g. the development of the tourism industry, which today is dominant in these regions [73, 229].

With the exception of urban tourism centers such as Davos or Zermatt, the majority of Swiss Alpine regions are rural and in some cases even peripheral. A number of mountain communities are geographically and functionally separated from metropolitan core regions (see also [3]) and suffer from out-migration, ageing, brain drain, etc. Nevertheless, it is important to keep in mind that Swiss mountain regions differ from other European mountain areas due to federalist policies (see e.g. [47]), which, from the past until today, have led to decentralized development dynamics. According to this, the federalist structure of Switzerland and location factors such as available space, the beauty of the landscape and regional identities are factors that make mountain regions attractive to live [16, 17, 61, 73].

For centuries, the European Alps were affected by out-migration, especially of younger people. This process resulted in brain drain and in consequence to socially and economically destabilized traditional communities in the mountain regions [53]. In recent years, some Swiss mountain regions have become more attractive for working and living. They attracted amenity migrants [73], 'new highlanders[6]' (see Bender and Kanitscheider [10]; [49]) respectively 'new highlander entrepreneurs' (see [53]) and second home owners (see [81, 82]). With the in-migration of new types of residents, new uses such as living and leisure of Alpine regions represent new types of valorization of this landscape. As a result, the qualities of the landscape have become rare and marketable resources [90, 146]. Improvements to infrastructure and enhanced connectivity for commuters helped with these changes.

[6]New Highlanders are immigrants in mountainous areas that decide to move—mainly with their families—away from major centers and to work in a peripheral area. Due to modern telecommunication technologies, new highlanders are able to work from home and commute sporadic to appointments or meetings in core centers [49, 5]. New highlanders can also establish new firms or establish branch offices and become so-called 'new highlander entrepreneurs' [53].

These improvements may have led to shrinking distances between the urban and the rural, and have allowed "families to move from urban areas into mountainous regions while maintaining their workplace or school in the town linked by periodically, weekly or daily commuting" (Perlik 72: 2). Selective in-migration and the increased valorization of mountain regions have implications for the rural economy. Traditionally, mountain regions have been seen as places for leisure and travel for urban dwellers. Furthermore, the periphery is *inter alia* characterized by farm and non-farm agricultural industry that is dominated by SMEs, low levels of R&D and innovation, weakly developed clusters, few knowledge providers, low production, low rates of entrepreneurship, weaker financial capacities of companies and a place shaped by interaction and information-related disadvantages due to its distance from core regions (see e.g. [21, 24, 23, 102]). In recent years, the characteristics of peripheral regions changed profoundly and digitalization plays a relevant role.

4.2.1 Rural Change and Digitalization

In recent decades, rural economies have changed substantially. Their function of traditional primary production became challenged by new consumption patterns. This implies a shift towards a more consumption-based rural economy. The rural does not only serve as a "picturesque backdrop to urban development", but also as a place with diverse functions and economic opportunities [93, 633–634]. While there is little question about these changes in the past, future changes such as the influence of digitalization and their effects on rural population are uncertain (see e.g. [111, 630]).Technological improvements may lead to a rediscovery of mountain regions, not only for leisure, but also for work. Woods [111, 623] notes that "the shift towards a consumption-based economy involves different priorities for land management and planning, leading to localised conflicts". Other key drivers of rural change are urbanization, globalization, environmental change, political and ideological pressures and technological change. Technological change implies that "new digital and communications technologies are creating new economic opportunities in rural areas and reconfiguring rural service delivery and the practice of everyday life in rural communities, as well as reshaping agricultural practice and geographies" [111, 623]. In this regard, digital technologies induce profound changes in rural economies and communities.

Rural economies have seen their traditional economic base in decline in recent years. Shifts in roles and functions of agriculture served as a starting point for examining rural transformations such as "demise of productivist agricultural models, opening opportunities for a substantial growth in demand for new uses for rural space (e.g. amenity, recreation, conservation, residential) and creating new conditions for actors to pursue their demands both in the market place and in the political system" [94, 1–3]. As stated by Hill [38, 43], "perhaps the most pervasive myth, and one that still dominates the rationale behind much current policy intervention, is that agriculture is the driver of the rural economy". Furthermore, the economic role of agriculture and forestry in rural areas seems to be less important [38, 43]. New perspectives for rural economies are "new orientations within their extended productions systems" such as bio-economy, biotechnology, experience, creative activities and realizations or displacements of activities from the core to the rural resp. periphery [21, 224–226]. De Souza [21, 224–226] also highlights that ICT and improved communication facilities become relevant for this. As De Souza [21, 122] argues, the periphery cannot keep pace with the digital revolution and continues to be left behind.

The position of being left behind may be detrimental for the periphery's economy. As stated by Grimes [34, 175], "there is a real danger that peripheral rural areas will become increasingly disconnected from the opportunities presented by the new digital economy". In addition, the competition for rural SMEs can become more intensified in the digital economy: "Despite the efforts of development agencies to help rural SMEs to benefit from the opportunities arising from ICTs, there is a real threat that rural areas may become further marginalized as a result of competition from outside their areas" [34, 181]. This shows that contradictory developments in terms of digital connectivity can emerge in rural areas and particularly in mountain communities, as the heterogeneous set of actors in these communities may not experience the change towards new types of rural economies in the same ways. Moreover, the contribution of ICTs for rural businesses can also be limited and the associated hype with the telecommunication sector should be more questioned [34, 189]. Disparities in levels of participation of community members (individuals, businesses, institutions, etc.) in the digital economy are significant and may produce a consistent digital divide between urban and rural areas [34, 188].

4.2.2 From Digital Divide to an Urban-Rural Digital Divide

Debates around this digital divide are ongoing and the geographic perspective has become quite relevant. In this sense, digital divides do not only exist between the rich and the poor, but also between metropolitan and rural areas [45, 31]. Studies on the digital divide assume that the division is still widening between urban and rural regions (see [11, 556], [87, 363], [88, 558], [105, 457–458]). On a spatial level, the digital divide can be analyzed as some sort of 'urban-rural digital divide', which, according to Philip et al. [74, 394], "has quickly become an entrenched facet of exclusion facing rural communities". The 'urban-rural digital divide' [11, 27, 69, 74, 87, 95] places the technological concept of 'digital divide' in a spatial tension, where the technological aspect of digital divide is challenged by the geographic urban-rural context. Salemink et al. [87, 363] differentiate this by saying that "newly developed technologies are likely to be urban-led and based on ubiquitous connectivity, designed without consideration for rural needs. This dominant and largely urban rationale leads to the perpetuation of the urban-rural digital divide".

In this sense, "many rural communities are unable to exploit the full potential of the Internet and thus continue to be at a comparative disadvantage to the majority of their urban counterparts" [75].

The debate assumes that rural areas run a risk of falling further behind due to lacking digital connectivity in terms of broadband access [109]. Furthermore, rural and remote areas with unstable satellite, wireless and mobile Internet technologies are facing challenges of speed and reliability of the Internet [2, 63]. The resulting status of 'remoteness' can lead to economic and social disadvantages. Practices of daily-urban-life, such as online (social) networking, online banking, online shopping and working, can be a challenge for unconnected rural communities [103, 581]. As a consequence, "people who live and work in remote areas are unable to adequately benefit from the high value-added services currently available via the network" [57, 20].

Yet, businesses and societies in rural areas may effectively benefit from enhanced Internet connectivity (see e.g. [2, 69, 75, 103]). Furthermore, as our case study shows, policies push digital development in these regions. Efforts in order to improve ICT can support business innovation, the efficiency of public administration and foster social inclusion [57]. While the benefits are often discussed and presented, the actual receptiveness by actors in peripheral communities for digital connectivity is still unclear (see e.g. [2]). Even when access to broadband technology is assured, it is not certain that rural residents will participate in a modern (online) society, due to the "willingness or ability of residents to adopt" these new technologies [103]. Having access to digital connections does not imply that people will use it [19, 70].

The digital divide may also result in a digital rural penalty [87] that can lead to negative consequences for the economic competitiveness of businesses in rural regions. This leads to a paradox where "regions most in need of improved digital connectivity, i.e. rural regions in decline, are the regions which are the least connected and included" [87]. One aspect of this penalty is poor broadband availability [88]. However, Irvine and Anderson [39, 20–23] proved in an earlier study that the use of ICTs is essential, for example, for peripheral hospitality businesses in order "to remain competitive and to attract and manage visitors". According to Roberts et al. [80, 358], the access to digital infrastructure plays a crucial role for working and living because "if digital telecommunication infrastructure and applications are not equally available to all, regardless of location, those working and living in not served or underserved areas, such as many rural areas, are disadvantaged". Businesses in rural areas need continually to develop and stay connected with other businesses to remain viable [104, 178]. In this sense, Internet and ICTs may compensate the penalty and problems of physical distance by providing new economic opportunities [103, 586].

On a broader level and related to the emerging discussion of urban-rural linkages, new technologies have "changed the nature of distance" [40, 5]. With broadband access, remote areas do not have to be remote anymore or perceived as the so-called 'hinterland'. Following the argumentation of Anderson [3, 97], peripheral regions are closer than before, because of new technological improvements. He highlights telecommunications and transportation improvements, which "lessened the distance between the core and the periphery". Furthermore, telecommunication developments and infrastructure have strong effects on the interaction between urban and rural areas [106, 273, 274]. According to Anderson [3], physical spaces move closer together through digital innovations that help to overcome physical distance. McIntyre [56, 230] strengthens this argumentation and observes that progresses in communication technologies and transportation lead to increased mobility, which brings "rural and urban communities closer together in both character and space" [56, 241], Ref. to Barnes and Hayter [8]. As a result, technologies like ICTs help to overcome physical distances through advancements in mobility, so that people can live further away from their workplaces [14, 4]. As a result, the actual physical borders between urban and rural areas tend to disappear and the traditional dichotomous understanding of urban and rural may become outdated [16, 157]. This in turn may lead us to think about and question the traditional sharp distinctions between the urban and the rural, which may become obsolete (see [48]).

4.2.3 Adoption of Digital Technologies from a Community's Perspective

Scholarly debates around the digital divide tend to not address the effects of digital connectivity on rural communities and individual community actors. Nevertheless, a community focus seems relevant as the local needs and demands of rural community actors are not uniform and can strongly vary. In order to address these issues, Salemink et al. [87, 361] called for "a new research agenda for better understanding the impacts of rapid technological developments". Our case study is inspired by this new research agenda and focuses on the lack of research on the level of communities particularly in the context of mountain areas. In light of this perspective, the research on digitalization and its effects on rural areas can be divided in two main strands:

- *Connectivity issues* deal with digital connections of places and regions and derived economic benefits. This place-based perspective of the supply side deals with issues such as deployment costs and economic impacts. A relevant theme are material inequalities and connectivity of regions, places and households. In addition, the main focus is "on the lack of digital connectivity in rural areas, which in the literature is referred to as the digital divide, urban-rural divide, or rural digital divide" [87, 362], Ref. to Townsend et al. [103]. Salemink et al. (2017: 362) identified four subthemes such as 'telecommunications markets', 'technologies in rural areas', 'regional development' and 'policy and regulation' that stand in relation to the connectivity issues and the lower level of connectivity in rural areas plays a relevant role.

- *Inclusion issues* deal with themes that are people-based [87], 362, 368). Research in this theme focuses on social inequality issues such as ICT use and development and the ability to participate in the information society [87, 365], Ref. to Mariën and Prodnik [50]. Inclusion research emphasizes factors and mechanisms behind ICT adoption [87, 362]. Salemink et al. [87, 365] identify three subthemes such as 'diffusion theory research' (diffusion of ICT in time and space), 'digital inequalities research' (people's knowledge, attitudes, skills and aspirations) and 'digital inclusion policy research' (inclusion into the digital society of digitally deprived people in rural areas).

As suggested by Salemink et al. [87], connectivity and inclusion research should be combined in a community-based approach. The community focus allows for more detailed insights into the variety of community actor's local needs and demands of digital connectivity and use. As Salemink et al. [87, 369] argue, the design's purpose for such an integrated approach is to bundle connectivity and inclusion research, which can be used for analyses in the context of specific communities.

Why is the community level promising and relevant? Salemink et al. [87, 369] argue that the urban-rural digital divide cannot be solved by generic policies. Instead, rural areas and communities are in need of more customized policies as telecommunication companies are not able to satisfy diversities of individual needs and demands. This is why the community level becomes important as the scale where generic and individual levels converge. In consequence, social and economic aspects are brought together and the supply side and the demand side are addressed in terms of connectivity and inclusion in a 'community-based approach' (Fig. 4.1).

The community-based approach adds a new perspective to research on digitalization and rural development and serves as the impulse for our case study. The community focus can generate deeper insights regarding the community's local

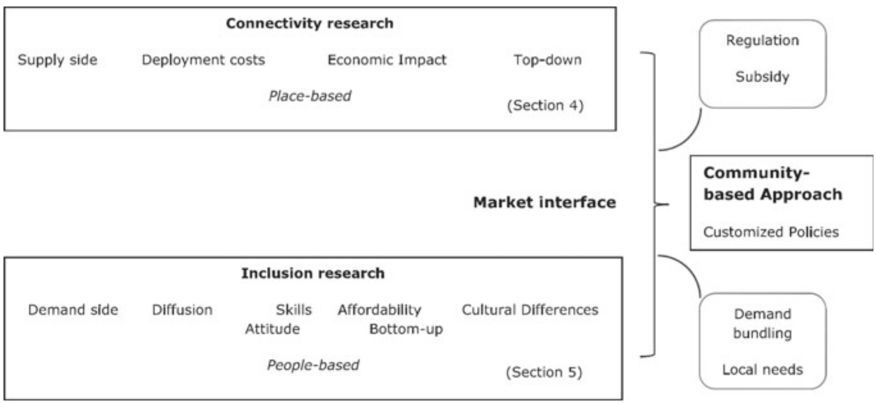

Fig. 4.1 Combination of research on connectivity and inclusion in order to establish a community-based approach [87, 368]

needs. Such a community-based approach generates a more profound understanding of these local needs within communities. Our community-case study addresses this niche by integrating both research strands in order to generate a more nuanced understanding of the varieties of local needs and demands in terms of digitalization in a mountain community. The community case study focus serves as a method in order to illustrate how experiences of digital change vary between different actors in the mountain community. While new economic opportunities can be created, contradictory experiences may emerge due to community actor's different levels of experiences with digitalization. This also has implications for the changing rural economies. Digitalization can indeed enable linkages to core regions, yet, not all actors may benefit from it. Focusing on the community allows us to detect such nuances.

4.3 Methodology—Community Case Study

For this study, we followed the community-based approach and adopted an integrated approach that incorporates multiple perspectives at the actor level. This allows us to focus on various needs at the community level. Our methodological approach answers the call for a more 'community-based research agenda' by Salemink et al. [87]. The community is understood as a set of actor groups,[7] to which the individual actors are grouped. With this procedure, the community itself is differentiated and subtleties resp. differences between the actors can be explored. In this sense, however, the community is not seen as just one actor, but rather as a constructed assemblage of various individual actors.

Our community case study is set at the community level in the region Engiadina Bassa/Val Müstair in Switzerland. We followed an embedded single-case design, where the case (the community) and its units of analysis (defined as actor groups) were analyzed in more detail (see e.g. [35, 112]). The 'embeddedness' of the case study allowed us to analyze various units of analysis *within* the case that were put together to generate an image at the broader level of the case (see also [63, 268–269]). We selected the single-case design instead of a multiple-case design, because single case studies can generate a deeper understanding. The careful study of a single case allows to question prevailing theories and can generate new and adequate insights [35, 11].

Following Yin's [112] typology of case studies, the 'context' in this study is the ongoing digitalization process in a peripheral mountain region. The 'cases' are the communities of the Alpine mountain region Engiadina Bassa/Val Müstair, which consists of two valleys: Engiadina Bassa and Val Müstair. Salemink et al. [87] do

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[7]We understand the term 'actor groups' as a collective term for actors and individuals that share similar characteristics in terms of interests and actions such as e.g. clubs, organizations, unions, businesses or social groups that are homogeneous [42, 18–19], [96].

not further specify their understanding of 'community' and do not define who is part of the community resp. of whom the community is made up of. However, the community can be understood as a social and organized network of individuals and actor groups that interact (common goals, identity or interests) with each other and have a sense of 'togetherness' [25]. Communities are traditionally defined as groups in which individuals are connected or organized around common values and predominantly live in the same place [46, 572]. The vague term depends on the context and purpose [22, 418].

In summer 2018, we conducted a total of 46 guided semi-structured interviews with community actors and experts in the case study region of Engiadina Bassa/Val Müstair. The semi-structured interviews were complemented by various informal talks during the fieldwork. We followed the snowball sampling approach, in which we first contacted and interviewed key informants who put us in touch with other community actors. With this procedure and in combination with document analysis, all relevant actor groups were identified. During our fieldwork we identified nine sub-groups in the community, which can be described as firms and entrepreneurs (SMEs), municipal administration (mayors, planners), religion (pastor), health care (human and veterinarian), schools (teachers and pupils), service providers, second home owners,[8] tourism (organization and related businesses) and cultural institutions (national and natural parks, art center, archeology).[9] All interviews were fully transcribed with the MAXQDA12 software. After that, we conducted a qualitative content analysis that allowed us to handle the large data material and to generate systematic and generalized insights (see Mayring [54, 55]).

4.3.1 Case Study Region—An Unusual Case

Switzerland is a small country in the middle of Europe and mountains take up a large share of its territory. While the country is highly urbanized, its Alpine mountain regions are quite important not only environmentally, but also in terms of identity, culture and leisure, resources and tourism. Yet, many communities in these Alpine regions are subject to deeply rooted economic changes such as out-migration, ageing, structural economic changes, etc. (see e.g. [57, 61, 71, 97]). Young people tend to move to the cities in search of better job opportunities, for education or just for living the urban lifestyle. This out-migration leads to structural changes in the peripheral community.

[8]Next to their primary home, second home owners possess a second accommodation (a house or an apartment) that is temporary used. 49.02% of accommodations in the case study region are second homes that are not inhabited permanently [29].

[9]Number of interviews by actor group: firms and entrepreneurs (13), municipal administration (5), religion (1), health care (4), schools (7), service providers (3), second home owners (2), tourism (5), cultural institutions (4). Additional expert interviews (2) were conducted.

Many Alpine communities develop initiatives and programs to address these structural changes. One example is the initiative 'miaEngiadina' that was started in 2014 in the region of Engiadina Bassa. We chose to focus on this initiative and the region for our case study because of its pioneering aspects in terms of digital rural development. The initiative has set itself the goal of developing the case study region with fiberglass implementation and offering additional services such as co-working spaces. Its motivation is to establish an innovative and sustainable model for the region's future. As the initiative's slogan 'your first third place' shows, it is their vision to transform the region into a place for retreat, inspiration and networking, where existing jobs should be preserved and new ones created. In order to achieve these goals, the initiative hopes to attract knowledge workers and companies. Ultimately, the initiative aims to create an alternative vision and sustainable development for the region by emphasizing digital connectivity [58].

miaEngiadina was first initiated by a small group of visionaries who originally come from the region. Today, the project is based on a broad set of private and public actors. The initiative is also supported by public funds from the 'New Regional Policy' [79], a regional development program jointly funded by federal and cantonal agencies [97]. At the time of writing this chapter, the initiative continues to expand fiberglass development into the region, establishes an educational platform for schools, constructs a new campus for innovation called 'InnHub', expands to the neighboring region of Upper Engadine and supports other regions and cantons interested in establishing similar digital development efforts. miaEngiadina targets different actor groups in the region (second home owners, tourism, SMEs, Schools, etc.). The initiative is seen as a milestone project [97] and it is well known in Switzerland and beyond.

The region Engiadina Bassa/Val Müstair consists of five municipalities. Approximately 9.300 inhabitants live in an area of 1.197 km^2. The region is strongly dependent on tourism. Employment is primarily in the tourism sector and most businesses are small to medium-sized. Despite the fact that the buildable land area has been growing over the past two decades, the region is facing outmigration (−3.3% between 2010 and 2016) and the number of employees is declining [29].

Regarding digitalization, it seems relevant to keep in mind that the Swiss Alpine regions differ from other Alpine areas due to federalist politics (see e.g. [47, 92]). For example, the Swiss telecommunication company 'Swisscom' received the basic services concession. The largest shareholder of Swisscom is the Swiss Confederation and Swisscom has the highest market share in terms of broadband Internet access. As the basic services concessionary, Swisscom was assigned to provide at least a minimum data transfer rate of download 3/upload 0.3 Mbps for every permanent inhabited household in the whole country—also in remote areas [7, 101]. In order to ensure the provision of basic services, most of the households in the mountain areas are connected to the Internet with a minimum speed rate.

Our case study region is highly relevant for analyzing community experiences of digitalization for several reasons: First, the peripheral mountain region Engiadina Bassa/Val Müstair is an 'unusual' case (see [112, 52]) due to Swisscom's basic services concession. Switzerland has one of the most developed network coverage in Europe [57, 13]. In 2017, 99.0% (EU28: 80.1%) of all Swiss households and 93.2% (EU28: 46.9%) in rural regions had access to NGA[10] broadband [41]. Second, the case study region is of interest due to digitalization processes taking place currently. The project 'miaEngiadina' pushes digitalization in the region proactively. At present, transformations are taking place and the expectations and outcomes can be analyzed in situ. Our interviews therefore addressed current changes and expectations of community actor groups for the future. Third, the project miaEngiadina targets different actor groups in the region (second home owners, tourism, SMEs, Schools, etc.). The targeted level of the project matches the community-based research agenda (see [87]). Fourth, the case is also of interest because current digitalization efforts can be questioned critically due to the already existing accessibility (by basic service concession) to the Internet in this region.

4.4 Results—Chances and Pitfalls of Experiencing Digital Connectivity in the Periphery

Broadband and the use of ICTs became indispensable for a large variety of actors in the mountain communities we analyzed. All interviewees mentioned that the Internet and the use of computers and smartphones became an essential part of social life and everyday work. As our interviews show, traditional analog work such as for example crafts, medical examinations, teaching, retail, construction work by architects and construction firms, monitoring of animals and vegetation in a natural park, managing a hotel or conducting archeological research are nowadays supported in a variety of ways by digital technologies and connectivity to the Internet. This shows that digitalization has become an omnipresent topic in everyday lives in mountain communities. Furthermore, digitalization influences all types of economic activities and sectors and has the potential to transform traditional rural economies. In this section, we show that digital technologies can encourage new economic opportunities for various actors in the mountain community and that linkages to core regions can be created. In addition, we also discuss how digital connectivity can entail contradictory and in some cases even negative experiences and developments. Nevertheless, these experiences strongly vary between the actors. In this regard, our data show that while the interviewees positively notice the chances and opportunities of digitalization for their work and everyday lives, they also take rather critical stances and show anxieties.

[10]NGA (Next Generation Access) are fixed-line broadband access technologies that achieve download speeds with at least 30Mbps. It is a combination of technologies such as VDSL, DOCSIS 3.0 and FTTP [41, 4].

4.4.1 New Economic Opportunities

Regarding technological improvements to the digital infrastructure, broadband Internet connection is not a new phenomenon in our case study region. However, most of the interviewed persons, firms and organizations are not yet connected with fiberglass broadband technology. The rollout and connection processes are still under development. While the infrastructure is still being built, the initiative miaEngiadina already triggered various projects in the case study region. For example, several co-working spaces have been built and are already operating in the region. One of the co-working spaces is located in the region's main village Scuol and offers 20 workplaces. The largest one is situated next to Scuol in the building of the High Alpine Institute Ftan, an international high school, in the village of Ftan. Around 40 co-workers can find a place in it. The third co-working space is located in Ardez, another smaller village only twelve minutes away by bus from Scuol, where two co-workers can find a place for work [58].

The establishment of new co-working spaces in the mountain community goes along with new production structures for rural and peripheral areas and its changing economies. The emergence of co-working and creative work in the mountain community shows how activities, which are traditionally seen mainly urban, are relocating to peripheral regions (see [21, 224]). This can also be seen as countryside commodification and the development of a more consumption-based economy (see e.g. [111, 623]). As a result, amenities such as remoteness, landscape and nature become re-valorized and serve as impulse for new economic opportunities. The initiative and the establishments of co-working spaces reinforces these changes as they aim to bring new types of residents to the region.

In this regard, the initiators and representatives of the local initiative also provide a "very large network to various Swiss companies" from which especially start-up businesses can profit, as stated by the initiative's co-initiator: "I have directly or indirectly supervised or accompanied various start-ups or arranged contacts where they have proven to be very valuable." Digital nomads or workers from start-ups and other cooperations who can work spatially unbound are targeted clients in order to work in one of the co-working spaces. These multilocal workers are an "interesting group" and "these are people who travel all over the world and I effectively believe that you can spend some time in Bali, but just as well spend a few weeks in the Engadine". The attraction of this so called "work tourism" is one of the initiative's goals, as mentioned by the co-initiator:

> There is also a lot going on in the co-working area. In Scuol, we now have more and more people in the co-working space who use it. At the same time, we opened a new co-working space in Ftan and Ardez. We have more and more requests from partners who want to do their own co-working with us.

miaEngiadina and the associated infrastructure development allows for co-working in peripheral mountain regions and with the establishment of these dedicated work spaces, a new business model has been created. Co-working spaces in Swiss Alpine regions are a phenomenon of recent times. They represent a new business opportunity, which aims to relocate urban workplaces and lifestyles to the periphery in hope to attract new (part-time) residents and customers. Co-working spaces are not only a core element of the initiative, they are also widely promoted by Swiss policymakers and practitioners (see e.g. [108]).

While these spaces represent new models of work and doing business for a mobile workforce that originates in the urban realm, our interviews show that digitalization also provides potential for new opportunities for other, more traditional businesses. As mentioned by the owner of the large hotel, he is already planning the construction of a fully digitalized hotel in the periphery:

> We want to construct a very modern, contemporary digital hotel. We want to make a modern hotel where you can book 24-hours a day via AirBnB and self-check-in. You can book a room with or without cleaning and everything can be booked digitally such as skis, the ski subscription and the ski instructor. Everything is digital. A 24-hours hotel in the mountains. This is our idea and we are working on it.

While the fully digitalized hotel has not been built yet, the project shows how digitalization triggers innovative thinking by established actors. Another opportunity that was triggered by the ongoing digitalization efforts was mentioned in the interview by the owner of a fashion boutique. In recent years, shopping underwent a shift towards online shopping. Nevertheless, the analog shopping experience has not disappeared entirely. The owner of a fashion boutique mentioned how he recognizes digitalization and takes advantage of this development:

> We have started many years ago with an online shop. That is about 15 years now. It was a very simple shop and it grew without any budget. That led then to a good additional income. Today it is actually already a little professionalized. So today this is already existential, because the business here on site actually tends to decrease and online business increases.

The case of the fashion boutique owner shows that although the Internet negatively influences on-site retail, digitalization also offers new possibilities by entering online retail. He noted that “it’s not bad for us if things go on like this, we also benefit”. The example of the fashion boutique owner shows how digitalization can also help to expand traditional retail business concepts. It can therefore be a source of innovation in peripheral mountain communities.

While in some cases digitalization shows such positive effects, this is not necessarily true for every retail business in our case study region. The owner of a photo shop did not share the same positive experience in the interview. He observed that the Internet forced price competitions for electronics, which made it almost impossible for him to compete in online retail. Nevertheless, he mentioned social media as a positive factor: “I will make sure that I am there on all the channels. Also, for example, to communicate promotions. And also, that you are always subject of conversation there.” While he also offers a selection of pictures that can be purchased on his website, this online retail is not that relevant. It seems to be more relevant for him so stay in conversation with customers and to reach new clients.

The examples generally illustrate that (digital) technological change, as mentioned by Woods [111, 623], is indeed a driver for creating new business opportunities in mountain communities. Nevertheless, there are also contrasting developments and negative experiences with digital technologies, which may lead to more marginalized positions of some businesses due to the competition from outside (see [34]).

4.4.2 Digitalization and Distances Between Periphery and Core

Digital technologies such as the Internet and ICTs allow working in multiple locations while certain types of tasks can be done via cloud software and Internet applications. The use of digital communication technologies influence distances between core and periphery (see e.g. [3, 56, 106]). The empirical data shows that overcoming of physical distances through digital technologies is a highly relevant issue that was mentioned by the majority of the interviewees. Especially the immediate access to information and time saving communication channels via smartphones and the Internet lead to changing perspectives of community members on being peripheral or central. This represents a significant advantage for mountain communities, as stated by one of the mayors who were interviewed:

> It is our advantage, that the distance becomes short. It was insurmountable before and these are the new chances today. We can communicate with the center and you can come from the center and work in our community. At the same time, you have the work here, in the center or vice versa. We can find solutions together or search and solve problems where you do not have the know-how locally. You can generate very short and efficient work.

As mentioned by the mayor, the Internet can bring core and periphery closer together in terms of multilocal work arrangements. Being geographically peripheral in terms of work that can be done remotely does not seem to be a penalty anymore. Relevant information is accessible from everywhere, as long as Internet connection is available.

Mayors, policymakers and the initiators of miaEngiadina are obviously aware of this potential. Yet, other economic actors also see this potential to overcome physical distances via the Internet and use of ICTs. One example is the healthcare sector. All interviewees of this actor group highlighted the significant relevance of the Internet and use of ICTs for their work. They specifically mentioned easier communication with patients, being more up to date with on-time information and being able to provide better health care—not just for humans, but also animals. The interviewed veterinary doctor reverberates the relevance of the Internet in order to provide better health care:

> Communication with specialists reduces the distance. It becomes irrelevant. I could also do the same with specialists abroad or somewhere else. However, this is actually a national thing, we stay there in Switzerland and you know who is who and you know who to ask and to whom you have confidence. So that's important for us, it brings us closer.

Having the opportunity of immediate access to second opinions and health experts in urban regions is a major change to the traditional provision of health care in the periphery. Telemedicine became increasingly relevant in order to provide adequate health care services also far away from urban core regions, as mentioned by a member of the larger hospital's executive board: "We have also recognized that thanks to digitalization the peripheral regions are moving closer to the center and a bridge can be built, which would otherwise not have been possible."

Next to telemedicine, digitalization also gives doctors in peripheral mountain regions direct access to up-to-date medical knowledge, which, as mentioned by the family doctor, is an important improvement for their work in the periphery. Because distances to important knowledge sources such as libraries and experts that are most often located in core regions are quite large. As a result, the Internet can profoundly compensate this penalty:

> Information is of course very important, because the further away you are from any library, the happier you are the quicker you get to the information in the Internet. There are many open source articles. You always find them. […] Especially the half-life of our medical knowledge is short. Therefore, they say, anesthesia is two or three years I think and for the other medicine it is maybe five or six years. That is the half-life of medical knowledge, which means that after that time half of it is outdated, no longer up to date. The atlas of anatomy does not change so fast, but otherwise therapies, diagnostics and possibilities change fast.

As stated by the family doctor, the Internet reduces the physical distance to knowledge sources and enables instant access to medical knowledge online. This is relevant for providing up-to-date medical services in the periphery. Nevertheless, access to written knowledge is just one part of digitalization and its relevance for health care. On the other hand, as stated by the veterinary doctor, the Internet is a time saver and allows comparing prices of medicine. Two important aspects that have a direct financial impact especially for independent doctors who are often few in numbers in the periphery. All interviewees in the health care actor group noted the positive experiences with telemedicine and the opportunities that come along with enhanced digital connectivity.

Another actor that may profit from shrinking distances is the international high school. Digital technologies do not only affect school lessons, they also provide new teaching opportunities and direct economic benefits. Because schools in the case study region are significantly smaller than in urban areas, the educational offerings are smaller too. However, digitalization triggers new opportunities and can be "economically interesting", especially in terms cooperation with other educational institutions in order to reduce the peripheral penalty, as stated by the school director of an international high school:

> We receive students from all over the world. We also want to be connected here. We have the ideas that we could cooperate with schools in the medium term. With a Chinese university, one could also collapse the Mandarin lessons. As an extreme example, so that our Chinese pupils could also be in class with China. Because, as a relatively small school, we cannot provide the full range of education from our perspective with the classic school model. […] In the medium term, our school will be two-third international and one-third regional; perhaps from Switzerland. Moreover, there will certainly be new demands on us. I have now given the example of Mandarin lessons, where if, for example, we do not have enough Chinese pupils, we will not be able to bring a Mandarin teacher up here. However, this could also be a sales argument for us. On the one hand, it is a Swiss school where our students can graduate here. They get to know the culture. And on the other hand, we could still take something from these cultural circles, where they come from, into the school.

Furthermore, the cooperation with other educational institutions in order to combine classes via digital communication paths has become a viable vision. In this sense, national and even international collaborations can be created that can save costs and enlarge the school offerings. This in turn can increase the school's attractiveness and educational offerings. As our interviews showed, school representatives in the mountain community are highly aware of the possibilities of digitalization and they are already thinking about harnessing its potential. This is connected to miaEngiadina's efforts to connect the region's schools with fiberglass broadband and efforts to build online platforms that connect schools, teachers and pupils within the region.

The interviews and mentioned examples illustrate that digital technologies can bridge physical distances within the case study region itself and can bring the periphery closer to the core and vice versa. Certain types of work and communication can be done in various places as examples from our data show: digital connectivity enables external maintenance of machines and robots of a local brewery, allows to simultaneously manage a bed and breakfast in the periphery and a daycare center in the city or can speed-up work processes due to immediate data transfer from person to person over larger distances within the periphery itself or with core regions. While these examples show a certain bridging between core and periphery and many interviewees stated that digitalization links periphery and core in cognitive ways, it still cannot overcome physical distances per se. In this sense, direct contacts that rely on physical proximity such as for example with customers are still relevant and important.

This section's selected examples illustrate how ICT use and the Internet indeed contribute to transforming processes of various forms of distances between the core and the periphery. This finding goes along with the assumptions from the literature that technological improvements of telecommunication technologies lessen the distance between core and periphery (see e.g. [3, 56, 106]). In general, while the physical distance between the case study region and the core remains unchanged, the Internet and the use of ICTs bring urban and peripheral actors closer to each other within the digital space. Linked to this is also the aspect of speed and time saving by not having to travel from one location to the other to access information and knowledge. Reflecting upon changing rural economies, new types of linkages between the core and the periphery emerge through digitalization and can bring businesses, organizations and institutions in the periphery closer to the core.

4.4.3 Contradictions of Digitalization in the Periphery

As outlined above, digitalization seems to bring many positive aspects to mountain communities. Yet, as our interviews also show, various actors make contradictory experiences with digitalization. Emerging contradictions due to digital connectivity imply that digitalization not only has upsides, but also downsides in the periphery. This leads us to a more nuanced and dialectical understanding of digital transformations in the periphery and a discussion of its unfavorable effects. Peripheral businesses can see new economic opportunities in the Internet, but at the same time, competition is increasing too. Furthermore, the impersonality in the Internet can lead to new insecurities for peripheral businesses due to higher flexibility of clients in the digital economy. Also second home owners experience contradictory transformations when they find themselves in a dilemma of being constantly digitally connected and enjoying the recreational amenities of the periphery in terms of not being connected and distant from everyday life at the primary home's location. Second home owners, which represent a rather large actor group of the mountain community, seek the peripheral environment in order to enjoy the nature and landscape. The president of the second home owners association in the case study region said the following:

> The highest priority for most second home owners is that they can simply meet their expectations up here. For many this means: nature, sports in winter and summer, but also a certain distance from 'daily routine'. Especially that you live in a different surrounding from home and do not feel like being a slave of various facilities or having to check every ten minutes for a possible new email. There are many of us who simply turn off their mobile phones on a daily basis.

The periphery serves them as a place for leisure and gives them distance from everyday life in the urban core. Yet, ICTs and the Internet are constant companions in order to access information during the stay in the second home.

Contradictions at the community level and within individual actor groups became obvious in a variety of interviews. For example, as digital technologies profoundly transform the hotel industry, new platforms in the sharing economy were created, data and statistical monitoring became more precise, infrastructures were added and business models became digitalized [44]. In practice, however, through digitalization hotels can adapt more specifically to the needs of their guests, as explained by the owner of the largest hotel in the region: "We need to have people [guests] who can be managed differently. Much more efficient, faster and more flexible. New products for new guests. And that is where digitalization comes in." He also mentioned the advantage of advertisement in the Internet, because "we can't do without it anymore. Classic advertising is practically disappearing today". While customers can be attracted with online advertisement, online booking platforms became an indispensable tool for the hotel industry in Swiss mountain regions. Booking procedures became simplified and can be done faster by both customers and suppliers. All interviewed hotel owners mentioned the time saving aspect of online booking. In addition, the managing director of a booking platform for holiday apartment rental and event organizer mentioned the high relevance of these online platforms: “I think we are the ones who are present at the moment on the right platform and our apartments are booked above average compared to many other apartments.” She goes further by emphasizing that digitalization infiltrates her daily work because “we work every day, with all projects digitally. Be they events, most of which we only advertise online, or data management. If someone nowadays could no longer register online for a bike race, then we simply have no more registrations. This is an everyday topic and I notice that we stand in front of a radical change that is taking place”.

In times of online booking, hotels are undergoing profound changes in terms of customer care and communication between hotels and customers. In contrast, while the booking procedure and transaction became facilitated due to digital technologies, personal contacts between staff, hotel owners and customers seem to decrease more and more: “Our generation is such that we actually like to know what the guest’s name is, what he sounds like on the phone, how he writes. This became very impersonal now”, as stated by the owners of the medium sized hotel. These kind of personal relations seem to be relevant, as they continue, especially for the hotel industry in mountain regions:

> It is also an important part of guest houses in these small villages. If you fall into this impersonal, then you have no chance to survive. In a city, many new, modern and big hotels are opened. There is a constant supply of customers. Simply by the size. In contrast, here this supply does not come. The guest who is here we must be able to keep it and say that he talks about us and he comes back again. The supply does not come automatically like now in Lucerne where new hotels just keep coming up.

The son of the owner of the medium-sized hotel added to this that “the repeating guest is much more important up here than in big cities”. The repeating guest seems indispensable for the medium-sized hotel, but here the Internet is seen critical, as “you do not get that much [repeating guests] from online stories”, as mentioned by its owner. These statements by the owner of the medium sized hotel and her son contradict the benevolent perspectives of online booking platforms as digitally enhanced communication tools between hotels and their guests. More precisely, they emphasize that this kind of impersonal relation between hotels and customers can be detrimental to run a hotel business in the periphery. The greater flexibility of today’s customers due to impersonal online booking and cancellation procedures create new types of insecurities for these businesses.

Criticism in terms increasing impersonality due to ICT use was also mentioned by other actors. Personal contacts and interactions are still a relevant issue in the digital age. And it seems even more so in the rather small, peripheral communities. As stated by the family doctor, medical examinations are still done best in person and not via the Internet: “The physical examination, it just doesn’t work digitally.” The same is true for schools, as mentioned by the school director because the school is still “a pedagogical place”. She also had doubts concerning the strength of digital networks:

> You have the opportunity to really do networking and form new networks. I think that is a huge opportunity. On the other hand: How strong are these networks? That is the other question. Alternatively: What is the value of personal conversation? Can it really replace that? Or what gets lost? That could also be downsides. But we don't know.

The same criticism towards impersonality due to the use of digital technologies was mentioned by the director of the Swiss National Park: "The conversation with you would not take place the same way on the phone. From that point of view it is still a peripheral region and will remain so." He indeed favors the personal face-to-face interaction instead of communicating via digital channels. A perspective also shared by the director of the region's tourism organization: "Something gets lost in between. It makes many things easier, but I am still convinced that it needs human exchange and human contact." The same is true for the interviewed architect. She mentioned that overcoming distance with digital technologies entails dangers:

> The danger is that the contact between people becomes less. You can do everything with distance. I no longer have to be physically on site with the client, because I can send everything digitally, we can watch it together via face time or with a video call. Maybe the danger is that it will become more impersonal. That would be a shame. Face to face is still the most important thing.

The new possibilities by joining meetings in form of video conferences was a relevant topic mentioned by various actors. Yet, it is also one where skepticism emerged, as mentioned by the director of the smaller hospital:

> We had also studied whether we wanted to do this in the future by video system or something. Nevertheless, I have to say that we break away on it as a peripheral region. Personal contacts are 90% more important to me.

The broad coverage of the community that our interviews allows shows that digitalization entails a large set of contradictions. One of the interviewed carpenters, for example, mentioned that the Internet's transparency could improve working processes between him and his customers: "Actually only an advantage, you save a lot of time to discuss the outline, because he [the customer] already knows from the beginning what it is about. And one advantage or disadvantage, which I interpret as an advantage, is that it has a completely different transparency." In the same interview, he explained "what you can also observe well, the whole market for kitchen construction is completely down. Because the transparency is so high. A Bosch refrigerator in Germany does not even cost half the Swiss refrigerator". This example illustrates how the Internet, on the one hand, can improve working processes and, on the other hand, can make these obsolete due to enhanced price transparency. In this sense, for good or bad, customers in the periphery can also buy their products and services anywhere and do not depend on the carpenter's offerings in the periphery.

The other interviewed carpenter notes another downside of digitalization, because it implies "that you have to communicate a lot more". He goes on to explain that "maybe 30 years ago you had for the same amount of work maybe five phone calls a day. The rest of the time, we had worked productively. Nowadays you have 25 emails instead of five phone calls". In contrast to a larger manufacturing firm in the region, which has special staff for online communication, the carpenter with its smaller carpenter's workshop loses analog work productivity, as he has to do both digital communication and analog work.

As shown in this section, digital connectivity can be a double-edged sword. It offers advantages such as accessing information, expanding local retail to the online world, simplifying booking procedures or enhancing transparency for local businesses. Yet, these advantages go hand in hand with negative experiences made by various interviewees. In more detail, communication via digital channels such as video conferencing or online booking platforms saves time and can shorten the distance to other actors outside of the periphery. However, this form of communication is more impersonal. In addition, transparencies regarding products and their prices increased due to the Internet. While this can simplify work operations, price comparison has become a problem especially for smaller local sellers. These developments can lead to further marginalization of peripheral regions and their communities (see [34, 181]).

This section showed that digital technologies and their influence on rural communities and economies and also the hype of digitalization can be questioned critically (see [34, 189]). The contradictions can have various origins and effects, as shown by the examples above. Actors in the periphery experience advantages that also have a flip side. In general, these experiences highlight the differentiated critical perspectives on digitalization by various actors. While economic downsides of these contradictions predominantly affect smaller and perhaps structurally weaker businesses, organizations and institutions, contradictory topics such as improved communication versus greater impersonality or faster access to information vs. constantly being connected are issues experienced by most actors.

4.4.4 Differences of Digitalization in the Mountain Community

This section discusses barriers for rural communities in order to exploit the potentials of digital connectivity (see [75, 307]). These barriers affect various actors in different ways. An actor group that experienced profound digital changes in the case study region are businesses and entrepreneurs in the secondary and tertiary sectors. As the empirical data shows, enhanced Internet connectivity and ICT infrastructures seem to be related to high financial costs and this aspect divides the community. While larger businesses, cultural institutions, hotels and hospitals welcome the advantages of digitalization, smaller actors criticize the high costs of enhanced digital connectivity. These differences in financial prowess can lead to stressful situations especially for less powerful actors with fewer resources. This is illustrated in more detail by using the example of the healthcare actor group, where differences within the group are larger and, to a certain extent, more existential in comparison to another group.

Stable and fast fiberglass Internet is embraced by the community's large health care actors. For example, a member of the larger hospital's executive board stated that "we as a peripheral institution, thanks to digitalization we can connect to larger institutions". This is relevant for either finding staff in a peripheral region and facilitating the access for doctors who live at a distance to their workplace, as mentioned by the leader of the hospital's IT group. Through electronic health services, medical aid or supervision can be provided at larger distances. As mentioned by the director of the smaller hospital, the process of e-health development "is even prescribed from above. There is a legal resolution that we actually have to implement in 2020". In contrast, however, digitalization and the upcoming preparations for e-health can bring up new challenges for a hospital in the periphery. The implementation and maintenance of digitalization has larger dimensions for hospitals than for private users. This is also reflected in the finances. In addition to fiberglass broadband access, there are also high costs such as technical equipment and further training for doctors and nursing and administration staff. The interviewed managing director of the smaller hospital criticized these high costs:

> This is certainly something that can almost kill us in terms of costs. You have to be honest about that. Last year these costs were for our small company, with a total turnover of CHF 8 million, already at CHF 160,000. These will continue to grow. One can say for sure that it is a high amount. Moreover, I think with e-health we will certainly be CHF 100,000 higher at some point, once all this has been implemented. You have to ask yourself where its limits are and where you can use synergies.

In addition, the same interviewee mentioned that the canton's administration does not provide enough financial support for this financial risk. The canton creates the law, but when it comes to implementation, the hospital is left alone. A possible containment of the problem could be using synergies with other hospitals. A venture that, as mentioned in the interview, seems to be difficult such as technical differences in patient or accounting administration still exist.

However, digital technologies have their price. As a result, the case study region's institutions with smaller financial resources have restricted access to digital technologies. While the larger and prestigious Swiss National Park is equipped with fiberglass broadband and up-to-date digital technologies, the smaller institutions struggle with the costs for digital connectivity, ICT use and maintenance. In this regard, the commercial director of the art center explained, "I think the problems with using social media platforms are management and resources, because we are just a small team and if you use social media, you have to do well and make good use of the channels". In addition, she mentions that "the topic is certainly speed and dependency, how fast the whole IT develops. We have an external IT company that supports us, but that costs a lot and then you always think three times about whether you take the phone in your hand. And that's a challenge, if you have no idea about an IT problem or just superficial knowledge, then you are quickly in a fix" and the artistic director continues in a humoristic way that "one is also dependent on the specialists. It's like a car, you can't repair it yourself". This example of the art center shows that it is not all about only purchasing digital infrastructure but also the upcoming cost for its maintenance. In consequence, the example gives to understand that with lower financial budget, digitalization can also lead to interruptions of everyday work processes and stress. The latter is also the reason why the art center used to be cautious when placing its open calls for residencies in its artist house on online platforms:

> Of course you could find us on the Internet, but we did not want to advertise too much for the artist residency, because then we would have received too many applications that we could not have handled in the small team.

At a more general level, the art director explains that "it's the downside that you're totally dependent on all this machinery. Sometimes I think we can no longer all function normally together, we are so dependent". He explained furthermore that the continuous use of digital technologies in combination with the Internet leads to an inappropriate acceleration that one needs to learn how to handle it.

The results in this section show that experiences of digital connectivity in the mountain community can vary between actors and actor groups. The community focus (see [87]) gives more insights in the varieties of the actor's needs and demands of digitalization. As shown in this section, digital differences can arise due to different financial resources of actors. Smaller and financially weaker actors cannot benefit the same way from digital connectivity as financially stronger ones. In addition to the fiber optic connection, this connectivity also entails additional costs for maintenance and new projects such as e-health, which can be very costly. However, there is no general solution for becoming digital in the mountain community, as differences in use and needs can strongly vary. This heterogeneous image gives to understand that becoming digitally connected is a process that does not take place the same way for all actors. A closer look at the actor's needs, demands and financial possibilities shows that digital connectivity may also arise new problems for financially weaker actors in the mountain community. The community-based approach (see [87]) was helpful in order to detect differences of individual experiences of actors made with adoption of digital technologies in the mountain community.

4.5 Conclusion

Digitalization does not by-pass mountain communities without traces. The aim of this chapter was to analyze how the peripheral community in the Swiss mountain region of Engiadina Bassa/Val Müstair experiences digital change. Our findings show that digital connectivity offers chances but also entails crucial limitations for various actors in the periphery. Moreover, not all actors can participate in digital change equally. Divergences between actors must be taken into account and cannot be ignored. As such, larger firms, organizations and institutions in the periphery can profit more than smaller, financially weaker ones. Due to high costs of digitalization, inequalities and insecurities can arise in the peripheral mountain community. Yet, enhanced digital connectivity can encourage the development of new business opportunities and work patterns in the periphery. In addition, urban-rural linkages can be created due to digitalization. There are new challenges and negative implications such as additional workload, speed and stress as well as the impersonal character of communication that starts to emerge through digital connectivity.

According to this, the findings of the case study provide us various opportunities to reflect upon changing rural economies. In the digital age, conceptual distinctions between urban and rural/peripheral must be questioned, as digital urban-rural linkages provoke a blurring of distances. Digital technologies can bring rural areas economically and socially closer to the core and vice versa. This finding shows also the relevance for fast broadband connections in peripheral areas, which is a technology that enhances these kinds of relations in time and space. Another relevant finding is that the commodification of the countryside can enable new business opportunities that also profit from digitalization. Nevertheless, the findings also show that smaller actors in the rural economy face major (financial) challenges for digital connectivity. Given digital development, various parts of the rural economies are changing differently and individually for various people.

The chapter contributes to theorizations of peripheries, core regions and their relations. In the digital age, space, place, time and distances in between undergo profound transformations. Digital technologies create urban-rural linkages and challenge the traditional perspective on urban-rural dichotomies. It is replaced by an integrated perspective that considers both spatial entities together in a dynamic field of tensions by linkages, which also take place in digital space such as the Internet. In doing so, digitalization leads to a flexibilization of space with dynamic linkages than rigid dichotomy. In this sense, digitalization goes beyond the urban-rural divide in its topographic extent, as digital urban-rural linkages can be created within the dispersed mountain community itself or between the mountain community and urban cores.

Our community-based approach underlines the relevance of a more differentiated and critical understanding of digital transformations for the peripheral actor's varieties in the background of urban-rural linkages as digital divides between actors and actor groups still exist. The community-based approach (see [87]) proved to be helpful for case study research about digital transformations community case. Focusing on both supply and demand provides a more integrated perspective. At this point, the project miaEngiadina comes into play in order to provide a more adapted accessibility that matches the special local needs and demands of the large variety of actors in the mountain communities. Perhaps it can also be understood as getting control over the community's digital future (see [88, 556]). However, the enhanced focus on a larger variety of actors asks for a larger sample and a conscious and careful approach research procedure, which goes broader instead of the deepness.

There are also limitations of the presented research in this chapter. For a peripheral community, the empirical data cannot confirm if digitalization is a success story or not. In addition, we cannot clarify whether digitalization can indeed eliminate digital divides and whether digitalization can effectively counter larger dynamics such as out-migration, re-migration or ageing of the mountain communities (see also [57, 19–20]). Further research is needed in order to explain this current phenomenon in the Swiss peripheries. Furthermore, the data in our research cannot explain if digital transformation has larger transformational effects for the periphery's economy compared to other technological revolutions in the past. The results of the case study cannot be generalized in the first place due to its single-case design. It is limited by its geographic context and the analyzed case. Nevertheless, the outcomes may be generalized in terms of transferring them to other regions in similar geographic settings. In this way, the study can lay a fundament for future empirical research on changing rural resp. peripheral economies in the background of digitalization. Future interdisciplinary research is needed in order to improve the understanding of digital rural and peripheral economies and societies, by conducting more qualitative research. This would help to analyze urban-rural linkages, the relocation of creative or knowledge-based work from the city to the periphery (through for example co-working infrastructure), dynamics and procedures of preparation for digital connectivity in the periphery, effects of digitalization on innovation in the periphery and digital multilocal work arrangements (e.g. digital nomads) between cities and peripheries. Furthermore, digital divide and digital technologies such as fiberglass broadband must be questioned critically due to upcoming technologies such as mobile 5G.

The topics of digitalization and co-working spaces became a larger issue for practitioners, politicians and policy makers that hail their potentials in order to keep the periphery vital or to re-vitalize again. As shown in our case study, the beneficial effects of using the Internet and ICTs vary between different actors. A more differentiated debate in terms of the various characteristics, needs and demands of actors must take place. Thus, only increasing speed seems not to be sufficient for all kind of actors in the peripheral community (see also [98]. The empirical data shows that, in the well connected case study region, digital inequalities did not arise due to lacking digital connectivity for online activities [75, 316]), but rather in terms of its financeability and maintenance. The findings show that there is no universal solution for all actors in the mountain communities and differences and inequalities should be given more attention and recognition (see [87, 369]). The variety of local needs in the case study shows that policies indeed should be more customized and flexible concerning the adaptation in mountain communities.

The case study contributes new insights and a nuanced understanding of different effects of digitalization on mountain communities. Becoming digitally connected in mountain communities is not a uniform process, but rather experienced individually, which calls for a more diversified perspective on effects of digitalization in rural resp. mountain communities. In doing so, the case study gave deeper insights on the receptiveness of digital connectivity in peripheral communities (see [2]). Furthermore, the study adds a more differentiated perspective on urban-rural digital divides at the community scale (see [87]). Due to digitalization, new urban-rural linkages emerge in forms of online communication, multilocal work arrangements, relations between customers and firms or social contacts between family members and friends, which are relevant for researching peripheries (see e.g. [14, 16, 18, 23, 37, 52, 68]). These findings go along with the questioning of sharp conceptual boundaries between the urban and rural (see [48]), as digital communication technologies can foster the interaction between the core and the periphery (see e.g. [3, 56, 106]). Concerning the widening of the digital divide between urban and rural regions (see e.g. [11, 556], [88, 558], [87, 363], [105, 457–458]), the case study illuminates that, depending on actor varieties, the digital divide is widening and shrinking at the same time. These findings go along with reflections on changing rural economies and technological change as one of its key drivers as new business opportunities emerge (see [111, 623]). These changes by new digital and communications technologies go also hand in hand with re-evaluations of the periphery's qualitative values and characteristics such as landscape, nature and tourism. The relocation of activities from the core to the periphery (see [21, 224]) encourages a new questioning of the rural idyll and a new valorization of peripheral amenities and marginalization (see e.g. [12, 32]) in the background of changing rural economies through digitalization.

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Chapter 5
Digitalization and Its Impact on Life in Rural Areas: Exploring the Two Sides of the Atlantic: USA and Germany

Mareike Meyn

Abstract On both sides of the Atlantic, rural areas struggle to maintain social services, access to education, possibilities of employment etc., under the pressure of demographic developments such as aging and an exodus of young, qualified citizens. Therefore, it is crucial to take a closer look on possible solutions, using digitalization as a means to empower people in rural areas. Digitalization implies more than technology—it also includes the skillset and the mindset involved in using digital technologies. Digitalization needs a strategy: Applied in a holistic way, digitalization creates change and can be used as a catalyst for community empowerment. This chapter presents insights on how today's digital possibilities are employed in rural areas within the U.S. and Germany. It draws from the essay "Digitalization: Status Quo and future trends—a new impact on life in rural areas" by Mareike Meyn. Findings are that digitalization offers tremendous potential for rural communities: Applied in a well thought-out way, digital possibilities can not only create change, but may also create a future leapfrog effect for rural communities.

5.1 Introduction

Digitalization is changing dynamics—not only in many industries, but also in terms of how society functions. The digital transformation—or should we call it "digital revolution"—in accordance to the industrial revolution which probably influenced our society as much as this new transformation—is already happening. Big data, collaboration tools, new (required) competencies—all these are both opportunities as well as challenges for everyone, including people, governments, companies, organizations or living environments.[1]

[1]This chapter draws from the essay "Digitalization: Status Quo and future trends—a new impact on life in rural areas" by Meyn [32].

M. Meyn (✉)
Andreas Hermes Akademie, Bonn, Germany
e-mail: m.meyn@andreas-hermes-akademie.de

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It is certain that the wealth of a nation is based on adapting digital tools in the near future [28]. New expectations and hopes come up as any digital information can be delivered and received regardless of space and time. On both sides of the Atlantic, governments developed digital strategies that embrace the opportunity to innovate more with less, to improve the quality of life and this in a safe, secure way [6, 10, 50, 52]. Thereby, the broadband expansion is perceived as an essential necessity for further development.

Digital possibilities create change. This change is necessary, especially when one looks at rural areas in Germany or the U.S. and their struggle to maintain social services, access to education, possibilities of employment and the like, under the pressure of the demographic development such as ageing and exodus of young, qualified citizens.

The U.S. and Germany are two countries which are quite different from each other in terms of size, population, politics etc., but united in their endeavor to use the full potentials of the digital age. In the U.S. there are many innovative, digital hubs in urban centers such as in Seattle, San Francisco or New York, where people, so it seems, know how to use all the opportunities of the digital age. But not only in urban settings, but also in some rural parts of America such as Mississippi, where some unique strategies on how to transit into the digital age can be found and will be presented in this paper. Also for German rural communities, it is crucial to adapt and use digital possibilities, without denying the need to critically scrutinize digitalization and the change it brings. The "Smart Villages" in Rhineland Palatinate or the "Smart Countryside" project in North Rhine Westphalia are two examples on how this can work.

There are many attempts on both sides of the Atlantic, to make use of digitalization. Therefore, the aim of this research project is, to find out more about the linkage between digitalization and rural areas' progress and share best practices. Hence, the research question, which structures this paper, is:

How can rural areas within the U.S. and Germany benefit from digitalization?

In 2019 "Digitalisierung" is one of the most used words in Germany. It could be translated as "digitalization" and is used by many, but with various implications. Generally, it refers to innovation and new technologies and is either used to describe hardware updates or refers to access to (high-speed) internet [31]. In the U.S. this looks differently: Here, "Digitalization" is not much used at all. Instead, much diverse terms to describe innovative technologies can be found. "Digitization" is one of the basic terms and refers to converting information into a digital format.

However, in this paper the concept goes further than broadband and internet-connectivity. Digitalization implies not only the technical way of converting information, but the opportunities digital technologies can create. For this research it is defined through three aspects: (1) broadband access and high-speed internet (2) adaptation of digital technologies and (3) combination of the data that is produced to create smart solutions. And this is all accompanied by a change of mindset of all participants on how to use digital tools and integrate them in their daily life.

Strategies for the digitalization of rural regions can change dynamics: A well-defined, individually fitted strategy can help to change negative trends through applying digital technologies in an all-encompassing way [29, 23]. Thus, basic premise of the paper is that the employment of digital possibilities must be viewed with a holistic approach. Not only the infrastructure broadband, but also tools, skills, inspiration, imagination and some sort of encouraging structure are needed to adapt and empower through digitalization!

The research was conducted with the overall goal to get new ideas about the nature of digitalization within the U.S. and Germany and its possible implications on rural areas. For the U.S. part, findings are based on the results of semi-structured interviews with public/governmental institutions, think tanks, developers, researchers, (technical) sociologists, journalists, independent advisors, leading companies as well as small start-ups.[2] This research was funded through a McCloy Fellowship on global trends by the American Council on Germany. In order to make a comparison possible, general research on German rural communities followed.

The paper presents insights on how Americans and Germans employ today's digital possibilities in rural areas regarding general information about rural areas, their image, digitalization in both countries, and the political framework. It finishes with a description of recent best practices and a conclusion.

5.2 Rural Areas and Digitalization in Germany and the U.S

The U.S. and Germany are two countries which are quite different from each other in terms of size, population, politics etc. The following sections will shortly introduce the two countries: Their rural areas, their transformation into the digital age and their political framework on the federal level for the enhancement of digitalization.

Rural Germany

Looking at digital strategies for community development in Germany, most research focuses on "smart cities" and specific urban ways to employ digital possibilities [20, 39]. This focus on cities is not astonishing: After years of counter urbanization and suburbanization in the 1970s–1990s which were characterized by declining city-populations in larger cities, this population development trend changed tremendously [44, 193–196].

Starting from the 2000s, the urban population generally increased and rural population declined [25, 320]. According to the Worldbank [53], 23% of Germans live in rural areas. Depending on the source and measurement of "rural areas" there

[2]Interview Partners for the research in 2017 are listed here: [32, 14].

are different figures: According to the BBRS [1] more than 30% of Germans live in rural areas. Based on the definition provided by the EU, approximately 66% of the German population lives in sparsely populated areas and intermediate density areas. This refers to around 56 million people [13]. According to the Federal Ministry for Food and Agriculture [4, 5], around 47 million people were living in rural areas in 2016. That said, rural areas still play a major role in German politics, since they are the living environment for many citizens.

The perception of rural areas in the wider population is biased: On one hand side, people perceive rural as romantic, picturesque, living a traditional life in harmony with nature and many customs in solidarity with others. On the other hand, the term "rural" evokes thoughts of desperate remoteness, narrow-mindedness, shrinking and aging communities with limited public services [33, 2]. However, in surveys both rural and urban residents consider themselves similarly satisfied with their lives [55].

Germany: Digital Age

The turn of the millennium marked the time, where digital possibility started to be noticed by a wider public: In 1998 Google was founded, in 2004 Facebook started and in 2007 the first iPhone was released with following apps for all aspects of life.

As access to broadband increased [45], more and more digital tools entered peoples' life and opened up new opportunities for information collection, networking, entertainment, new business ideas as well as jobs that did not exist before. Using digital tools in daily life and living environments happened naturally.

However, Germany is considered as not using its full potential by underestimating digital possibilities [34, 38, 30 ff]. One reason is that the deployment of broadband is still making baby steps. Poor broadband connection can lead to inefficient infrastructures which might hinder economic success, therefore decrease local tax income [16, 1]. It may lead to a lack of skilled employers, can decrease the value of properties in the affected areas and therefore is held responsible to a general decreased attractiveness of the region (ibid.)

However, according to the Federal Ministry of Transport and Digital Infrastructure, only 50% of rural areas can offer broadband with a speed of 50 Mbits/s [7]. So it is no surprise that until recently, rural areas did not play a big role in discussions about digitalization in Germany.

Germany: Political Framework for Digitalization in Rural Areas

Generally, digitalization is perceived as *"fundamental technological trend"* for both society and industry [8]. In 2014, the Federal Government announced the Digital Agenda and launched the "*Network Alliance for a Digital Germany*".

Given that Germany's goal is to proceed to "*Gleichwertige Lebensverhältnisse*" which means achieving equal living conditions in all parts of Germany, broadband deployment is one part of the infrastructure on the way to these conditions. So the goal is to deploy broadband in every part of Germany. In rural and sparsely populated regions, the market driven broadband deployment was and still is difficult and was not completed, since it was not economically efficient for the providers to invest. That is why in 2015 the federal broadband funding program was announced. Like the U.S., Germany also aims on becoming a lead in the 5G market [8].

Furthermore, the German Ministry of Food and Agriculture recently announced the pilot project "*Smarte LandRegionen*" in which up to seven counties in rural areas will be contributing to the exploration of the benefits digitalization might bring [3].

One short notion on net neutrality, because it recently played an important role in the U.S. context: Net neutrality is regulated by the European Union, which established common rules for non-discriminatory treatment of internet traffic, which in the end protects the end-user and therefore also small villages who can present themselves without any constraints on the WWW [9, 6].

Rural U.S. America

The share of U.S. citizens with broadband at home is not increasing much [26]. The "*digital divide*" which refers to inequalities between individuals in access to information and communication technologies (ICTs), plus disparities in terms of knowledge and skills needed to access ICTs, is prevalent in the U.S.[3] [35, 49]. Thereby, "*the gap between rural and urban populations has remained remarkably consistent*" over the years [36]. This is concerning, especially if one recalls a study which found that poverty rates in areas with a high-speed connection were significantly lower than those that did not have broadband [46].

The relationship between urban and rural America is displayed in recent elections and national policies. 18% of U.S. Americans live in rural areas, which refer to roughly 58 million people [53]. In the U.S., the term "rural" is measured in various ways and U.S. institutions rely on different definitions, such as that the U.S. Census Bureau which defines rural as the area which is not classified as urban and bases its definition on population size and density [48]. Depending on the definition, population thresholds differentiate rural and urban communities range from 2500 up to 50,000 [42, 10]. According to the U.S. Census Bureau, about 47 million adults "18 years and older" live in rural areas [47].

Seidemann points out the interconnectedness between urban and rural settings, also concerning the digital infrastructure: An increase in broadband deployment "*inure to the benefit of statewide and regional urban areas […].*" due to rural purchasing power, employment and tax revenues made possible by this infrastructure [42, 18]. Notwithstanding these interconnectedness, the same article also shows the demographic and economic shifts within the U.S.: "*economic activity tends to follow population shifts*" (ibid.) Therefore it is interesting to note that in 1990, for the first time more than 50% of Americans lived in metropolitan areas larger than 1 million people and that already the 2000 Census showed that America is becoming a suburban nation (ibid: 15). This shift may explain the change in the

[3]The digital divide can also be observed by comparing States within the U.S.—there is a correlation between low income States with low population density and their low rate of internet connectivity [49]. Access to ICTs varies, depending on income, age, race and education (ibid.).

recognition of rural by many parts of the urban population: The land between the innovative bubbles is referred to as "*flyover-zone*" and many old-fashioned stereotypes come up when talking to people who are not familiar with rural parts of their country and the same happens vice versa [32].

In the event of the last presidential election, many Americans sense some sort of disconnection between the two Americas. This disconnection happened already before the election and is based on a generalizing view which implies that "*there are no similarities between rural and urban communities around which common cause can be built*." [30, 7].

More than two years after U.S. president Trump got elected, the sentiment of rural residents did not change, but is instead described as path from *"resentment to division to deadlock"* [2].

However, the "*wellbeing of each place is strongly influenced by what is happening in the other and on finding opportunities to work together*" [30]. Recognition is a mutual process and should be considered as important from both rural and urban residents.

USA: Political Framework for Digitalization in Rural Areas

Some programs which promote rural broadband deployment and the usage of it exist in America. One is the National Telecommunications Cooperative Association (NTCA), which has set up a program, called the "*smart rural community program*".

Another program was the Tech hire 2015 initiative by the White House, which connects unemployed U.S. citizens with tech-jobs and has its own section focused on rural tech in the U.S. South Central Appalachia region [51]. The funding supports public-private partnerships to help train citizens in valuable skills for tomorrows job market (ibid.) Today, the initiative transitioned into the operational program of Opportunity@Work, a non-profit organization, and is still committed to empower U.S. citizens to start a career in technology fields [37].

In a recent announcement, the Federal Communications Commission (FCC) declared "*to create a $20.4 billion Rural Digital Opportunity Fund headed by the agency. This money will extend high-speed broadband to up to 4 million homes and small businesses in rural America. These next-generation networks will bring greater economic opportunity to America's heartland, including some of the great jobs building infrastructure, and they will help support future 5G technologies*." [52]. Furthermore, one major aim is that the U.S. will be leading the world in 5G deployment (ibid.). 5G could be a solution for the "last mile issue" and may help extend broadband in rural areas [41]. Low-latency 5G might also be the solution for agriculture and health care in rural areas (ibid.).

Yet, low-density communities still exist in many parts of the U.S. without the necessary broadband infrastructure and broadband carriers have no economic interest to change that [23, 127].

So far, there are some efforts to bridge the digital divide. It is interesting to observe what kind of policies under the Trump presidency of the U.S. emerged so far. One important policy for rural communities is the net neutrality.

The policy approach: Net neutrality and its importance for rural America

"*Net neutrality*" is a regulation which requires Internet Service Providers to treat all data the same and not charge differently or discriminate data based on who uses the internet or what kind of content is exchanged. With the replacement of Tom Wheeler as chairman of the Federal Communications Commission through Ajit Pai, net neutrality got repealed. A recent initiative by the U.S. House of Representatives failed to reinstate net neutrality in April 2019.

The absence of net neutrality has some serious implication for rural America. One major concern is that small rural businesses, which rely heavily on e-commerce, may not have the resources to pay for faster delivery of content and therefore cannot compete with bigger businesses (interview with Roberto Gallardo in Meyn [24]. Without net neutrality, users may be prevented to visit certain websites: The abolition of time and space constraints through the internet—the rural villages webpage is just one klick away from the cities' online presence—is going to be obsolete.

5.3 Setting Sails for the Digital Age

Best practice: "Smart Villages" in Rhineland Palatinate and the "Smart Countryside" project in North Rhine Westphalia

Within Germany, there are many rural projects with a focus on using digital tools and fast internet to improve life in well defined areas. Most of these projects focus on only one aspect, such as improving the knowledge of rural childcare-givers on digital tools [15]. Others focus on the improvement of medical aid in one rural region [43].

In rural Brandenburg a group of young activists created a co-working space which offers "*Space for anyone to be inspired, concentrate, work, and play in the countryside*" [11]. This space provides not only the technical option for telework, but also the community and surrounding needed to become creative. Another example is the "Kiebitz-Klasse" on the German island Langeooge, where primary school kids use digital tools to escape the remoteness of their island, exchange and network with schools from all over the world [14].

Often, these projects, which focus on only one or two aspects of life in rural areas, are reference enough to call the region, where there are applied *"smart"*. However, as Kaczorowski and Swarat [29, 32] point out: Using the word *"smart"* in order to address digitalization and therefore just referring to one project is not following the holistic approach which is necessary to be develop in order to generally enhance rural communities opportunities.

Examples of using digital tools are shared on various platforms, national ones such as the German Federal Ministry of Food and Agriculture—BMEL [5], or also European ones such as the European Network for Rural Development (ENRD) platform, which provides best practices across Europe [19]. For the German section it shows 14 projects, ranging from broadband deployment, a mobile app to experience ancient reality or various other projects with focus on agriculture (ibid.).

Within the ENRD framework, a thematic group is working on the topic of "*smart and competitive rural areas*" [18]. This thematic group explores and exchanges knowledge on how to revitalize rural services through digitalization. Currently, it is developing practical orientation for the emergence of smart villages and how EU financing instruments such as the Rural Development Programs can support villages who want to become smart (ibid.).

In the following part, two German regions on their way to become digital will be described:

The project "Smart Villages" was initiated in 2015 by the Fraunhofer IESE institute and various partners. It aims on opening up new opportunities for the participating villages. Until today, several villages in Bavaria (Steinwald-Allianz and Spiegelau-Frauenau) and Rhineland-Palatinate (Betzdorf-Gebhardhain and Eisenberg-Goellheim) participated in the project. For this paper, focus is on the village Betzdorf.

Betzdorf is located in the south-west of Germany, in Rhineland-Palatinate. The project was initiated by the Ministry of Internal Affairs and Sports Rhineland-Palatinate and the Fraunhofer IESE Institute. It runs until 2019 and total budget is €4.5 million. General aim is to include many different aspects of life in the digital strategy. As Roger Lewentz, Home Secretary, Rhineland Palatinate, puts it: "*The project aims to show in practice, how intelligent interconnections of different domains can support young and old residents in rural areas by creating an attractive living environment, within the context of demographic change.*" [17, 2].

Therefore, the four major objectives of the project are: First, the focus on innovations, which add value to the local "*smart ecosystem*". Second, to develop cross-sectoral solutions. Third, to establish a *"culture of collaboration"* between local residents, authorities and industry. Fourth, to create a sustainable project which uses affordable digital solutions [17, 1].

In the beginning of the project, associations of municipalities were encouraged to submit their project ideas regarding the usage of digital solutions to improve quality of life in their region.

The project of the municipality of Betzdorf targets local commerce, communication and volunteering. In a first step, residents and local entrepreneurs discussed the concept and possible solutions. A prototyping followed, in which mostly apps were created as possible solutions (ibid.). During the last years, a local app *"BestellBar"* was developed [21]. This app is a regional marketplace, where local vendors can sell their products. Here, more than 35 entrepreneurs sell more than 1200 products. One of the issues people face in rural areas such as Betzdorf, is the question of transportation. So the Bestellbar also operates with a service called "*LieferBar*". Here, volunteers can register in order to help delivering packages to their neighbors. Volunteers can thereby earn a virtual currency called "*Digitaler*". This currency can be used to get other benefits within the region. Furthermore, a service called "*DorfNews*" was developed and is used to inform residents by the municipality, local media and various organizations (ibid.). The "*DorfFunk*" application is completing the above mentioned apps by providing a way to organize one's life in the village and also contributing by adding news, organizing car-pooling or offering individual services to others.

Modern "*Nachbarschaftshilfe*", translated as practical help in the neighborhood is made really easy. Tracking user behavior of local residents, shows that the services are used (ENRD [17, 3]. One of the reasons for the ongoing success of the services is the "*living lab*" approach of the project, in which residents are encouraged to participate in the process of defining how their smart village should look like. With every service, the digital village project gets one step closer to their goal of establishing a "*unique ecosystem, in which digital services are developed involving all parts of the society […].*" (ENRD [17, 3]. Currently, the *"LoesBar"* app is being developed, with the aim to improve communication between residents of the digital villages and their administration [21]. As a general result, the whole region gets more attractive and the quality of life can improve.

However, after governmental funding will stop in 2019, it still is to be determined, whether Betzdorf and the other smart villages will continue their journey in exploring digitalization and its potentials for their rural communities.

Smart Countryside in North Rhine-Westphalia

Ostwestfalen-Lippe is a rural area in North Rhine-Westphalia, where in the last years more than 250 km of fiber were deployed, enabling this rural region to access the internet with an average of 30 Mbps [16, 2]. In the "*Masterplan for the Digitalization of Ostwestfalen-Lippe*", several goals were made: First, to inform small and medium size entrepreneurs about the potentials as well as challenges of the digitalization. Second, to come up with solutions for the digital development of rural entrepreneurs and startups. Third, to create visions for the future of work and life in rural areas. Fourth, to plan centers for digital competence and living labs, also with the goal to enhance education. And fifth, to adopt results in the whole region of Ostwestfalen-Lippe (ibid.).

The Smart Countryside Lippe/Hoexter project is also based on the Masterplan. The project is funded by the EU EFRE program and the State of North Rhine-Westfalia. It aims on *"bringing new people together, supporting new ways of thinking and delivering social innovation by using digital tools."* [16, 2]. In the future, it should serve as a blueprint for other rural areas within Europe.

In the Smart Countryside, residents are key stakeholder: In a bottom-up approach, they are the ones to decide on the future of their region [54]. The rural communities of the Smart Countryside agreed on five key topics during the project period 2016—2019 [16]: A "*Digital Village Platform*" with a marketplace, news, chat- and search and find option. Moreover, they decided for a "*Caring Village*", open to local residents searching/offering help. Local residents also decided for a "*Living Platform*" in which the topic around smart living is being discussed. Additionally, they chose to implement a "*Faith Platform*" with online church service.

Smart Countryside also includes digital education with trainings and educational events: Digital skills are being taught to volunteers, who in a next step are going to be local experts on digital questions such as data security, digital farming, E-commerce, E-law [16, 3].

By applying a bottom-up approach, the Smart Countryside project uses local potentials such as the regional history of strong participation and the prevalent interest in sharing local knowledge. The project establishes a change of mindset though ongoing creation of awareness by their peer group and opens up possibilities for residents to participate in the process. This is of tremendous importance, since digital services should always respond to real existing needs.

Best practice: The intelligent Communities in Mississippi

The digital age makes no distinctions. It is disrupting everything in its path, and if you plan to play catch-up or wait it out, chances are you will fail.

Roberto Gallardo, Associate Professor and Extension Officer at the Intelligent Communities Institute in Mississippi

Not only an open mind or strong networks are necessary to embrace digital possibilities, but also a certain infrastructure. In Mississippi 64% of its population have access to wired broadband,[4] which makes it the 50th most connected State within the U.S.—A ranking which does not surprise, when knowing that Mississippi is the poorest State of the U.S.[5] [22]. To create intelligent communities here and show the whole world that there can be some best practice found in Mississippi is against all odds and might go along with the thesis that small communities with a lack of opportunities are the ones that are very experimental and open to innovation.

It is of utmost relevance, to include rural communities in the process of digitalization. Thereby a well-tailored strategy to rural communities needs must be created. An all-encompassing strategy to transit a community into the digital age is the intelligent community approach. The Intelligent Community Forum (ICF), a think tank with a focus on urban communities, has developed this approach and Roberto Gallardo, Extension Service Officer of the Mississippi State University, has applied it in a unique way on rural communities in Mississippi. Gallardo works for the Mississippi State University Extension Service Intelligent Community Institute (MSUES-ICI), which assists rural communities to "*plan for, transition to, and prosper in the digital age.*"

The MSUES-ICI is part of the Extension Service—the major stakeholder for promoting digitalization in rural Mississippi. The Extension Service is a "*public-*

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[4]The Federal Communications Commission (FCC) defines broadband access as speeds of at least 25 Mbps down and 3 Mbps up. [56].

[5]"*The typical Mississippi household earned $40,593 last year, well below the national median income of $55,775. Mississippi also has the highest poverty rate in the country, with 22.0% of residents living below the poverty line.*' [22].

funded, non-formal educational system that links the education and research resources of the United States Department of Agriculture (USDA), land-grant universities, and county administrative units." [40, 1] Major goal of the Extension Services is to advance agricultural innovation, extend knowledge and implement community development programs.

The Extension Center for Technology Outreach (CTO) "*enhances the Mississippi State University Extension Service outreach to rural communities by providing leadership in technology information, adoption, training, and support*" for Mississippi State residents [12].

The CTO's goals are to increase usage of broadband technologies in Mississippi, improve Mississippians access to information, enhance their knowledge of how to incorporate technical solutions in their daily life and become digitally literate as well as to generally increase the interest in STEM[6] related topics (ibid.).

According to Roberto Gallardo, the digital transition takes place through an educational planning process using six criteria identified by the ICF. Gallardo thereby makes a clear distinction between smart and intelligent communities: Whereas smart communities use innovations related to the Internet of Things (IoT) to improve their effectiveness and reduce costs, intelligent communities' focus is more on the community's development [23, 42]. There are six characteristics of an Intelligent Community: (1) broadband connectivity (2) digital equality (3) innovation (4) sustainability (5) a knowledge workforce and (6) marketing (ibid.). These six elements provide a holistic view on community development in the digital age. By combining different community development theories with a specific emphasis on self-help and sustainable capacity building, Gallardo created the "*rural outreach process*" which helps rural communities to display the ICF's six characteristics (ibid.: 136).

The rural outreach process can be adjusted according to the rural community's needs. However, usually the process starts with increasing the awareness and an understanding of the implication of the digital age. It is essential for the whole process to involve as many community members as possible. After that, a survey, called *"checklist"* is given to the community, to do a self-assessment. Once this is done, a report on the findings and possible recommendations on what to do next will be discussed with the community. This is where top down meets bottom up: Recommendations are made by the MSUES-ICI, and the final decision on which of these recommendations to follow through are made by the community. Already existing resources, such as existing networks are connected and integrated within the approach, which is very important to point out. One should bear in mind that rural areas often already offer many resources people need for the transition into the digital age.

It is important to note that the whole process is open to every member of the community and is meant to start a conversation about the community's own way to achieve their goals. When the community agrees upon the next steps to take, an

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[6]STEM (Science, Technology, Engineering, and Math).

action plan is formulated. This plan is defined by the community - the extension officer is (just) the moderator of the process. Oftentimes, additional programs by the Extension Service are pointed out, if they suit the community's needs: The CTO has several additional programs to the MSUES-ICI, which are worth presenting here, since they are also integrated into the holistic approach on how to transition into the digital age and may be applied in rural areas around the world.

One important CTO program is the 4-H Robotics Youth Development Program which engages 4-H youth across the state in STEM subjects and teaches how to program robots. The 4-H movement has been around for many decades and can be referred to as one of the first maker movements within the U.S.

Furthermore, there are other digital literacy programs and workshops with the aim to improve technology skills in word, excel, power point, knowledge about phishing, Malware/Spyware, cyberbullying and the like. Additionally, specific courses target the digital literacy of teachers.

The Master of Innovation Program (MIT) helps to create some digital equality by placing technology volunteers in communities with the aim to better assist Mississippi residents with their technology needs. The tech volunteers receive fundamental training by the CTO.

Another interesting program is the Virtual Incubator Program (VIP), which assists small businesses and farmers in improving their online presence with workshops on social media and web design so that local products can be found online all over the world—where these unique products are more than welcome. Oftentimes, there is not even the need for a Computer, but only a Smartphone and an Email address improve the sales of small rural businesses tremendously. Additionally, the program for rural entrepreneurs of the American Farm Bureau also supports local farmers.

The E-Front Door Initiative assists communities across Mississippi to improve their online reputation. During the program, a rural community's virtual presence is assessed by public relations majors of the Mississippi State University who also crosscheck it later on with the reality. Afterwards recommendations on possible improvements are made.

Telework can also be a solution incorporated into the ICI's holistic approach. It can help rural communities with sufficient internet access, to moderate unemployment and brain drain, plus increases tax revenues of local communities [23, 70]. Therefore the ICI cooperates with Digital Works—a nonprofit organization in Ohio, which offers rural residents access to online jobs. However, one also has to make sure that the telework is not happening in precarious conditions.

All programs and theoretical aspects aside, the important question is, if the community really wants to make a transition in the digital age: "*It is also possible that rural communities do not yet understand that they have to get on board with digital technologies and platforms. They may not realize that they have as much to gain as urban areas if they embrace a digital mindset. This leads us to the crucial question: How do we extend this awareness and knowledge to rural communities?*" [23, vii] Getting the message out and creating awareness and excitement about the issue is the essential and most difficult part of community development.

In Mississippi, some elements help to get the message out: First, the international connection with the ICF helps to justify and back up some of the changes required to become an intelligent community. The ICF can also recognize a rural communities' success by nominating them for their worldwide awards. Second, the extension officer Roberto Gallardo is extremely passionate about the topic and well accepted in the communities he serves, additionally, he is send by the Extension Services, which is a major stakeholder in rural Mississippi and thus very well linked, widely accepted and in general a trusted institution. Third, local key individuals play major role in the process of adaptation, and are from day one incorporated in the intelligent community concept. Desired improvements of problems many rural communities face cannot simply be solved by internet-connection but rather need an active ownership of a digital vision to create a culture of innovation and agility. Such ownership is also created by community hubs, like the East Mississippian Library, where a 3-D-Printer can be found, and kids and adults alike can learn in a safe environment with digital tools.

Roberto Gallardo addresses local leaders, especially mayors and economic developers. These local champions also target groups within their community, to convince residents to get involved in the process. Sometimes, some unusual strategies are being applied, such as the one from a mayor who invited all the young kids of his village to eat pizza and to present them the possibilities by getting broadband access. A very smart move, since especially digital natives understand the need for digitalization. Thereby it is important to reflect that digital tools are just the means to empower a community. A method in assessing a community's needs, could be design thinking, to make sure, programs are tailored to residents' needs. Also, when discussing how else a community can be motivated to get involved in a project, many interview-partners pointed out that they "*need to have some skin in the game*"; to invest something (time, money, other resources) in order to stick and continue their community development projects [32].

The intelligent communities approach applied in Mississippi is just starting.[7] Thus, it does not come as a surprise that no participating rural community has completed the rural outreach process, yet. Only time will tell, how these communities proceeded. Thereby the question of the evaluation of such a process remains. The detailed action plan is already a great base for self-evaluation. Furthermore, embedded storytelling might give some other rural communities an idea of how an intelligent rural community can look like.

[7]A map of participating communities can be found here: ICOP Communities [27].

5.4 Conclusion

Digitalization varies, not only across the Atlantic, but also within the examined countries. However, one finding is similar in both contexts: Digitalization offers tremendous potentials for rural communities. Applied in a well-thought of way, digital possibilities can create a remarkable change. An encouraging structural framework and therefore the recognition of rural communities' needs, ways of distributing knowledge, as well as a mindset to embrace digital possibilities were identified as impacting most on the development of rural communities. Coming together, learning from each other is one important thing and in our digitalized world it has never been as easy as now. Therefore, the research question of this paper can be answered in such way as that digitization can play an important role for the empowerment of rural communities in Germany, the U.S. and also in other rural settings around the world.

However, a holistic approach to digitization is not easy to follow through, especially since the access to high-speed internet is still not given in rural Germany and rural America, where the digital divide is prevalent. Of utmost relevance for rural development is broadband and how it is used. If there are no approaches and policies on how to apply and use digital technologies, the chance to bridge the digital divide between rural and urban areas has not been taken.

In the beginning of this chapter, digitalization was defined as implying three aspects: (1) broadband access and high-speed internet (2) adaptation of digital technologies and (3) combination of the data that is produced to create smart solutions. However, the example in Mississippi shows that fast broadband is not even needed to already start the process of transforming into the digital age. Small steps, holistic thinking and engaging key stakeholders in rural communities are important means to empower rural communities for their future. The Intelligent Communities in Mississippi, as well as the Digital Villages and the Smart Countryside project in Germany, give hope that if rural communities can combine their strengths with a strategy on how to transform into the digital age, they can improve their living conditions.

A lack of infrastructure, recognition and political will can significantly hinder rural communities' digital empowerment. Also, absence of best practice examples or exchange with other regions makes it more difficult to get impulses about how to imagine and build one's future. Thereby, one major exhilarator for development is dissemination—communication must be more effective and must reach out to various users in order to make an impact, as shown by the intelligent communities in Mississippi.

Digitization is not about making rural communities grow out of their comfort zone. It is more about retaining, stabilizing and enhancing a chosen lifestyle with the amenities of the digital age.

One has to keep in mind that digital tools are just the means to empower rural communities: They are enabler and help rural communities to participate and experience the world without constraints. Thereby the desired improvements of problems many rural communities face cannot simply be solved by broadband infrastructure, but rather need an active ownership of rural citizens taking action and shaping their digital world according to their needs.

Findings/suggestions other rural communities all over the world might use are:

- Digital technologies are only the catalyst to empowerment.
- Digitalization is an abstract concept, which is defined in various ways. Therefore communities need to tangibly experience the possibilities of the digital age.
- Active Ownership is necessary to understand the implications of the digital age and make informed decisions about future policies, also in rural areas. Thereby local champions are essential.
- Digitalization requires new structures: The old thinking of separate sectors with isolated responsibilities will not get rural communities any further. Following the logic of the digital in analogue contexts is needed to enhance and empower rural communities. Digital tools can help to improve conditions in rural settings. This was shown on both sides of the Atlantic.
- Rural communities' efforts to transit in the digital age should be documented and made available.
- Other structures of knowledge sharing and learning emerge and can be valuable in rural settings, such as the living labs. These labs could serve as actual physical space for exchange and might be included in rural libraries.

Furthermore, new forms of partnerships between urban and rural approaches to employ digital tools are promising. The fact that digitization decouples people from distance constraints, opens up the chance for more impulses for both urban and rural communities: Whether it is the U.S. Extension Center for Technology Outreach or the German Frauenhofer IESE Institute—some impulse from outside of the villages contexts is used to make digitalization happening.

In a nutshell, digitalization in rural areas can help to answer questions related to public transportation in rural setting, car-pooling, minimizing commute between rural and urban areas, all issues around care-giving, enhancement of volunteering, participation in the policy making process, creating new value chains for rural entrepreneurs and many more. The creation and usage of digital, new data is another topic to be addressed in the near future.

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Chapter 6
Government Versus Private Sector-Led Smart Village Development Policies and Programs in India

Tej Karki

Abstract In recent years, India has made innovative attempts to develop villages. Two of the latest are the government-run programs, Provision for Urban Amenities in Rural Areas (PURA), and Member of Parliament Model Village Plan (MPMVP). PURA aims for injecting urban amenities and job opportunities in villages. The MPMVP intends to improve the wellbeing of selected gram panchayats (model villages) through a bundle of coordinated programs. Side by side, private sectors have run a very successful smart village development programs in Gujarat, Bihar, and Puducherry. This paper reviews both the government and private sector-led smart village development policies and draws lessons for the future. This research found that the private-led smart village programs were more effective than the government-run PURA and MPMVP. The reason is that the private sectors earn goodwill and trust by addressing critical village needs, and through that goodwill, they expand their social contribution to the entire village. Whereas, the top-down government-run smart-village programs claim big but deliver little due to shifts in political mindset, lack of earmarked funding, and weak local-implementation capacity.

Keywords Smart village policy · Information technology-driven villages · Private leadership in village development · Central bureaucracy in village development · Village development plan

6.1 Introduction

Village in India includes both the cluster of houses and the surrounding cultivated land [1]. There are 650,000 villages in India, where 70% of the people live [2]. The Planning Commission of India defines "Village" as a settlement with a maximum

T. Karki (✉)
Lovely Professional University, Jalandhar, Punjab, India
e-mail: tejkarki@gmail.com

Northeastern University, Boston, USA

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population of 15,000 [3]. The village is the smallest administrative unit in India from where a decentralized form of governance is envisaged [4]. This form of governance has existed in India since the Vedic era, where 'Sabha,' a group of village heads addressed most village issues [4]. Today Gram Panchayat (Village Panchayat) has replaced the 'Sabha.' The Gram Panchayat (GP) represents a cluster of villages with similar socio-economic and geographical characteristics [4]. The GP is in existence since 1958. Mahatma Gandhi was among the prominent leaders who talked extensively on what an Indian village should look like [5]. He envisaged that a village should have perfect sanitation, cottage with sufficient light and ventilation and use of locally available building materials.

Gandhi imagined a dust-free village lanes and streets, a place of worship and common meeting place, common cattle grazing grounds, cooperative dairy, primary and secondary schools, and a panchayat to settle disputes [5]. He also expected that a village should be self-reliant, self-governed, democratic, fair, and participatory and inclusive in decision-making [5]. What Gandhi was essential doing in his time was trying to outline the attributes of a smart village for India. In recent years, both the government and private sectors have made attempts to create smart villages in India. This paper reviews both the government and private sector-led smart village development policies and draws lessons for the future.

The remaining sections of the chapter are organized in the order as follows. Section 6.2 presents background and literature on smart village. Section 6.3 explains the current challenges in Indian villages. Section 6.4 presents new Indian village development policies in particular: Provision for Urban Amenities in Rural Areas (PURA), and Member of Parliament Model Village Plan (MPMVP). Section 6.5 presents a case study of four private sector initiated smart villages: two from Gujarat, one from Bihar, and one from Puducherry. Section 6.6 presents the overall findings from both the government and private sector initiated smart village programs. Section 6.7 provides a conclusion, and finally, Sect. 6.8 lists out a range of policy recommendations.

6.2 Background

Today, in the era of information technology, scholars are trying their best to figure out what a village should look like similar to what Mahatma Gandhi tried a long time ago. The idea that is gaining currency today is a smart village. According to Holmes and Thomas [6], 'smart village' is a model in which, energy access acts as a catalyst for a range of development outcomes. If managed correctly, technology 'leapfrogging' could lead to rapid improvements in healthcare, nutrition, education, and economic security in remote villages. Villagers could thus have the opportunity to capture many of the benefits of urban life while retaining valued aspects of rural life and ensuring balanced development at a national level. Smart village is about pooling community efforts and strengths of people and integrating it with information technology to provide benefits to the rural community [7].

Smart village improves its networks and services through digital and communication technologies and embraces innovation and knowledge for its residents [8]. It believes in bottom-up and public-private community partnership and put community in the driving seat of decision making [8]. A smart village should ensure proper sanitation facility, good education, better infrastructure, clean drinking water, health facilities, environment protection, resource use efficiency, waste management, and renewable energy [3].

According to Darwin [2], the smart village is about empowering the villagers with technology and enabling them to create value. Darwin argues that a smart city should have six characteristics. First, a village should have an ecosystem that leverages its resources as well as those of surrounding villages, generate revenue, and lower its costs and risks. Second, it should have an economic development platform that allows many external businesses to access its resources to profit from them. Third, the village should have a brand that creates an identity and is known for something of value that is unique. Fourth, the village should have a community that self-organizes network of people who collaborate by sharing ideas, information, and resources to build a robust ecosystem—when all else fails the community remains to rebuild itself. Fifth, the village should have a business model that creates value for its people and others outside its ecosystem by utilizing lean and cost-effective state of the art technologies. Finally, the village should be a sustainable unit that generates a triple bottom line: (a) people (b) profit and (c) planet [2]. The literature primarily reveals the following message regarding the smart village concept:

- Smart village benefits village-residents by making a meaningful connection between people and information technology
- Smart village could enhance access to clean energy and essential health services
- It promotes community-driven decision-making and facilitates public-private partnership for village development
- Smart village improves access to basic sanitation, clean drinking water, and education
- Smart village takes care of social, economic, and environmental needs of villages.

All these ideas have value, but their needs and priorities may vary from nation to nation. For example, for the western world, access to essential services may not be a priority; they might be interested more in advanced information technology. However, for India, the sanitation, education, and computer literacy would come first before they move to the information and communication technology applications.

6.3 Current Challenges in Indian Villages

Seven decades after Mahatma Gandhi's legacy, several challenges continue to persist in Indian villages. About 25,722 villages or 304 million people have no access to electricity [9]. Many villages in remote areas have inadequate educational facilities, irregular water and electricity supply, improper sanitation, poor road connectivity, and infrastructure [9]. Lack of access to essential utilities and livelihood opportunities have instilled a sense of deprivation and dissatisfaction among villagers and pushed villagers to migrate to towns and cities [9, 10]. When the village migrants fail to afford decent housing in cities and towns, they end up living in slums, and create another set of urban problems [9].

Many programs initiated by the central, state and local governments on village development have been less successful in the past, mainly due to lack of comprehensive approach to village development [11]. The sector-driven approach (road, water supply, health) could not bring the result as expected [11]. In 2011, infant mortality in the rural area was 46% (urban 28%), and the illiteracy rate was 31% (urban 15%) [11]. Twenty-eight percent of villages in India continue to defecate in open spaces [12]. In 2015, piped water supply in rural areas was available to only 47% of rural habitations [12]. These situations prompted the government to make more holistic village development attempts in India. Some of those programs were the provision of urban amenities in the rural area (PURA) and member of parliament model village plan (MPMVP).

6.4 Recent Indian Village Development Policies

6.4.1 Provision for Urban Amenities in Rural Areas (PURA)

The central government launched PURA in 2003 [13]. The objective of the program was to inject urban amenities and employment opportunities in villages to retain population in villages and reduce rural to urban migration [10]. The idea creator of this program was the former president APJ Abdul Kalam. PURA aims to connect villages by roads, communication networks, and establish professional and technical institutions (knowledge centers) in a holistic way [14]. For this purpose, the PURA involves private players for village infrastructure development for ten years in the selected villages [14]. The pilot phase of PURA was implemented from the year 2004 to 2007, with the consent of the Planning Commission and a total budget of (Indian rupees, Rs. hereafter) Rs.[1] 30 crores. The authorities selected seven clusters in seven states with a budget of Rs. 40–50 million per cluster [10]. The nature of projects implemented were water supply and sewerage, village roads,

[1]One US dollar is Rs. 68.79 on July 30, 2019 exchange rate.

drainage, solid waste management, skill development, street Lighting, telecom, electricity, village tourism, rural market, and training institutions.

However, with the changes in political leadership, the project priority started to shift. Minister of Rural Development, Ramesh, openly stated PURA as a failure [14]. He held the view that the focus should be on water supply, sanitation, physical infrastructure as opposed to talking about knowledge connectivity [14, 15]. He also opined the view that there is more urgency on the need for services in villages which are neither rural nor urban [15]. As a result, the Rural Development Ministry shifted its focus from villages to 2000 new towns that have been identified by the 2011 census [14]. According to Dabas [13], PURA failed due to a lack of coordination between the center and the state governments. Dabas [13] further reports, according to one person from the ministry of rural development: "Public-private partnership (PPP), became a major bone of contention as the center chose private players and gave them the liberty of site selection without taking consent from the states." In some cases, private players were allowed to run projects for their self-interests [13].

6.4.2 Member of Parliament Model Village Plan (MPMVP)

It is not uncommon in India that every new government brings its village development policy as corrective measures to the earlier ones. Prime Minister Narendra Modi at the beginning of his first term in 2014, launched MPMVP to improve the wellbeing of selected gram panchayats (model villages hereafter) through a bundle of coordinated programs under the overall guidance of the member of parliaments (MPs). The MPMVP aims to improve access to public services in villages, ensure socio-economic development, and create a role model for the rest of the villages [11]. The MPMVP allows every Member of Parliament (MP) to select and develop one model village in their constituency. In the first five years (2014–2019), the MPs are allowed to adopt the model villages (MV) in three phases: 2014–16; 2016–18; and 2017–19).

MV selection criteria and the role of MP: According to the latest guidelines, the MP may choose any Gram Panchayat with a population of 3000–5000 people in the plains, and 1000–3000 in hilly, tribal and challenging areas [11]. In districts where this village population size is not available, Gram Panchayats having population closest to the above mentioned range may be chosen [16]. MPs can choose any village (meeting these population criteria), except their own or their spouse's [17]. There is no other criterion [17]. The primary roles and responsibilities of an MP under MPMVP are as follows: Identifying the Gram Panchayat, facilitating the planning process, mobilizing additional resources as and when required under the plan, and filling in critical gaps using Members of Parliament Local Area Development (MPLAD) funds.

Institutional arrangements: Two National-level Committees would monitor the implementation of the Scheme. The Rural Development Minister would head one Committee and include Ministers in-charge of planning and program implementation [11]. The second Committee will be headed by the Secretary, Rural Development with representatives from various other ministries/departments relevant to PMMVP. State-level Committee is headed by the State Chief Secretary, and the committee includes experts from various disciplines. The Secretary of the State, Rural Development Department would serve as member convenor to this Committee.

MPMVP goals: The MPMVP's goal is to instill social values of village development [5]. Those values are: people's participation; enabling the weakest and the poorest in the village; ensuring social justice and gender equality; instilling dignity of labor, community service and volunteerism; promoting cleanliness and ecological balance; mutual cooperation; self-help; self-reliance; transparency and fundamental rights; and duties in line with the Indian Constitution [5].

MPMVP village-development-plan preparation process: MPMVP requires that each selected village prepare a village development plan and get approval from the village council [18]. The MP will involve villagers to develop village development plans. The plan would identify village needs and priorities and get approval from the District Level Committee and State Level Empowered Committee (SLEC). At the district level, monthly review meetings are conducted for each Gram Panchayat under the chairpersonship of the concerned MP. Each project is reviewed in the presence of representatives of the participating line departments. The progress is updated to the state government.

MPMVP activities: The MPMVP broadly has laid out eight activities. They are the personal, human, social, economic, environment, basic amenities and services, social security, and good governance. The personal development would focus on good hygiene behavior and practices, healthy human-physical activities, reducing risky behaviors such as alcoholism, smoking, and substance abuse [5]. The human development aspect covers universal health and education, immunization, balancing sex-ratio, nutrition for all age groups including, girls, children and mothers, adult literacy, and e-literacy. Social development encourages volunteerism, encourage the participation of villagers and youths in local development, promote sports and other interactive cultural activities. The economic development would cover Improve the quality of agriculture, including enhancing soil condition, establishing seed banks, livestock development, organic farming, agricultural-services, micro-irrigation, and micro-enterprises. The environment development intends to provide better toilet and sanitation coverage, solid and liquid waste management, tree plantation, watershed management, rainwater harvesting and reducing all kinds of pollution [5].

MPMVP's basic amenities and service provision commitments: The basic amenities and services would provide decent homes for all homeless or those living in temporary homes, water, road, drainage, bank, internet coverage, telephone connectivity, and CCTV installation in public spaces [5]. The social security covers pension and welfare funds to eligible families, including old, disable and widows, life, and health insurance for residents. The good governance covers time-bound service delivery, holding of female and children council in the village to listen to their needs. Responds to the public grievances in written within three weeks [5].

Funding mechanism: MPMVP does not have its fund [18]. Resources can be raised through: Funds from existing schemes, such as the Indira Awas Yojana; Pradhan Mantri Gram Sadak Yojana; Mahatma Gandhi National Rural Employment Guarantee Scheme; and Backward Regions Grant Fund; The MPLAD funds; The gram panchayat's revenue; Central and State Finance Commission Grants; and Corporate Social Responsibility funds.

Achievements: As of 2018, 1448 villages (out of 6433) were selected for MPMVP [19]. A total of 61,994 development projects were implemented in the selected villages, and nearly half of them (30,913) has been completed according to the latest government report [19]. It was found that 427 villages had achieved 100% children immunization in the 0–6 age group, 252 had reported 100% institutional delivery, 526 had reported 100% Mid-Day meal coverage in schools, and 171 have reported an electricity connection in every household [19] (Table 6.1).

Challenges: Despite some success, the MP's interest in the project is in a downward trend. In phase one, 703 out of 786 MPs adopted villages as required by the MPMVP [20]. In phase two, 466 MPs adopted, and in phase three, the number drastically dropped to only 172 MPs [20]. According to one senior official from the rural development ministry, this decline in the MP's interest in MPMVP is due to lack of funds to develop a village [21]. As there are no specific funds for MPMVP, MPs have to tap into other resources like funds from existing schemes, the gram panchayat's revenue, CSR funds, and the like [21].

However, according to Sharma [19], some government officials had a different take. The officials said that everything depends on the leadership exhibited by the MP in MPMVP and their experience has been that wherever an MP has taken an active interest and made frequent visits, work has happened in the adopted village. "It is an MP identifying gaps in the village, prioritizing them and marrying them with various schemes of the Centre and the state government. If the MP, the village sarpanch and the Block Development Officer (designated as charge officer for each adopted gram panchayat) work as a team, the results would show up," a senior government official said.

Sharma [19] talked to a few MPs, and their comments on the program were: "One, the scheme has no budget of its own. Everything depends on the central and

Table 6.1 MPMVP implementation trend

Status of implementation	
Total MPS (Lok Sabha and Rajya Sabha)	790
Total villages adopted so far as of 2018	1448
Projects proposed in these villages	61,994
Project completed as of 2018	30,913 (50%)

Source Sharma [19]

state government schemes. That brings in much bureaucracy…also, politically, it is tough for an MP to select three villages in his constituency and ignore the others.

A closer look at the official data suggests that 46% of Union ministers have not identified a village in phase III [22]. Lok Sabha members from 13 states/union territories (UTs) and Rajya Sabha members from 16 states/UTs have not identified villages in phase III [22]. In Uttar Pradesh (UP), out of 108 MPs (both houses), 56% have not adopted villages. In Maharashtra, 88% of the 67 MPs have so far not identified villages for adoption [22].

In March 2017, Jayapur village near Varanasi, under MPMVP, got new roads, solar electricity provisions, toilets, and piped water [20]. However, due to lack of administrative follow-up, the program did not last long. The bathroom built started degrading, people sold the installed solar panels, and unemployment continues to be a challenge [20]. After Jayapur, PM Modi adopted two more villages in 2016, and one of them was Nagepur. In this village, a solar plant was scheduled to be setup. After ten months of negotiation, the private company that agreed to set up the plant refused to pay for the land and left [20]. No school teaches beyond class five; there is no hospital nearby [20]

One MP had adopted Taroda village in Wardha district in Maharashtra in 2014 [23]. The villagers were complaining that the MP took all the funds to develop his village located nearby, instead of focusing on the adopted village [23]. Shrinivas Chambhare, a villager, said, “Ramdas Tadas, our MP, visited this place (selected villae) only five times in five years [23]. Look around the village; there are no proper streetlights; there is no regular supply of water [23]. These are basic facilities, forget about the beautification of the village that is mandatory under the Adarsh Saansad Gram scheme” [23].

6.5 Case Study of Smart Villages Created Through Private Initiatives

As mentioned above the MPMVP promotes e-literacy for health and education, internet coverage, telephone connectivity, and CCTV installation in public spaces [5]. However, there is no specific research on how many MPMVP villages have adopted smart technologies. Whatever information exists is in bits and pieces and not much on technological aspects. However, some private individuals and non-governmental organizations have brought concrete results by converting waste to electricity, using ICT for cashless banking, capturing solar energy for village electricity, and creating a network of computers in villages for e-education. The section that follows presents a case study of four smart village interventions: two from Gujarat, one from Bihar, and one from Puducherry.

6.5.1 Punsari Village, Gujarat

Punsari village, barely 100 km from Ahmedabad, could be a textbook case of development. The village has free WIFI, water purifying plant, waste generated electricity, air conditioned schools and CCTV camera in public spaces for security. This work was completed at Rs. 160 million and under the leadership of Himanshu Patel, a 33-year old Sarpanch (village head) [9]. The village houses 6000 villagers. The village head provided Wi-Fi connectivity in the entire village [9]. The village is producing its electricity from the village waste [9]. There is a 66 KV sub-station that supplies power to the village. The village's future aim is to generate electricity surplus so that they can sell it to the government, make revenues, and use those revenues for the welfare of the people [9]. The village installed a Reverse Osmosis (RO) plant in 2010 to supply clean drinking water to the village people [9]. The RO drinking water-supply plant delivers 20 liters of water to each household at 4 Rs. [11].

Every household has a toilet that makes the village open defecation free zone, the prime goal of the central government's mission (Swachh Bharat Mission). The number of school dropouts in the village has reduced after air-condition-installment in classrooms, furniture improvements, and CCTV camera surveillance [11]. The twenty-five CCTV cameras surveil village public places. There are 120 waterproof speakers installed to inform people about new schemes and initiatives. There are two banks in the village which have been successful in opening accounts of every household. The village has ATM for cash withdrawal. Furthermore, the village has established skill development centers, health care centers, and veterinary centers.

Himanshu Patel, as a young man tried to improve the condition of the village at the personal level, but when he failed to improve the village at the personal level, he fought for village head election, got elected and finally materialized his dream [24]. Before the village head took the position in 2006, there was no electricity, water supply, and better law and order situation [24]. Many families had migrated to other places; the village had a debt of Rs. 120,000, and 328 families were living below poverty. After the village head took office, he turned around the situation [24]. The Ministry of Rural Development awarded Punsari as the best village in 2011.

6.5.2 Akodara Village, Gujarat

The Akodara village in Sabarkantha district in Gujarat has a total population of 1191 people and 250 households. All the village residents use the various cashless system for payments of goods and services [9]. The village has installed a Wi-Fi tower for internet connectivity [9]. The ICICI bank has adopted the village under its Digital Village Project in 2015 [25]. All households in the village have saving accounts in local ICICI Bank branch [25]. Through the assistance of the bank, all transactions in the village are carried out through digital modes like SMS, net-banking, or debit cards. The bank has provided training to villagers to embrace digital technology to reduce dependence on cash, and has offered mobile banking in Hindi, English, and Gujarati languages. It also has a social website. The villagers' most essential transactions such as selling agricultural produce to the market, and selling milk at the co-operative society have been made cashless [25]. It has primary, secondary, and higher secondary schools equipped with smart boards, computers, and tablets. The village is a role model to show how e-banking can be practically implemented in Indian villages without much difficulty to make India cashless economy [25].

6.5.3 Dharnai Village, Bihar

Dharnai is a small village in Jehanabad district in Bihar near Bodhgaya in eastern India with 2000 citizens [26]. For over 30 years, high-tension electric wires passed by the village without lighting up a single home [26]. The village was near the national highway, railway station but without electricity [27]. People were forced to depend upon kerosene, cow dung, and diesel plants for electricity in the village [27]. However, on July 24, 2014, the situation changed. The village was declared as energy independent. People from a non-governmental organization, Greenpeace, came to Dharnai in 2014 to provide solar electricity in the village. Within three to four months, they installed solar street and home lights and made the village having twenty-four-hour access to electricity [28]. The 100-kw solar-powered micro-grid provided quality electricity to more than 2400 people living in this village [28]. Besides, the electricity served 50 commercial operations, two schools, a training center, and a health care facility [27]. As a result of this, Dharnai gained the status as the first village entirely run with solar electricity [27], at a time when 300 million people in India live without access to electricity [28]. The initial project cost was Rs. 30 million [27]. A battery backup ensures round the clock electricity in the village [27].

The incoming of solar-powered electricity into the village revolutionized the lives of the people here, especially women and children. The access to the energy created opportunities for women and girls by increasing access to both public and personal spaces, including toilets after dark [26]. Women no longer needed to finish preparing meals before the sunset [26]. It allowed children to study even beyond the daylight hours [27]. The solar-powered pumps have provided access to freshwater to the farmers [27]. People are now able to charge their mobile phones regularly and have access to the internet [27]. Streets could be accessed at night, and make-shift shops sprung up underneath the street lights [26]. It made the whole community safer [26]. This solar electricity supply is a small first step to reach the larger Indian goal of producing 100 GW of solar capacity by 2022 [27]. The solar electricity supply at Dharnia is a Decentralized Renewable Energy System (DRES) that uses a micro-grid network to cater to the needs of different population. DRES has several benefits [29]:

- Low cost of starting up due to smaller project scale
- Less distribution/access issues when energy is produced locally
- Community-owned approach allows local control without reliance on government or big companies
- No ongoing costs beyond upkeep to have electricity versus paying for the electricity with a centralized grid.

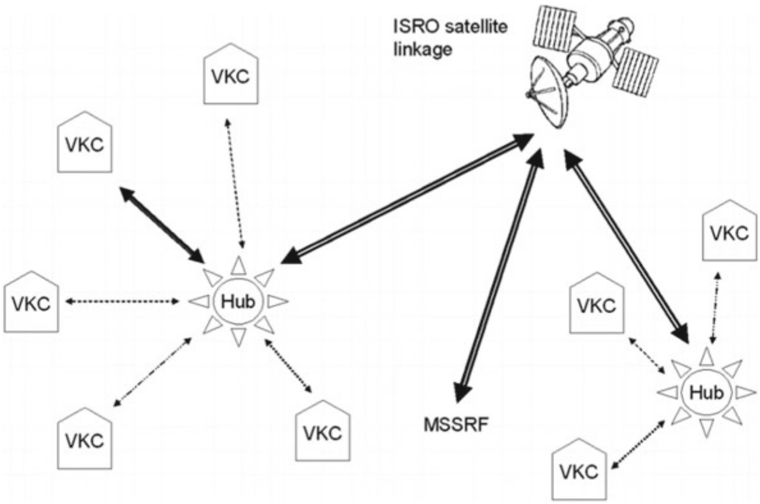
6.5.4 Village Knowledge Centers, Puducherry

In 1998, the M. S. Swaminathan Research Foundation (MSSRF), a non-profit organization foundation started the "Village Knowledge Centers" project [30]. The idea was to select villages in rural Tamil Nadu and the Union Territory of Pondicherry (both in southern India) and provide information regarding farming, education, health, weather, jobs, loans and aid opportunities through telecommunication infrastructure and computers [30]. The purpose was also to reduce the digital gap and gender divide in rural India using information and communication technology [30]

The village is served through digital communication system by creating spokes and hub in the region. Spokes are village knowledge centers (VKC), and hubs are Village resource centers (VRC). One VRC serves about 20–30 VKCs. Each VKC is linked with the VRC (hub) through Motorola VHF Radio in a two-way communication hub-and-spokes model [31]. The VRC is linked via satellite communication with MSSRF in Chennai and ultimately to the internet. The program started with a network of ten VKCs and one VRC in 1998 through 2003. The communication is established through computers, printers, telephones, very high frequency (VHF) duplex radio devices, and other accessories. It has e-mail connectivity through a dial-up telephone service that facilitates both voice and data transfer. Between 1998 and 2003, the MSSRF started the program with a network of ten VKCs and one VCR. The ten VKC centers were Kizhur, Emblam, Veerampattinam, Poornangkuppam, Pillayarkuppam, Thirukanchipet, Kakitheerthalkuppam, Nallavadu, Koonichampet, and Periyakalape. The VRC is located at Villanur (Fig. 6.1).

Each VKC has one or more desktop computers, at least one printer, radio communications equipment, a wireless tower antenna mounted on top of the building, and in some cases, a video kiosk. These are maintained by the villagers [30]. The videos enable visitors to play and watch video-tutorials on farming, health, and other topics. The computers have Microsoft Office, Net Meeting, games, publishing software, databases containing information related to health, education, agriculture, commodity prices, and government job vacancies [30].

The information in the databases is updated at regular intervals (sometimes daily) by downloading the updates from the VRC servicing the VKC [30]. Each VKC also has a public address system from which the VKC volunteers could quickly disseminate critical and useful information to the homes in the village.



Source: Julian Swindell

Fig. 6.1 VKC connection with the hub (VRC) *Source* Julian Swindell

In addition, each VRC and VKC has complete training videos and CDs for the "Microsoft Unlimited Potential Program (MUPP) [30].

Each VKC selects and helps promising youth to undergo various types of computer skills training. The training sessions are held at the appropriate VRC. Additional on-line, video and CD-based training materials, and exam practice materials are available for use by the trainees at the local villages through the VKCs [30]. VKCs provides the latest information to the villagers so that they can earn, live a better life, and be a part of the development. The village should pay the electricity bill for VKCs.

The VKCs provide information such as new government schemes, prices of the commodities, examination results, importance of hygiene, loan schemes techniques of agriculture, methods of cultivation, latest market price, and weather alerts. The VKCs are quite as successful as a project. Villagers utilize the knowledge provided through VKCs, and the village women who work for VKCs also feel more confident and empowered.

The papers that critically evaluate the Puducherry VKC and VRC programs are rare. Most of the information about the VKC programs are no latest, and most of them are published around 2007. The materials found were less critical about the program and more applauding in nature. Only some anecdotes on the VKC benefits are found. For example, Swaminathan [32], also the architect of the village knowledge center program said in an interview that the VKCs were able to figure out eye camps and help a lady for her cataract operation. In other instances, the VKC had managed to arrange a veterinary doctor and save a farmer's cow.

Next, Nelson et al. [33] found a couple of stories of people who benefitted from the VKC in Pillaiyarnatham village in Tamil Nadu. A woman with two school-going children and her husband working in a cotton mill in daily wages was looking for an opportunity to raise her income to raise her children. She decided to join a computer literacy course, but she did not have enough money for such a course. She somehow found out that the village knowledge center is offering free Microsoft office training. She took advantage of that training and received a certificate. After the training, she got employed with a handsome salary of Rs. 5000 as monthly earnings. This job opportunity relieved her in many ways to raise her children and manage household expenditures. Another lady was facing insects problem on her black gram farming and she was about to abandon the farming. She approached the village knowledge center and got advice from the VKC facilitator and help find the right medicine to eliminate the insects and continue black gram farming.

6.6 Findings

The review of the literature shows that the government-run projects such as PURA have been marginalized due to political ego and mindset of subsequent ministers responsible for running the program. The MPMVP expects comprehensive village development but with no direct financial commitment; it is dependent on the funds of the other programs. Village development is a full-time task, but the task is given to the MPs who could only work part-time (their fulltime task is lawmaking). The government programs start with huge physical infrastructure commitments but end up delivering too slow and too little due to weak local implementation mechanism.

Whereas, the private sectors earn goodwill and trust by addressing critical village needs and through that goodwill, they expand their social contribution to the entire village. Punsari village became smart not because of the MPMVP but the active leadership of a private individual, a young man who even fought village election, got elected, applied his social skills, ran various smart projects in the village, and finally, won awards.

Akodara village shows how the involvement of a private bank in village development can make the entire village go for cashless payments and money transactions. The Dharnai, Bihar, shows how a private solar-technology savvy nongovernmental organization could change the socioeconomic and educational life of the entire village through solar energy generated electricity. The Puducherry case shows how a professor establishes computer networks in villages and change the lives of people stuck in remote rural regions, by disseminating information about job skills, agriculture, and veterinary knowhow. These villages have met some of the expectations that many smart village scholars were arguing for:

- Smart village benefits village residents by making a meaningful connection between people and information technology
- Smart village could enhance access to clean energy and essential health services;
- It promotes community-driven decision-making and facilitates public-private partnership for village development
- Smart village improves access to basic sanitation, clean drinking water, and education
- Smart village takes care of social, economic, and environmental needs of villages.

Although the villages were not networked with sophisticated ICT networks, they have tried their best to use the available technologies based on local priorities and needs, and showed an indication of a move towards a comprehensive smart village future.

The experience from the four smart villages presented in this paper shows that the programs that are not chained by central and state bureaucracy, done purely by the innovative commitment by individual, bank, and NGO can bring changes faster than the MPMVP model of village development. A village leader, a professor or an NGO if they are committed, they can directly go and work in the village with no bureaucratic jigsaw puzzle of approvals. This research found the following weaknesses of the MPMVP in India.

MPs are lawmakers, not development managers: This extra homework for MPMVP overburdens MPs. They end up in the controversy of the selection of some villages and upsetting others in the constituency. Why programs need the title of the MP or Prime Minister and how it would make a difference is not clear.

Parachuting and helicoptering from the center and state: Center and state are regulating and monitoring the program with too little reference to local government and village committee's roles and responsibilities. There is no word on how the village capacity would be enhanced to carry on the projects. Parachuting or helicoptering from center and state would not help for the day to day management of the local issues. Why center and state prescribe, dictate, and engineer the local program; why local governments and villages are less engaged and trusted.

Without educating and empowering village committee staffs and leaders, the program may not sustain: Current smart village policy is almost silent on how the local capacity would be enhanced. It hardly elaborates the roles and responsibility of the village head (sarpanch) who is supposed to steer the village. On the contrary, the policy document says, the district collector is in-charge of managing and funding the program. The government model village guideline does not mention what the role and responsibility of the village head and villagers is. The document is silent on how the program addresses a lack of technical skills and human resources in the selected model villages.

The crowd of MPMVP activities risks losing focus: MPMVP villages risk getting lost in the jungle of programs and layers of bureaucratic approvals, and hardship on procurement of funds. There is a probability of the MPMVP being a victim of the disinterest of the MPS, low interest or incapacity of local government or village committees.

Focus is too broad and not specific: health, education, agriculture irrigation, literacy, decent homes for homeless, pension, women, and children council. The project components of other programs are also included in MPMVP program in the name of convergence further confuses and puzzles people on which program is run by which program and makes program evaluation difficult.

Village development plans: Village development plans are carried out by technicians and consultants by keeping the villagers as a witness. Often such reports and maps are shelved but never used. Unless the villagers find that the plan is focusing on their critical needs, they will observe but not listen.

Vertical and horizontal coordination needs make the MPMVP tasks cumbersome: Since the program wants to cover issues related to several ministries and departments, it would be too hard to garner efficient support and coordination from the various expert ministries, departments, and agencies. These agencies often are overloaded with their departmental tasks, and they may not feel obliged to provide regular guidance and support to MPMVP projects.

Program dependent on the outside fund is bound to be in trouble: There is no separate funding for MPMVP and it should depend on the mercy of funding by other programs, including MLAD. This dependence is an indication of project failure.

MPMVP programs are vulnerable to priority shifts due to the changes of ministers: Like a minister of rural development openly criticized the PURA and diverted the program priority from rural village to towns, the MPMVP too could face the similar situation with the changes in ministers, MPs, and the government.

A dearth of comprehensive policy evaluation research: No detailed research on critical evaluation of the policy exists. Mostly, government documents are available that does too little other than praising the program. An Internet search shows no comprehensive evaluative publications. Some New Delhi based NGOs provide policy description, but mostly they are less critical and act like information relaying agency. The Indian government and national scholars in many cases rely on studies carried out by foreign consulting agencies such as McKinsey, Bloomberg, KPMG, and Deloitte. The quality and comprehensive research carried out by Indian scholars are rare. Over relying on foreigners for domestic research is embracing a new culture of knowledge colonialism.

6.7 Conclusion

Governments initiated smart village development policies should start with a simple educational program created, funded, and implemented by the village (instead of a bundle of programs). After learning and building trust from the educational programs, the village should gradually move towards physical and infrastructural programs. This process would build local capacity, allows more space to learn, and makes the task easy to implement. On the other hand, the comprehensive MPMVP programs contingent upon external sources of funds and part-time supervision of

MPs are prone to failure. The case studies show that the Indian government should inspire more private individuals, banks, NGOs, professors, and social workers for doing commendable innovative smart village programs as we saw in Punsari, Akodara, Dharnai, and Puducherry. The government should publicize these best practices nationally. More incentives and rewards should be in place to encourage private initiatives. These private initiatives are more likely to be efficient as they do not have to go through complex bureaucratic procedures, and their programs are less vulnerable to the fluctuation of political interests.

6.8 Policy Recommendations

Relieve MPs from the controversy of village-selection and village-development job: Let the MPs do their lawmaking work for the nation. Let the village associations decide which village to select a model village. Let the village decide (not the MP, center or state) what is the model village priority, and how they want to implement.

Empower and enhance the capacity of the village government to manage their jurisdictions: Center should send all the financial, technical and consultant resources to the village and let the village decide how they want to use these resources. Do not start from everywhere, start from somewhere. For example, instead of spending enormous time on village development plans, focus on the village's critical needs like the Punsari, Akodara, Dharnai, and Puducherry villages did. Once you succeed in addressing the critical needs, people would be in a listening mood, they trust you, then move from there gradually toward preparing village development plans.

Focus on the village's institutional capacity: Enhance the local capacity of villages in terms of technical workforce, computer resources, training, and working environment. Without enhancing village's institutional capacity, achieving a sustainable smart village would be difficult. The government-run smart-village should inspire, educate, and train village head on how to make his village smart.

Promote innovative local leaders and non-governmental organization: Instead of promoting heavily loaded MPMVP programs, the government should identify and incentivize committed local leaders, innovators, professors, and social workers in making a difference in society through smart technologies. The government can set aside grants and fellowships to encourage these agencies.

A secure separate fund for the village development program: Avoid creating village development programs dependent on the sources of the other programs. The project may stall if the external sources chose not to provide funds for the village development program.

Go for soft programs rather than the capital intensive and time taking physical programs: The physical works such as roads, bridges, canals are essential, but they are capital intensive and time-consuming. However, soft actions such as information technology-led education as we saw in Puducherry, can provide immediate relief to the community. If they get solar power, they can read and write; if internet education centers are available, they can get knowledge tips to solve their health, agriculture, and skill problems and make them socio-economically better. Once the overall trust level and mood of the village is alleviated, gradually the physical infrastructure and capital-intensive programs should follow.

Promote quality evaluative research: Since India is experimenting ambitious, smart village, smart city and housing for all programs for the 21st century, it needs more quality evaluative research that will nudge policymakers to stay on track and inspire for innovative approaches. It would be hard to know how the policies and programs are doing in India without quality research. More incentives should be provided to the Indian researchers in universities and academic institutions to produce quality research in internationally reputed journals. Over-reliance on foreigners on Indian research is not a healthy practice.

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Chapter 7
Can Haphazard Growth in Urban Villages Be Prevented? Experience from the Ahmedabad-Gandhinagar Region

Sweta Byahut and Jay Mittal

Abstract This chapter examines the challenges associated with planning and regulating haphazard growth in urban villages in the Ahmedabad-Gandhinagar region of Gujarat, India. The capital city of Gandhinagar, also known as the Gandhinagar Notified Area, was developed in the 1960s by the state government using eminent domain. The Gandhinagar New Capital Periphery Control Act was enforced in 1961 to maintain pristine rural environment in the peripheral area of Gandhingar, freezing urban development for over 40 years, even thought here was high demand in the local land market. The private sector was not allowed to participate in Gandhinagar's development, which constrained the local land markets, created artificial scarcity, and inflated prices, resulting in illegal and haphazard growth around urban villages. This chapter discusses the specific strategies undertaken to adopt more market-oriented land readjustment (LR) mechanism to accommodate new growth around high growth villages. The villages experiencing intense development pressure were identified, and LR plans were systematically planned and implemented that carved lands for installing village infrastructure, curbed informal growth, while providing a framework for planned, organized, and regulated development. It further highlights the opportunities that smart visualization technologies can offer for enhancing urban design scenarios for improved outcomes for formulating place-based regulations.

Keywords Gandhinagar Development Plan · Land readjustment · Urban villages · Urban design scenarios · Peri-urban development

S. Byahut (✉) · J. Mittal
Auburn University, Auburn, USA
e-mail: sweta.byahut@auburn.edu

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7.1 Introduction

More than half the world's urban population is living in cities of the global south, and almost all of the future population growth in the world will also happen in cities of the global south. Demographic and economic growth are resulting in expansion of the traditional compact city into the per-urban rural hinterlands. This peri-urban growth can be thought of as landscapes of mixed land uses and mixed livelihoods that lie between urban and rural spheres [1]. The seareas typically have higher population density than the rural areas and generate higher GDP. Due to their proximity to urban areas and desirability, they are transforming to urban land uses, and moving away from agriculturally productive land uses. While peri-urban areas are experiencing loss of rural area (agricultural land, fertile soil, natural landscapes), but still lack urban attributes (have lower density, lack of services and infrastructure, lack of accessibility) [1, 2]. These are also favorable location for regional infrastructures as well as tertiary sector growth such as new office parks, logistics, and institutional developments. The multiple challenges that cities in the global southface due to rapid urbanization and economic growth are even more acute for the peri-urban areas, such as lack of access to shelter, infrastructure and services, weak local governments, and environmental concerns [3]. Modern town planning has been influenced and shaped by market forces, political elites, and growing middle-classes for much of the 20th century because it provided profits in land and a desirable quality of life. People who could not take advantage of the land ownership and development have been excluded spatially and economically. These are often the farmers and original owners of the land, who lose their lands in the development process, giving rise to exploding informality. In planned cities such as Brasilia and Chandigarh, the informal cities have grown up beside and beyond the formal cities because they have been excluded from the planning process (ibid.).

From a sustainable land development perspective, when the ecological footprints of the city expand, there are serious implications to the peri-urban interface. It can increase the pressure on carrying capacity and miss the production opportunities. The uneven and continuous urbanization takes place in areas because of land speculations, changing economic activities of higher productivity, and informal and illegal activities [2]. Marshall and Dolley [4] are also concerned about rapidly growing exclusionary urbanization in developing countries across South and East Asia. While the marginalized informal urban and peri-urban residents experience the negative impacts of urbanization including displacement, environmental degradation, and health risks, the urban elites drive the peri-urban development agenda. This results in the remaking of urban and peri-urban places, and the rural and peri-urban poor are negatively impacted by the environmental and economic risks of urbanization [4]. Allen [2] insists that these areas need to be treated as a network where planning and policy initiatives are established for multi-sectoral, interrelated, and complementary activities, and should be perceived as "actions upon rural-urban pressures and flows" type of intervention.

Urban villages in the periphery of large metropolitan regions in India have been consistently stressed with growth pressure, which brings about rapid changes in population, land uses, and livelihoods [4]. Some of the key factors that are found to influence the degree of changes include proximity to the city, rural values, immigrant population, industrial development, proximity to the highway and to the bypass, and commercialization [5]. Often, land conversion from peripheral to peri-urban land is thought to be the outcome of "market's invisible hand" and 'agglomeration economies', directing the resources to highest market prices [6]. Typical development process involving land acquisition (using eminent domain) across several villages such as in Gurgaon, has led to dissatisfaction among residents and antipathy towards local urban authorities [7].

This chapter explores some of the planning challenges in dealing with existing villages on the urban periphery, when they are threatened to be engulfed by urban sprawl. It examines regional growth patterns in the Gandhinagar-Ahmedabad region, and discusses how the well-established and versatile land readjustment (LR) planning tool has been applied innovatively to ensure planned development in high-growth villages in this stressed and rapidly urbanizing region. It also discusses the process and challenges of introducing a market based land development mechanism in planning of a mid-20th century new town built on an outdated top-down planning model that is irrelevant in modern times. Further, it demonstrates that incorporating a place-based urban design approach in the land readjustment process can help achieve desired urban form in new towns such as Gandhinagar.

7.2 Approach

The methodology includes an extensive review of relevant literature to understand the land development processes of the new town of Gandhinagar, and the application of the land readjustment process in Indian cities. A review of several planning documents for Gandhinagar was undertaken, including the following reports of the 2011 Gandhinagar Development Plan: Part 1: Studies and Analysis [15], Part 2: Proposals and Policies [39], and Part 3: General Development Control Regulations [40]. Supporting planning documents were reviewed, including various surveys, studies, analyses, drawings and urban design studies produced in the plan-preparation process, and consultation meetings. Gandhinagar's original 1966 Master Plan was also examined, as well as the recent Development Plan update for the year 2024. Field visits were undertaken to several areas within the Gandhinagar-Ahmedabad region and specific villages. The first author Dr. Byahut served as the Project Manager for the Gandhinagar Development Plan and Implementation Strategy for 2011 while employed with Environmental Planning Collaborative (EPC) at Ahmedabad, India. This chapter draws considerably from her professional association with this plan from 2000 to 2002.

7.3 Land Development and Periphery Control from 1960 to 2000[1]

After gaining independence in 1947, India adopted an ambitious city-building program, building several new towns including the capital cities of Chandigarh and Bhubaneshwar (in the 1950s) and Gandhinagar (in the 1960s). In 1960, the erstwhile Bombay state was divided into two separate Gujarat and Maharastra states. Ahmedabad served as Gujarat's temporary state capital. The original Master Plan for the Gandhinagar Notified Area (GNA) was completed in 1966, and a new capital city was built for the recently created Gujarat state. In 1970 Gandhinagar was declared as the state capital of Gujarat. Gandhinagar is located only 15 miles (22 km) north of Ahmedabad, which is India's fifth largest city, and also one of its fastest growing, with a metropolitan population of approximately 7 million today. To build Gandhinagar, 57.38 km^2 of land was acquired by the state government in bulk at substantially low market value from farmers using eminent domain. The original 1966 Gandhinagar Master Plan drew inspiration from the Chandigarh Master Plan, the world-renowned new town designed by Le Corbusier in the 1950s. Mr. Mewada, the chief planner of Gandhinagar had earlier worked under Corbusier on the planning of Chandigarh. It was also influenced by the planning of Bhubaneshwar by Otto Koenigsberger [9]. Some concerns were raised early on about Gandhinagar's original master plan because it lacked supportive infrastructure and policy support for business growth. Newcombe, a British academic who examined the original Gandhinagar plan on the invitation of Mr. Mewada, noted that the government had ignored the private sector in the planning of Gandhinagar, and suggested that the city should modify its economic policies and provide incentives for easier land availability to attract businesses and population [9].

The GNA planned area is 42.88 km^2 and is divided into 30 sectors separated by wide Town Roads, with a large government administrative complex (The Secretariat) and civic buildings at its center, industrial areas to the north, and considerable green areas to the east and south along the River Sabarmati. The sectors were based on the neighborhood unit planning concept that became popular in the mid-20th century [10]. The neighborhood unit was conceptualized by Perry and Stein in the 1920s in the United States as a basic city building block and for designing the neighborhood [11, 12]. Most sectors in Gandhinagar are 1000 m x 750 m in size and 75 ha. in area. Each residential sector was planned for about 7000 people, with central areas set aside for public facilities, shopping, schools, playgrounds, parks and other cultural and social amenities. Internal curvilinear streets are in the form of a loop, with provisions for bike and pedestrian paths that were not built. Employment areas (such as the Secretariat, government offices, industries, civic center, institutions, and commerce) were separate from residential areas. In spite of being located in an arid region, Gandhinagar is one of the greenest capitals globally, with a grand central vista, large

[1]This section draws from Byahut [8] paper entitled "The unique challenges of planning a New Town: The Gandhinagar experience".

ornamental gardens, regional parks, and a new urban forest created by planting 4 million trees [13]. Gandhinagar's green space availability is 147.5 m^2. per person, which is by far the highest in the country, and almost three times that of Chandigarh [14]. Gandhinagar is well connected with Ahmedabad and the international airport by three excellent highways, and is much dependent on Ahmedabad that provides many more industrial, commercial, transportation, educational, and recreational facilities. A strong functional relationship exists between Gandhinagar and Ahmedabad because of their connectedness and proximity. Significant number of people work in Gandhinagar, but live in Ahmedabad.

In Gandhinagar (or GNA), all land development and disposition was by means of highly regulated and strictly controlled state government allotments and auction process. Initially, the reserve price in auctions was kept low to encourage people to live in Gandhinagar, however growth was slow due to controlled land disposal and lack of social and recreational amenities. Majority housing comprised of state government employee quarters, and whatever limited private housing was also primarily owned by government employees. An array of housing types was built according to employee ranks, and residential lots (ranging from 50 to 1650 m^2) were also allotted to them. In 1997, about 7500 lots (about 930 ha.) remained vacant, which had the capacity to accommodate 56,500 additional residents. Additionally, 15% land in the GNA still remained un-plotted, and was not available to be auctioned or to be allotted [15]. Lots for residential, commercial, or industrial developments were only available through government auctions, but the state had not conducted auctions in over a decade. Overly restricted development policies, a tightly controlled land market, and highly regulated prices resulted in an artificial scarcity of land (in spite of high lot vacancy), unrealistically high prices, and overall stagnation of growth in GNA.

Initially, GNA was planned to accommodate 150,000 residents, but in 1974, the target population was increased to 350,000 for the year 2015. However, given constrained growth, the revised target population is unlikely to be achieved even by 2031. The population of GNA in 2001 was 195,985, and after 10 years, in 2011 it increased to 206,167, gaining only about ten thousand people over ten years (Census of India 2011). Because growth was constrained in the GNA, the villages abutting it were particularly stressed due to growth pressure and high demand generated due to frozen land development conditions within GNA, and witnessed considerable growth of informal settlements.

The peripheral areas of the GNA were also stressed due to intense development pressure due to their proximity to Ahmedabad and the economic opportunity that it presented. Similar to Chandigarh, the Gujarat New Capital (Periphery) Control Act was enforced in 1960 to further discourage growth and maintain a rural green belt within a 5 mile (8 km) radius from the outer boundary of the GNA [9, 15–19]. This Act was modeled on the Punjab New Capital (Periphery) Control Act of 1952, which was implemented around Chandigarh city for a variety of reasons: to prevent proliferation of suburban and haphazard development around the city, to discourage land speculation outside of the urban core, to protect and enhance the Chandigarh's celebrated urbanism, and to continue the rural way of life and protect agricultural lands [16]. In Gandhinagar too, the primary purpose of periphery control was to prevent conversion of agricultural lands to urban use and maintain a natural green belt around the city. Exemptions were only allowed were for building places of worship and religious use, as well as agricultural uses and construction of roads [17]. In 1965, an amendment to the Act permitted limited residential development within a small 200 or 400 m radius around *gamtals* (village settlements or village built-up areas) based on the size of village to allow for some natural expansion [20]. Because of periphery control, non-agriculture (N.A.)[2] permissions in rural areas were sparingly given, freezing all land development in Gandhinagar region for four decades, contributing to artificial land scarcity and unrealistically high prices.

However, unlike Chandigarh where there was no other large city located nearby, Gandhinagar was built in close proximity of Ahmedabad, one of India's largest and fastest growing cities. A recent study found that urban built up area increased by almost 20% in Ahmedabad city between 1997 and 2017 [21]. It was unrealistic of the government planners who prepared the original Gandhinagar Master Plan in 1966 to expect that Gandhinagar would be able to grow in isolation from the strong pull of Ahmedabad, being located only 15 miles north of it. They had visualized future expansion of Gandhinagar towards the north-west, in the direction away from that of Ahmedabad [22]. This was opposite of where development was most likely to happen, which is towards the south in the direction of Ahmedabad. Over time, the highly desirable lands between Ahmedabad and Gandhinagar experienced an intense real estate demand from the private sector for residential and commercial developments due to spillover effects of Ahmedabad, leading to large-scale speculative investments in the 1990s. Plot-wise land use survey of the area and a review of land records revealed that by 1999, N.A. permissions for approximately 300 hectares of land had already been approved in Gandhinagar region outside of the GNA, and another 125 hectares of land had already developed without permissions. Of the 550 hectare developed in rural areas, approximately 375 hectares were for residential use [15]. Villages located south of GNA closer to Ahmedabad and/or along major highways particularly witnessed haphazard growth around their gamtals, and considerable illegal development along major highways and intersections.

7.4 Land Development After Implementation of the 2011 Gandhinagar Development Plan

Recognizing these regional growth pressures largely attributed to Gandhinagar's artificially constrained land development situation and proximity to Ahmedabad, the state established a new statutory regional planning authority in 1996 to plan and

[2]In Gujarat, non-agriculture (N.A.) use permissions are granted by the state land revenue department, which functions independently from the urban development department.

regulate development in the periphery of GNA. This authority was named the Gandhinagar Urban Development Authority (GUDA) and its jurisdiction included 54 km^2 of GNA area and surrounding 39 villages, totaling 387 km^2. GUDA was tasked with preparing a comprehensive, long-range, statutory Development Plan (DP) under the Gujarat Town Planning and Urban Development Act (GTPUDA) of 1976 [23]. In 1999 GUDA appointed Environmental Planning Collaborative (EPC), a professional urban planning and development management firm based in Ahmedabad for preparing its first DP. The plan aimed to transform Gandhinagar from a quite administrative center to an economically vibrant city that is able to respond to a rapidly urbanizing economy, moving away from state-led eminent domain to private-sector participation through land readjustment mechanism [8]. A key planning objectives was to promote balanced regional growth, particularly in areas outside the GNA, and planning for fast urbanizing villages in the Gandhinagar-Ahmedabad region [15]. As part of the planning process, meetings were organized with each of the 39 village councils to determine their individual needs and constraints.

When the preparation of the 2011 Gandhinagar Development Plan was initiated in 1999, it was quite uncommon for public-sector planning and mapping in India to be computerized. Existing maps had been hand-drawn and traced over multiple times using decades old topographic survey sheets. Over time this resulted in multiplication of errors and a loss of accuracy. During the computerization process, planners typically spent months preparing the base map. All plans and maps in the 2011 Gandhinagar DP were computerized, including the parcel-level base map that was painstakingly put together by digitizing multiple topographical survey sheets and errors corrected using satellite imagery. This was the first such major comprehensive plan prepared in India where all planning and mapping was fully computerized.

The original 1966 Gandhinagar Master Plan had conceptualized the existence of Gandhinagar and it future growth distinct and isolated from Ahmedabad. In contrast, the 2011 Gandhinagar DP responded to the land development challenges and growth opportunities in the larger Ahmedabad-Gandhinagar region. The 2011 plan proposed urban expansion of Gandhinagar to the south in the direction of Ahmedabad, recognizing that due to physical proximity of Gandhinagar and Ahmedabad, future growth is likely to merge the two cities together [39]. New urbanizable areas in GUDA was not only planned for Gandhinagar's growth, but also absorb some of the spillover population and economic activities from the much more dynamic Ahmedabad city. Lands for future development in GUDA's DP were identified along the highways connecting Gandhinagar and Ahmedabad. Additionally, nodal developments were planned around seven fastest growing urban villages (see Fig. 7.1), along with vast areas near the river for large institutions, corporate investments, and regional green spaces. A no-development zone was delineated along the Sabarmati River and the Narmada Canal with limited low-impact development. Specifically, the GUDA DP identified two types of urban expansion areas outside the GNA [39]:

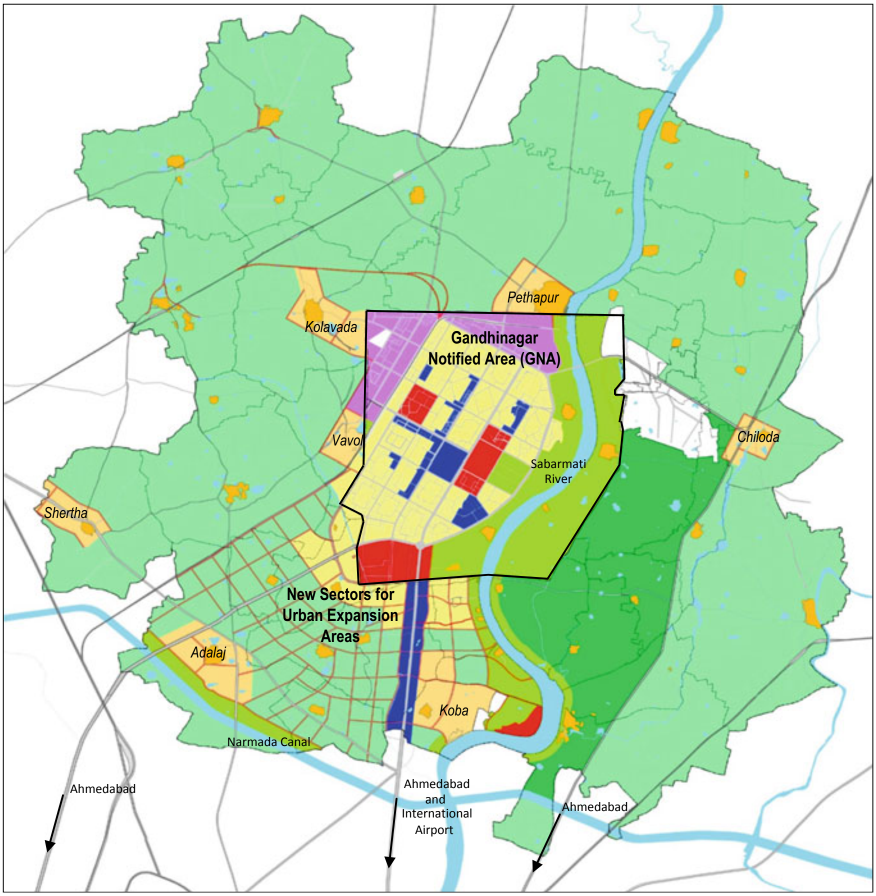

Fig. 7.1 Gandhinagar Development Plan for 2011 showing location of nucleus villages. *Source* EPC

(1) *New sectors for urban expansion*—this consisted of medium-density residential zone adjacent to the GNA along main growth corridors, and low-density residential areas towards the river (see Fig. 7.1). Urban expansion areas earmarked south of the city were planned to be consistent with Gandhinagar's characteristics, maintain its distinct identity as a clean and green city, and continue its generous space standards and sector-neighborhood approach.

(2) *Nucleus villages*—these were located outside the GNA and near highways connecting GNA with Ahmedabad. A medium-high density village expansion zone was earmarked around seven rapidly growing villages to facilitate affordable housing for villagers and migrants. Three of the seven nucleus villages (namely Pethapur, Vavol, and Kolavada) were located adjacent to the

GNA, three villages (namely Adalaj, Koba and Shertha) were located south of GNA along major highways leading to Ahmedabad, and one village (Chiloda) was located to the east of GNA on a major highway intersection (see Fig. 7.1). The villages were zoned for residential and mixed use, and supported agriculture based economic activities of the villages, with a planned medium-high residential density of 312.5 persons per hectare upon saturation.

The Gujarat New Capital Periphery Control Act was partially repealed by the state government in 2003 to allow for new urban growth and enable implementation of the 2011 DP [24]. As a result, between 2001 and 2011, GUDA's population outside of GNA increased by over 46,000 people (Census of India 2011). During the same time period, the population inside GNA increased by less than 7000 people. Sudden availability of land for urban development in Gandhinagar–Ahmedabad region saw a rush of land transactions and new developments, much of it a result of spillover effect from Ahmedabad city. More recently, since 2010 there has been a rush of large scale retail, entertainment, residential, and institutional developments between Gandhinagar and Ahmedabad on both sides of the river with the implementation of two of the state's ambitious anchor projects (Knowledge Corridor and GIFT City), transitioning the region towards technology and finance industries. GUDA's recent revised Development Plan for the target year 2024 earmarks vast areas for these projects. The revised plan update further strengthens village planning by identifying areas for village expansion around all gamtals in GUDA area and along several approach roads [25].

7.5 What Is Land Readjustment?

Land is a state subject in India, and delivery of serviced urban land in Gujarat state is managed via a two-step process as defined in the GTPUDA [23]. First, a macro-level Development Plan (DP) is prepared for the planning region which is revised every ten years. Second, planning of this DP proposal is further detailed at land parcel level via neighborhood-level land readjustment (LR) plans. These local LR plans are called Town Planning Schemes (TP Schemes) in Gujarat state. Cities in the state of Gujarat have successfully used it to facilitate planned development and provide serviced urban land in rapidly urbanizing areas. Land readjustment in Gujarat follows a quasi-judicial process defined in the Gujarat Town Planning and Urban Development Act of 1976 [23]. LR have been successfully applied in Ahmedabad and several other cities of Gujarat [26]. In the LR process, the areas meant for LR are first surveyed, and detailed parcel level layout plans are prepared for the newly delineated areas in the DP to provide planned future urban development. Low value, in accessible, and irregular shaped farmland are first polled and then lots are reconstituted into regular-shaped lots for urban development after carving out land for roads, infrastructure and other amenities. The LR provides public road access to all new lots and infrastructure such as water supply, sewage,

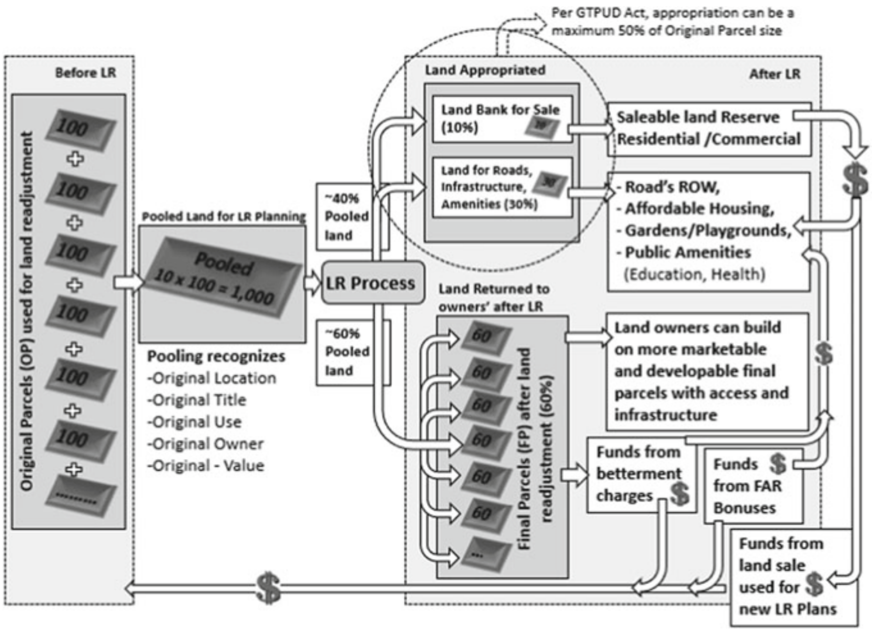

Fig. 7.2 Simplified illustration of the land readjustment process. *Source* Adapted from Mittal et al. [36], Byahut and Mittal [37], and Mittal [30]

and streetlights. In the process, the development authority appropriates approximately 30–40% of the original lot area to develop open spaces and roads, affordable housing, parks, and other amenities.[3] As shown in Fig. 7.2, the landowners get back approximately 60% of their original lots, with regular developable shape, lots with direct public street access, and infrastructure, which makes them more valuable and more suitable for urban development. LR is considered a market-friendly, democratic, and equitable method of land development [27]. The process is also self-financing, as gains in property values after readjustment and rezoning for urban use are manifold, and pay for the cost of infrastructure and facilities development [28–31].

The LR technique was introduced in Gandhinagar to create a private land market and reduce land speculation, relax state control, and avoid the use of eminent domain or coercive bulk land acquisition. GUDA's 2011 DP determined that future development would not adopt the previous land acquisition model, but will be facilitated through private sector development by LR plans that benefits the original land owners. Urban expansion areas outside of GNA but contiguous to it maintain the sector-type neighborhood character and are equivalent in shape and size to the

[3]GTPIUD Act of 1976 allows for up to 50% land deduction from the original lot by authority during reconstitution.

existing sectors within GNA, but their development mechanism involves the private sector through implementation of LR plans. LR would also be applied for planned development of the 7 high-growth nucleus village in the periphery of GNA. The Development Plan proposed major grid roads to demarcate the LR plan areas for more detailed physical planning via LR tool.

Gandhinagar's approach for growth and future land development is quite distinct from that of Chandigarh's. In Gandhinagar, periphery control was selectively repealed to implement the GUDA's DP using LR technique. In this process original landowners were made partners in development so that they would share the benefits of land value appreciation after rezoning and readjustment. In the case of Chandigarh, the state governments[4] of Haryana and Punjab, as well as the Chandigarh union territory, selectively used the periphery control and indulged in large-scale land development and speculation themselves, marginalizing the villagers who were then forced to approach the courts [16]. Chandigarh's plan for 2031 continues with eminent domain policy, identifying 17 pockets on the periphery for acquisition for urban expansion [32, 33]. Gandhinagar's alternative development model of applying LR in villages located in the former periphery control area makes an interesting case to study.

7.6 Land Readjustment for Planned Development in Villages

Of the 39 villages in GUDA area, 7 were identified as nucleus villages for implementing LR plans to ensure planned development around their *gamtals* (village settlements or built-up areas). These villages were selected due to intense urbanization pressures, because of their vicinity to both Gandhinagar and Ahmedabad, their strategic location along the highways or adjacent to GNA [15, 39]. Nucleus villages were identified based on their population growth rates, land records and N.A. permissions granted, detailed lot level land use surveys, extent of land already converted to non-agricultural use without permit, extent of unauthorized developments around gamtals, real estate demand, and also their existing social and physical infrastructure that can support growth. From 1991 to 2001 these seven villages experienced more than double the decadal growth rate as compared to other villages, and were potential growth nodes in the process of transforming into small towns. If left unplanned, these villages would turn into messy, unplanned towns.

A detailed total station land survey was undertaken to aid in the preparation of LR plans for these villages. Major features of these LR plans were incorporated in the 2011 DP to ensure that compatibility with proposed developments and to secure

[4]Chandigarh is the capital of both Haryana and Punjab states, but is a centrally governed Union Territory.

necessary right of way [39]. A village expansion zone was demarcated around the gamtals based on growth projections and physical features such as *talavs* (lakes) and *nalas* (natural drains), river edge, important village roads, and highways. These physical features helped define the boundaries of the LR plans. During LR planning, major roads were incorporated from the DP proposal into the LR plans to ensure contiguity between existing and new developments and retain village access. Detailed urban design scenarios and built form analysis of nucleus villages was undertaken.

Chiloda village was experiencing high growth due to its location on a major highway intersection, only 5 km east of GNA. The gamtal has an undulating approach road, a village pond with surrounding open space around it, and a stream running next to it. Significant illegal encroachments and informal activities had already emerged around the highway intersection turning into a minor growth node, and the approach road had been encroached upon by small shops on both sides (see Fig. 7.3a). Unregulated and haphazard informal sector (commercial and residential) encroachments along narrow village roads were creating unhealthy living conditions in the absence of water supply, sewage, and other infrastructure, further aggravating the problem. If left unplanned, it would lead to unplanned, haphazard growth (see Fig. 7.3b). In LR planning scenario, approximately 60% of the original lot is returned to the landowner as final lot after reconstitution, and approximately 40% land is deducted by the authority (see Fig. 7.3c). The village gamtal was defined by a peripheral road around them, important roads connecting villages were retained and strengthened, and land for development were reconstituted along these roads. Low-rise, high density, and compact rural character of gamtals was retained. Lower intensity residential, retail, and agriculture-based economic activities are specified in LR area with character complementary to the gamtals. Commercial and

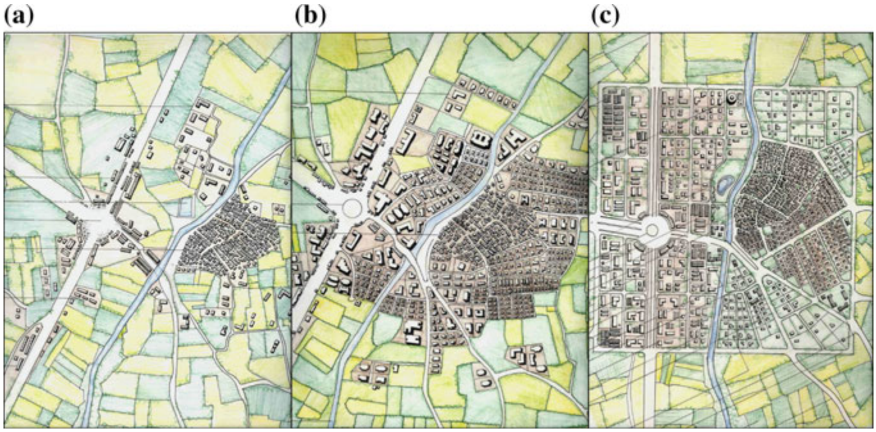

Fig. 7.3 Urban design exercise illustrating development scenarios for Chiloda village. From left: **a** village gamtal and existing developments, **b** unplanned future growth scenario, and **c** planned development scenario using land readjustment. *Source* EPC

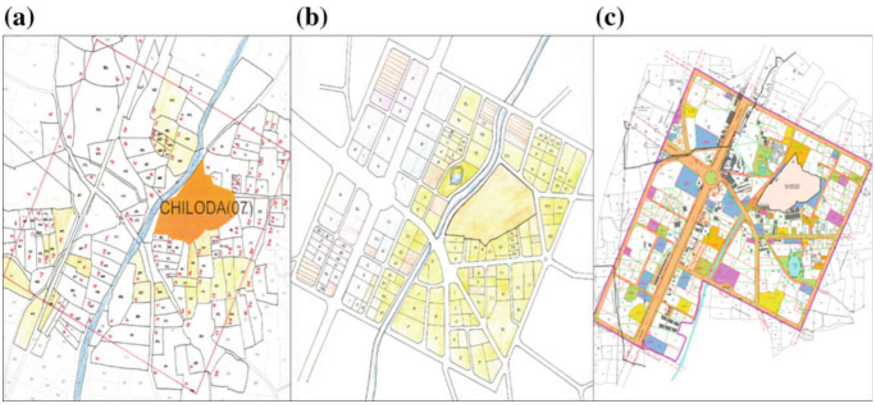

Fig. 7.4 Land readjustment for Chiloda village. From left: **a** original land holdings, **b** reconstituted final lot scenario, and **c** Draft TP Scheme No. 17 for Chiloda sanctioned by GUDA in 2006. *Source* EPC

light industrial developments is permitted along the highway. The village pond and stream were retained, with parks and gardens organized alongside.

To prepare a LR plan for Chiloda village, first the areas falling under the LR plan were demarcated based on non-agricultural (N.A.) permission records, illegal encroachments, and expected future growth. Agricultural lots were considered as original lots and allotted temporary numbers before land reconstitution (see Fig. 7.4a). Of the 40% land appropriated by the authority, about 15–18% was utilized for streets, 5% for open spaces, and rest for public amenities, affordable housing, and resale to finance LR planning (as illustrated in Fig. 7.4b). LR plan of approximately 147 hectares was prepared by GUDA in 2006 which is shown in Fig. 7.4c [34, 35]. In the village expansion zone, FSI was 1.25 and the permissible height was 10 m (3 stories, in addition to a parking floor).

7.7 Urban Design Scenario for Adalaj Village

Adalaj is one of the largest villages in Ahmedabad-Gandhinagar region, having a population of approximately 12,000 in 2000. Over 30 industries located in the village employed more than 1600 people. It was identified as a nucleus village due to its strategic location close to Ahmedabad and highways, high growth rates and population size, future residential development potential, and also for recreation and tourism development potential. It is located southwest of Gandhinagar near national highway towards Ahmedabad. Adalaj is well-known for the historic 15th century *Adalaj-ni-vav* (stepwell), which is an architectural monument of national importance protected by the Archeological Survey of India. In 2001, the step well and its surrounding areas were in a state of neglect. Four village tanks and a medieval settlement are an integral part of the village. Adalaj gamtal is approximately 25 hectares with several illegal construction cropping up all around it.

Figure 7.5 shows the land readjustment plan for Adalaj via TP Scheme No. 11 that was completed by GUDA in 2006 [34, 35]. For planning purpose, the village area was divided into three zones—an existing village, a recreational and tourism area, and new areas for urbanization. A rectangular road grid was superimposed to define the gamtal that divides the area into blocks of about 4 hectares each. Open spaces and institutions are located along important nodes to create public places. A “no development” zone was demarcated around the stepwell, and inappropriate structures were relocated from this area. GUDA also implemented urban design and landscaping improvements in the historical complex.

For Adalaj village, detailed urban design scenarios were prepared post LR planning to illustrate possible built form outcomes and develop localized area-specific development regulations. Since these simulations were undertaken after the LR plans were completed and land reconstitution was already under implementation, they illustrate possible development scenarios based on the LR

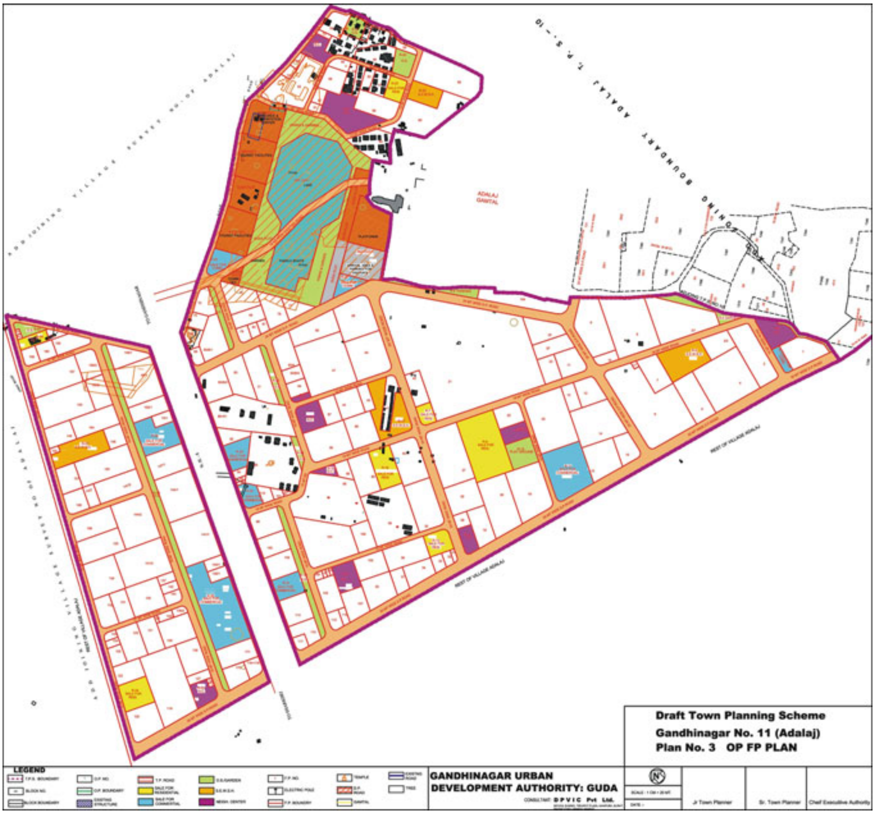

Fig. 7.5 Draft TP Scheme No. 11 for Adalaj prepared in 2006. *Source* EPC [38]

outcomes. This scenario retains the final lot distribution after land reconstitution, the street network and the land use distribution of the LR area. Design guidelines were based on the development potential, street network, land uses, and final lot distribution in the completed LR plan. The scenario provide a starting point to enable visualization of the possibility of creating a variation in urban form and character, organizing built form and open spaces, creation of a continuous street edge by selectively defining built-to-line, as well as formulating urban design guidelines in relation to lot size, margins, height, distribution of uses, and road hierarchy (see Fig. 7.6). To organize the built form in relation to the street edge and consolidate open spaces, guidelines defined minimum open space requirements, location of individual lots, block sizes, and margins based on road widths.

In this scenario, the built form is organized in relation to the street edge by defining build-to-line and front setback for each lot to ensure a uniform character along streets. Strategic height and bulk variation is envisaged for three specific sub-zones: taller 7-storied (21 m) buildings permitted in Zone A along the highway, 5-storied (15 m) buildings along 24 m. loop road in Zone B, and 4-storied (12 m) residential buildings along inner 18 m. roads in Zone C (see Fig. 7.7).

Fig. 7.6 Organizing built-form and open spaces. *Source* EPC [38]

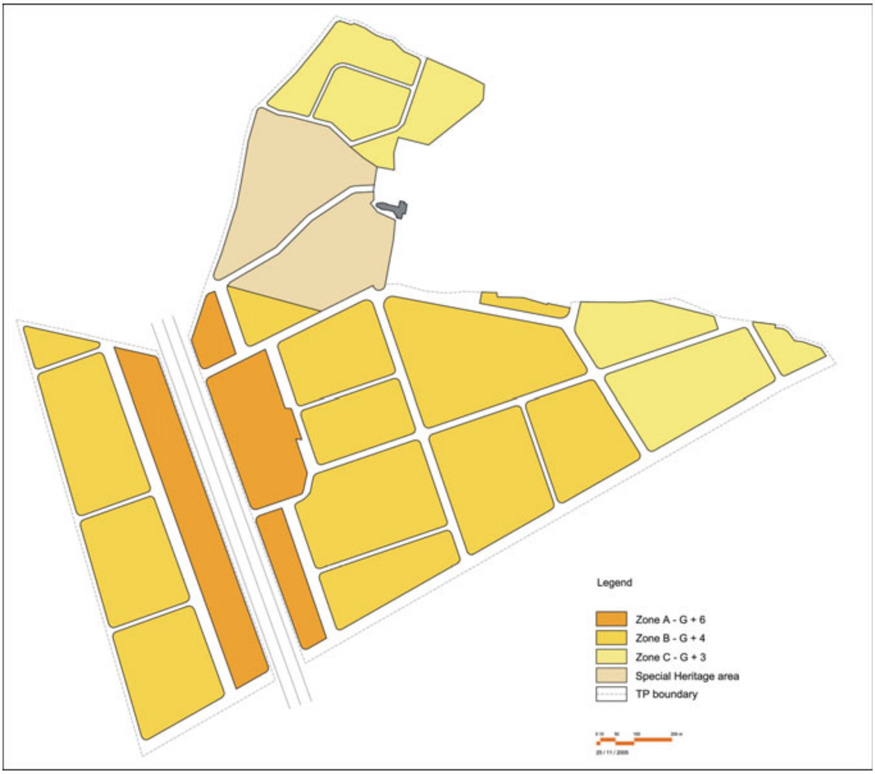

Fig. 7.7 Strategic height and bulk variation. *Source* EPC [38]

Further, a built-to-line is specified along several streets to generate a walkable, compact and urban environment. It would create a street edge with development creating a definite built along major streets (see Fig. 7.8).

An outside building envelope for each lot regulates the overall urban character, and also provides for flexibility and variation in architectural design. The desired urban form is generated by consolidating lots belonging to the local authority, inter-connecting open spaces, and placing public amenities near them. The intensity of development varies for the three subzones—it is highest along major roads and reduces away from them, ranging from a maximum building height of 7 floors in Zone A along highways for commercial and industrial uses, to a low of 4 floors in Zone C on inner streets for mainly residential use (see Fig. 7.9). Considering these guidelines, a building envelop for each lot is defined, demarcating the volume within which the owner can built. The building envelop regulates the overall urban design while allowing flexibility for variation in architectural styles.

Urban design scenarios were then applied to formulate local development control regulations for Adalaj that are specific for the three subzones with strategic height and bulk variation. The regulations specify permissible maximum building

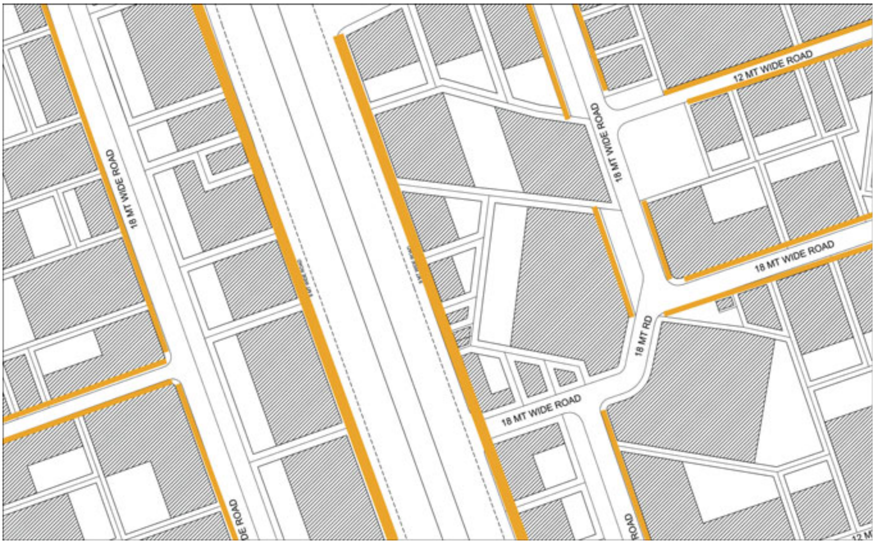

Fig. 7.8 Definite street edge diagram. *Source* EPC [38]

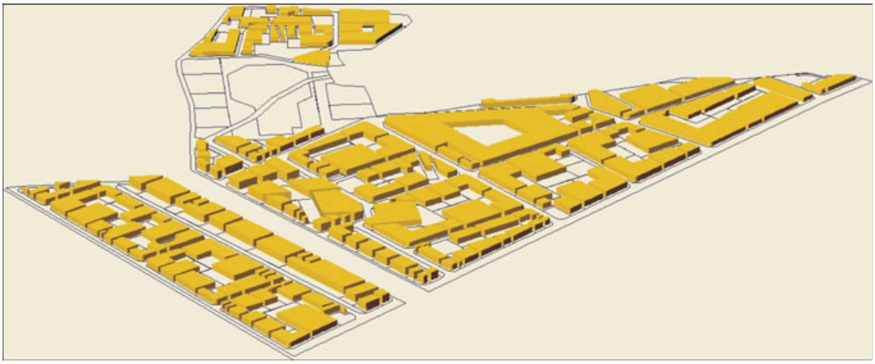

Fig. 7.9 Building envelop view. *Source* EPC [38]

height, FAR, open space requirements for larger lots, maximum ground coverage, front margin or built-to-line requirements, side and rear margins, and other requirements. These area-specific regulations were determined based on the desired built form outcomes, and are more nuanced as compared to the regulations included in the broad-brush 2011 Development Plan. The purpose is to achieve an overall homogenous character of the area, while keeping the flexibility of architectural variations for future development within individual lots. These contextual variations have the potential to generate a range of future development scenarios that are possible within the defined regulatory framework. Figure 7.10 illustrates one such possible built form scenario outcome. Several such scenarios can be prepared using

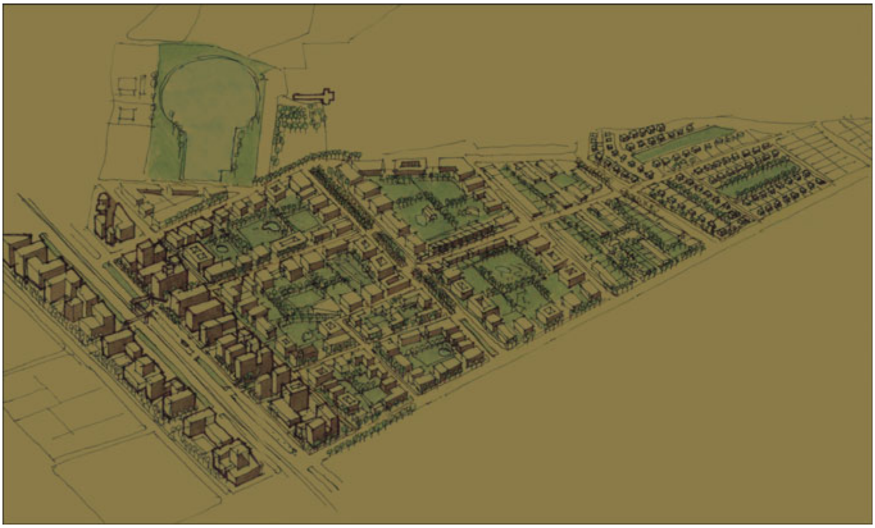

Fig. 7.10 A possible development scenario. *Source* EPC [38]

computerized visualization and mapping software (such as AutoCAD, GIS, Sketch up, etc.) in an iterative process to determine the desired built form outcomes. In the case of Adalaj, these were also combined with high-quality hand-drawn sketches. These were then used for framing corresponding area-specific development regulations. However, in the case of Adalaj, these were only visualization exercises, as the new regulations prepared were not actually incorporated in the statutory land readjustment plan (TP Scheme). Adalaj was therefore a lost opportunity to incorporate smart visualization technology and computing in the LR process.

Ideally, the general development control regulations formulated in the broad-brush 2011 Development Plan [40] should have been superseded by regulations that should have been prepared as part of the land readjustment process to achieve the desired urban form. While in this case, LR regulations at the neighborhood scale were not prepared as part of the statutory LR process, they are more nuanced and have been informed by detailed urban design scenarios—taking into consideration current conditions, growth projections, and the urban context and place. The Gujarat Town Planning and Urban Development Act of 1976 that regulates the preparation and implementation of both Development Plans and TP Schemes in Gujarat state does not provide any guidance on incorporating urban design guidelines or street character or urbanism principles [23]. However, the legislation does allow for separate regulations to be prepared under TP Scheme which can supersede Development Plan regulations in the TP Scheme planned area. In practice this rarely happens as separate regulations are not typically formulated during TP Scheme, and regulations incorporated in the Development Plan continue to apply in TP Scheme areas. This type of urban design analysis using smart visualization techniques can be an added layer of analysis in land readjustment planning and inform the character of future developments. Desired urban form over a large region can be achieved by consolidating lots belonging to authority, determining street character and walk ability, and by inter-connecting neighborhood and community open spaces and placing public amenities near them. It is even possible to develop higher density corridors and create real estate development opportunities in a larger area by coordinating multiple adjacent LR layouts [36].

7.8 Discussion

This chapter describes how the 2011 DP helped Gandhinagar city and its peri-urban area transition from a state-led eminent domain land development approach towards more equitable, fair, and more participatory LR planning process. It was a radical departure from eminent domain for promoting growth and creating and operationalizing a private real estate market. It also shows how place-based urban design studies using scenarios can improve density variation and land use mix in the planning process, as well as help achieve a desired urban form in planned growth.

In practice, while hundreds of land readjustment plans (TP Schemes) are implemented by development authorities in Gujarat state on a regular basis, these typically are implemented in peri-urban areas contiguous to the core metropolitan city. In this process, the urban villages cease to exist (other than their settlement areas), and are absorbed in the expanding urban core. LR plans have rarely been implemented in villages that are not contiguous to the urban core, nor have they been implemented for the specific purpose of regulating growth in urban villages and improving village infrastructure. The Gandhinagar experience highlights the versatility of the LR tool which can also be used to promote planned development in urban villages to promote balanced urban, regional, and rural growth. In adopting the nucleus village planning approach, GUDA emphasized the connectivity of the rural and urban systems and development of infrastructure in both rural and urban areas, rather than only strengthening rural linkages with major cities. It conceptualized a continuous and linked system created by rural, peri-urban, and urban developments that constitute a multi-dimensional continuum.

The Adalaj village case demonstrates the potential of smart technology to be used for visualization of the resultant urban form, which can then be applied to formulate form-based building regulations. However, because it was not incorporated in the statutory LR process, it was a missed opportunity to use smart technology to guide development in Ahmedabad's urban periphery. The urban design scenarios as illustrated for Adalaj highlight the opportunities that smart visualization technology can offer to enhance urban design scenarios, as well as improve outcomes for formulating place-based building regulations for urban villages. They illustrate the potential for smart visualization techniques to be applied in LR to achieve the desired urban form outcomes. While scenarios have been used by planners for a long time as a key tool to for planning and policy analysis, the potential exists to expand their application to the field of urban design to determine urban form. Furthermore, multiple scenarios can be prepared which can help respond to a range of growth scenarios to guide future regional development. A range of urban design scenarios can also inform appropriate and context-specific development regulations (or form-based codes) for corresponding growth scenarios. With the right tools, smart visualization techniques can help planners respond dynamically to growth, help achieve the desired built form, and shape the character of future development in India's urban periphery.

7.9 Conclusions

This chapter has provided insights into the unique challenges of planning for urban villages around a new town, and discussed the application of the LR mechanism in the context of planning for urban villages in an organized manner. It has discussed the strategies undertaken to dismantle state-controlled land development regime in Gandhinagar, and the process of adopting more market-oriented land readjustment (LR) mechanism to accommodate new growth. High-growth villages experiencing intense development pressure were identified, and LR plans were systematically planned and implemented that carved lands for installing village infrastructure, curbed informal growth, while providing for their planned, organized, and regulated development. It further highlights the opportunities that urban design scenarios prepared using smart visualization technology can offer for formulating place-based building regulations, as well as enable planners to meet a variety of built form and planning objectives.

This chapter is relevant and useful for urban and regional development agencies in India. Even though there is a presence of multiple agencies and jurisdictions, these regions usually lack the means to plan for balanced urban and regional growth, and are at a loss when dealing with peri-urban villages that are fast turning into messy small towns. Future research can examine the role of the versatile LR tool in planning urban villages, and to understand suitable land development mechanisms that can prevent haphazard growth around villages, provide village infrastructure, in a manner that does not deprive villagers of their lands. This chapter has shown that LR is equitable and beneficial to village land owners, enhance the growth potential of the villages, and harmoniously integrate them in the larger region.

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Part II
Smart Agriculture and Water Management

Chapter 8
Information and Communication Technology for Small-Scale Farmers: Challenges and Opportunities

Shahriar Shams, S. H. Shah Newaz and Rama Rao Karri

Abstract With the rapid growth in the world population, food production is going to be the biggest challenge for the 21st century. Industrialisation and urbanisation are taking away the available agricultural land and hence there is immense stress on the food production to cater the enormous growth of population. The farming community are struggling to meet the increased demand for food production due to limited agricultural land. Natural calamities, extreme weather events and wider variations in rainfall and temperature, destructing crops and reducing yields, thus affecting farmers' incomes and livelihoods. Unsustainable agricultural practices further worsen the soil fertility and capacity to retain water, thus result in soil erosion. These problems can be minimised by utilising the Information and Communication Technology (ICT) to the farming community, especially small-scale farmers. The advances in the agricultural practices and up-to-date weather/climate information, immensely help the farmers to implement the best practices and contribute to sustainable agriculture. This chapter focuses on the need of ICT to provide the best sustainable practices and optimised water management, which can revolutionise farming technology. An assessment of various available technologies based on user-friendliness, affordability and pros and cons are discussed in detail for appraising their applications by the small-scale farmers.

S. Shams (✉)
Civil Engineering Programme Area, Universiti Teknologi Brunei (UTB),
Jalan Tungku Link, Gadong BE1410, Brunei Darussalam
e-mail: shams.shahriar@utb.edu.bn

S. H. Shah Newaz
School of Computing and Informatics, Universiti Teknologi Brunei (UTB),
Jalan Tungku Link, Gadong BE1410, Brunei Darussalam
e-mail: shah.newaz@utb.edu.bn; newaz@kaist.ac.kr

KAIST Institute for Information Technology Convergence, 291 Daehak-ro,
Yuseong-gu, Daejeon 34141, South Korea

R. R. Karri
Petroleum and Chemical Engineering, Universiti Teknologi Brunei (UTB),
Jalan Tungku Link, Gadong BE1410, Brunei Darussalam
e-mail: karri.rao@utb.edu.bn

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Keywords Agriculture · Climate change · Cloud computing · Information and Communication Technology (ICT) · Small-scale farmers · Wireless sensor networks

8.1 Introduction

Farmers often find it difficult to practice climate-smart agriculture due to lack of clear understanding and interpretations of the latest weather and climate information, which significantly influence the agricultural activities. The incomes and livelihoods of farmers depend on agricultural yield, which relies on extreme weather events or interannual variations in rainfall and temperature that can result in the destruction of crops or reduced yields. Soil reduce water retention and crop yield capacity could arise from unsustainable agricultural practices leading to an indirect effect on ecosystem degradation and habitat loss.

Small-scale farmers depending on household members for the agricultural works mostly comprise of small farms with less than two hectares of cropland with a major focus on producing staple food for household consumption [1]. According to the World Bank's Rural Development Strategy [2], small-scale farmers have been identified with limited resources including land, capital (low asset base), skills and labour. Particularly in Asia there has been significant decrease in farm size (China's 0.56 hectares in 1980 to 0.4 hectares in 1999; India 2.2 hectares in 1950 to 1.33 hectares in 2001; Philippines 3.6 hectares in 1971 to 2 hectares in 1991; and Pakistan it 5.3 hectares in 1973 to 3.1 hectares in 2000) due to urbanisation and rapid industrialisation [3–5]. It is estimated that there are altogether 500 million small-scale farmers out of which 87% are in Asia/Pacific region. The majority of these small-scale farmers are from China (193 million), followed by India (93 million). Three other Asian countries with a large number of small-scale farmers are from Bangladesh (17 million), Indonesia (17 million), and Vietnam (10 million). Small-scale farming has contributed to the "Green Revolution" in many Asian countries. The total value of agricultural output is significant as for example farm output exceeds 50% in India though the amount of land used by small-scale farmers is only 44% due to higher use of labour, and a generally higher index of cropping intensity and diversification. One of the major challenges the farming community is like to face is the impact of climate change resulting in an increase in temperature [6, 7], fluctuations in rainfall patterns [8], increased intensity and frequency of flash floods and droughts [9, 10]. They pose a threat to food security and the livelihood of millions of people [11]. With the climate changes, the farmers face difficult challenges which can be mitigated by interpreting the variations in the seasonal climate conditions and adjust their agricultural management practices accordingly in terms of plantation, irrigation and harvesting. Generally, either the land is over irrigated to overcome dry weather or under irrigated expecting wet conditions. The decision in applying the right amount of water at the right time depends on the soil moisture, plant growth, and availability of sunlight. This holistic application of irrigation can be further aided by automatic irrigation, guided by advancements in ICT. This approach will assist farmers to know "when to plant" and specifically "which crops or crop varieties to plant", and "when and what amount of water" to apply for various types of plants. This chapter focuses on the need and mitigation measured for water management with the application of the expert systems, automatic fertigation (use of appropriate sensors) and smart, optimized water irrigation. This framework provides a sustainable eco-system.

8.2 Challenges Faced by Small-Scale Farmers

Small-scale farmers are facing a number of challenges while producing food in a sustainable manner. They are more vulnerable to climate change as compared to large-scale farmers, due to lack of awareness and limited financial capital [1].

8.2.1 Poor Water Management and Water Shortage

Poor water management such as flood irrigation results in excessive use of water in many countries of Asia while during the dry period, the absence of water deteriorates agriculture productivity. The rising demand for non-agricultural uses of water is leading to water scarcity and severely limits the expansion of irrigation. Unsustainable extraction of surface water and overexploitation of groundwater can result in falling of groundwater table. As a result, small-scale farmers have to rely on more costly pumps due to the high suction head. Besides, improper application of fertilizers and pesticides lead to water pollution and damage the productivity of crops.

8.2.2 High-Value Agricultural Products

Small-scale farmers face a number of problems producing high-value agricultural products due to labour-intensive, stringent food safety and quality standards as well as high volatility in prices, thus resulting in high market risk. Small-scale farmers in the semi-arid region are more vulnerable to crop shocks, particularly when it comes to natural calamities and disasters (e.g. El Nino in the Philippines, Tsunami in South East Asia and flash floods in Bangladesh). Use of ICT to forecast natural disasters and taking proper remedial techniques are the biggest challenges for small-scale farmers.

8.2.3 Impact of Climate Change

Small-scale farmers in poor developing countries are more vulnerable to the impact of climate change. Even moderate change in weather conditions ($\cong$1 °C for wheat and maize, ≅2 °C for rice) can reduce yields significantly, due to less resistant to their heat tolerance [2]. How to accommodate plants or crops from moderate warming using the greenhouse environment is a major challenge for small-scale farmers due to limited resources and the availability of funding.

8.2.4 Institutional Innovations for Productivity

Small-scale farmers can enhance productivity through new agriculture dominated by value chains. However, the most important challenge is promoting contract farming. These supply chains have high-value exports, which is done both through private and public sector initiatives.

8.2.5 Affordability

Farmers' preferences and willingness to pay for smart agriculture technologies vary significantly based on potential benefits and costs of procuring the technology. Farmers' priorities may differ from technology to technology based on their age, gender, landholding size, income level, farming system and location, the financial subsidy provided by Government or semi-governmental agencies.

8.3 Information and Communication Technology (ICT)

ICT can play an important role in disseminating information to small-scale farmers on the forecasting of weather, selection of production technologies and potential agricultural input and output prices. Many successful examples of ICT usage benefiting small-scale farmers are growing. As a case study, an "agribusiness division of Indian Tobacco Company (ITC) sets up 6400 Internet kiosks called e-Choupals in nine Indian states, reaching about 38,000 villages and 4 million farmers. This program was started in the year 2000 and proposed for five years. Later, it was extended for another two years due to its success. During this program, the farmers are trained and given free information on local and global market prices besides the weather, and best farming practices. They have been able to purchase goods such as wheat, soybeans, coffee, shrimp, and pulses through the e-Choupal network valued at $400 million [2]. With the introduction of smart agricultural technology, traditional agriculture has been transformed using advanced ICTs, eventually contributing to significant improvements in agricultural productivity and sustainability. Smart farming aided by ICT reduces the ecological footprint". With advances in ICT, it is possible to create an update and remote sensor network, thus allowing continuous monitoring of the farm.

8.3.1 Remote Monitoring and Control

In order to actualize smart farming, the role of sensors and actuators is significantly important. With the rise of technological advancement in semiconductor technology, the cost of sensors is declining rapidly.

8.3.1.1 Sensors and Actuators

A sensor is generally referred to a device, module or subsystem that can sense any particular event or any change of its surroundings and can notify to this information to other nodes (e.g. local gateway) in a sensor network. Broadly speaking, in a Wireless Sensor Network (WSN), "a sensor node is comprised of four basic modules: sensor/actuator module, a communication module, a processing module and power source module". The role of the sensing subsystem is to sense any particular event, whereas the connectivity subsystem is in charge of forwarding the sensed information to another node in a WSN. The processing module of a sensor node transforms the sensed data into a specific format for notification while the power source module supplies power to the sensor node. A wide variety of sensors are used in the agricultural field for detecting temperature, moisture, water level, conductivity, salinity etc. as shown in Table 8.1.

An actuator is a module or subsystem of a machine, and it is responsible for actualizing an action (e.g. moving or controlling any subsystem) when it receives a control message. For example, an actuator module may be responsible for opening the valve of an irrigation facility or opening a window for ventilation. Similar to the sensor module, an actuator requires communication module in order to get instruction remotely and provide its current status whenever required.

Wireless communication technologies can play a significantly important role in collecting data from sensors and controlling the actuators installed at a farming facility remotely. With the rapid technological advancement, most of today's sensors are equipped with tiny communication module allowing transferring sensed data to a remote place. To date, there are several communication technologies available that a sensor communication module can use in order to communicate

Table 8.1 Sensors for different types of data collection [12–14]

Sensors applied for agriculture	Sensor available for the relevant data
Soil	Moisture content, temperature, conductivity, salinity, water level, dielectric permittivity, rain/water flow and water stress estimation
Plant	Moisture content, wetness, temperature, CO_2 concentration, hydrogen, photosynthesis
Weather	Temperature, light intensity, wind speed, wind direction, humidity, atmospheric pressure

Table 8.2 Comparison of communication technologies [14, 16–19]

Parameter	ZigBee (IEEE 802.15.4)	Bluetooth Low Energy (BLE)	Wibree (baby bluetooth)	WiFi (IEEE 802.11)	LoRaWAN	WiMAX (IEEE 802.16)
Frequency band range	868/915/ 2400 MHz	2400 MHz	2.4 GHz	2.4 GHz	EU: 868 MHz and 433 MHz USA: 915 MHz and 433 MHz MHz (USA)	2–66 GHz
Data rate	20/40/ 250 Kbps	1024 Kbps	1 Mbps	11–54 Mbps	250 bps–5.5 kbps	75 Mbps
Cover age range	1–100 m	30–300 ft	5–10 m	40 m (indoor) 140 m (outdoor)	Urban (3–6 km) Rural (15 km)	3 miles
Cost	Low	Low	Low	High	Very low	High

with other nodes in a WSN, including ZigBee, Bluetooth, Wibree and WiFi. These communication technologies vary greatly in terms of capacity and coverage. Depending on the geographical area covered by a wireless network, they are classified them into different types: Wide Area Network (WAN), Local Area Network (LAN) and Personal Area Network (PAN). A comparison of different wireless communication technologies is given in Table 8.2. Among all the communication network technologies, ZigBee is considered to be a cheap and power-efficient solution [14].

8.3.1.2 Wireless Communication Technologies

ZigBee communication technology offers low power, low data rate and long battery lifespan, making it a good choice for smart farming, industrial automation and smart home applications [15]. Aside from this, the protocol stack of ZigBee is relatively less complex compared to the other protocols (e.g. Bluetooth or Wi-Fi). A Zigbee based network can accommodate 65,000 nodes. In order to expand battery lifespan, ZigBee node supports low to the very-low duty cycle (the active duration for transmission is very small). It supports multi-hop routing and ad hoc network topology (not a fixed topology), thereby making ZigBee as an ideal choice for deploying in a dynamic environment [15].

Unlike ZigBee, Bluetooth Low Energy (BLE) is designed to provide high data rate within a short-range [15]. This is a low-cost solution developed for portable devices that have limited power storage capability. It supports both point-to-point and point-to-multipoint connection wireless technology, allowing fast data sharing within the neighbouring Bluetooth devices. Basically, ZigBee and BLE are the communication technologies designed for short-range communication using unlicensed Industrial, Scientific, and Medical (ISM) spectrum. There are many other communication technologies for short-range communication with low data rate support, such as the Infrared Data Association (IrDA), HomeRF, and Z-Wave. ZigBee, BLE, IrDA, HomeRF, and Z-Wave are popularly used for wireless PAN communication.

Wifi is a wireless communication technology for facilitating LAN communication based on the IEEE 802.11 standards. There are different variants of IEEE 802.11 standards (e.g. 802.11a, 802.11n, 802.11ah) with different coverage and data rate capacity. The IEEE 802.11 standard supports both Ad hoc (there is no device for coordination. Each device in the network needs to relay others packets) and infrastructure mode (an access point coordinates communication among the devices with Wifi interface) for communication among the devices in a LAN. A single access point (base station) can serve hundreds of devices. Wifi supports eight Quality of Service (QoS) classes, allowing service requirement of the verity of applications running at end-user devices. Further, the power consumption footprint of a Wifi access point is relatively low (10–13 Watts) and devices power consumption for communication is low as well, thereby allowing long battery lifespan.

WiMAX (World Wide Interoperability for Microwave Access) facilitates point-to-multipoint connection within the coverage of a WiMAX Base Station (BS). The signal from a BS can reach up to 3 miles with a data rate of 75 Mbps when transmission frequency 2–66 GHz band. WiMAX wireless spectrum can be operated over both licensed and unlicensed band (ISM)—unlicensed spectrums are more widely adopted. The BS can set the data rate for each station residing in its coverage depending on received signal strength [19]. Additionally, WiMAX supports five QoS classes, allowing the network to serve different applications (media content, web browsing, streaming media) with different QoS requirement [20]. WiMAX falls under the Wireless MAN (WMAN) category due to its wide geographical area coverage.

For long-range communication Long Range Wide Area Network (LoRaWAN) wireless communication technology was introduced by LoRa Alliance. LoRaWAN is a single frequency network with long coverage allowing a large number of devices to be connected through a single LoRa base station. In Europe, the frequency used is 868 MHz whilst the USA and Asia are 915 and 433 MHz, respectively. In terms of coverage, LoRaWAN gateway could receive a signal from end-device as far as 15 km in the rural area and 2–5 km in an urban area. The data rates vary according to distance and message duration. According to Lora Alliance, LoRaWAN data rates range from 0.3 kbps to 50 kbps. In Europe, the data rates range from 0.3 kbps to 22 kbps, and US data rate is 0.9 kbps [16, 21]. Similar to LoRaWAN, IEEE 1902.1 standard introduced RuBee, which uses very low frequency (131 kHz) carrier for long-range communication, allowing 128-byte data packet transmission. RuBee equipped devices require ultra-low power consumption for communication (a sensor with a RuBee interface can have a battery life of several years).

8.3.2 Data Aggregation

With the rising importance of ICT in precision agriculture, we have been witnessing significant progress in developing sensor platform that can collect data from different sensors, filter out invalid data (preprocessing of data), make decision based on the obtained data from sensors, control the actuators, and pass the data to the end-users' applications (e.g. it may forward data to a web server which can be readily accessed by farmers to get update). Initially, to collect data from the sensors in a farming facility and control the actuators, the sensor platform requires a gateway which is generally installed close to the farming facility [22]. Furthermore, this local gateway may communicate with the associated applications running in cloud servers in order to store the time series sensor data and get insightful meaning from the data. Figure 8.1 illustrates two different scenarios. In the first scenario (see Fig. 8.1a) all the sensors and actuators are communicating using PAN network interface (e.g. Zigee) with the gateway, and the gateway uses WMAN communication interface (e.g. WiMAX interface) to communicate with BS. The PAN coverage area data is forwarded using Ad hoc mode. Once data is received at the BS, it is responsible for forwarding the data to the remote cloud server. The second scenario is almost the same except the sensor and actuator data communication approach. Here, they use the WMAN communication interface to send data to the BS directly (an infrastructure mode communication approach). Instead of a gateway (a separate standalone network component in a farm), farming data collection gateway functionality can be implemented in a BS of wireless communication technology (e.g. WiMAX, LoRaWAN, WiFi) in order to collect data [19].

Data from sensors can be regularly polled from the gateways. The inter polling interval for data collection from different sensors may depend on several factors, including accuracy of the rate of change, network bandwidth, data storage and processing capacity at the gateway, and residual battery power of the sensors (more frequent polling of data would reduce sensors' battery life). Instead of polling each sensor periodically, as an alternative approach, the sensors may send any data to the gateway only when a certain condition becomes true. Such an approach is generally referred to as the trap mechanism. The processing capacity of a local gateway may not be sufficient in the case when a farm has many sensors and actuators. In such a case, a local gateway may need to rely on remote cloud servers for data processing.

The growing number of IoT devices has led to realize the importance of enriching computing and storage capacity at the network edge and access segment. Considering this Cisco coined the concept of Fog computing, which is a relatively small computing facility embedded in the network equipment of edge and access segments (e.g. base stations, switches, routers) [23]. Therefore, another alternative

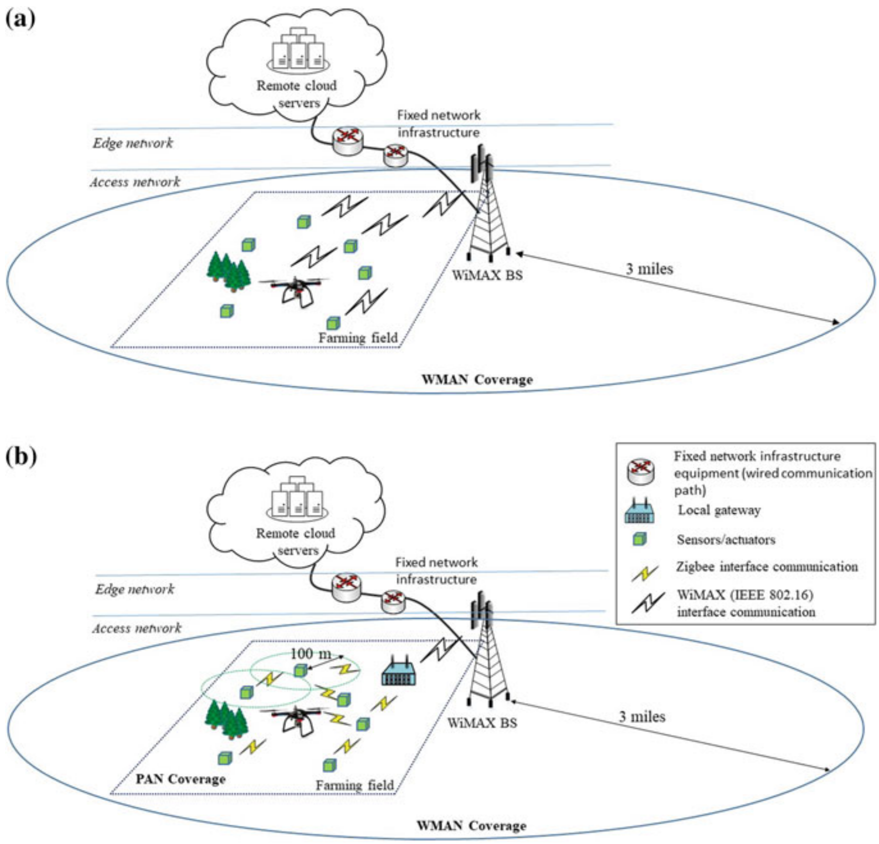

Fig. 8.1 Wireless communication technology in smart farming: **a** sensors/actuators are communicating with the gateway using wireless PAN, **b** sensors/actuators are communicating using a WMAN communication interface

option for aggregation and preprocessing of the data from the remote sensors and actuators would be at the routers and switches in edge and access network segments in the case when the local gateway has limited computational capacity.

Inevitable growth in semiconductor research domain has a leveraged capacity of the networking equipment significantly. Therefore, the data aggregation gateway in the network may conduct a preprocessing operation before further processing (e.g. storing or analyzing). The preprocessing operation may include filter the data on the fly (e.g. removing duplicated data, erroneous or incomplete data). By doing so, the gateway would be able to reduce the amount of data for processing and storage load [24]. Further, the gateway could be the decision centre for controlling any actuators in a smart farming facility [25]. For example, it may control remotely an irrigation system or the windows of an indoor farming facility for ventilation whenever required.

Table 8.3 Gateway functional capabilities

Major functionalities	Description
Monitor	Monitor sensors' reading
Control	Control the actuators installed in a farm-based on predefined logic
Data processing	Removing erroneous and redundant data, analyze data (support data visualization), data format change, etc.
Data security	Integrity and verifying source of data collected from sensors. Encryption and decryption of exchanged data in order to maintain confidentiality
Communicate with Cloud and clients' devices (e.g. phone, tab)	Send the preprocessed or raw data to the cloud and receive instructions. Get instruction from farmers
Data and instruction storage	Store data and instruction for short or long term
Instant decision making	Based on collected data make an instant decision (e.g. opening a window for ventilation)

Drones and agricultural vehicles (e.g. weed detection and terrain levelling) can also be used for data aggregation point if they are equipped with data aggregation gateway functionalities [26]. If the sensor data is not very delayed sensitive (i.e. delay tolerant), drone or any agricultural vehicle assisted data gathering would be a feasible solution in smart farming.

There are several sensor platforms available with different functional capabilities. Among them, some of the well-known sensor platforms are SmartFarmNet [22], SensorCloud [27], and IBM Bluemix [28]. An overall summary of the functional capabilities of a gateway of the existing sensor platform is presented in Table 8.3.

8.3.3 Cloud Computing in Agriculture

Cloud computing provides on-demand service to its clients from anywhere, anytime and anyplace. This would empower farmers with new applications that will use the data collected from different sensors to infer various farming condition/context and assist farmers in making a better farming decision. We have been witnessing tremendous contribution that Cloud is making to leverage other sectors, including industries, infotainment and health services. Likewise, Cloud will contribute to increasing agricultural yields while reducing cost, save time, minimize risk, and environmental impacts. Broadly speaking Cloud can leverage the following areas significantly.

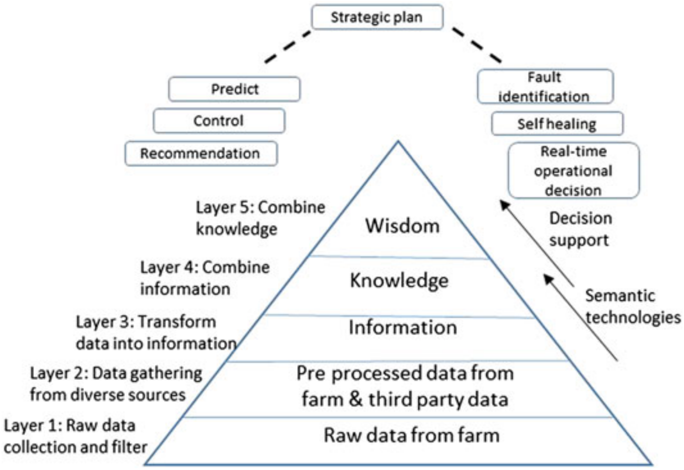

Fig. 8.2 Gaining wisdom in smart farming from data [29]

8.3.3.1 Farming Automation

Cloud service can transform data into context and piece different information together collected from various sources to come into a conclusion (see Fig. 8.2). Such ability of Cloud has been propelling the growth of other automation technologies (e.g. home and building automation, industrial automation). In the near future, our farming would become mostly data-driven and data-enabled decision making [30] due to rapid cost reduction of sensors and the necessity of increasing quantity and quality of yields in firming production. Data from different sensors installed in a farming facility will be fed into cloud-based applications to make a critical farming decision. Cloud can host different applications that will make a decision depending on context derived from input data. Besides controlling different actuators in a farming facility (e.g. automatic sprayers in row crops), Cloud can control flying drones and autonomous tractors (a tractor make its own way to the farming area) [2].

8.3.3.2 Experience Sharing

Cloud would be the repository to store all the farming data from different sensors. This can also record all relevant experience from the farmers. Depending on the requirement, the information can be disseminated to a particular farmer or a group of farmers. There would be several possible approaches to information dissemination, including voice-based service, text message and interactive video conference service [31].

8.3.3.3 Computational and Storage Support

Over the last several years, research on simulating the impact of the factors like pests, plant diseases, and climate pattern on agricultural yield loss has been widely studied [32]. The findings of these research impart that simulation can significantly contribute to making a better decision for the farmers, thereby increasing agricultural yield and offering sustainable agriculture to our society. Further, to understand biological systems and their relationships, a large volume of the dataset is required (the dataset is increasing stupendously over the past few years). The requirement of data-intensive computation (e.g. biological systems analysis and agricultural simulation) has propelled increasing demand for large computation and storage facility. Cloud computing can come into play to help the agricultural sector by offering a utility model of computing (computational power as a service) and storage (storage as a service) [33]. Cloud can offer highly scalable and available services to its customers, depending on requirements. Therefore, it can pave the way for rapid growth in the agricultural sector. For a smart farming facility, an application (a process) run in a Cloud server that collects various data from the farm and other third-party sources (e.g. weather forecast, pollution pattern, pest and diseases related information) in order to gain knowledge and capability. Such a process we can visualize from Fig. 8.3. Semantic web and machine learning technology will allow the application for smart farming intelligent (understand the meaning of data, develop knowledge and take action accordingly).

SmartFarmNet [22] is one of the sensor cloud platforms for smart farming applying semantic web concepts to understand the meaning from sensor data. Here, we briefly explain some major opportunities Cloud can offer to smart farming.

- Data analytics: A Large amount of data can be analyzed to get insightful meaning using predictive modeling and crop failure risk analysis models [30].
- Pest and diseases modelling: To make a strategic farming decision, understating different types of pest and diseases is increasingly important. How the factors like climate change, soil pH condition, pollutants and any invasive species may affect a particular plant should be realized in order to make a strategic farming decision. To get such insights, data from various sources (e.g. weather forecast data, air pollution patterns) need to be analyzed [32]. Cloud can provide a platform where state of the art knowledge and technology can be brought together to improve pest and diseases modeling accuracy. The farmers can be readily advised the appropriate time and amount for fertilizer and pesticides they should apply in their farming facility land in order to reduce loss if there is any pest or disease attack. The platform might predict pest and diseases attack pattern based on its input information and provide guidelines to the farmers in order to avoid such an unexpected situation.
- Fault identification: As Cloud has a large processing capacity, obviously, it can perform better data pre and post-processing. During the preprocessing phase, the Cloud should be able to better understand any faulty reading of a sensor or actuators by correlating their data. Similarly, any faulty operation in farm

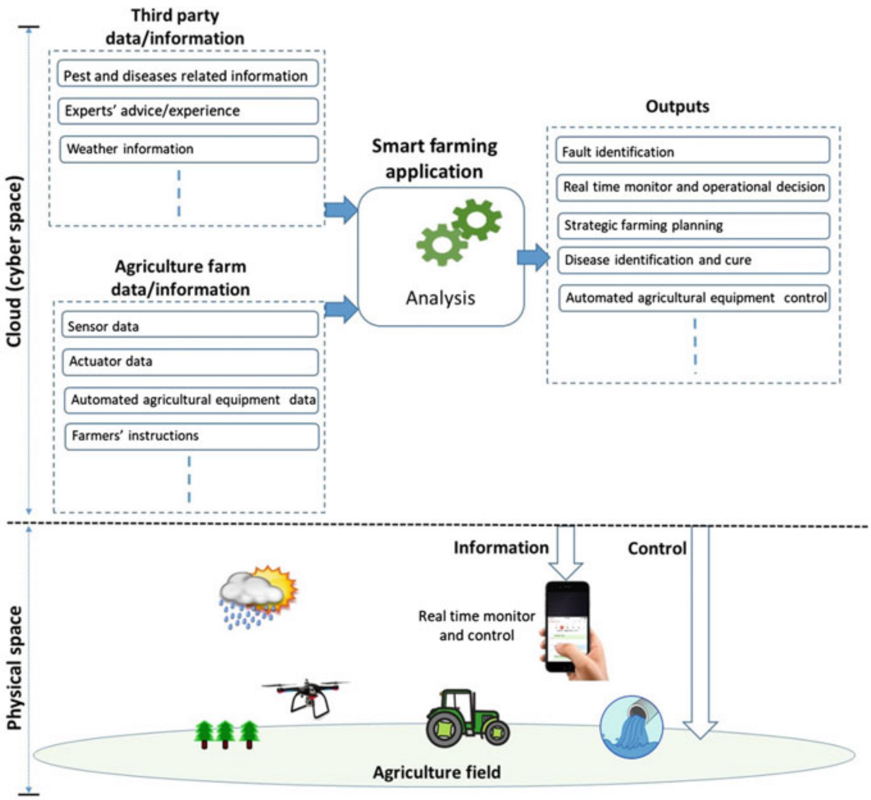

Fig. 8.3 Cloud assisted smart precision farming

management should be identified readily. Fast fault identification will offer a bigger window of opportunity to recover from any catastrophic failure of a system or change a farm operational plan that would lead to having a better outcome from a farming facility.

- Accumulating intelligence: Cloud brings information from diverse sources (see Fig. 8.3). For example, while deciding the amount of water should be irrigated within a certain amount of time in a farming land to meet certain soil moisture level, it may take into account possibility of rain which can be obtained by integrating the weather API in the farming application running in a cloud server.
- Real-time monitor and operational decision: Large computing and storage power will facilitate fast decision making, allowing a farm to be assessed almost real-time. For example, during lightening, valuable electronic equipment might be fried due to an electrical surge from a lightning strike. In such a situation, for instance, the application in Cloud for monitoring and making a decision of a farm can remotely take necessary action itself or may notify the farmers to take any necessary action.

- Crop harvesting period selection: The cloud platform (the application) may recommend the appropriate crop harvesting time taking account factors such as an increased amount of agricultural yields and profit (market value of the yields).

8.4 Role of ICT in Automated Agriculture

The robots that are used in agricultural purpose are referred to as agricultural robots. With technological advancement, we are witnessing the rapid proliferation of machinery in all spheres of life. In particular, both in the agricultural and industrial sector the growth has been astronomical. In many countries, the ageing population is increasing, and birthrate is declining. This is resulting in reducing the number of people in the labour force group in those countries. Furthermore, the global population is rapidly increasing. All these factors are contributing to moving automated agriculture-related research and development activities in breakneck pace. In a farming facility, automated equipment can be referred to as a system that does not require any manual intervention during its operation. Some commonly automated agricultural equipment are harvesting robots, driverless tractors and sprayers, and drones. Drones could be used for taking pictures of plant leaves to identify types of diseases the plant may have based on the image analysis and providing expert advice based on the expert-based decision support system. Besides, based on the weather condition built in an irrigation system can operate as per the water requirements.

8.4.1 Automatic Irrigation

Irrigation scheduling techniques depended on soil, crop and weather conditions and based on those conditions, and it is necessary to decide when to irrigate and how much water to be applied. To overcome this dependency and aid in decision making regarding irrigation scheduling, automatic irrigation has gained momentum. Automatic irrigation can be two types: fixed-rate and variable rate, as stated in Table 8.4. ICT can be used for automated farm management. All the automated equipment (sensor, actuators) are connected through communication interfaces. A smart application running on a gateway or the Cloud can be operated automatically. Bhatnagar and Poonia [34] demonstrated a prototype model for irrigation based decision support system by implementing a wireless data acquisition network to collect climate data. Soil moisture, temperature, weather conditions and sprinkler position were monitored remotely using the Bluetooth and GPS technologies. Goap et al. [35] developed an IoT based smart irrigation system by predicting soil moisture based on a machine-learning algorithm with smart irrigation scheduling

Table 8.4 Types of automatic irrigation system

Fixed-rate	Variable-rate
Cheaper with fixed control of water application. No correlation of water application with the weather condition	Cost-effective with the optimum application of water-based on weather condition
Fixed control of irrigation time and water flow	Variable control of irrigation time and water flow
Irrigation systems use ON/OFF controllers. These controllers cannot give optimal results for varying time delays and varying system parameters	Artificial Neural Network (ANN) based intelligent control system for effective irrigation scheduling
Designed based on the open-loop controller. It functions are predetermined, i.e. when to start/ end watering with time delay intervals fixed. In this case, it does not determine whether the desired output or goal is achieved or not	Designed based on closed-loop feedback. In this type of controller, the necessary sensors are required to check the right amount of water needed for irrigation

Table 8.5 Application of agricultural production system models

Application area	Ref.
Farmer advice	[48, 49]
Yield gap analysis	[50–52]
Tools for farmers	[53]
Climate change and adaptation	[54–57]

using field sensors and weather forecast data. The developed smart irrigation system integrated a site-specific irrigation controller with infield data feedback and supported the decision making and real-time monitoring of irrigation operations. Issues like energy consumption for autonomous operation of sensor nodes dictate design and development issues including communication, protocols and deployment. The use of WSNs which comprises of battery-powered nodes consumes a large amount of energy [36], and therefore, solar-powered based nodes are greatly preferred [37, 38].

During the past decade, crop system models dominated by DSSAT [39], APSIM [40], CropSyst [41], EPIC [42, 43], STICS [44] and DSSAT-GREET [45], DSSAT-CSM [46] have evolved as agricultural production systems models with rapid expansion while less emphasis on model improvement [47]. The agricultural production system model has a wide range of applications, as shown in Table 8.5.

8.4.2 *Automatic Fertigation*

Automatic fertigation is used to overcome the intensive and laborious process (fertilization such as broadcasting, manual spreading and spraying) of applying fertilizers to increase the soil fertility through adjustable settings for nutrient concentration, water flow, time and length of delivery and other parameters that directly affect plant growth and plants productivity. The precise and optimal application of fertilizer at the root zone of plants is a complicated task which can be made simple and easy through the pinpoint application of fertilizers at the right time, at the right place using sensors. An automated fertilizer applicator consisting of input, decision support and output modules using GPS technology, real-time sensors and Bluetooth technology was built by Cugati et al. [58]. The input module is used to provide GPS and sensor data values to Decision Support System (DSS) that calculates the optimal quantity and spread pattern of fertilizer based on real-time sensor data acquisition through Bluetooth communication modules to regulate fertilizer application rate. He et al. [59] developed and integrated optimal fertilization decision support system by using sensors to acquire real-time data of soil moisture, conductivity, temperature, PH value, air temperature, humidity, CO_2 concentration, illumination etc. This system used wireless sensors LAN using the IEEE 802.11 protocol (WiFi) and GPS analysis server.

8.4.3 Precision Agriculture

Precision Agriculture (PA) is known as precision farming, information-intensive agriculture, prescription farming, target farming [60]. Taylor and Whelan [61] defined PA as integrated information and production-based farming system that is designed to increase long-term, site-specific and whole-farm production efficiency, productivity and profitability while minimizing unintended impacts on wildlife and the environment. PA has been emerging as the next great revolution in agriculture, which emphasizes agricultural developments with a particular focus on production, economic, and environment. It can pinpoint the exact location of the farm that requires specific attention to manage plant disease or to improve soil condition by optimizing the use and varying the rate of inputs, such as fertilizer, across a field based on the need identified by GPS guided grid sampling. PA technology encompasses four key information technologies, namely location determination (via GPS), GIS, computer-guided controllers for variable rate application (VRA) of crop inputs, and sensing technologies for automated data collection and mapping. Among the four, GPS and GIS have been more widely used [62] to increase yields for row crops, hay production, pasture management, and other agricultural activities. Besides, this approach can be used for mitigating leaching problems [63].

8.5 Challenges in ICT Based Precision Farming

There are several challenges that need to be addressed in order to make ICT based precision farming into its full potential. Here we discuss some of the major issues that should be addressed in future research.

- Sensor network security: Most network sensors are deployed in the farming area left open, and they are prone to have physical attacks. Due to limited computational and power supply in sensors, strong security mechanism management in sensors is hard to implement. In WSN, mostly the communication takes place in broadcast nature allowing the network to be exposed to attackers. Some of the common attacks in WSN are eavesdropping, denial of service and tampering data [64]. For example, an automated agriculture facility may take a wrong operational decision if an attacker tempers or injects false data in WSN. An automated agriculture facility needs to understand the possible security threats (some of them could be deliberate or accidental). It should set possible safeguards to combat against any security threats.
- Reliable and available network infrastructure: Real-time monitoring and control of an automated agriculture facility are increasingly important. Communication network infrastructure is key to develop a successful automated agriculture facility. The network segment connecting BS with the remote Cloud has a significantly important role. Any failure in a communication network may isolate an automated farm from remote monitoring and control system (farmers would not have any idea about the current status of their agriculture farm in such a situation). Many of the farming equipment and sensors/actuators information is mission-critical (the information should reach at the decision centre within a certain time frame). A communication network infrastructure may fail to due to many reasons, including application failure, network device failure, network interface failure and communication path failure. A highly reliable and available network needs to be designed for the agricultural farming facility. It must be noted that a highly reliable and available network we can achieve mainly by increasing capital and operational expenditure.
- Cost of sensors and actuators: Currently, the price of sensors and actuators is still not affordable for the farmers in the developing and underdeveloped countries.
- Power supply availability: Many types of equipment in an agricultural farming facility would require a continuous power supply from the grid. Due to natural disaster or accident, failure of power supply would lead to having a catastrophic effect on the entire farming facility. Therefore, redundant power sources, including battery and renewable power source, need to be installed in order to provide uninterrupted power supply to the farming facility.
- Educating farmers: Technology is progressing at a breakneck speed. However, a major portion of the farmers in the developing and underdeveloped countries are not educated. This would result in the poor adoption of new technology.

Uneducated farmers would show a less favourable attitude towards accepting ICT based farming management compared to the educated one [65]. Therefore, to allow ICT to leverage our future farming, ICT literacy, level of awareness and education of farmers need to be improved.

- User-friendly applications: Some farmers do not have ICT literacy. Hence, they may be reluctant to use ICT based farming management. The applications for controlling and monitoring farm need to be designed such that farmers can easily understand.
- Metadata, semantics, and ontology: In order to provide advanced intelligent systems based on collected data and information, we have been witnessing significant research progress in this domain. Nevertheless, more research effort is needed to realize automated smart farming.
- Fast fault identification: Identifying fault in sensors/actuators, farming equipment and communication network equipment would be another challenging issue that should be addressed in future research.
- Analysis paralysis: Huge amount of data collected from sensors/actuators and other sources without a meaningful way to understand would not bring any advantage in smart farming. Finding meaningful data would lead to providing useful information (and knowledge).

8.6 Conclusion

Small-scale farmers in developed/developing countries can be immensely benefitted by updating their farm's practices in terms of irrigation and plantation by implementing best water management through ICT and data management. The use of remote sensors, automated technologies, drones, cameras, climate-based intelligent irrigation system, professional expertise and continuous monitoring from a remote location through smart handheld devices can revolutionize the agricultural farms, both in terms of better yields and contributing to the nation's Gross Domestic Product (GDP). With the advancements of practices and technology, these contributions to the farmers in small-scale farming are gaining momentum with continuous support to various stakeholders ranging from small-scale farmers to policymakers. There are numerous opportunities for further development of ICT and bringing to every corner of the words. The challenges lie in keeping the cost of such technologies within the affordability of small-scale farmers; while promoting awareness through various media platform to reach them. Thus, this technology advancement farming practices not only increase the agricultural yields but also supports to maintain a sustainable ecosystem.

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Chapter 9
Big Data for Smart Agriculture

Nidhi

Abstract The enormous challenges that agriculture is facing today as consequence of negative impact of climate change must be dealt with by adopting advanced digital technologies. These technologies generate massive volumes of data, known as Big Data, e.g., sensors on fields and crops provide granular data points on soil conditions, as well as detailed information on wind, fertilizer requirements, water availability and pest infestations. The continuous measurement and monitoring of physical environment has enabled to proceed for adopting smart agriculture. Smart agriculture helps in automated farming, collection of data from the field and then analyses it so that the farmer can make informed decision with respect to optimal time of sowing/planting of the crops, optimal time for application of pesticides, insecticides, and fertilizers starting with sowing, and time for harvesting crops in order to grow high quality and larger quantity of crops. The scope of Big Data in not only confined to farm production but it influences the entire food supply chain. To extract information from large volumes of data so generated require a new generation of practices known as "Big Data Analytics". Big Data, if unlocked intelligently, and analytics has the potential to add value across each step and can streamline food processing value chains starting from selection of right agri-inputs, monitoring the soil moisture, tracking prices of market, controlling irrigations, finding the right selling point and getting the right price.

Keywords Big data · Smart agriculture · Analytics · Digital technology · Real-time information

Nidhi (✉)
Department of SMCA, FBS&H, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, India
e-mail: nidhi_96@yahoo.co.in

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9.1 Introduction

The incessant increase in the complexities of agriculture as consequence of negative impacts of climate change along with numerous other factors has forced different stake holders to ponder about various risks and their mitigation strategies. Need for a concerted effort, to manage the risks at diverse front as well as at different scales as fine as possible, is being strongly felt. Agriculture sector across the globe is grappling with myriad issues ranging from land degradation, water contamination, climate change, socio-cultural development, governmental policies, market fluctuations thus adding uncertainties to the food security [1]. These uncertainties challenge agriculture to improve productivity, while reducing its environmental footprint, which currently is approximately 20% of anthropogenic greenhouse gases (GHG) emissions [2]. And hence efficient agricultural practices require complex approaches based on several disciplines intertwined among them. There has been continuous development in crop growth modeling and yield monitoring [3] together with global navigation satellite systems [4] for precise localization of point measurements in the field thereby helping to develop spatial variability maps [5], a concept known as precision agriculture [6].

Until now the agricultural research and development activities have relied heavily on crop growth modeling based on different types of data to achieve better understanding about the agriculture system. However, with the digitization of most of the processes, emergence of different social network platforms, use of different kinds of sensors, adoption of hand-held digitization devices and explosion in the usage of internet, massive amount of data is being generated at an unprecedented pace. The digital technologies like remote sensing [7], cloud computing [8], Internet of Things (IoT) [9] create vast pool of data and are better capable of handling complex, multivariate and unpredictable agriculture. Data helps to formulate a concerted approach to agriculture by integrating different aspects of farming, viz. biological, chemical, physical, ecological, and economic and social sciences in a comprehensive way. The data generated for each of these aspects can now be integrated across different localities, through special techniques, to develop a more robust advisory for farmers triggered by real-time events. For example, the initial uses of yield monitors may include information on yield over varying topography, while farm level data on soil nutrient testing and information on varying soil fertility which farmer uses to fine tune sub-field production. And when these same data aggregated with thousands of other farmers, gives rise to *Big Data*. Coble [10] suggests that Big Data refers to “large, diverse, complex, longitudinal, and/or distributed data sets generated from click streams, email, internet transactions, satellites, sensors, videos, and/all other digital sources available today and in future”. Thus Big Data can help to devise tailored solutions for farmers for dealing with specific challenges. As a consequence the notion of “*Smart Agriculture*” has arrived which extends beyond the concept of precision agriculture. Precision agriculture enables precise localization of measurements of different parameters in the field to create spatial variability maps, whereas Smart Agriculture leads to decision making based on data enhanced by context, situation and location awareness, triggered by real time events [11].

The imprecise nature of agriculture systems forces to rely more on data intensive processing and analysis to tackle with impending challenges. The complex and diverse data obtained across different aspects of agriculture offer myriad opportunities by integrating them to support evidence based decision making. Given the massive volume of big data so generated, a set of advanced techniques and technologies known as “big data analytics” is required to extract meaningful insight in a reasonable timeframe so as to help farmers and other stakeholders to derive economic value from it. Big Data Analytics is the term used to describe a new generation of practices [12, 13], designed so that farmers and other stakeholders can extract economic value from very large volumes of a wide variety of data by enabling high velocity capture, discovery, and/or analysis [14, 15]. Hence the potential of applications of Big Data in agriculture is being realized by various stakeholders ranging from farmers, food and agribusiness industry players, researchers and policy makers.

The paper is organized as follows. Section 2 explains the characteristics of big data, how its peculiar properties differentiate it from data, followed by discussion on the concept of big data and smart agriculture in Sect. 9.3. Section 9.4 describes the various sources of big data for agriculture system followed by tools used to handle the big data in Sect. 9.5. Section 9.6 focuses on potential of big data in agriculture while Sect. 9.7 highlights the challenges for application of big data. The paper ends with concluding remarks in Sect. 9.8.

9.2 Characteristics of Big Data

The complexity of handling Big Data is highly associated with its typical characteristics defined by following dimensions [16]:

(1) Volume (V1): It refers to the size of data collected. Massive generation of data requires efficient means of storage as well.
(2) Velocity (V2): It refers to the pace at which the data is becoming generated as well as the time window in which data is useful and relevant. Thus it also involves the capability to understand and respond to the events as they occur. Early warning systems can be developed with the help of real-time data generated by sensor networks to provide timely information to decision makers. For instance, to identify pests and animal diseases [17].
(3) Variety (V3): The complexity and diversity of relevant data is one of the most promising dimensions of big data. The factors leading to variety in big data include varying sources (e.g. images, videos, remote and field based sensing data), temporal (e.g. collected on different dates/times), and resolution (e.g. different spatial resolution images).

(4) Veracity (V4): It refers to the quality, reliability and potential of the data and data sources so that it can serve as evidence base for critical decision making.
(5) Valorization (V5): It refers to the ability to propagate knowledge obtained from data leading to sustainable solution.

In spite of the above characteristics, big data lacks accuracy and stability and compromises with V4 i.e., veracity. According to [11], big data is less a matter of data volume than the capacity to search, aggregate, visualize and cross reference large datasets in reasonable time. It is about the capability to extract information which was not possible earlier [13].

9.3 Big Data and Smart Agriculture

Both Big Data and Smart Agriculture are relatively new concepts. Smart Agriculture extends the concept of Precision Agriculture, the existing tasks for management and decision making based on data are enhanced by context, situation and location awareness. It has the feature of real-time assistance to carry out agile actions, especially in cases of suddenly changed operational conditions or other circumstances (e.g. weather or disease alert). The assisting features include intelligent assistance in implementation, maintenance and use of the technology as well. The application of Big Data in relation to Smart Agriculture is gaining momentum to ensure profitability as well as sustainability. Agriculture stands on the cusp of digital revolution with sensors and smart machines being used in farm equipment on fields and crops. Data in agriculture encompasses maps and data on soil physical and chemical properties; records on past management practices; weather vagaries; yield related information etc. Hence assessing the impact of real-time events like sudden change in operational conditions or other circumstances like weather or disease alert has become possible than ever before. Farmers are able to take informed decisions regarding fuel, labour, and fertilizer, pesticides, soil and water conservation to achieve sustainable yield and quality of crop. However the application of Big Data in agriculture is not only about primary production; in fact it plays a major role in improving the efficiency of entire supply chain and hence Smart Agriculture may be perceived as an efficient path leading to sustainable agriculture [18, 19]. At the same time, to turn the enormous mass of data into compact, structured, manageable and ready for use information in a specific decision making context poses a great challenge. Because the end users presume the robustness of the data in terms of their authentic sources, rigorous processing and interoperability according to their decision context. Hence there lies a vast responsibility on ICT experts, data scientists and domain experts and requires collaboration between different stakeholders having different roles in the data value chain. In big data applications, the value chain refers to a set of activities from data capture to decision making to create value from data [18, 20].

9.4 Sources of Big Data

Big data may originate from various kinds of sources, e.g., farmers' field i.e., from ground sensors (chemical detection devices, biosensors, weather stations etc.), data collected by governmental and other organizations (statistical yearbooks, governmental reports etc.) [12, 17], online repositories and web services, data from airborne sensors (unmanned aerial vehicles, airplanes, satellites) [21, 22], real-time web data from private companies, crowd sourcing based techniques from mobile phones (information about plants, crops, yields, weather conditions etc.), feeds from social media, tweets, blogs, research reports, articles etc. [23]. Various agricultural applications require different sources of big data to address the problem it tackles. For example, crop, soil and animal related research use ground sensors deployed at field, climate change applications use data from weather stations, information on land mapping from satellite, data on insurance and finance from several government and non government records and so on. Big data is heterogeneous (types and formats) and differs in volume and velocity. Each agricultural area has different sources of big data to address the problem it addresses. For instance, crop, soil, animal related issues use ground sensors deployed at field, whereas weather stations are employed in weather and climate change applications, land mapping etc.

9.5 Tools for Big Data Analysis

Given the heterogeneous nature of big data and high dimensionality, extracting information from it requires sophisticated tools and techniques. It is analyzed using various algorithms, techniques or combination of methods like machine learning, statistical analysis, modeling, cloud platforms, GIS geospatial analysis, image processing, wavelet analysis, vegetation indices, MapReduce analytics etc. Machine learning is a multidisciplinary field of computer science, artificial intelligence and statistics that gives machines the ability to learn without being strictly programmed. Machine learning tools are used in prediction, clustering and classification problems while image processing is used when data originates from images and remote sensing. Applications of image processing towards agriculture provide the earth observation data which supports increased area under agriculture, increased crop intensity and productivity, etc. Remote Sensing data can provide the data related to groundwater helping in irrigation, flood management. Cloud platforms together with MapReduce enable large-scale storage, pre-processing, analysis and visualization of data, while GIS are used in geospatial problems, Cloud computing is the provision of computer or IT infrastructure through the Internet. It offers provision of shared resources, software, applications and services over the internet to meet the elastic demand of the customer with minimum effort. It can include various databases soil-related, weather-related, crop and farmers-related all stored at a single location with easy accessibility for the end-users such as farmers, experts, consultants, researchers etc. easily any time from any location through the devices that are connected to the cloud system. Vegetation indices are frequently used for crops/soils mapping.

9.6 Potential of Big Data in Agriculture

Big data is being proved as an important game changer in otherwise ailing agriculture due to ever increasing several challenges. Its potential as an aid to arrive at innovative solutions for enhanced agricultural productivity and simultaneously minimizing its environmental footprint is being realized. It is expected to help farmers to usher in a new era of farming known as Smart Agriculture by adding value at each step starting from selection of right agri-inputs, monitoring the soil condition, controlling irrigations, tracking prices of markets, finding the right selling point and getting the right price. For instance, spatial data mining techniques are used with agriculture big data to identify crops vulnerable to climate change and natural disasters; their supply chain maps help in predicting geographic choke points of these sensitive crops; detailed data on consumer and market behavior are used to improve food access and maintain quality. Thus big data based Smart agriculture enables smart decision making and it can be visualized at four levels:

Descriptive: Spatial and temporal variability in soil, land cover, crop and weather characteristics are described and stressors, traits, or infectious disease risk factors that need better management are identified.

Prescriptive: The collected data and associated maps of individual characteristics, traits, or exposures to infectious agents are used for a prescriptive analysis to determine necessary farm management interventions.

Predictive: A predictive analysis using historic datasets related to soil, crop, weather and market models is conducted to forecast crop yields. It can also be used to improve decision making to forecast spread and limit the impact of infectious agents on crops and livestock.

Proactive: Crop development and stress on multiple farms are observed proactively over large regions and time scales and further pooled and mined to obtain relationships between site characteristics, weather and crop performance under varying management conditions. These relationships can be used to customize management practices and seed selection to local conditions.

Some of the specific areas where big data can play a major role for agriculture may be listed as:

(1) Crop yield: Enhancing crop yield is the ultimate objective to achieve global food security. The data from a wide variety of sources leads to improved crop and seed quality to increase global food production. Also timely availability of data for sowing and harvesting help the farmers to deal with price volatility of perishable crops like potato, tomato, coriander, onion, thereby avoiding the situation of market glut to a greater extent.

(2) Resource conservation: Sustainable development requires optimized usage of farm inputs. Spatial soil maps consisting information on soil properties can help in deciding right amount of fertilizer requirement, sensor data on soil moisture and local weather can help farmers to devise adequate irrigation schedules thereby avoiding the excessive use of fertilizers as well as preventing wastage of water.
(3) Tackling with pests and diseases: Early signs of diseases and pest incidences can be obtained though plant monitors and a forewarning system can be devised well in advance to tackle with them. This way the farmers can manage the spread of pathogens to prevent catastrophic losses.
(4) Financial aspects: The historical data on lending pattern of agricultural enterprises can help financial institutions to assess the financing needed for smallholder family farms. A logical, data driven algorithm can be developed to help bankers by enabling them to have access to data on likely crop output from farmer's field. Insurance companies can also be benefitted to design the premium based on weather, soil, pest and output data.
(5) Post-harvest losses: To keep a tab on the movement of farm products through agri-food supply chain, a traceability system can be developed through web enabled devices. The factors responsible for wastage during storage (pest, rodents, moisture) and (high temperature, excessive pressure, humidity) can be identified thus leading to an efficient farm to fork system. Big data also makes it possible to improve packaging and labeling of food products and detecting spoilage by monitoring the canned food products.

9.7 Challenges for Big Data in Agriculture

While Big Data seems to be alluring in agriculture, its application is yet to achieve its full potential because of certain challenges hindering its wider adoption by different stakeholders. Some of the pertinent issues regarding big data are:

Limited infrastructure for data storage: The specific characteristics viz. volume, variety and velocity of Big Data require significant resources to manage. The rate of increase in data is much faster than the existing processing systems. The storage systems are not capable enough to store these data. Infrastructures are needed for efficient data storage, management and real-time processing of high-dimensional datasets.

Restriction towards data sharing: The logical integration of big data from multiple sources is one of the important challenges. Data ownership is an important issue and in turn it gives rise to concerns regarding its security and privacy. Also there are compatibility issues that big data suffer from as they are generated through diverse sources. And hence many private agriculture datasets are stored locally rather than on cloud computing platforms. Farmers are also concerned about the potential misuse of information related to their farming activities by seed companies.

Lack of talent pool: The large amount of unstructured and heterogeneous big data needs intelligent processing and analytics. Skilled data scientists and domain experts are required to work coherently to extract economic value information from data.

Lack of governance: There is lack of governance in general related to agricultural big data till now. Government departments should buy data from private bodies to improve accuracy, frequency and timeliness of the data collected.

9.8 Conclusion

Big Data is changing the scope and organization of agriculture with an aim to meet the objectives of food security and sustainable productivity. With these larger objectives, Big Data applications are expected to extend from farming to entire food supply chain. Real time data is being made available with the help of advanced technologies like IoT, wireless connection of all kinds of devices in farming and the supply chain. Sensors and robots produce non-traditional data such as images and videos. The enormity of the data so produced is leading to data revolution and is expected to enhance decision making capabilities to a level that was not possible earlier. New start up companies are lined up to offer efficient applications to farmers like sensor deployment, benchmarking, risk management etc. However, with such large scale data collections, we have been witnessing *data rich, information poor* conundrum. Big data analytics provides a solution to deal with this conundrum in various fields. It is less about the size of data and more about the combination of technology and advanced analytics to create a new way of processing information in a more useful and timely fashion. Its application in agriculture has been largely driven with the objective to improve productivity and sustainability along agri-food supply chain, thus giving rise to the concept of Smart Agriculture. The increasing availability of big data and analysis techniques is expected to boost more research and development towards Smart Agriculture, thus addressing the global challenge of producing higher-quality food on a larger scale and in a more sustainable way. The farm management and operations will undergo a drastic change by access to real-time data and real-time forecasting. In spite of acknowledging its high potential for Smart Agriculture, some of the challenges impede its wider adoption by different stakeholders. A host of issues are there which need to be addressed to harness rich dividend of Big Data applications in agriculture. Some of the key issues are quality of data in terms of reliability, integration of data from heterogeneous sources, its processing and analytics to extract meaningful information which require skilled data scientists and domain experts.

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Chapter 10
Smart Farming: An Overview

Ahmad Latif Virk, Mehmood Ali Noor, Sajid Fiaz, Saddam Hussain, Hafiz Athar Hussain, Muzammal Rehman, Muhammad Ahsan and Wei Ma

Abstract Increasing population and abrupt weather fluctuations around the world has put huge pressure on agricultural food products for quality and sustainable food production. Revolution and advancement in food growing agricultural practices become advanced with the passage of time. In this modern age, improved technology-based agricultural practices are replacing the existing old-fashioned farming practices. These novel technologies are quite efficient but still require the consistent attention of researchers and scientists for better application and output of this technology. Smart farming involves the integration of information and communication technology for better utilization of resources from sowing, irrigation,

A. L. Virk
College of Agronomy and Biotechnology, China Agricultural University,
Beijing 100193, People's Republic of China

M. A. Noor (✉) · W. Ma (✉)
Institute of Crop Sciences, Chinese Academy of Agricultural Sciences,
Key Laboratory of Crop Physiology and Ecology, Ministry of Agriculture,
Beijing 100081, People's Republic of China
e-mail: mnoor@caas.cn

W. Ma
e-mail: mawei02@caas.cn

S. Fiaz
Department of Biochemistry, University of Okara, Okara, Pakistan

S. Hussain
Department of Agronomy, University of Agriculture, Faisalabad, Pakistan

H. A. Hussain
Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing 100081, People's Republic of China

M. Rehman
School of Agriculture, Yunnan University, Kunming 650504, People's Republic of China
e-mail: muzammal@ynu.edu.cn

M. Ahsan
School of Computer Science and Technology, Beijing Institute of Technology,
Beijing, People's Republic of China

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fertilizer, pesticide, and herbicide application, and finally harvesting. But this system involves autonomous vehicles, robots operated through GPS and connected through smart applications. The precise application of this technology along with Internet of Things (IoT) supposed to be the helpful technology for farmers to uplift their living standards, with high production and profit and also can be a good indicator for food security. Nowadays, there are still limitations for the adaptation and conversion of smart farms due to high cost, non-availability of internet, and lack of application knowledge in the farming community. In autonomous vehicle and drones, there are also some major gaps regarding their application (positioning), efficiency, and workload. So, this area of research needs more explorations.

Keywords Smart farming · Precision agriculture · Computer applications · Remote sensing

10.1 Smart Farming

Agriculture is a key source for food over the world. Recently, climate change and variability exacerbated potential harmful effects on worlds' agriculture. It is expected that over two billion more people will be part of the world in 2050. But weather uncertainty in some regions put negative repercussions on agriculture and food production. For sustainable food production, world agriculture has to use agricultural resources with more precision and in time decision for maximum resource utilization [1]. Since farming, farms maintained by record-keeping and now farm management involves electronic devices with more precision and decision making. In the past, many efficient and resource-use technologies have been used in agriculture farm management but most of them were not effective. Net profit of farm can be increased through the coordination of available resources with their judicious and timely use. Now, this is managed by computer and electronic devices to get maximum food and net profit [2].

10.1.1 Smart Farm?

Smart Farm (SF) includes the integration of information and communication technologies into farm equipment and sensors for use in crop cultivation and food production system. In this advanced technical era, internet of things (IoT) and various electronic instruments(robots and artificial intelligence) with data transformation and signaling facilities worlds i.e. smart homes, smart health care and now it turned to the agriculture sector. Nowadays farmers can leverage IoT to enhance their farm efficiency such as irrigation, fertilization, harvesting information, and climate forecast by monitoring with sensors to improve their decision making [3]. This advancement enables farmers to make better decisions in the management of their farms by efficient utilization of available resources, producing suitable yield and more income [4].

10.1.2 Autonomous and Robotic Labor

The labor shortage is being considered as a major impediment in crop cultivation in recent years. The prevalence of the skilled labor shortage affected food production in almost all crops and even transforming permanent changes in the cultivation sequence. That will be a major threat to sustainable food production. The important causes for the labor shortage include higher wages for labor in the nearby cities and towns [5]. To tackle this issue for sustainable food security and modern agriculture looking to use autonomous robots and labor. Robotics and Autonomous Systems (RAS) are set of electronic and mechanical equipment's that operates through the software technology for special purposes. Each set after integration can be used for one or more tasks. RAS can be more effective and time-saving technology in coming days, but now this technology is facing some hurdles such as low operation efficiency in extreme weather conditions [6].

10.2 Replacing Labor with Automation, to Produce More and Higher Quality Food

Migration of the village population to the cities is a major cause of labor shortage, as well as low income in the village, is also considered as the main contributor in the current global labor shortage issue. Although the world population is increasing and expected to increase modernization has reversed the scenario. So, developed countries also attained much success in the field of robotic labor and automation.

10.2.1 Driverless Tractor

In the 19th century, the intervention of the tractor is a big source of revolution in field crop planting and harvesting. This invention makes agricultural practices more easy and efficient and in some soil (heavy clay) put negative repercussion e.g. compaction. At that time this revolution diverted from animal-drawn tillage and transportation implements [7]. But in the near future, autonomous machinery is going to be a modern and electronic revolution for the farming community. Automated tractors (driverless tractor) integrated with hardware and special-purpose designed software are working more efficiently changing agricultural machinery [8, 9].

However, driverless tractors operated by monitoring sensors that help to run and recognize a tractor to field boundaries i.e. GPS for mapping and navigation, IoT connected to remote sensors and monitoring system, and radars for object detection in the field. This diverse system was developed to operate a tractor in several conditions and practices, such as spraying of crop canopy for the management of insects, diseases and selective weed treatments, either these weeds managed by spraying herbicide or flame burning in the fallow land driven by automated tractor [10, 11]. But this technology is expensive and small scale farmer cannot use due to higher implements cost. Moreover, the struggle is going on by the scientist to make this technology economically viable.

10.2.2 Automatic Watering and Irrigation

Agricultural irrigation water is becoming scared not only in arid and semi-arid regions but also in the high rainfall regions. Because of the uneven distribution of rainfall pattern not successfully used by most of the crops [12]. In this modern age, subsurface drip irrigation (SDI) plays a vital role for judicious use of water as per the requirement of the crop. But this system still needs to maintained by the operators. In order to improve its efficiency and ensuring water demand of the crop, efforts for SDI assembling with moisture level detectors are helpful in better crop germination and yield.

10.2.2.1 IoT-Enabled Sensors for Moisture Determination

In order to acquire more precision in water utilization (IoT) solution, involves special ground-based sensors for data recording and processing, are narrowing the gaps between the computer application and applied science. IoT based smart irrigation system helpful to simulate the irrigation needs of the crop and field with sensing of edaphic factors like soil temperature, moisture and evaporation rate, and temperature air humidity and also can predict future water requirement of the crop linking with the weather forecast from the Internet in specific a region [4, 13]. The structure of this system relies onan algorithm, which detects sensors data and integrating with weather elements e.g. rainfall, humidity, temperature, and UV for future prediction [14, 15]. This improved technology has the potential to increase judicious water application and use according to crop stage and requirement. Additionally, SDI can be linked with fertigation (irrigation water plus fertilizer), that not only increase irrigation efficiency (20–305) but also decrease fertilizer especially nitrogen losses (20–40%) as well as increase crop yield (10–20%) depending upon soil, crop and environmental conditions [16, 17].

10.2.3 Crop Health, Weeding, and Spraying

Innovation in agricultural takes the faraway farming community from old agricultural techniques. Integration and application of machine learning and Artificial Intelligence (AI) make it easy for farmers to detect diseased patch, heavy weed infestation, and crop health through image processing (Fig. 10.1). Along with this innovation, drone technology is also widely adopted in many smart farms for spraying of herbicides, pesticides, fertilizer broadcasting by using image processing through Normalized Difference Vegetative Index (NDVI) or near-infrared (NIR) sensorsthat are linked with crop health index [18, 19].

10.2.4 Planting and Sowing

Induction of machine is not a new idea in the field of agriculture, but their efficiency is still a question. In the early 1960s autonomous machinery introduced into agriculture for research and development [20]. Automation and robotics introduced by western societies in last decade to tackle the problem like, large production area, increasing labor wages, health issues for labor to work in extreme conditions and to grow more food in order to compete with other countries to earn more revenue. Although automation and robotics have many challenges for efficient working in the field, for sowing and cultivation purposes it faced fewer challenges and snugly adjusted into the farming system because this technology is easy to operate [21]. Current agricultural machinery needs more energy to operate but modern

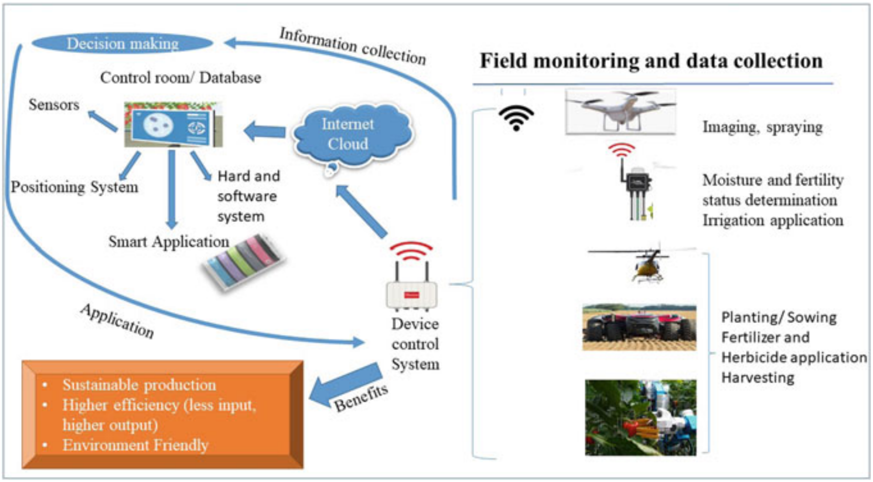

Fig. 10.1 Sketch map of agricultural farms monitoring through advanced computer-based monitoring tools

mechanization has the potential to save fuel consumption and the has the ability to work more efficiently then existed machinery [22]. Moreover, current agricultural machinery is heavy and reported many times for soil compaction. Whereas, modern machines are small light weighted that are easy to drive and operate [23]. Before sowing each crop seed require favorable conditions to grow as discussed below.

10.2.5 Seedbed Preparation to Reseeding

Land preparation is the primary focus of each farmer, in conventional farming heavy machinery is used to invert and manipulate the soil in order to make fine seedbed. Although modern robotics have not the ability to invert the soil in-depth (i.e. as like chisel plow) on the other way, these robotics and machines do not put huge pressure onto the soil surface to make tough for seed sowing. Therefore, that can be managed with consistent use of autonomous machines and robotics [23]. The next step is the sowing of seed into the soil that can be done through geo-positioning seed on the seedbed. This needs only RTK GPS connected with the seed drill and attachment of infra-red sensors below the penetrating chute. When seed goes into the soil, it cuts infra-red ray and activates a data logger that navigate the position of seed. In the end, a simple kinematic model calculates the actual position of seed placement [24]. Reseeding is mainly used for again plantation of seed due to seed germination failure or false seed placement before. In this regard, modern machinery and robotics are the best choices because conventional seeder cannot do this job because in continuous planting only gaps need to be filled. Similarly, transplanting or gap-filling also related to this phenomenon. A punch planter through image processing and identification can be used for this purpose.

10.2.6 Planting from the Air

Seed planting form air is mainly practiced due to large sowing area, areas with a steep slope or for the areas where seed sowing is very difficult. Particularly, forest seeding and early plantation method are very useful through helicopters. Helicopters are more efficient as compared to airplanes for seeding purposes because the helicopter can hangover relatively near the ground surface and cost-effective [25]. For this type of planting, Chadwick and a barrel seeder mainly used in the helicopter. Chadwick seeder is suspended beneath the helicopter with a cable that contains seeds and operated through the small engine, seeds are dropped by automated seed gate and seed dropping intensity controlled by the inside of the helicopter. Whereas, the barrel seeder controlled manually and can cover an area of about 14 m. But Chadwick seeder is more efficient and superior than barrel seeder [26]. However, the seed rate of each crop varies for air planting. On the other hand, lighter and smaller seeds are difficult to spread over an area [25]. No doubt, this planting method brought a revolution in the field of agricultural but in developing countries, it is difficult to implement due to their small landholding and less revenue.

10.2.7 Harvesting from Field

Harvesting from the field involves picking only those parts of the plants that are economically viable, according to the required size, shape, color and the, more importantly, maturation stage of the fruit. Harvesting through robotics involves mainly two objectives, (i) the efficient ability of the robot to sense the fruit part and quality (i.e. maturity), (ii) picking of fruit without damaging the fruit [23]. Mainly is robotic for picking in tunnels or from field fixed with three CCD cameras, one is used for illumination and other two facilitate a stereo vision for reorganization (detection and localization) of fruit. When fruit is detected, third camera (positioned on end effector) then used for detection of fruit shoot, at last with the previous data the end effector modified through tilt mechanism and reaches to specified fruit. After fruit grasping, fruit attached to the shoot is cut with the help of scissor-type tools and placed into a tray successfully [27, 28]. For harvesting of different crops, different algorithms, 3D environments, a sensor for object detections (mainly cameras with near-infrared light spectrum range) are required due to different shape, color, and size of the fruits. For each crop, different angels needed to detect the fruit of the crop. For example, at least five viewpoints are required to detect the sweet pepper crop [29]. Hayashi et al. [27] reported 52.6% of success rate from strawberry harvesting that still needs to be improved. As well as damage rate after harvesting should be taken into consideration.

10.2.8 Drones for Fields

In the recent past, the drones have made an entry into human life and augmented lifestyle in many ways such as insecurity, agriculture and many more. An autonomous flying tool that has a pre-planned flight or controlled by remote is called a drone. In agriculture, mainly drones are used for imaging for the identification of weeds, planting area, fertilizer and weedicide application, and real-time weather forecasting [30]. For agricultural use autopilot drones with a camera are mostly used connected through GPS (Fig. 10.1). In the near future, drones are considered as best farmer tool that will reduce labor load, precise fertilizer, and pesticide application and save the environment. In one way drones facilitate human life, on the other way these drones have some limitations such as expensive technology and limited load for spraying and carrying [18]. Different sensors are used for takeoff, flying, and landing of the drone. Sensor (Accelerometer, gyroscope, digital compass, and barometer) helps the drone while the flight to detect motion (position and speed) in the environment. In agriculture, drones controlled through GPS. The GPS sensors detect specific field information from geostationary satellites. Minimum three satellites are required to define longitude and latitude and one satellite assessed the altitude of the UAV. Basically, the satellite data is merged with other data for a higher level of precision and accuracy. Furthermore, attached cameras with drones are basic equipment in most drones, use of vision algorithms to fly drones autonomously. [30]. This vision helps in agricultural field through disease and weed identification and for crop health monitoring [18].

10.2.9 Yield Analysis and Mapping

Yield mapping is devised management strategy to cope with grain shortage and availability. This strategy is not being used in this era of technology. Previously it is used for estimation through the flow of the grain in the combine and based on rotations the yield estimated. Greater fluctuation in environmental conditions needs to estimate yield production from the field after each and every weather disaster. Although, in this stage, yield mapping is modified through GPS, satellite and drone imaging. In 90s many scientists tried to evaluate yield based on spatial and temporal variability [31] from Australia in 1995–1996 [32] to the USA and they found large differences in spatial and temporal in yield. Grid-based information is collected from the space in many ways (online, imaging) and estimated the yield of a specific location. But there are still limitations for yield mapping due to moisture variations and soil heterogeneity [33].

10.3 Future Challenges, Opportunities, and Prospects

Without any doubt, smart farming is helpful for farming community with real-time alerts, help in managements and precise use of agricultural resources for sustainable food production. But this system involves innovative technology that is expensive, as well as the farming community, is not well aware, especially in the developing countries. The main challenge is the small landholdings and the farmers are unable to adopt smart farming with limited knowledge and skills. The main identified reasons from the developing countries are as follows:

- Internet connectivity:
  Smart farming relies on the internet and builds a connectivity bridge between farmer smart communication device and field-based sensors for real-time information and management. But in most villages and farming communities have not to access all the time to the internet. That makes difficult for the adaption of smart farming.

- GPS signals:
  GPS signal transmission is difficult in some areas such as hilly, forests and field with a dense tree planting. That system has to be improved for better communication and alerts.
- Energy requirement:
  Data collection and processing centers and many IoT based sensors need energy for a successful application. Whereas, already developing countries are running out of energy resources. So, this maybe a major hindrance for the adaptation of smart farms.
- e-wastes:
  Technology is rapidly growing and updated hardware's needs to be adjusted with the passage of time and the older one will be obsolete. The major problem maybe the disposing of the e-wastes during the developing stage.

10.4 Conclusion

Agriculture production is experiencing a modern revolution and has involved the use of communication and information technology. The technological revolution in agriculture farming led by the improvements in robotics and sensing technologies looks set to disrupt the advanced practices. Use of modern agricultural technologies is must because it can increase production and can reduce the input cost. Several aspects of modern autonomous machinery can give great benefit when applying them in agriculture, especially in smart farming. In the future, smart farming can be a powerful tool for farmers for the efficient use of resources and real-time management. But this is a sketch of farming controlled by a high input of revenue and technology. That might be difficult for some developing farming communities until they will be provided by subsidy. This relief can create a revolution in every part of the world and can secure food availability for the growing population.

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Chapter 11
The Vertical Farm: Exploring Applications for Peri-urban Areas

Kheir Al-Kodmany

Abstract This chapter reviews recent advances in greenhouse technologies, including hydroponics, aeroponics, and aquaponics, and explains how they have provided a promising future to the vertical farm concept. It argues that compact high-tech agriculture is not only applicable in dense urban areas but also in peri-urban areas. Indeed, new high-tech systems represent a paradigm shift in farming and food production and offer suitable and efficient methods for peri-urban farming by minimizing maintenance and maximizing yield. Upon reviewing these technologies and examining project prototypes, we find that these efforts do plant the seeds for the realization of efficient and compact forms of large-scale indoor farming. The chapter, however, speculates about the consequences, advantages, and disadvantages of the vertical farm. Economic feasibility, codes, regulations, and a lack of expertise remain major obstacles in the path to implementing the vertical farm.

Keywords Food security · Climate change · Environment · Health · Economics · Ecology · Sustainability · Innovative technology

11.1 Introduction

In principle, the vertical farm is a simple concept; farm up rather than out [1–4]. Generally, the body of literature on the subject distinguishes among three types of the vertical farm [5–7]. The first type refers to indoor farming that contains tall structures with several levels of growing beds, often lined with artificial lights [8].

Please note that this chapter builds on the author's work; see for example "The Vertical Farm: A Review of Developments and Implications for the Vertical City," *Buildings* 2018, 8, 24; https://doi.org/10.3390/buildings8020024.

K. Al-Kodmany (✉)
Department of Urban Planning and Policy, College of Urban Planning and Public Affairs, University of Illinois at Chicago, Chicago, IL 60607, USA
e-mail: kheir@uic.edu

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The second type takes place on the rooftops of old and new buildings, atop commercial and residential structures as well as on restaurants and grocery stores [9, 10]. The third type of the vertical farm is that of the visionary, multi-story building. In all cases, crops are grown in vertically stacked layers or multiple levels. A common thread among these types is the employment of high-tech farming methods that increase yield, reduce the use of water, soil, and land while attaining higher produce quality. The vertical farm concept also aims to reduce food travel between production and consumption places and improve environmental health by eliminating or reducing the use of fertilizers, herbicides, pesticides, and fossil fuel. Overall, the vertical farm promises to revolutionize the way we produce and supply food to satisfy the needs of growing population.

Vertical farming is particularly an important topic since it involves multiple disciplines of natural sciences, architecture, engineering, and high-tech fields. It generates a remarkable synergy among these fields and harnesses latest and greatest advancements in sciences and technologies to improve food production while saving the environment. This is manifested in all development stages: thinking, planning, designing, and building prototypes. Interestingly, vertical farming affects the three spheres of sustainability: the social, economic, and environmental. That is, it has implications in the areas of health, food security, cost, supply, and transportation as well as issues related to air, water, and soil pollution [5–7]. Because it promotes condensed form of food production and consumption, the vertical farm supports “compact living,” which is advocated by the sustainability movement. For example, in a vertical farm, farmers do not need to drive a tractor or pull a plow in a vast field; instead, they use machine learning and artificial intelligence to grow crops in a vertical, condensed arrangement. In addition, the vertical farm is intended to be located near places where people live, thereby reducing travel distances and time as well as associated air pollution.

This research proposes applying vertical farming in peri-urban places and smart villages. The rationale explains, “The planet’s population is growing, and the amount of arable land is diminishing. There are threats from climate change and pressure on resources, like water …, agriculture is being squeezed at one end by pressure on finite resources, and at the other by never-ending demand” [9]. Vertical farming ensures sustainability of food supply because it is independent of weather conditions, be it unexpected rain, frost, snow, flooding, or prolonged drought. It is also free of obstinate weeds and invasive pests. “The natural world is full of uncertainty and lot of farming is still based on good luck and guesswork” [9]. More and more customers desire food supply characterized by being fresh, safe, healthy, wide-ranging, and accessible. Luckily, advances in science and technology are becoming a major game-changer in food production.

Therefore, justifications of introducing the vertical farm to smart villages include responding to food security and climate change threat, reducing vehicle miles traveled (VMT), and improving health, economic, environmental, and ecological conditions, as well as taking advantages of technological advancements, discussed in this chapter [8–11].

11.1.1 Food Security

Food security has become an increasingly vital issue; and therefore, embracing efficient farming, such as that employed in vertical farming, is desirable. Indeed, demographers anticipate that world population will dramatically increase in the coming decades. At the same time, land specialists (e.g., agronomists, ecologists, and geologists) warn of rising shortages of farmland [4–6]. For these reasons, food demand could exponentially surpass supply, leading to global famine. The United Nation (UN) estimates that the world's population will increase by 40%, exceeding 9 billion people by the year 2050 [12]. The UN also projects that by 2050 we will need 70% more food to meet the demands of 3 billion more inhabitants worldwide [12]. Food prices have already skyrocketed in the past decades, and farmers predict that prices will increase further as oil costs increase and water, energy, and agricultural resources diminish [7–10]. The sprawling fringes of suburban development continue to eat up more and more farmland. On the other hand, urban agriculture has been facing problems due to land scarcity and high costs. We desperately need transformative solutions to combat this immense global challenge [8–11].

11.1.2 Climate Change

Climate change has contributed to the decrease of arable land. Through flooding, hurricane, storms, and drought, valuable agricultural land has been decreased drastically, thereby damaging the world economy [7, 11–13]. For example, due to an extended drought in 2011, the United States lost a grain crop assessed at $110 billion [14–16]. Scientists predict that climate change and the adverse weather conditions it brings will continue to happen at an increasing rate. These events will lead to the despoliation of large tracts of arable land, rendering them useless for farming [17–19]. It is common for governments to subsidize traditional farming heavily through mechanisms such as crop insurance from natural causes [20–22]. Furthermore, traditional farming requires substantial quantities of fossil fuels to carry out agricultural activities (e.g., plowing, applying fertilizers, seeding, weeding, and harvesting), which amounts to over 20% of all gasoline and diesel fuel consumption in the United States. We need to understand that "food miles" refers to the distance crops travel to reach centralized urban populations. On average, food travels 1500 miles from the farm field to the dinner table [8, 15]. In special circumstances—cold weather, for example—food miles can rise drastically as stores, restaurants, and hospitals fly produce in from overseas to meet local demands. On a regular basis, over 90% of the food in major U.S. cities is shipped from outside. A 2008 study at Carnegie Mellon concluded that food delivery is responsible for 0.4 t of carbon dioxide emissions per household per year [23, 24]. This is especially important given the increasing distance between farms and cities as a result of global urbanization. Sadly, the resulting greenhouse gas emissions from food transport and agricultural activities have contributed to climate change.

11.1.3 Urban Density

Vertical farming offers advantages over "horizontal" urban farming for the former frees land for incorporating more urban activities (i.e., housing more people, services, and amenities) [7]. Research has revealed that designating urban land to farming results in decreased population density, which leads to longer commutes. "If America replaced just 7.9% of its whopping one billion acres of crop and pastureland with urban farms, then metropolitan area densities would be cut in half" [4, p. 71]. Lower density living incurs higher energy use and generates more air and water pollution. The National Highway Travel Survey (NHTS) indicates, "If we decrease urban density by 50%, households will purchase an additional 100 gallons of gas per year. The increased gas consumption resulting from moving a relatively small percentage of farmland into cities would generate an extra 1.77 t of carbon dioxide per household per year" [23]. Despommier details space efficiency of vertical farms. He suggested that a 30-story building (about 100 m high) with a basal area of 2.02 ha (5 ac) would be able to produce a crop yield equivalent to 971.2 ha (2400 ac) of conventional horizontal farming. This means that the production of one high-rise farm would be equivalent to 480 conventional horizontal farms [24, 25]. Consequently, a vertical farm will reduce vehicle miles traveled (VMT) significantly and simultaneously reduce air pollution.

11.1.4 Health

Conventional farming practices often pay inadequate attention to inflicted harm on the health of both human and the natural environment [7, 8, 10]. These practices repeatedly cause erosion, contaminate soil, and generate excessive water waste. Regarding human well-being, the World Health Organization has determined that over half of the world's farms still use raw animal waste as fertilizer which may attract flies, and may contain weed seeds or diseases that can be transmitted to plants [1]. Consequently, people's health is adversely affected when they consume such produce. Further, growing crops in a controlled indoor environment would provide the benefit of reducing the excessive use of pesticide and herbicide, which create polluting agricultural runoff [25]. According to Renee Cho, "In a contained environment, pests, pathogens, and weeds have a much harder time infiltrating and destroying crops" [25]. When excess fertilizer washes into water bodies (e.g., rivers, streams, and oceans), a high concentration of nutrients is created (called eutrophication), which could disturb the ecological equilibrium. For example, eutrophication may accelerate the proliferation of algae. However, when it dies, microbes consume algae and suck all the oxygen in water, resulting in dead aquatic zones [8]. "As of 2008, there were 405 dead zones around the world" [25]. In indoor farming, "everything that is required to grow crops—light, atmosphere, temperature, water, and nutrients—is supplied, controlled and constantly monitored to produce data that in turn is used to develop better techniques and better results" [9]. Further, indoor vertical farming employs high-tech growing methods that use little water (about 1/10th of that used in traditional farming) by offering precision irrigation and efficient scheduling [25, 26]. This can have a significant ameliorative effect since demands on water will increase as the urban population grows. Traditional agricultural activities use more than two-thirds of the world's fresh water, and farmers are losing the battle for crop water because urban areas are expanding and consuming more water. The water crisis is likely to become severer as climate change causes warmer temperatures and proliferates more droughts [25].

11.1.5 The Ecosystem

Further, proponents of the vertical farm argue that traditional agriculture has been encroaching upon natural ecosystems for millennia. For example, according to Dickson Despommier, "Farming has upset more ecological processes than anything else—it is the most destructive process on earth" [4, p. 7]. In the past half century or so, the Brazilian rainforest has been severely impacted by agricultural encroachment, with some 1,812,992 km^2 (700,000 mi^2) of hardwood forest being cleared for farmland [4]. Despommier suggested that encroachment on these ancient ecosystems is furthering climate change. In this way, indoor vertical farming can reduce the agricultural impact on the world's ecosystems by restoring biodiversity and reducing the negative influences of climate change. If we employ vertical farms to produce merely 10% of the ground area they consume, this might help to reduce CO_2 emissions enough to develop better technological innovations for improving the condition of the biosphere long-term. By eliminating fertilizer runoff, coastal and river water could be restored, and fish stock of wild fish could increase. Wood, et al. summarize this point by stating "The best reason to consider converting most food production to vertical farming is the promise of restoring [the] services and functions [of ecosystems]" [26, p. 110].

11.1.6 Economics

Proponents of the vertical farm also argue that it will supply competitive food prices [27]. The rising expense of traditional farming is quickly narrowing the cost gap. For example, when vertical farms are located strategically, it would be possible to reduce travel distances between farms and consumers, thereby reducing transportation costs [27]. Vertical farms also utilize advanced technologies and intensive farming methods that can exponentially increase production. Researchers have been optimizing indoor farming by calibrating, tuning and adjusting a wide-range of variables, including light intensity, light color, space temperature, crop and root, CO_2 contents, soil, water, and air humidity [27–29]. Additionally, the high-tech environment of indoor farming can make it fun to farm. Hence, a technology-savvy younger generation can be enticed by the practice, grooming a new breed of farmers. Further, vertical farming provides impetus in the development of innovative agricultural technologies [27].

11.2 High-Tech Indoor Farming

Progressively, indoor farming relies on most recent advances in technology and sciences. It attempts to take advantage of new machinery and equipment to enable growing greater number of crops in any place, at any time. New technologies and innovative farming methods tend also to be efficient in using resources such as water and light, consequently reducing production costs. They are also increasingly environmentally friendly, abating air, water, and soil pollution. This section reviews and illustrates major methods and technologies involving indoor farming.

11.2.1 Farming Methods

Researchers have advanced myriad methods of urban and vertical farming in the hopes of contributing to sustainable food production. Advanced farming methods could provide greater yields and use far less water than traditional farming [28, 29]. The design, layout, and configuration of these high-tech farms would provide optimal light exposure, along with precisely measured nutrients for each plant. Designed to grow in a controlled, closed-loop environment, these farms would eliminate the need for harmful herbicides and pesticides, maximizing nutrition, and food value in the process. Indoor farmers could also "engineer" the taste of produce to cater to people's preferences [30]. Researches intend to develop, refine, and adapt these systems so that they can be ultimately deployed anywhere in the world to provide maximum production and exert minimum environmental impacts. Surely, they represent a paradigm shift in farming and food production and scholars view them as not only suitable for city farming but also to peri-urban farming [5]. These systems (mainly hydroponics, aeroponics, and aquaponics) and associated technologies are rapidly evolving, diversifying, and improving (Table 11.1). The chapter explains these systems in a gradual manner, from simple to complex.

11.2.1.1 Hydroponics

Hydroponics is a method of growing food using mineral nutrient solutions in water without soil. Encyclopedia Britannica defines hydroponics as "the cultivation of plants in nutrient-enriched water, with or without the mechanical support of an inert medium such as sand or gravel" [27, p. 8]. The term is derived from the Greek

Table 11.1 High-tech indoor farming

Farming method	Key characteristics	Major benefits	Common/applicable technologies
Hydroponics	Soilless based, uses water as the growing medium	Fosters rapid plant growth; Reduces, even eliminates soil-related cultivation problems; Decreases the use of fertilizers or pesticides	Computerized and monitoring systems Cell phones, laptops, and tablets Food growing apps Remote control systems and software (farming-from-afar systems) Automated racking, stacking systems, moving belts, and tall towers Programmable LED lighting systems Renewable energy applications (solar panels, wind turbines, geothermal, etc.) Closed-loop systems, anaerobic digesters Programmable nutrient systems Climate control, HVAC systems Water recirculating and recycling systems Rainwater collectors Insect-killing systems Robots
Aeroponics	A variant of hydroponics; it involves spraying the roots of plants with mist or nutrient solutions	In addition to benefits mentioned above, Aeroponics requires less water	
Aquaponics	It integrates aquaculture (fish farming) with hydroponics	Creates symbiotic relationships between the plants and the fish; it uses the nutrient-rich waste from fish tanks to "fertigate" hydroponics production beds; and hydroponics bed cleans water for fish habitat	

words *hydro* and *ponos*, which translates to "water doing labor" or "water works." The use of water as a medium for crop growing is not totally new, but the commercial introduction of hydroponics arose only recently [28]. The National Aeronautics and Space Administration (NASA) researchers have seen hydroponics as a suitable method for growing food in outer space. They have been successful in producing vegetables such as onions, lettuce, and radishes. Overall, researchers have advanced the hydroponic method by making it more productive, reliable, and water-efficient. And, currently, the use of hydroponics in industrial agriculture has become widespread, providing several advantages over traditional soil-based cultivation.

One of the primary advantages of this method is that it could eliminate or at least reduce soil-related cultivation problems (i.e., the insects, fungus, and bacteria that grow in soil) [28–30]. The hydroponic method is also relatively low-maintenance as well, insofar as weeding, tilling, kneeling and dirt removal are non-issues. The hydroponic method also provides a less labor-intensive way to manage larger areas of production [8, 31, 32]. Furthermore, it may offer a cleaner process given that no animal excreta are used. Furthermore, the hydroponic method provides an easier way to control nutrient levels and pH balance. According to Ebba Hedenblad and Marika Olsson, "In soil, many factors, such as temperature, oxygen level, moisture, and microorganisms, affect how soil-fixed nutrients are made accessible to plants since the nutrients are being dissolved in water through erosion and mineralization. Therefore, the hydroponic method may result in more uniform [produce] and better yields, as the optimum combination of nutrients can be provided to all plants" [30, p. 17].

11.2.1.2 Cylindrical Hydroponic Growing Systems

The Volksgarden or cylindrical Omega Garden hydroponic growing system is a rotating-system technology where plants are placed inside rotary wheels. When wheels spin, plants rotate around centralized induction lights. The wheels rotate once every 50 min using a low-horsepower motor (it is possible to run the wheels via wind turbines and solar panels). In advanced rotary systems, the "plants rotate constantly and slowly around the light source, and their roots pass through a nutrient solution when they reach the bottom of the orbit. Turning at a constant rate allows the plants to take advantage of orbito tropism (based on the impact of gravity on growth) to grow bigger, stronger and faster" [32, pp. 28–29]. The Volksgarden system also provides a compact arrangement for the plants' roots in rock wool, thereby allowing the plants to grow more quickly than in traditional hydroponics [32].

Importantly, the "Ferris wheels," can multiply their capacity by adding "extreme verticality," i.e., stacking units. To appreciate the efficiency of the system experts have noted, "Each cylinder holds 80 plants, and six cylinders are stacked together about 20 ft high at each station" [32, p. 28]. This adds up to 480 units per station requiring only 3.4 m^2 (36 ft^2) of space. Green Spirit Farms plans to fit 200 stations compactly in one of its vertical farms to grow 96,000 plants per year. For comparison, "conventional basil growers average 16,000 plants per acre (43,560 ft^2), less than 20% of the production Green Spirit Farms could have in just 7200 ft^2" [32, p. 28]. Furthermore, the Volksgarden system efficiently uses distilled water, requiring one-tenth the water used by traditional hydroponic systems. "Their distillation process allows multiple reuses of water. Rather than discarding the nutrient-dense liquid that remains after the produce has been harvested, it can be re-distilled and reused" [32, p. 29]. Furthermore, the Volksgarden system entails virtually no evaporation because the liquid reservoir for the growing system is closed. Additional water savings are provided by harnessing rainwater, collectively minimizing the demand on municipal water systems [32].

11.2.1.3 Ultrasonic Foggers

Scientists have designed ultrasonic fogger systems to minimize maintenance and maximize yield. They envision using them for myriad horticultural applications, including hydroponics, to provide multiple benefits such as [33]:

- Supplying upper roots with nutrient enriched fogs that penetrate deep into root tissues, keeping them moist, well-nourished, and free of decay [16].
- Promoting the growth of minuscule root hairs, which exponentially increase the root's ability to absorb water, nutrients, and exchange gases [32].
- Reducing the use of water and nutrients by up to 50% [32].
- Reducing the need for bulky and costly growing mediums [33].
- Efficiently using space, as the units are compact and designed to be fed by a remotely located reservoir [33].
- By integrating ultrasonic foggers, hydroponic systems come close to aeroponic systems [33].

However, there are some concerns that the hydroponic method relies heavily on chemicals whereby all of the nutrients supplied to the crop are dissolved in water [29]. A hydroponic system is based on chemical formulations to supply concentrations of mineral elements [30]. Liquid hydroponic systems utilize floating rafts and the Nutrient Film Technique (NFT), and they largely rely on non-circulating water culture—though, new recirculation systems can be applied in NFT techniques [30]. Further, some complain that the produce is tasteless because of all the added chemicals in the system and because the roots do not get adequate oxygen [30]. These shortcomings are partially addressed by the aeroponic method.

11.2.1.4 Aeroponics

Aeroponics is a technological leap forward from traditional hydroponics. An aeroponic system is defined as an enclosed air and water/nutrient ecosystem that fosters rapid plant growth with little water and direct sun and without soil or media [34]. The major difference between hydroponics and aeroponic systems is that the former uses water as the growing medium while the latter has no growing medium. Aeroponics uses mist or nutrient solutions instead of water, so it does not require containers or trays to hold water. It is an effective and efficient way of growing plants for it requires little water (requires 95% less water than traditional farming methods) and requires minimal space [34]. Plant boxes can be stacked up in almost any setting, even a basement or warehouse.

The stacking arrangement of plant boxes is structured so that the top and bottom of the plants are suspended in the air, allowing the crown to grow upward and the roots downward freely. Plants are fed through a fine mist of nutrient-rich, water-mix solution. Because the system is enclosed, the nutrient mix is fully recycled, leading to significant water savings. This method, therefore, is particularly suitable in water-scarce regions. An additional advantage of the aeroponic method is that it is free of fertilizers or pesticides. Furthermore, research has revealed that this high-density planting method makes harvesting easier and provides higher yields. For example, one of the aeroponic experiments with tomato in Brooklyn, NY, resulted in quadrupling the crop over a year instead of the more common one or two crops [34].

11.2.1.5 GrowCube

Recent research and technological development take the aeroponics method to a higher level of productivity and efficiency. For example, GrowCube has proposed a new aeroponic prototype through the high-tech cube, which contains five light plastic plates that spin via a rotisserie-esque wheel and are lit by a strip of light-emitting diodes (LEDs) that provide the necessary light for photosynthesis [34]. At the top of the cube, a device sprays a nutrient-rich mist. The cube and its devices are controlled and managed via computer and software, and sensors inside the cube communicate with the computer to optimize the microclimate. The cube is also pressurized and equipped with an ultraviolet germicidal lamp and a high-efficiency particulate absorption (HEPA) filter, as well as "bug-killing filters in the pipes where the nutrient mixes are pumped" [34].

Consequently, the microclimate inside the cube is bug-free, making its produce free of pathogens. Remarkably, IT companies are developing special apps and food growing food recipes, increasingly available online. Consequently, the aeroponics system and the entire growing process can be optimized remotely [34]. "When it comes time to planting, simply stick your seeds in a growing medium … and download the iOS app. From there, you can select and download a 'grow recipe' from the cloud …. Users are also encouraged to tweak and fork the recipes as they see fit, helping to improve the growing and to offer variations. So if you want crisper lettuce, you can select that as an option" [34]. Furthermore, by conducting the work autonomously, the computer-controlled environment reduces human errors and minimizes the effort of growing food [35].

With such a computerized system, almost anyone could become a sophisticated farmer. What is more, the computerized system will help to "engineer" taste and other characteristics producing crispy or spicy produce! GrowCube has managed to produce "herbs, flowers and foodstuffs like wheatgrass, microgreens, pea-shoots and even 28 heads of lettuce," and it plans to produce fruits such as grapes [34]. The prototype is costly and will likely benefit from economies of scale when it is produced in masses. Consequently, GrowCube plans to expand the project by producing hundreds of these high-tech cubes [34].

11.2.1.6 Solar Aquaculture

Solar aquaculture involves growing high-quality fish protein in small, clean, translucent, and controllable ponds that are exposed to sunlight. Microscopic green algae (nonflowering plants lacking a true stem, roots, and leaves) live in the pond with the fish and grow by absorbing nutrients from the water. In addition, sunlight that strikes the pond helps the algae to grow and causes the water to become warmer. Fish and algae grow faster in warmer water. This method could be suitable for vertical farms, enabling higher rates of production in limited spaces. A solar pond that is 1.5 m high, 1.5 m in diameter (5 ft high, 5 ft diameter) and contains 2,649 L (700 gal) of water can produce an annual growth of 18 kg (40 lb) of fish [35].

In addition to supporting fish, solar ponds can serve indirectly as storage units for solar heat. Algae capture about five percent of the entered solar energy while water absorbs the rest (95%). The pond makes air cooler during the day, given that much of the incoming sunlight is stored as warm water rather than hot air. In contrast, the pond warms the air at night as it releases heat. As such, heat from a solar pond can substitute for heating a greenhouse with gas, oil or wood or electricity, thereby saving on energy. However, the solar pond requires extensive maintenance because of the fish waste and some of the un-eaten food that transforms into waste. These problems are addressed by closed-loop systems and the aquaponic method.

11.2.1.7 Aquaponics

Aquaponics is a bio-system that integrates recirculated aquaculture (fish farming) with hydroponic vegetable, flower, and herb production to create symbiotic relationships between the plants and the fish. It achieves this symbiosis through using the nutrient-rich waste from fish tanks to "fertigate" hydroponic production beds. In turn, the hydroponic beds also function as bio-filters that remove gases, acids, and chemicals, such as ammonia, nitrates, and phosphates, from the water. Simultaneously, the gravel beds provide habitats for nitrifying bacteria, which augment the nutrient cycling and filter water. Consequently, the freshly cleansed water can be recirculated into the fish tanks. In one experimental project, aquaponics consisting of wetland pools containing perch and tilapia, whose waste provided nutrients for greens, solved the principal problems of both hydroponics and aquaculture as mentioned above [36] (Fig. 11.1).

Researchers envision that the aquaponic system has the potential to become a model of sustainable food production by achieving the 3Rs (reduce, reuse, and recycle). It offers bountiful benefits, such as [36]:

- Cleaning water for the fish habitat
- Providing organic liquid fertilizers that enable the healthy growth of plants
- Providing efficiency since the waste products of one biological system serves as nutrients for a second biological system
- Saving water since water is re-used through biological filtration and recirculation. This feature is attractive particularly in regions that lack water
- Reducing, even eliminating, the need for chemicals and artificial fertilizers

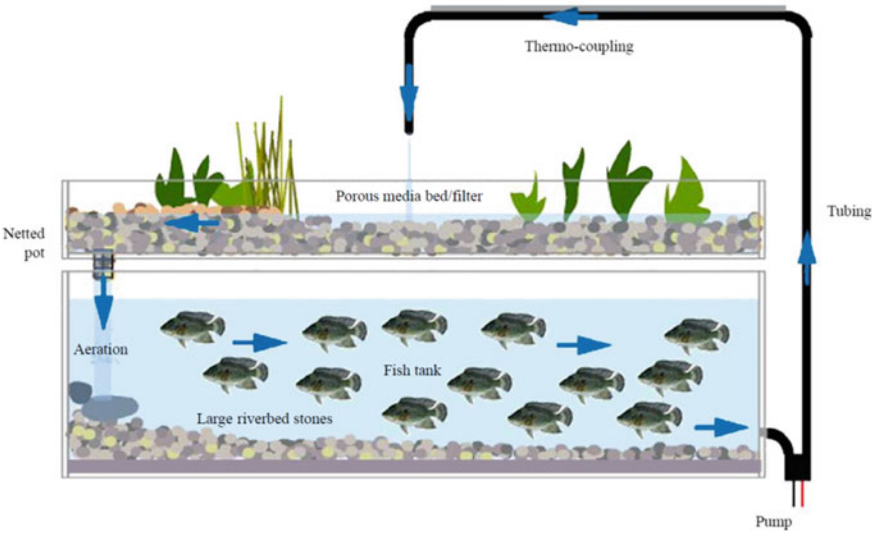


Fig. 11.1 Basics of an aquaponic system. Adapted from [19]

- Resulting in a polyculture that increases biodiversity
- Supplying locally-grown healthy food since the only fertility input is fish feed and all of the nutrients go through a biological process
- Facilitating the creation of local jobs
- Creating an appealing business that supplies two unique products—fresh vegetables and fish—from one working unit.

Consequently, aquaponics is preferable to hydroponics. However, aquaponic systems continue to be at the experimental stage, having had limited commercialized success. This is because the technologies necessary to build aquaponic systems are relatively complex, requiring the mutual dependence of two different agricultural products. For this reason, aquaponics also requires intensive management [36].

11.2.2 Lighting Technologies

One of the important components of successful vertical farming is sound lighting. Available LED technologies provide only 28% efficiency, an efficiency rate that should be increased to about 50–60%, at a minimum, to make indoor farming methods cost-effective [37]. Fortunately, experimental developments in LEDs have reached that mark [37, 38]. Dutch lighting engineers at Philips have produced LEDs with 68% efficiency. Such an increase in lighting efficiency will dramatically cut costs. Also, a Dutch-based group called PlantLab has recently invented a lighting technology that could help to grow food on a small footprint. According to Michael

Levenston, "This invention replaces sunlight with LEDs that produce the optimal wavelength of light for plant growth. Contrary to the sun, traditional assimilation lighting, and TL lighting LED only omits one color of light. No energy is wasted with light spectra that are not used … by the plant" [38]. As such, the new lighting technology provides the correct lighting colors plants need for photosynthesis—blue, red, and infrared light.

Furthermore, new "induction" lighting technology simulates the color spectrum of sunlight to foster the growth of vegetables and fruits. "The light uses an electro-magnet to excite argon gas as its light source, instead of a filament. For this reason, [it] uses much less energy and can last up to 100,000 h, twice as long as an LED light" [39]. It also generates more heat than LED light, but less than an incandescent bulb. Therefore, the lights create enough heat for growing plants without wasting energy to heat the entire building. Moreover, the light units are calibrated to create an "ideal" microenvironment by producing high-quality lighting that is similar to daylight. These units are also long lasting, with a life span of about one decade, and are sold at affordable prices.

11.2.3 Farming Operation

Researchers predict that farming operations will be fully automated in the near future. For example, monitoring systems will be widely implemented (in the form of sensors near each plant bed) to detect a plant's need for water, nutrients and other requirements for optimal growth and development. Sensors can also warn farmers by signaling the presence of harmful bacteria, viruses or other microorganism that cause disease. Also, a gas chromatograph technology will be able to analyze flavonoid levels accurately, providing the optimal time for harvesting. These specific technologies are not totally new. Their development has been ongoing and will likely proliferate in the near future [39].

11.2.4 Farming from Afar

One of the promising ideas under development is "farming from afar". The cell phone, its software and apps, will ultimately handle much of the day-to-day attending of crops, and vertical farmers will be able to manage multiple farms remotely. New apps will allow farm managers to adjust "nutrient levels and soil pH balance from a smartphone or tablet, and sound alarms if, say, a water pump fails on a vertical-growing system … So if I'm over in London, where we're looking for a future vertical farm site to serve restaurants, I'll still be able to adjust the process in Michigan or Pennsylvania," as Paul Marks explained [40]. Farming from afar will drastically reduce operational costs by reducing labor and will provide considerable convenience, flexibility, and efficiency in managing farms. Further, by engaging new information technology and working with new online applications, farming could become an exciting and fun activity.

11.2.5 "Closed-Loop Agricultural" Ecosystems

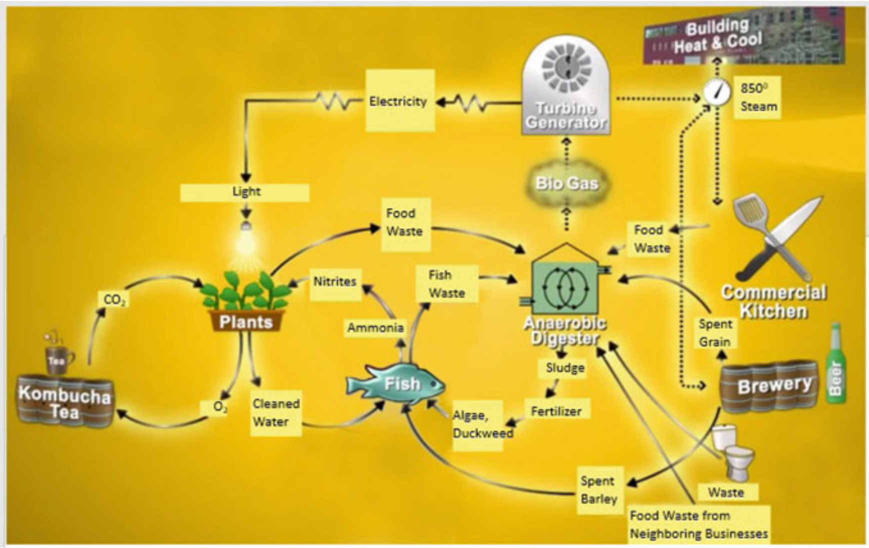
"Closed-loop agricultural" ecosystems intend to mimic natural ecosystems that treat waste as a resource. Similar to aquaponics, the waste of one part of the system becomes the nutrients for the other. The closed-loop system recycles and reuses nearly every element of the farming process—dirty water, sewage, and nutrients. Food waste can also be converted to compost. In a closed-loop system, everything remains in the system, leading to a zero-waste outcome. This results not only in drastic decreases in waste but also in the creation of energy and other byproducts such as bedding and potting soil [41].

11.2.5.1 Anaerobic Digester

An anaerobic digester is a biogas recovery system that converts food waste into biogas to produce power and heat [41]. The Plant, a vertical farm in Chicago, has employed an anaerobic digester that captures the methane from 27 t of daily food waste to produce electricity and heat. Figure 11.2 illustrates how The Plant has integrated an anaerobic digester in its employed closed-loop system (also see Sect. 11.3.3 on The Plant). Similarly, Great Northern Hydroponics (GNH), in Quebec, Canada, has employed a cogeneration machine that reduces its heating costs and reliance on fossil fuels. GNH's power production has increased such that it is capable of selling electricity back to the Ontario Power Authority, decreasing the province's dependence on fossil fuels [42, 43].

11.2.6 Renewable Energy

Some vertical farms have implemented, and others have proposed employing wind turbines and photovoltaic panels to supply power. Other systems, such as thermal systems that collect solar heat and warehouse refrigeration exhaust, are also under consideration [44, 45].



Main features of the closed-loop system:

- At the heart of the system is an anaerobic digester that turns organic materials into biogas, which is piped into turbine generator to make electricity for plant grow light.
- The plants make oxygen to the Kombucha tea brewery, and Kombucha tea brewery makes CO_2 to the plant.
- Waste from the fish feeds the plants and the plants clean the water for the fish.
- More fish waste goes to the digester along with plants' waste, waste from outside sources and spent grain from the brewery.
- Spent barley from the brewery feeds the fish.
- Sludge from the digester that becomes algae duckweed also feeds the fish.
- Along electricity, the turbine makes steam which is piped to the commercial kitchen, brewery, and the entire building for heating and cooling.
- Therefore, the kitchen produces Kombucha tea, fresh vegetables, fish, beer, and food, all with no waste.

Fig. 11.2 An illustration of an integrated food production through a closed-loop system. Adapted from [41]

11.2.7 Integration Within Utility Infrastructure

Future proposals, for example by Plantagon, envision the integration of vertical farms with the utility infrastructure symbiotically. The proposal envisions that the vertical farm will collect organic waste, carbon dioxide, manure, $CO_{2,}$ and excess heat from plants and factories, and transform these into biogas for heating and cooling. In this way, the vertical farm not only could grow food but also help to develop sustainable solutions for better energy, heat, waste, and water use [46].

11.2.8 Redefining Vertical Farms

The aforementioned technologies are redefining the vertical farm as "a revolutionary approach to producing high quantities of nutritious and quality fresh food all year round, without relying on skilled labor, favorable weather, high soil fertility or high water usage" [24]. These new systems add advantages to vertical farming, summarized in Table 11.2.

Table 11.2 Advantages of high-tech vertical farming systems [42]

1. Reliable harvests	Controlled indoor environments are independent of outside weather conditions and would provide consistent and reliable growing cycles to meet delivery schedules and supply contracts
2. Minimum overheads	Production overheads would decrease by 30%
Low energy usage	The use of high efficiency LED lighting technology ensures minimum power use for maximum plant growth. Computer management of photosynthetic wavelengths, in harmony with phase of crop growth, further minimizes energy use while ensuring optimized crop yields
Low labor costs	Fully automated growing systems with automatic SMS text messaging would require manual labor only for on-site planting, harvesting, and packaging
Low water usage	Vertical farms would use around 10% of the water required for traditional open field farming
Reduced washing and processing	Vertical farms would employ strict bio-security procedures to eliminate pests and diseases
Reduced transport costs	Positioning of facilities close to the point of sale would dramatically decrease travel times, reducing refrigeration, storage and transport costs in the process
3. Increased growing areas	Vertical farms would supply nearly ten times more growing area than traditional farms
4. Maximum crop yield	Irrespective of external conditions, vertical farms can provide more crop rotations per year than open field agriculture and other farming practices. Crop cycles are also faster due to controlled temperature, humidity, light, etc.
5. Wide range of crops	The vertical farm would provide a wide range of crops
6. Fully integrated technology	The vertical farm would be fully monitored, controlled, and automated
Optimum air quality	The temperature, CO_2, and humidity levels of the vertical farm would be optimized at all times
Optimum nutrient and mineral quality	The vertical farm would use specially formulated, biologically active nutrients in all crop cycles, providing organic minerals and enzymes to ensure healthy plant growth
Optimum water quality	All fresh water's contaminants would be removed before entering the vertical farm
Optimum light quality	High-intensity low-energy LED lighting would be specifically developed and used for maximum growth rates, high reliability, and cost-effective operations

11.3 Vertical Farm Project Examples

Since vertical farms have been located often in urban areas, the following examples serve as "inspirational" to peri-urban areas. Pioneering projects in urban areas embrace advanced technologies and methods that are easily transferrable to peri-urban areas. To a great extent, the examined projects offer "blueprints" to smart village applications. Among the pioneering vertical farm projects to spread across the U.S. are those carried by companies such as Green Spirit Farms, FarmedHere, The Plant, and Green Girls.

11.3.1 Green Spirit Farms

Located in New Buffalo, Michigan, Green Spirit Farms (GSF) is a professional food company that has openly embraced vertical farming. The New Buffalo facility has grown out of a former plastic factory. The building contains about 3716 m^2 (40,000 ft^2) of space and sits on an 11-ha (27-ac) site. As standard practice, GSF will enter older vacant industrial or commercial buildings to supply produce nearby urban markets. It aims to provide local markets with high quality, fresh, pesticide-free, non-genetically modified organism (GMO) foods at affordable prices. The company chooses to grow products with a high local demand like lettuce, basil, spinach, kale, arugula, peppers, tomatoes, stevia, strawberries, and Brussel sprouts. It sells its produce locally to grocery stores and restaurants and to a host of small "Harvest Markets," which sells directly to consumers. GSF runs vertical organic farms in Atlanta, Philadelphia, Canada, and the United Kingdom [45]. The company has a strong belief in vertical farming. According to Green Spirit Farms' Research and Development Manager Daniel Kluko, the future of farming is heading in one clear direction: the vertical. "If we want to feed hungry people this is how we need to farm … We cut out the risk of traditional farming, the labor, and most of the equipment costs … This is not a niche business, it's not something novel, this is a necessity for the human race to continue to live" [46].

GSF has advanced several technologies to grow vegetables. These include the Volksgarden Rotary Garden unit, referred to as a Rotary Vertical Growing Station (RVGS), and a multi-level tray system, referred to as a Vertical Growing Station (VGS). GSF has lately commercialized rotary and vertical farming systems using patented techniques to grow local vegetables, herbs, and some fruits, and has opened vertical farms in repurposed industrial buildings, including one in East Benton, Pennsylvania. The new facility constitutes a major expansion compared to GSF's first facility in New Buffalo, Michigan, containing 1715 vertical growing stations that will produce herbs, leafy vegetables, peppers and tomatoes, the equivalent of 81 ha (200 ac) of farmland harvested year-round. This is enabled by facility's efficiency, which uses "98% less water, 96% less land, and 40% less energy" than would be required by traditional agriculture [46]. It is expected that the facility will create over 100 jobs to support the local economy. GSF has invested about $27 million to establish the vertical farm and received financial aid, including a $300,000 Pennsylvania First Program grant, $303,000 in Job Creation Tax Credits, and a $45,450 Guaranteed Free Training grant to train new employees [47]. The location has appealed to Green Spirit because of its proximity to large local markets, with most of its produce selling within approximately 75 miles of the farm [47]. In summary, the vertical farm project provides a useful example of adaptive reuse established through a strong public-private partnership. This has been made possible through the collaboration between GSF and several agencies, including the Commonwealth of Pennsylvania, Lackawanna County, Benton Township, and the Greater Scranton Chamber of Commerce.

11.3.2 FarmedHere

FarmedHere is a company that was founded in 2011 and has recently expanded to three locations in Illinois: Englewood, a Chicago Southside neighborhood; Flanagan in downstate Illinois; and recently in Bedford Park, a Southwest Chicago suburb. As the company grows, it expects to supply 6% or more of the Chicago area's demand for premium green and culinary herbs. The company also hires local youths through Windy City Harvest, a Chicago Botanic Garden-led urban agriculture-training program targeted to underserved youths. FarmedHere received the USDA (the U.S. Department of Agriculture) Organic Certification at the end of 2012 [48]. The company's product is spreading in several grocery stores, including Whole Foods, Chicago-area Mariano's Fresh Market, Green Grocer, and possibly soon at Trader Joe's and Meijer. FarmedHere was able to receive financial support from Good Food and Whole Foods, the farm's largest customers. The company expects that it has a market niche given the recent generational demands for healthy and organic foods. These new businesses also expect to obtain subsidies from tax-increment financing as well as property-tax breaks for reviving industrial properties [48].

Bedford Park's facility is about 8,361 m^2 (90,000 ft^2), much larger than both the first facility in Englewood (371 m^2 (4000 ft^2)) and the second facility in Flanagan (929 m^2 (10,000 ft^2)). Bedford Park's facility, about 24 km (15 mi) from downtown Chicago, is now hyped as the first of its kind and the largest indoor vertical farm in America [48]. It was opened in 2013 and is expected to become a new model for growing produce efficiently in a high tech manner. The farm resides in a two-story, windowless warehouse, and is designed to occupy the full extent of the space. Currently, the farm consists of two structures with large growing beds lit by fluorescent lighting. The first structure contains the aquaponic system where water circulates between fish tanks, feeding plants that rest in cutouts on Styrofoam "floats" above. The second structure contains the aeroponic system, with water misters underneath that spray the exposed roots of the plants. Workers plant the seeds and grow seedlings on racks that then are transferred into the growing systems. After about a month, the crops are harvested and packaged manually in a cooling room at the facility, and then shipped the next morning to grocers in Chicago's metropolitan area [49].

By stacking aquaponic and aeroponic systems vertically, the facility contains 13,935 m^2 (150,000 ft^2) of growing space, or about 1.4 ha (3.5 ac). Planting in a controlled environment with ideal humidity and temperature ensures optimal growth. FarmedHere produces about 136,078 kg (300,000 lb) of leafy greens and plans to grow to what will eventually amount to more than 453,592 kg (a million pounds) of chemical, herbicide and pesticide-free leafy greens yearly [49]. It also plans to expand by producing peppers, tomatoes, and other popular vegetables. Their aquaponics produces fish and organic herbs—basil and the like—while their aeroponics produces leafy greens like arugula and watercress. For space efficiency, plants are grown on six shelves that receive artificial fluorescent lighting and that are attended by workers using scissor lifts. The aquaponics method filters the nitrogen-rich waste of the tilapia fish and uses it to feed plants, and the hormone-free tilapia are bred in four 3028-L (800-gal) tanks, where water is ultimately recycled to create a closed loop that reduces water use by 97%. Therefore, the system is efficient in its use of water and space.

These new facilities also provide "on-demand farming" meaning they are flexible and responsive to market demands. For example, demand may suddenly increase for particular types of mixed greens or mini greens. "We could change the whole system … and pretty much within the next 14 to 28 days, we [would] have a full grown plant, whatever the market requires" [50]. However, the prime obstacle these farms face remains the electricity needed to grow the plants and heat the space. Because of exorbitant energy bills, some indoor farms have been closed down. Dickson Despommier, in his book "The Vertical Farm: Feeding the World in the 21st Century," stresses the fact that energy remains the primary hurdle [4]. Nevertheless, vertical farmers are trying to find solutions by exploring solar and wind power as well as methane gas as ways to generate electricity, or by supplementing artificial light with natural light through windows and skylights. Other farmers are experimenting with flickering lights sufficient to grow plants with little power [50].

11.3.3 The Plant

Located in the heart of Chicago's derelict stockyards, the almost century old site of The Plant has a long history of food production as a former meatpacking facility and the former home of Peer Foods. The four-story, 8686 m^2 (93,500 ft^2) red brick warehouse is now set to become a major net zero vertical farm where the operation is fueled by food waste [51]. The zero-energy facility relies on an on-site Combined Heating and Power (CHP) system that contains a large anaerobic digester that converts food waste into biogas to power, heat and cool the building. The anaerobic digester captures the methane from 27 t of food waste daily and 11,000 annually and burns it to produce electricity and heat. The Plant plans to turn the facility into a food business incubator, research lab and educational and training facility for vertical farming. The building's transformation, which started in 2010, was completed in 2016 [51].

The Plant is currently producing greens, mushrooms, bread, and Kombucha tea. Eventually, the facility will combine a tilapia farm, beer brewery, Kombucha brewery, communal kitchen, an aquaponics system, and green energy production. "We're working to show what truly sustainable food production and economic development looks like by farming inside an old meatpacking facility, incubating small craft food businesses, brewing beer and kombucha, and doing it all using only renewable energy that we make onsite. By connecting outputs of one business to the inputs of another, we are harnessing value from materials that most people would throw away" [51]. The conversion of the space into a vertical farm and food business incubator was partly made possible by a $1.5 million grant from the Illinois Department of Commerce and Economic Opportunity (DCEO) to support the development of a comprehensive renewable energy system [51].

11.4 Discussion: Opportunities and Challenges

Overall, vertical farming represents a proactive thinking approach that aims at ensuring human sustainability. However, while mainstream literature and practical projects have focused on applying vertical farming in urban areas, this Chapter explores applying it in peri-urban areas. Justifications of introducing the vertical farm to smart villages include responding to food security and climate change threat, reducing vehicle miles traveled (VMT), and improving health, economic, environmental, and ecological conditions. Further, extensive technological advancement offers efficient agricultural methods that promise a new era of food production [8–11].

Indeed, many places already face food shortages, and food prices are skyrocketing due to increases in oil prices, shortages of water and the diminishment of other agricultural resources. The current traditional agricultural practices suffer from environmental and economic problems. As an answer to these problems, the vertical farm promises to grow food efficiently and sustainably by saving energy, water, and fossil fuels, reducing toxins and restoring ecosystems, as well as providing new opportunities for high-tech employment. We have seen the rapid growth of modest-scale vertical farming, and these projects have provided excellent examples of adaptive reuse of vacant industrials spaces [52–56].

Therefore, the vertical farm may offer opportunities in the three pillars of sustainability: environment, society, and economy (Table 11.3). It can offer a sustainable food-production model that supplies crop year-round with no interruption due to climate change, season, or adverse natural events (e.g., hurricane, drought, and flood). It has also the potential to provide greater yield per space unit—the ratio is 1:4–6, depending on the type of crop [57, 58]. Further, the high-tech cultivation methods of the vertical farm reduce demand on potable water. They are often

Table 11.3 Key sustainable benefits of the vertical farm

#	Benefit	Environmental	Social	Economic
1	Reducing food-miles (travel distances)	Reducing air pollution	Improving air quality improves environmental and people's health. Customers receive "fresher" local food	Reduce energy, packaging, and fuel to transport food
2	Reducing water consumption for food production by using high-tech irrigation systems and recycling methods	Reducing surface water run off of traditional farms	Making potable water available to more people	Reduce costs
3	Recycling organic waste	Save the environment by reducing needed land fills	Improve food quality and subsequently consumer health	Turn waste into asset
4	Creating local jobs	People do not have to commute to work and hence will decrease ecological footprint	Create a local community of workers and social networks with farmers	Benefit local people economically
5	Reduced fertilizers, herbicides, and pesticides	Improve the environmental well-being	Improve food quality and subsequently consumer health	Decrease costs
6	Improve productivity	Needs less space	Reduce redundant, repetitive work, and save time to do productive and socially rewarding activities	Offer greater yields
7	Avoid crop losses due to floods, droughts, hurricane, over exposure to sun, and seasonal changes	Decrease environmental damage and cleanups of farms after damage	Improve food security	Avoiding economic loss
8	Control product/ produce regardless to seasons	Produce regarding season	Increase accessibility year-round and improve respond to population demand	Fuel economic activities year-round
9	Using renewable energy	Reducing fossil fuel	Improve air quality	Reduce costs
10	Bringing nature closer to city	Increase bio-diversity	Improve health, reduce stress and enhance psychological well-being	Create jobs in the city

(continued)

Table 11.3 (continued)

#	Benefit	Environmental	Social	Economic
11	Promoting high-tech and green industry	"green technology" reduce harm and improve environmental performance	Encourage higher education and generate skilled workers	Provide new jobs in engineering, biochemistry, biotechnology, construction, maintenance, research and development
12	Reducing the activities of traditional farming	Preserving natural ecological system	Improve health of citizens	Saving money required to correct environmental damage
13	Repurposing dilapidated buildings	Enhance the environment. Remove eyesores and stigma from neighborhoods	Create opportunities for social interaction	Revive economy

efficient in irrigating plants, by targeting plant roots and reducing evaporation [59]. They may also recycle wastewater (grey, even black water) and harness rainwater. When fish farms are integrated, fish removes waste (esp. fish filet). The vertical farm can also produce energy by burning methane from compost. For example, the Plant Vertical Farm in Chicago and the Republic of South Korea VF factory convert waste to energy [60, 61].

When compared to traditional farming, the vertical farm may reduce the need for fossil fuel required for tractors, plows, or shipping. Traditional farming uses lots of fossil fuel; for example, conventional farming in North America consumes 20% of fossil fuel due to plowing, seeding, harvesting, fertilizing and so on [62, 63]. Due to its compact nature, the vertical farm can also reduce food travel distance (food-miles); distances between food production and consumption are minimized [64–66]. Further, the vertical farm eliminates the need of packing agricultural crops for long-distance transportation [67].

Indoor farming is immune to weather change, which affects traditional farming by changing temperature, water supply, and photo intensity. These factors often reduce produce yield; for example, droughts destroy crops every year worldwide [68, 69]. As such, the vertical farm will be important for food security especially as climate change threatens our cities. As mentioned earlier, Gotham Greens was the only fresh food supplier in New York during the Sandy Hurricane. Additional benefit of the vertical farm is providing an ideal growth environment for each plant that improves crop yield [70–73]. Advances in lighting technologies, for example, the LED systems, promise to, for example, the LED lighting, promises to increase yields as LED emits programmed wavelength of light for optimal photosynthesis of different types of crops. Luckily, the prices of these technologies are dropping [74]. The vertical farm provides an environment almost free of invasive pest species [70]. It also reduces, and possibly eliminates the use of mineral fertilizers, herbicides and pesticides, and nitrogen (N) and phosphorous (P), which have been causing environmental degradation by polluting surface water and groundwater [75–79].

The vertical farm may also provide socio-economic benefits by offering employment opportunities [80]. Building a vertical farm requires a multi-disciplinary team of architects, engineers, scientists, farmers, horticulturists, environmentalists, marketers, and economists. For example, industrial, mechanical and electrical engineers will be needed to design water recycling systems, lighting systems, heating, ventilation and air conditioning (HVAC) systems, seed and plant growth monitoring and harvesting systems. Computer experts will be needed to build databases and software applications. As such, the vertical farm offers new exciting careers in biochemistry, biotechnology, construction, maintenance, marketing, engineering, and research and development opportunities for improving the involved technologies [80–82]. Further, robotics and software engineers could also be needed [48, 83].

Our health is directly impacted by the food we consume and the vertical farm intends to supply quality, organic food [84, 85]. It could help consequently to reduce or stop the transmission of harmful infectious diseases for currently much produced food by conventional agriculture is polluted and carry bacterial diseases that endanger the lives of millions of inhabitants. That is, since the vertical farm product is not soil-based, it is likely to be not affected by polluted soil or irrigation water. Further, vertical farm's crops are rich in nutrients [86, 87].

Notwithstanding the promising future and large potential benefits, challenges and barriers in the path to the vertical farm implementation should be noted. Research has highlighted social resistance, where masses of people do not accept the alteration of traditional farming for it is the natural way to grow food [57, 88]. Importantly, the core argument against vertical farming is that growing food indoors requires more energy, effort, and resources than traditional farming [86, 89]. That is, "It is much more expensive, of course, to build a vertical greenhouse than to build a normal greenhouse" [52]. Despommier acknowledges that the costs of implementing vertical farms are high, particularly the start-up costs, and he calls on the government to provide the seed money to fund these projects. Apparently, to raise the required investment capital is a challenge. In short, in order for the vertical farm to be sustainable, it must be profitable.

Therefore, increasing the productivity of the vertical farm is the prime factor to make it prevail in the future. If the yield per hectare for indoor farming is much higher than traditional outdoor farming, "perhaps as much as up to 50 times, this factor will eventually outweigh the initial cost of land acquisition … and assuming 50-fold improved productivity, the break-even point may well be an estimated 6–7 years" [86, p. 295]. Such production will likely to offset the startup costs. Another drawback of the vertical farm is inability to produce all types of crops. In fact, current vertical farms produce limited crops such as lettuce, tomatoes, strawberries, and to less extent, grape, and soy products. Also, produced quantities are too small. Scholars indicate that in some incidence a spatial mismatch between locations of vertical farms and their catchment areas prevails. Overall, they found that in the near future, urban food will continue to come from distant rural areas [78, 87, 88].

Further, due to economic reasons, most vertical farms produce and then distribute leafy greens to restaurants, and local residents remain not the prime client. In the same manner, low-value agricultural commodities such as wheat continue to be economically unviable. Therefore, the current product of vertical farms is limited in scope and quantities. Overall, production volumes of vertical farms are small, particularly when compared to "limitless" acres of traditional farming. Further, scaling up vertical farming could be costly and complex [66, 89].

Another limitation is that current renewable energy sources, such as photovoltaic solar panels and wind turbines, produce little energy that would make it difficult not to rely on the electrical grid. It is only the plants at the building's perimeter and on the top level that could benefit from solar radiation [34, 90]. In this regard, it is important to employ rotatable stacked arrays of plants inside each floor of a high-rise enclosure so that plants receive maximum natural light [73].

11.5 Conclusions

Smart technologies are revolutionizing the ways we produce and supply food [9]. While vertical farming application has been emphasized in urban areas, this Chapter explored applying it to peri-urban areas. In addition to taking advantage of technological advances in food production, justifications of introducing the vertical farm to smart villages include responding to food security and climate change threat, reducing vehicle miles traveled (VMT), and improving health, economic, environmental, and ecological conditions.

Certainly, vertical farming has various advantages over rural farming, observed within the three pillars of sustainability: environmental, social, and economic. New high-tech cultivation methods, including hydroponics, aeroponics and aquaponics, largely challenge the need for soil-based farming for a range of crops. Advancements in greenhouse and supporting technologies such as multi-racking mechanized systems, recycling systems, LED lighting, solar power, wind power, storage batteries, drones as well as computing power, software applications, databases and The Internet of Things are likely to coalesce into efficient production systems in the near future. For example, farmers in New Zealand are using the Internet of Things to obtain optimal irrigation to their crops. Likewise, in Singapore, farmers use big data in the cloud and machine learning to analyze and produce optimal environmental models that result in better yields while reducing production costs. Similarly, by implementing Farm Beats program, Microsoft is leading new data-driven techniques stored in the cloud [9]. Increasingly, there is a need for interdisciplinary research and collaboration that promote collective thinking among the various disciplines involved in creating vertical farms [91–95].

Perhaps, in the distant future, there is the prospect of developing fully automated vertical farms. And hypothetically, if vertical farms were implemented, they will be able to increase food supply. However, there is still a need for more developments that scale up projects so that the economic and commercial feasibility and return on investment (ROI) are offered at best rates. As such, there is a need for research that accurately assesses the ROI of various types and sizes of vertical farms. There is a need to investigate the full life-cycle analysis (LCA) and the number of years to reach parity with a traditional farm [89, 95, 96].

The success of the vertical farm will depend not only on innovation in technologies but also on local conditions, including demand on certain produce by population, availability of labors, and farming conditions [97]. An effective organizational structure and sound leadership are also important factors. Creativity, stewardship, and inventiveness are critical ingredients for companies that venture into new businesses such as vertical farming. In a globalized world, competition is stiff, but the first to succeed may gain a competitive edge [97]. As such, robust and resilient business models are needed in a world characterized by increasing complexity, nonlinearity, and "glocal" exchanges of goods. According to Copenhagen Institute for Futures Studies, Instituttet for Fremtidsforskning "Tomorrow's innovative leader isn't necessarily the person in front with innovative ideas, but the one who discovers the front-runners and harvests their ideas to cultivate and nourish the innovative environment in his organization" [74]. Nevertheless, interest in vertical farming will increase as climate change prevails further and available arable land per capita declines [97].

One more serious obstacle remains concerning the increasing populations of developing countries. Do these countries possess the required technologies and technical expertise to implement the vertical farm? These countries are largely poor. Can we make the products of the vertical farm affordable to the poor? Furthermore, many of these poor populations live in slums, in food deserts, away from modern life. How can we make the produce of vertical farms accessible to slum populations? Ultimately, the effectiveness of vertical farming will depend on various local factors, including the demand and supply of food, population density, technological development, culture and eating habits, water and energy supply, as well as weather conditions.

11.6 Future Research

Vertical farming is growing rapidly, and this research barely scratches the surface of long and complex endeavor. Future research may examine specialized technologies and methods for various indoor farming systems. For example, hydroponic systems offer multiple methods, including Nutrient Film Technique (NFT), Wick System, Water Culture, Ebb and Flow (Flood and Drain), Drip Feed System and Aeroponic Systems. Further, there is a need for conducting quantitative research that gives accurate assessments of the benefits and shortcomings of various types of vertical farms. Importantly, future research should examine the issue of affordability of advanced equipment of vertical farming to developing countries. Researchers should invent, advance, and further develop local farming techniques to make vertical farm projects feasible in these countries. For example, they may invent recycling methods that reduce reliance on water, design local systems by capturing rainwater, and may capitalize on local solar power for providing natural light and energy.

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Chapter 12
Water Loss Management Through Smart Water Systems

Antonio Santos Sánchez, Karla Patricia Oliveira-Esquerre, Idelfonso Bessa dos Reis Nogueira, Pieter de Jong and Adelmo Aguiar Filho

Abstract One of the most basic challenges in urban areas is providing sustainable access to adequate quantities of quality water in order to sustain livelihoods, human well-being, and socio-economic development. Water poverty affects an important share of low income urban and rural population in the forms of limited, time-consuming and unsafe access to the resource as well as a high incidence of waterborne diseases. Universalizing access to potable water and sanitation by being efficient and avoiding waste of resources may be the most important challenge of water networks in future years. 'Smart water' consists in a group of emerging technological solutions that help water managers operate more efficiently and, in a smaller scale, also help consumers tracking and managing their water usage. The Internet of Things, cloud-based information storage and data analytics (Big Data) are at the core of that. A smart water system is based on a network of sensors embedded with electronics and software that allow getting real-time data of any measurable parameters such as level, flow, pressure, temperature, noise correlations or even water quality parameters, and make them available online. Furthermore, the management of data through statistical tools and algorithms can allow pattern recognition and modeling of the system, thus optimizing the operational performance of the water supply network and reducing pipe bursts, leakages and energy waste in the pumps.

Keywords Water loss control · Water management · Smart water systems

A. S. Sánchez (✉) · K. P. Oliveira-Esquerre · I. B. dos Reis Nogueira · P. de Jong · A. A. Filho
Escola de Minas, Federal University of Ouro Preto, Ouro Preto, Brazil
e-mail: sanchezbahia@gmail.com

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12.1 Introduction

The pressure on water resources will increase worldwide along this century due to the increase of population and economic development. Population levels are expected to increase at the fastest rate in emerging regions that are already undergoing a strong urbanization process. Investing in the water system's efficiency should be the first option to allow the cities avoiding water scarcity, as traditional water resources will no longer be guaranteed in enough quantity and quality. In that context, water utilities will have to be as efficient as they can to avoid any waste of water and energy. Water networks will be increasingly complex and may also treat and supply non-drinkable sources such as reclaimed wastewater. The good news is that recent technology breakthroughs such as the Internet of Things and artificial intelligence will allow achieving that higher standard of efficiency.

In this chapter, it is first discussed the water loss control in distribution systems. Related concepts such as sectorization, water audits, pressure management and proactive leak detection programs are addressed.

Then it is assessed the transition of water networks toward truly smart water systems. Thus, the architecture and functionalities of a smart water network are described with the aim to explain how such technologies can increase resilience against extreme climate events, improve the asset managing of water infrastructure, and operate the network efficiently to reduce leakages, pipe bursts and energy waste.

Finally, as smart water systems generate an incredible amount of data, the management of that data becomes a crucial issue. Statistical tools and algorithms allow processing that data efficiently, so it is reviewed techniques about the statistical treatment of data to improve its quality, as well as recent studies about pattern recognition and modeling in smart water systems.

12.2 Water Loss Control in Distribution Systems

Not all the volume of treated drinkable water that enters a water system will be finally registered by consumers' meters. That "lost" volume of water, which represents lost revenue to the water utility company, is due to real losses (leaks in the pipes and mains) and due to apparent losses (unauthorized consumption and also inaccuracies and errors committed by the metering system). The water loss indicator is the percentage of the total water losses over the amount of treated drinkable water that is supplied to the system. This indicator gives a good idea about the efficiency of a water utility company. Utilities from countries like Japan, Germany, Australia and New Zealand have water loss rates around 10% and even lower. In Brazil, water losses in distribution systems are on average 40.8% [1]. In the USA, water losses in distribution systems range from 7.5% in South Carolina to 31.2% in Philadelphia, with most utilities performing around 20% [2]. Water distribution systems in small villages typically have higher rates of water losses (around 5% or 10% higher) than big cities [2]. The main reason is that the lower concentration of population makes water loss interventions less cost effective. Water utilities that supply small villages have limited human and financial resources to operate and maintain networks that frequently cover large areas with sparse consumers. Independently of the size of the water distribution system, water losses represent a direct loss of financial revenue as well as a waste of two increasingly scarce environmental resources: water and energy. At a planning level, reducing water losses will contribute to reduce or stabilize future water withdrawals and therefore guarantee water supply.

Water loss control programs are fundamental in the management of water systems. Their aim is to plan a cost-effective strategy to control excessive losses, based on identifying the most viable interventions in the water system, and implementing them. As shown in Fig. 12.1, a water loss program comprises three essential parts: water audit, intervention, and evaluation of results.

A water loss control program is a continuous iterative process. It starts with a water audit, in which the utility tracks the volumes of water that flows from water sources to customers, in order to calculate water losses and performance indicators. At the end of the water audit, opportunities are identified and a strategy that consists of a series of interventions is set. The best interventions are selected according to their technical and economic viability. Interventions typically lie within one of these three groups: pressure management, proactive leak detection, or infrastructure replacement. After the intervention is completed, its results should be evaluated by measuring and verifying the actual water savings, or other type of economic and operational improvements. The results may also justify adjusting the management plan if needed. The revenue recovered from water loss intervention can be

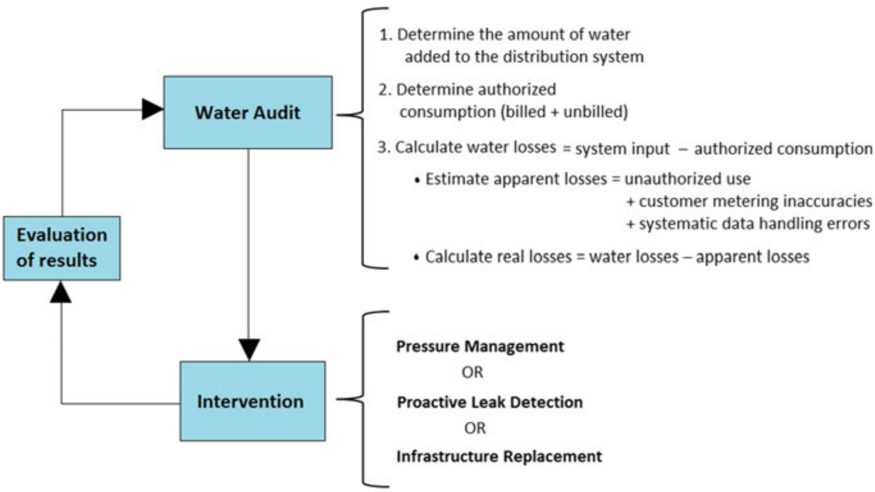

Fig. 12.1 Flowchart of a water loss control program

re-allocated to fund additional water loss control activities. Periodically, other iterations of the water loss program are started, with the aim to achieve the best cost-effective interventions.

The existence of a flow metering system is essential to conduct a water loss control program. During the water audit stage, it will provide input data for the water balance and for calculating water losses and later on the evaluation of results. It will be crucial to verify the water savings achieved by the interventions. The flow metering data of a water network comes from two main sources: in-line flow meters (turbine flow meters or the more modern ultrasonic meters) that provide the utility with operational data, and the customer meters, which provide information about billed metered consumption. In order to guarantee sufficient reliable data to conduct the water audit it is important to split and monitor the different supply zones or sectors that comprise the network.

The water network can be split into sectors to better monitor the flows that enter and leave each sector, which are often called District Metered Areas (DMAs). Monitoring those flows is particularly interesting late night, when urban water consumption is at its lowest. During nighttime (for example, from midnight to 5 h) flow is at its minimum and pressure rises to its maximum. Historical consumption data of that sector can be used to calculate the share of flow for a particular night that is due to actual consumption and what amount is due to leakages. Also, the minimum water flow registered at night within the different sectors can be compared, in order to identify those sectors with an abnormal consumption level which is indication of a higher incidence of leaks. That comparative should carefully take into consideration the different pressure levels, age of the pipes, and population density of the sectors. Sectorization is very useful to monitor the rise of leak rates in each sector and keep water losses under acceptable levels. However, sectorization also has costs (logging equipment and data retrieval system, construction of meter chambers), therefore, water network managers have to calculate the economic level of sectorization for the network, as well as the optimum size of the sectors to be monitored and which ones are to be prioritized.

Besides sectorization, customer metering is also a key part of the overall metering system of a water network, and an important source of information to elaborate the water balance and calculate losses. Therefore, it is important to be aware that customer meters have inaccuracies that tend to under-meter the authorized consumption of water, which has an impact on the apparent losses that are to be estimated. Customers' water meters are subjected to inaccuracies, which altogether can represent almost 20% of the total volume of water losses in a distribution system. This is the case in Brazil, where real losses are 72% of the total, while apparent losses represent the other 28%, being 19.6% customer metering inaccuracies and 8.4% unauthorized consumption [3]. The main cause of those metering inaccuracies is that water meters have limitations at measuring low fluid flows. In addition, a series of effects accumulate over time and contribute to the eventual under-registration of the flow: wear of mechanical parts, improper sizing or type of meter for the customer usage, improper installation, or aggressive water quality.

Positive displacement and multi-jet meters are accurate for low-to-moderate flow rates of households and commercial users, and therefore are widely used by utilities to measure consumption. Those types of meters have a minimum measuring threshold, typically around 10 L/h, so they do not measure trickle or drip flow, which can represent and important share of the total volume that passes through the meter. Turbine flow meters, consisting of a turbine immersed in the fluid, are less accurate at low flow rates although do not create apparent losses as they are used to monitor flow across an entire sector instead of measuring individual user consumption. There are other types of water meters that perform much better at low flow rates, such as droplet counter devices, compound meters, or non-mechanical devices (electromagnetic and ultrasonic water meters) but these are too expensive to be used at residential and commercial levels. An interesting and economically viable solution may be the installation of pulsed valves before the positive displacement or multi-jet type water meter. Those valves interrupt the passage of flows below the minimum measuring threshold and accumulate volumes of fluid that are later released as a flow that the meter can measure [4].

Metering inaccuracies represent a volume of water that is actually supplied to customers, and in that sense this type of losses is preferable to real losses (leakages) as they do not pose a direct threat to water resources or water quality. However, meters at the consumption points are the cash registers of water companies, and thus high metering inaccuracies have an impact on the economic sustainability of a water utility company.

Water Audit

A Water Audit involves the review of data recorded by the utility's process meters at different points of the distribution system and at the consumption points (the billed metered consumption). That data will serve to conduct a water balance and calculate water losses, with the aim of identifying the final destination of all the water that is put into the system. The IWA (International Water Association) and AWWA (American Water Works Association) propose a "top-down" water balance methodology that traces the flow of water from its sources to customer properties, as show in Table 12.1.

Utilities can use methodologies and software to compile a standardized water audit, for example the IWA/AWWA Water Audit Method [5]. The Excel®-based AWWA Free Water Audit Software (FWAS) is an interesting tool in concordance with that methodology [6]. Other specific data management software that can be downloaded freely is the CUPSS—Check Up Program for Small Systems, an asset management program created to assist small systems in water loss management as well as in operation and maintenance scheduling [2, 7].

Once the data from the metering system is gathered, it must undergo a statistical analysis to eliminate outliers and to assess the uncertainties of the data, mainly the under-metering of mechanical meters and the systematic data handling errors. Then the water balance (Table 12.1) can be conducted to calculate water losses as per the following steps:

Table 12.1 Water balance [5]

<table>
<tr><td rowspan="9">System input volume</td><td rowspan="4">Authorized consumption</td><td rowspan="2">Billed authorized consumption</td><td>Billed metered consumption</td><td rowspan="2">Revenue water</td></tr>
<tr><td>Billed unmetered consumption</td></tr>
<tr><td rowspan="2">Unbilled authorized consumption</td><td>Unbilled metered consumption</td><td rowspan="7">Non-revenue water</td></tr>
<tr><td>Unbilled unmetered consumption</td></tr>
<tr><td rowspan="5">Water losses</td><td rowspan="2">Apparent losses</td><td>Unauthorized consumption</td></tr>
<tr><td>Customer metering inaccuracies and data handling errors</td></tr>
<tr><td rowspan="3">Real losses</td><td>Leakage on transmission and/or distribution mains</td></tr>
<tr><td>Losses at utility’s storage tanks</td></tr>
<tr><td>Leakage on service connections up to point of customer use</td></tr>
</table>

1. First, calculate the total water losses as the water input minus the authorized consumption (the billed consumption, registered by the water meters).
2. Then estimate apparent losses, which are a sum of (I) unauthorized use, (II) customer metering inaccuracies, (III) systematic data handling errors.
3. Finally, calculate the real water losses (leakages and overflow of tanks) as the difference between water losses and apparent losses.
4. The result obtained for the real water losses should be validated though component analysis of real losses and a “bottom-up” analysis of real losses using district metered area (sectorization) and an analysis of minimum night-time flows.

The results of the water balance, based on metering data and estimates, should complement a Geographic Information System (GIS) linked to a detailed inventory of the water system (metering points, pipe sizes and types, reservoirs, list of water lines with quality complains and high incidence of detected leaks).

The main output of the water audit is the calculation of water losses through the water balance and further validation analysis. In addition, the water audit calculates a variety of performance indicators to assess the efficiency of the water utility, such as: Real losses (% or gallons/service connection/day), Apparent losses (% or gallons/service connection/year), Infrastructure Leakage Index (ratio), Non-Revenue water by volume (%), Energy indicators (kWh/m^3), and so on.

Once the water losses and the indicators are calculated, the next step is to determine the monetary valuation of existing water losses and the current level of expenditure to manage them. Each water system and utility has to track its various costs, which are to be considered in the assessment. In every water system, there will always be a small rate of water losses as completely eliminating them would be uneconomical. Therefore, the economic assessment should calculate the economic level of leakage that is appropriate, in which the utility does not spend more on loss control activities than the value of the benefit it expects to recover from the loss reduction. That economic level of loss will serve to establish performance targets. Those outputs will serve to plan a cost-effective strategy to control excessive losses. Figure 12.2 summarizes the inputs and outputs of a Water Audit.

The water audit should guarantee that only cost-effective water loss intervention strategies are pursued, and identify among them the most technically and economically viable strategies. The effect of those interventions can be modeled before their implementation, via the use of water network modeling and analysis software such as EPANET or KYPipe [8, 9]. A hydraulic model considers the system's operating parameters (flow rates, pressures, water quality, pipe sizes and age, etc.) and, once calibrated against field reality, can simulate how the system would behave after the implementation of the measures. After selecting the most appropriate intervention, the last step is to formulate an implementation plan and assess and allocate resources for it.

The IWA—International Water Association points to four basic strategies that can be used to reduce losses [5]:

1. Proactive leakage detection.
   Aims to reduce any backlog of leaks and keep losses from unreported leaks at an economic optimum. Within this strategy, it should be determined the economically optimum leak detection frequency.
2. Improve the speed and quality of repairs.
3. Pressure management.
   A rule of thumb is that 10% reduction in pressure results in 10% reduction in real Losses (leakages) [10]. Within this strategy, how much the pressure can economically and technically be reduced should be determined.
4. Infrastructure rehabilitation and replacement.
   Besides water savings, the direct and embedded energy savings by infrastructure replacement should be assessed. For example, the decrease in pipe roughness, bigger pipe diameters, and pipe retrofit resulting in fewer leaks will also result in energy savings.

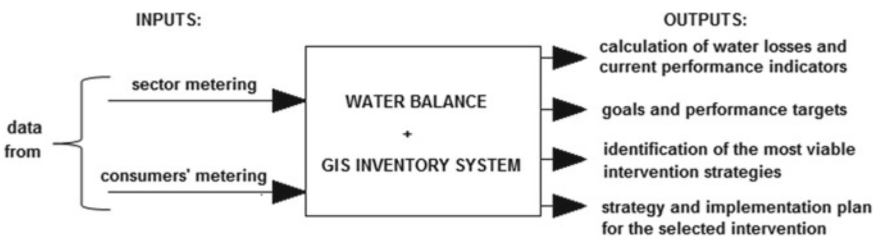

Fig. 12.2 Inputs and outputs of a water audit

Proactive leak detection, and improving the speed and quality of repairs are strategies that can be implemented in the short term. Pressure management and infrastructure rehabilitation involve greater investment and should be considered in the economic long term. In the following section, leak detection and pressure management are discussed in more detail.

Leak Detection

There are three categories of leakages [10]:

- Background Leakages—Continuously running small leaks that are undetectable with conventional leak noise detection equipment. Precisely, background losses represent the volume of water that is lost through small leaks and weeping joints at flow rates that are too small to be detected using detection equipment. This type of losses will flow continuously until they are found by chance during some other maintenance work or until they gradually increase to the point where they become detectable.
- Unreported Leaks—Leaks with moderate flow rates that escape public knowledge and are only identified through the active leakage control work of the water utility.
- Reported Leaks—Large leaks that are reported by customers, traffic authorities, or any other outside party due to their visible and/or disruptive nature.

Figure 12.3 illustrates the three types of leakages, together with the strategies to minimize their occurrence.

The leak detection techniques can be classified into four groups:

– Visual survey. These are reported leakages that surface above pipes or that are located in valves, hydrants, meters and other exposed parts of the network.
– Acoustic leak detection survey. This is the most common and inexpensive leak detection method. A trained operator uses listening devices in all available fittings on mains and service connections, as well as geophones above the pipes, searching for leak noises. The instrumentation ranges from simple mechanical listening sticks and rods to sophisticated geophones with digital filters.
– Step testing. This involves temporarily sectorizing parts the network. Small sections of the water distribution system are isolated and then have their supply measured during the minimum nighttime flow period though portable flow meters.
– Leak noise logger survey. Noise loggers are installed, permanently or temporarily, on pipe fittings such as valves and hydrants. They can periodically send "packages" of data automatically via a radiofrequency emitter, or log data in an internal memory until an operator arrives.

Leak detection equipment has greatly evolved in recent years. Acoustic equipment has incorporated electronic advances to assist the operator in detecting and to precisely locate leaks. In bigger size transmission mains, where leakages represent higher economic loss and can even disrupt the supply, more expensive

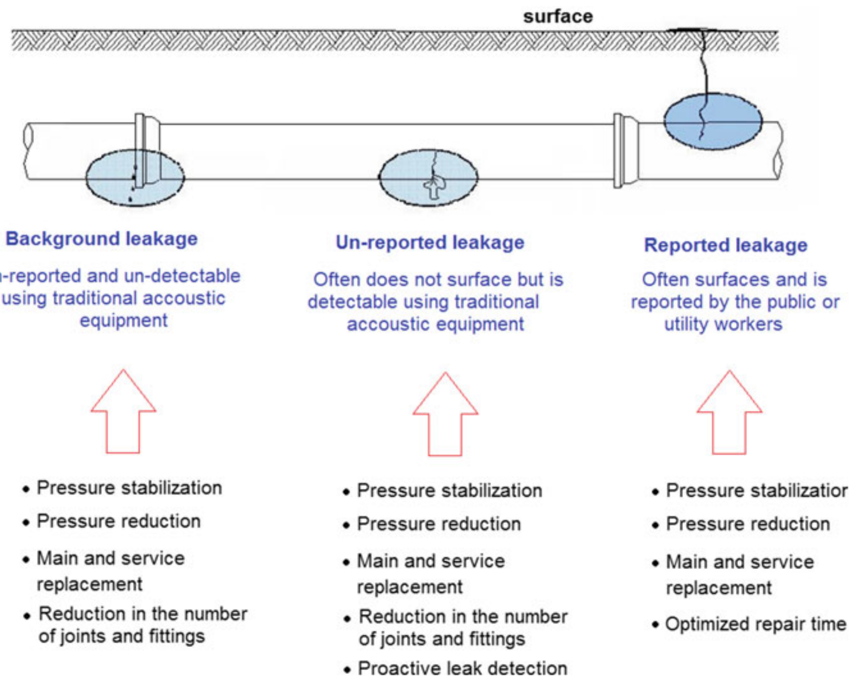

Fig. 12.3 Types of leakages and strategies to minimize their occurrence [11]

instrumentation has been developed such as above-surface radar or sensors inserted into the pipes. Pipe inspection through automated vehicles (robots equipped with cameras or sensors) is still not common in water networks, as is the case, for example, in the oil and gas industry, where PIGs (Pipeline Inspection Gadgets) regularly inspect the pipes and perform various maintenance operations. However, currently there are sophisticated mobile sensors for the inspection of water networks, such as free-floating inline acoustic leak detectors or streaming cables. The first of these consists in a small plastic ball that houses acoustic sensing equipment in its core and travels along the length of the pipe with the flow, recording the acoustic profile of the pipe. In the latter case, the sensor travels across the pipe pulled by a small parachute at its head, transmitting an acoustic signal through the streaming cable to a trained operator on the surface. Both instruments inserted into the transmission main have location sensors together with the acoustic sensors so they can pinpoint its exact location in the pipe when a leak signal is detected. Table 12.2 summarizes the set of equipment available for leak detection, for both small and big diameter pipes.

Table 12.2 Leak detection equipment

Acoustic equipment for household and distribution pipes	
Listening rods/sticks (mechanical and electronic)	Requires operator practice and skill; inexpensive
Ground microphones (geophones and hydrophones)	Requires operator practice and skill
Leak noise correlators	Computerized listening devices
Leak noise loggers	Provides long-term record over several days
Leak detection equipment for transmission mains	
Sensors inserted into the transmission main	Free-floating inline acoustic leak detectors
Acoustic fiber optics	For pre-stressed concrete cylinder large diameter pipelines
Inline acoustic leak detection (streaming cable)	For concrete or PVC large diameter pipelines
Infrared technology	Thermography of a wide surface area, to narrow the location of a leakage
Electromagnetic field detection	For pre-stressed concrete cylinder large diameter pipelines
Ground penetrating radar	*aka* ground probing radar
Chemical detection	Tracer gases and liquids

Water Loss Reduction Through Pressure Management
Water leakages depend on the water's pressure in pipes, according to the expression:

$$\frac{L_1}{L_2} = \left(\frac{P_1}{P_0}\right)^N$$

It expresses the relationship between changes in leakage (L) due to changes in pressure (P). The above expression is known as the "Fixed Area and Variable Area Discharge" theory [12]. The exponent in the pressure-leakage relationship is known as the N value. It generally ranges between 0.5 and 1.5, but an average N value of 1.0 and a value of 1.5 for background can be assumed [13].

Pressure reduction will reduce leakage due to two effects. First, as leakage flow is directly related to pressure, reducing pressure will reduce both background and leak flow rates. That's why pressure management is particularly effective in minimizing background losses or widespread small leaks across the system. In addition, a second effect is that burst frequency rates will also be reduced due to reduced stress on the pipe network [10]. Therefore, pressure management is also a valuable strategy to inhibit water main bursts from occurring and improving the lifetime of the water distribution system infrastructure.

Pressure management involves adjusting pressure to an optimum level of service, in which sufficient and efficient supply is guaranteed to legitimate consumers while at the same time pressure transients and excess pressure is avoided, therefore reducing leakages, pipe breaks and energy waste. There are three main strategies to achieve an effective management of pressure in a water network: split the network into different pressure zones, pressure control valves and pump controls.

Pressure Control Valves include various types of valves such as relief, reducing, sequence, counterbalance, and unloading valves. Pressure reducing valves are the most used to maintain reduced pressures in specified locations of hydraulic systems. They use a spring-loaded spool to control the downstream pressure to preset values, which are adjusted by a screw on top of the valve. When the downstream pressure increases to the valve setting, the spool moves and partially blocks the outlet port, thus controlling the flow that passes through the valve and this keeps pressure below the desired level.

Pressure can also be managed by varying the flow of water that is pumped throughout valves, recirculating a part of the flow, or controlling the pump rotation via variable frequency devices. The most energy-efficient solution is the use of variable frequency devices. These electronic devices can control the water flow by controlling the frequency of the alternated current and voltage that is supplied to the pumps' motors, and therefore the speed to which motors rotate. Modern variable frequency devices can act as programmable logic controllers so they automatically vary the rotation of the pumps, and therefore, the flow of water that is pumped, to maintain a preset value of pressure in the network.

Pressure management is commonly used by water utilities worldwide. It has also been used as a water conservation tool under emergency circumstances. For example, the city of Cape Town pioneered extreme water pressure reduction or "throttling" resulting in an intermittent supply, during the water crisis of 2014–2018. Meanwhile the water utility of São Paulo, Sabesp, made the installation of pressure control valves a key point of its strategy to face the 2013–2015 drought. Both strategies were essential in the successful response of those cities to the water scarcity threat they experienced. For instance, in the case of São Paulo the rate of water losses dropped from 35.8 to 30.6% after the widespread installation of pressure control valves [1].

There are some potential concerns with pressure management. First, minimal water pressures must be maintained to satisfactorily meet customers' varying water demands. According to the typical water demand profile of urban consumers, pressure drops to minimum levels during the central hours of the day, as demand (flow) is at its maximum and, during those hours, shortage could occur if pressure is too low. During nighttime, pressure typically rises as demand drops to its minimum. Therefore, it is important to develop a pressure management strategy that takes into consideration the effect of the water demand profile and varies pressure accordingly. Another potential concern is to provide sufficient pressure for firefighting flows, in accordance with local norms. Finally, an excessive low pressure could cause the backsiphonage or backflow of contaminants. If there is a link connecting a source of pollution and the potable network, and the latter is at lower pressure, there will be a net force toward the potable supply and polluting substances will tend to enter the potable network. Hydraulic systems of buildings count on backflow preventers such as air gaps and atmospheric vacuum breakers to avoid any link or channel (cross-connection) to potential sources of pollution. More serious is the case of underground leaky pipes, in which low pressure can allow possible intrusion of microbial and chemical contaminants.

12.3 The Transition Toward Smart Water Systems

Water poverty already affects an important share of low income urban and rural population in the forms of limited, time-consuming and unsafe access to the resource as well as a high incidence of waterborne diseases. As quality drinking water becomes increasingly scarce, it will be more unevenly distributed among society [14]. Universalizing access to potable water and sanitation by being efficient and avoiding waste of resources may be the most important challenge of water networks in future years.

It is also noticeable that most undeveloped parts of the world will undergo a strong urbanizing process in the next decades. In that sense it will be crucial to develop decentralized, low cost, and remote-controlled water systems capable of supply clean drinking water to a growing urban population, which is often located in risk or polluted areas such as slums or marginal lands with little infrastructure.

Other challenges of water networks in the actual context are:

- Conserve as much water as is economically viable, as traditional water resources will no longer be guaranteed in enough quantity and quality.
- Increase resilience against extreme climate events (droughts and floods).
- Manage an increasingly complex network that may also treat and supply non-drinkable sources such as reclaimed wastewater and rainwater.
- Manage the different pressure levels of the network sectors efficiently to reduce leakages, pipe bursts and energy waste.
- Asset management of an aging water infrastructure, while managing limited budgets.
- Minimize the awareness, location and repair time of leaks.

Overall, the water industry has a huge need to be more efficient. But recent technology breakthroughs have finally arrived to the water supply sector. Most water networks have already experienced a digital transformation, with an increasing number of sensors and automation in its processes. Automation components, sensors, telemetry and computers have been constantly reducing its price during the past two decades. Internet connection is widespread, affordable and reliable. This has led to a point where is viable to take another step and start a transition from "digital" to "smart". Thus industrial processes are experiencing a transition toward "Industry 4.0" and electricity networks are becoming smart grids capable of absorb increasing amounts of intermittent renewable energy while dealing with the new challenge posed by the rising of electric cars. The emergence of the IoT (Internet of Things) allows engineering smart buildings and even smart cities that can better manage their infrastructures, water and energy supplies or traffic flows. Similarly, water networks are undergoing transformations that will disrupt the way a water system is operated and managed, and will increase its efficiency to pace with the new standards required by the global water scarcity context. Besides water scarcity and regulatory requirements, the evolution toward smart water networks is also driven by market dynamics, or the constant need to adopt the technological advances to reduce costs, and the need for solutions to more cost-effectively manage billing and customer management, leakage rates, and energy consumption.

Water, energy and gas companies started to use smart meters to record and transmit consumption data and to generate the monthly bills. It soon became clear that the automation of the reading and billing process saved a lot of time and money when compared to the previous situation, where a human worker had to walk-through visiting all and every of the consumption points and annotate the meter readings [15]. The new walk-by/drive-by systems, consisting in a operator walking or driving through the streets while uploading the data from the meters, were eventually outpaced by advanced metering infrastructure, defined as two-way, fixed radio or cellular communications network. The meters now send their readings directly to the network, where they can be stored in the cloud. The consumer can also have access to that data to, for example, monitor its own consumption or get data about tariff periods or the quality of the water that is receiving [15].

Smart water consists in a group of emerging technological solutions that help water managers operate more efficiently and, in a smaller scale, help consumers tracking and managing their water usage. Those solutions are based on leveraging the Internet of Things, Big Data, and analytics. IoT offers the technological background (hardware and software) for data acquisition, transmission, and operation. The visual display of a myriad of data from the water network helps the water managers to monitor, optimize and take real-time decisions. Meanwhile, Big Data allows going a step further toward system intelligence. First, cloud-based information technology allows storing very large data sets. Secondly, through the application of artificial intelligence, the value of data can be can be maximized as those data sets can be analyzed by computational models to reveal patterns and trends. As a result, the water system becomes capable of gathering and analyzing data and also communicating with other systems. Most of the operation of the water system (pressure management, flow control, etc.) can be automated and optimized.

Following, it is discussed the architecture, key elements and functionalities of a smart water system.

Architecture

The concept of Internet of Things (IoT) refers to a network of physical sensors embedded with electronics and software that allows getting real-time data of any measurable parameters such as level, flow, pressure, temperature, noise correlations, etc. and make them available online. Figure 12.4 illustrates the flowchart of information across the different components: sensors, actuators, controller, data server and interface devices.

The microcontroller is the core of the system and acts as a data concentrator, receiving real-time data from the sensors and sending “packages” of information to the web server [15]. The web server makes the data available online, where it can be

Fig. 12.4 Architecture of a smart network (IoT)

stored, processed and analyzed. The system can be limited to only receive and display the information to human managers that will make the decisions, or can have some degree of system intelligence that allows operating some parts of the network automatically. Whether is human supervised or the system's algorithms, the microcontroller will receive the control orders (set points for variables such flow or pressure) and operate the components of the system (pumps, valves …). That is, a set of microcontrollers receive the sensor readings and transmits the data, and then receives the commands and operates the system. The "brain" of the water network (human or AI) communicates with the controllers to monitor the system and perform remote controlling of it.

Visual Display of Information

One of the most basics functionalities of a smart water system is to monitor the network. The system is fed at regular intervals with data from the sensors deployed across the network. That information can be displayed within a map interface that is linked to a Geographic Information System (GIS), in which each sensor node can be identified through geolocation. Figure 12.5 shows an example of such a map.

The aim of such interfaces is to visualize data in ways that make it easier for engineers to identify anomalies. Interfaces should be easy to view and to navigate, quick to update and represent a sufficiently broad context that allows extracting conclusions. Any operation variable exceeding threshold values should be automatically highlighted. In addition to that, the monitoring system could allow to set alarm threshold values, in order to automatically send SMS or emails to the water management team.

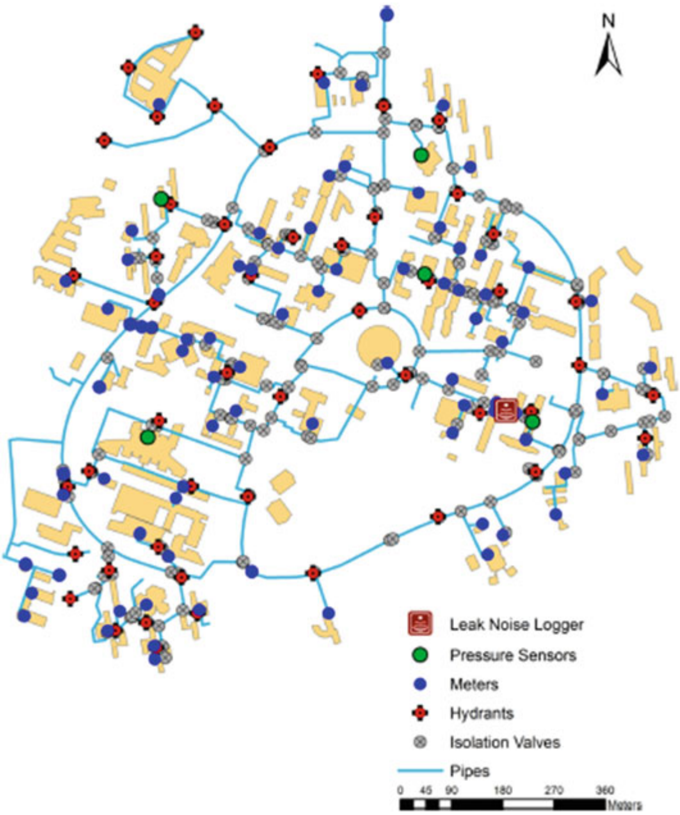

Fig. 12.5 GIS map of a water network [16]

Smart Metering

A smart meter is an electronic device that records one or multiple parameters and communicates the information to the system. A smart meter can be configured to track multiple parameters at the same time, such as static pressure, flow, temperature or chlorine levels.

Every part of the network, from hydrants and valves to pipes and meters can be equipped to collect—and in some cases analyze—data. It is now possible to monitor nearly every asset of a utility, which should conduct studies to determine the level of metering that is economically viable. Automatic Meter Reading (AMR) that record flow, particularly the ones used to record and bill water consumption, represent the biggest share of new-acquired smart meters by water utilities. Smart meters equipped with pressure sensors and noise correlators are slowly increasing their presence. Following, Fig. 12.6 shows a battery-powered water meter that can measure flow, pressure and temperature.

The above electromagnetic bulk water meter can be used for leak detection, quality control and pressure management systems in water networks. For metering

Fig. 12.6 Electromagnetic bulk water meter. *Courtesy* Khrone Messtechnik GmbH [17]

the water volume supplied to small consumers, two types of smart meters are widespread: pulsed water meters and non-intrusive ultrasonic meters. The latter ones are non-intrusive, more accurate and also more expensive. The information registered by both types of smart meters is processed by the water utility but it can also be accessed online by the consumer, which views it in the form of graphics and consumption reports, as Fig. 12.7 illustrates.

Fixed acoustic correlators are an example of a device that records and also analyzes the data before transmitting it, in order to report assertive data to the water utility. They evolved from noise loggers that used to be installed in valves boxes and other parts of the network and then picked up after some days of recording in order to retrieve and analyze the data with a noise correlation program. State-of-the-art systems, such as the ones showed on Figs. 12.8 and 12.9, are smart sounding systems capable of analyzing the acoustic signal themselves. They are equipped with proprietary filters that periodically compare the acoustic signal collected by the sensor to baseline acoustical signatures at each location. When an acoustical anomaly is identified, the meter sends a data file to an analysis module. That module automatically requests additional correlation data from surrounding meters and performs multiple correlation combinations to accurately target the location of the acoustic anomaly. If the leak is confirmed, the device sends a notification to the utility. In addition, such system is linked to a GIS that displays the information over a map of the network and enables an operator to view and manipulate a correlation graph. This greatly reduces the awareness time needed to detect a leakage, but also its location time, as the graphical data improves confidence in the exact location of the leak. Water managers can better schedule their field investigations and allocate the limited resources of the utility. Figure 12.8 shows a smart leakage detection system, consisting in acoustic correlators developed to be installed in fire hydrants. Traditional caps are replaced with “smart hydrants” equipped with the device. Those smart hydrants conform geolocated nodes that communicate with a central data collection hub.

Fig. 12.7 Ultrasonic (left) and pulsed mechanical (right) flow meters, provided with wireless transmitters. *Courtesy* Badger Meter, Inc. [18]

Fig. 12.8 Smart hydrant cap *Courtesy* Echologics and Mueller Co. [19]

When searching for locations to place noise correlators, fire hydrants are preferable than underground chambers or valve boxes because they offer a less aggressive environment as well as stronger and more stable radio signal due to the above-ground location of the antenna. Figure 12.9 shows another type of smart acoustic correlators linked to GIS that search for leakages in water mains.

Fig. 12.9 Monitoring water mains through smart acoustic correlators linked to GIS. *Courtesy* Echologics and Mueller Co. [19]

This type of non-intrusive monitoring platforms can be installed in a chamber or in any other location of a water transmission main where access to the acoustic signals of the water main can be obtained. They are typically placed 500–1000 m apart [19]. Data files are recorded at user-specified intervals and wirelessly uploaded for analysis. Each monitoring platform consists of a data processor, communication hardware and a battery power source. At assigned times that can be specified by the user, the collected data is uploaded to a server where advanced algorithms interpret the data, search for leak signals and generate reports. That is, data is uploaded to the cloud to be analyzed by software that automatically sends reports and sends alarms in case of leak events. A customized information interface is created for the utility to facilitate the visual display of data and the interpretation of the reports.

Communication Protocols

The widespread option for data transfer from permanently deployed battery powered communicating sensors has been the 2G mobile communications networks, in the forms of SMS for very small data volumes and GPRS for larger data transfer. Nowadays, 2G networks are on their path to obsolescence and being decommissioned to free up spectrum for higher capacity 4G. But cellular standards that could replace 2G such as LTE-M and Narrow Band IoT (NB-IoT) for 4G are still in their early stages. As they evolve during next years, sensors and actuators that were deployed early in the smart water network, and use 2G, could become incompatible with new communication protocols.

Mobile internet is evolving from 2G and 3G to 4G and 5G with some uncertainties about which would be the prominent communication protocol for the next years. Meanwhile, emerging communication protocols for low power remote sensor applications have arisen. They are called Low Power Wide Area Network Protocols (LPWAN), and the two main examples are Sigfox and LoRa. These are proprietary systems (closed source or non-free software) which generally operate in license-free spectrum of frequencies. Smart water utilities have to choose between mobile communications or the new proprietary LPWAN solutions. That is an important issue for the convergence of infrastructure communication i.e. the interoperability of communications infrastructure across a single water network and also across the different networks of water, gas and electricity.

As water utilities are increasingly investing in telemetry and smart system, they will have to deal with the issue of choosing a communication protocol that is affordable, doesn't become obsolete too soon or causes incompatibility between older and newer components. Maybe a reasonable strategy is to stick to mobile communications and work with 2G and 3G while, at the same time, preparing a roadmap in the expectation of moving to NB-IoT for new and replacement sensors in around 5 years' time [20]. System managers of water utilities should assure that the network is flexible enough to accommodate that transition.

Other key aspects about communication protocols are:

- The storage of large datasets will rely on cloud-based information technology.
- Cybersecurity will increasingly be a high priority. Protection against hacking incidents should be considered.
- Most sensors deployed on the water distribution network are battery powered. Batteries and costly, as well as the visiting the sites to replace spent ones. Protocols that make a smart data transmission can increase the life span of sensor batteries. LPWAN, for instance, offers low transmission and network costs and meter battery life-spans of 15–20 years.
- In addition to the above, it is important to notice that real -time transmission of data is not always necessary for the system to perform optimally. It is important to use battery power sparingly and only when it's needed, which means that the sensor communicates only when the information will be really useful. If the sensor has to be always on and frequently sending back data, the battery will be spent much faster. A more convenient configuration for data transmission in most sensors may be to give real-time priority to any alarm that could be generated, as well as the ability to respond anytime if asked, but otherwise deliver only a small but representative dataset each day.

New Business Models

Smart metering has allowed the development of new business models such as online prepaid water consumption. This system requires the installation inside the home or business of an internal unit that acts as the customer's interface. The customer will insert in it a "Smart Card" and information regarding the credit status, the volume of water remaining, tariffs and potential leakage alarms will be displayed.

Customers purchase credit at vending points using their smart card. At that point, data from the meter that was stored on the Smart Card is uploaded and sent to the utility headquarters. When arriving home and inserting the Smart Card into the internal unit, the internal unit will communicate, through wireless radio, with a external meter box that houses a water meter and a control valve. The solenoid valve will open and allows the costumer to use the volume that has purchased.

This business model offers advantages to both customers and water utilities. For the first ones, it offers a tool for water usage management and more control towards its expenses with water consumption. For the utilities, guarantees payment prior to water distribution and removes the need for a billing department or meter readers. Figure 12.10 shows an overview of such a system.

Asset Management and Scheduling of Repairs and Replacements
Physical assets like pipes, valves, pumps, wells, hydrants, treatment facilities and other infrastructure tend to deteriorate over time. That increases the cost of operation of the water network and eventually causes disruptions on supply. The main aim of asset management in the water utility sector is to achieve long-term sustainability and deliver consistent service in a cost-efficient manner [22]. Asset data is crucial to make informed, data-driven replacement and pro-active maintenance decisions that extend asset service life and reduce system failures. Figure 12.11 shows the five core components of asset management.

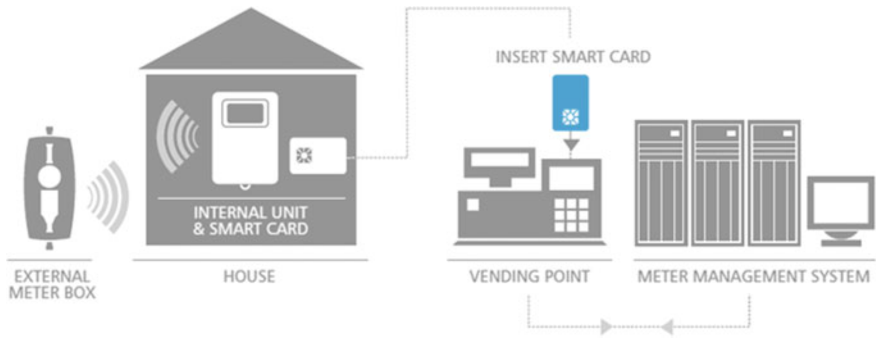

Fig. 12.10 Overview of a smart system for prepaid water consumption. *Courtesy* Universal Metering Ltd. [21]

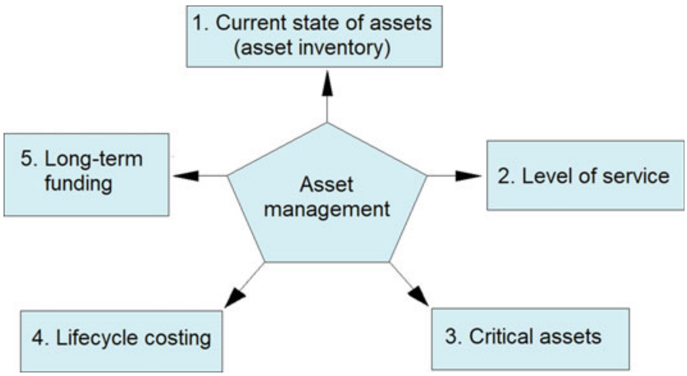

Fig. 12.11 The five core components of asset management [23, 24]

A smart water system relies on remote sensors that gather data and applies system intelligence to monitor and operate the network. Thus, it is easy to implement some asset management functionalities within that architecture. For example, a sensor that measures and transmits flow and pressure data in a valve can easily be adapted to also transmit data about wear or vibrations in the valve. The analysis of the data from a leaking detection system can also serve to detect which pipe sectors tend to deteriorate and burst more. By managing strategic assets according to their performance, utility managers can make better decisions about repairing, replacing or rehabilitating aging assets, and also develop an effective strategy for long-term funding. The evolution toward smart water networks will allow switching to maintenance based on continuous condition monitoring of assets, which as the following advantages:

- Create more accurate inspection schedules for predictive maintenance.
- Prolong the operational lifespan of assets with preventive service, maintenance and workload allocation.
- Perform timely corrective maintenance and repairs. In particular, rapid event detection reduces the awareness time of emerging problems, speeds up resolution times and gets ahead from eventual customers complains.
- As any failure in a component is rapidly detected and fixed, reduces the risk of escalation to a catastrophic failure that may also damage other parts of the system.
- Manage risk more efficiently and improve the response to emergencies produced by asset failures.
- Forecast the future needs for funding and prioritize investments that meet the system's actual requirements.

In sum, maintenance based on continuous condition monitoring of assets requires considerable capital investment in sensors and IT but reduces the overall cost of maintenance, extends asset life and, as rapidly detects leakages and malfunctions, also improves the quality of customer service.

Electric motors, smart devices, and pressure reduction valves (PRVs) are good examples of applications for continuous condition monitoring. Electric motors that power key components such as pumps can be provided with sensors that measure vibration, temperature, electrical parameters or running hours. Sensors will generate an alarm at any moment if temperature or vibration rise above threshold levels. If not, they will just keep logging the measures and send a report periodically that will serve for data-driven predictive maintenance.

The estate management of a large number of smart devices is new challenge that has arisen in smart networks. Thus, continuous condition monitoring applied to smart devices serves to identify issues such as loggers that are struggling to communicate or batteries that are nearing end of life.

Finally, a pressure monitoring system involves to monitor valve condition, flow, pressure, and transients across the network while optimizing energy efficiency for pumping operations. Pressure sensors located in pipes, valves and critical points collect maximum, minimum and standard deviation pressure values in each measurement interval. Data is used to operate the system in a way that minimizes water loss and energy consumption, but also to prevent failures through preventive maintenance and setting alarms when pressure reaches threshold levels. PRV condition monitoring typically uses 3 pressure readings, one from upstream, another downstream and the third from a control space. The monitoring system can even identify some causes of failure: maintenance required, if the valve is bypassed or incorrectly setup, or if it is unable to fully close or open. The system's engineers receive that pre-diagnosis together with the raw data from the monitoring system, which assists them in providing a quick response to the alarm.

Water Loss Reduction

A smart water system can reduce water losses by three ways. The first one is by manage pressure more accurately. The second is by improving asset management, because predictive maintenance and data analytics help preventing pipe burst and failures before they happen. The third way through which a smart water system reduces water losses is by reducing the time needed to be aware of and locate new leaks.

The total run time of a leak (T), which is the time passed since it occurs until it is repaired, has been found to be a crucial factor influencing the volume of water lost to leakage [10]. T (total run time) is the sum of A (awareness time), L (location time) and R (repair time):

A—Awareness time of leaks is the time passed since a leak occurs until it is detected. In other words, is the time needed for the operator to become aware that a leak exists. In urban areas a visible break in the mains will not take more than 24 h until it is reported but most leakages can only be found through active leak detection. In those cases, the awareness time depends on the utility's implementing or not an active leakage control program.

L—Location time is the time taken to pinpoint the source of the leak once the operator is aware of its existence. Location time is short for reported breaks that are visible. For unreported leakages, it depends if it has been detected through acoustic equipment or though night flow monitoring. Acoustic leak detection allows pinpointing the leak almost at the same instant that it is detected. Differently, regular night flow monitoring allows the utility to be aware of the new leak in a general area, but might take additional time to locate its exact location.

R—Repair time is the time to repair and stop the leakage flow, once the leak position has been identified.

Location time is difficult to reduce in the cases where night flow monitoring has indicated a general area that is leaking. In those cases, inspection crews equipped with acoustic instrumentation should be sent to the area and even the best team will take its time until pinpointing the leak. Repair time depends on trained crews that use the appropriate materials and are equipped with the adequate tools to safely repair leaks quickly and securely. It can be improved in the initial stages through training and equipment. Once repair crews are properly equipped and trained on a variety of fix techniques, so they achieve an excel level of expertise, it becomes increasingly difficult to reduce repair time. Meanwhile, awareness time can be reduced by active leakage search, by night flow monitoring, or by monitoring both flow and pressure and detecting "abnormal" values that are not coincident with the ones expected in the absence of leakages. There is more opportunity to improve awareness time at a lower cost, in comparison with location and repair time. To illustrate this situation, imagine the volume of water that is lost in a leakage of a size of 10 m^3/day. Let's suppose that a water utility manages to reduce the awareness time from 25 days to only 4 days, while maintaining the same time needed for location and repair. Figure 12.15 shows how such reduction of awareness time, which is technically achievable in most cases, would be translated in lesser volume of water lost during the leak event (Fig. 12.12).

In particular, awareness time could be greatly reduced by smart metering of pressure and flow, combined with artificial intelligence (AI). The supervision of the data from the smart meters allows detecting any disruption of "normal" values of flow and pressure that may be caused by leakages, allowing their early detection. But that task is time-consuming and requires a good knowledge of the behavior of the water system, which means that water utilities should divert high skilled human resource and allocate it for data monitoring and interpretation. The advances of AI, in particular mathematical modeling, data storage and processing speed allows delegating the monitoring and interpretation of the real-time, remote data to computers that automatically compare the received data to the network's hydraulic and water balance models. Human operators and engineers can still analyze data records to reach conclusions and improve the system's operation, as well as develop and calibrate the mathematical models. It is noticeable that through the advances on machine learning and pattern recognition, computers will progressively be capable of developing and calibrating the models by themselves.

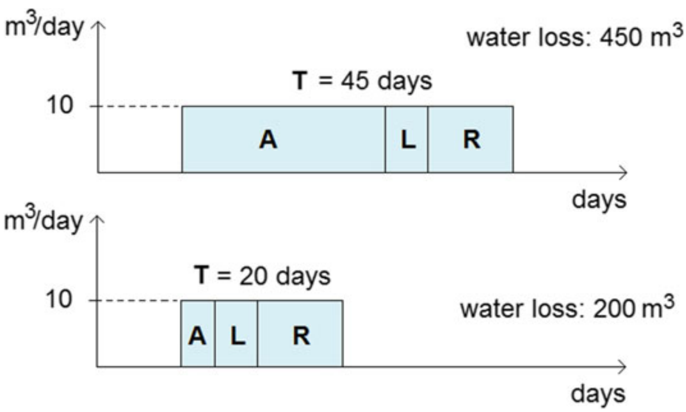

Fig. 12.12 Effect of the reduction of the "awareness time" on the leak loss volume

Resilience

The emerging water crisis is not exclusive of regions that face a rapid urbanization in developing countries. In the past two decades, a series of extreme drought events have affected heavy populated, wealthy areas: Melbourne in the 2000s (Australia's Millennium drought), California (2011–2017), São Paulo (2013–2015), Cape Town (2014–2018), parts of Texas (2018) and Brasilia (2018). For the first time at such large scale, those populated areas have been subjected to rationing and threatened with lack of supply. Water stressed megacities such as Los Angeles, Istanbul, Delhi, Beijing or Seoul have also shown vulnerability in their water supply in recent years. Among the above-mentioned cities, Cape Town in South Africa and São Paulo in Brazil offer two relevant study cases of resilience under urgent water scarcity threat, as both cities succeeded in reducing its water consumption, mainly through the control of the operation pressure and through demand management.

Unusually extreme and lasting droughts must be addressed through making a more efficient use of water resources. That can be achieved by (I) the use of "alternative" resources such as reclaimed wastewater, rainwater and desalination and (II) improving water conservation in industry, agriculture and cities. The latter, particularly reducing water losses in the network, is where a smart water system excels.

Water scarcity is going to be a main issue and most cities will have to improve their resilience with regards to it. The other side of the coin is extreme floods. In that sense, the architecture and functionalities of smart water systems allow re-engineering storm water management practices and urban infrastructure planning [25–28]. The concept of smart water can be applied to sewer systems, in order to conduct a continuous condition monitoring for improving infrastructure maintenance, to monitor sewer flooding and also to apply system intelligence and make optimum use of the existing infrastructure. An ideal application is to prevent sewer overflow.

An extreme rain event can cause an overflow of stormwater and sewage into creeks and rivers, polluting them and threatening lives and infrastructure. If it is raining heavily in a part of the city and the sewer system of some districts is overload, a smart sewer system can make use of the available capacity in other sectors where it hasn't rained. It would use sensors to monitor flows levels and operate valves and gates to divert the excess flow to other parts of the system that can handle it. A smart sewer system maximizes the use of existing assets and reduces the need to build large sewers and storage tanks. In sum, real-time sensing technologies can provide watershed-scale monitoring to produce quality data to drive decision-making, more rapidly and assertively. Smart sewer solutions introduce more flexibility in existing collection networks, which maximize storage and retention capacity of existing infrastructure through real-time control systems.

Automation of Pressure Management

Pressure management is vital to maintain water losses under acceptable levels. In addition, it can generate energy savings in the pump stations. A smart water system should enable remote control and automatic optimization of pressure across the network. Fed with real-time pressure and flow data from sensors located in control points, the system intelligence would calculate the optimal values for pressure and flow and operate PRVs and pumps. To operate the system and adjust those two variables, there are two main components: electronic actuated PRVs and variable frequency devices that control the rotational speed of pumps. Figure 12.13 illustrates a remote controlled PRV.

As can be seen in Fig. 12.13, a PRV used to remotely control pressure relies on a controller that communicates with the system and an Advanced Pilot Valve (APV). The PRV is typically a globe type diaphragm actuated pressure reducing valve with considerable diameter (>50 mm). The controller receives flow data from upstream the valve, as well as pressure data from sensors located upstream, downstream and also in a control point located under the influence zone of the PRV. Pressure and flow data are processed by an algorithm that automatically determines the optimal control curve that should be applied. The algorithm gets refreshed with new data inputs, so any changes in supply, demand, headloss, etc. over time are incorporated

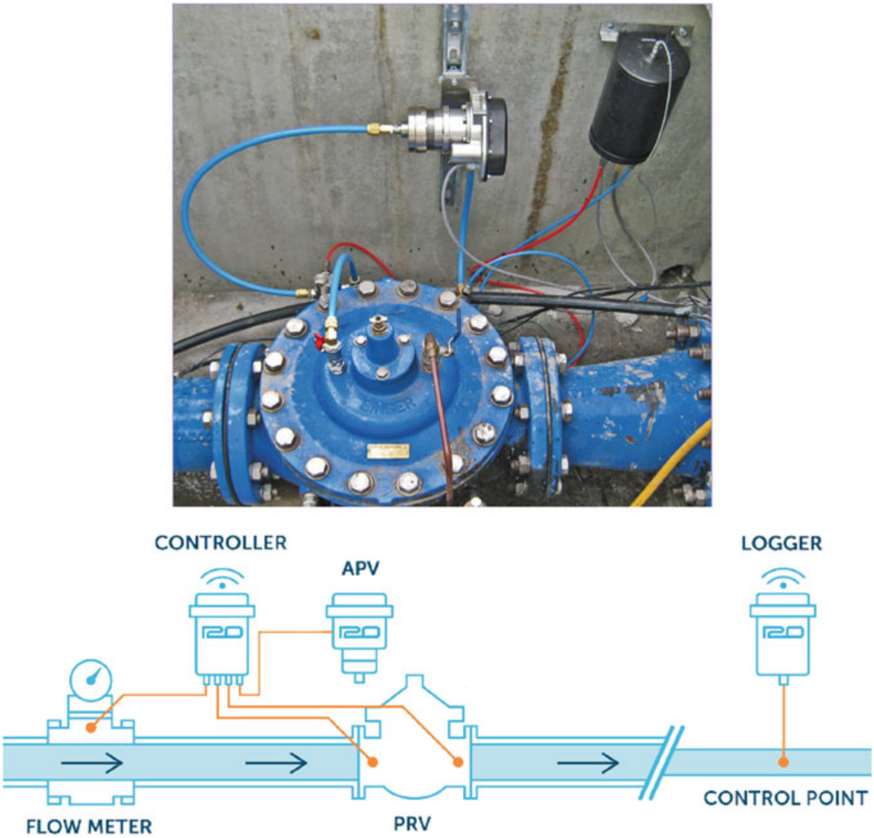

Fig. 12.13 PRV control. *Courtesy* i2O Water Ltd. [29]

automatically into an updated control curve without the need for any manual analysis or intervention [29]. The controller can adjust pressure in the control point, or automatically deliver target pressures at another critical point. The results of state-of-the-art systems for automatic optimization of pressure can be very satisfactory, as Fig. 12.14 illustrates.

Though the implementation of a system as the one described above, the water network obtains a set of new functionalities:

- It can be used just for remote control, implementing a control curve that human engineers have manually calculated. The controller would control pressure by adjusting it at any moment to a fixed outlet value.
- Under automatic optimization mode, not only the control task but also the calculation of the pressure is delegated to the system itself. The algorithms would determine the optimal control strategy to achieve a targeted minimum control point pressure. The system automatically adjusts for flow-related headloss and delivers smooth and accurate control. Depending on the level of artificial intelligence involved in the algorithms, the system could learn and adapt to seasonal, cultural and growth-related changes in demand over time.
- If an event is scheduled to happen (for example, a cultural or sportive event that is going to have a significant influence in water consumption), its requirements in terms of flow and pressure can also be scheduled in advance using a simple calendar function. That will guarantee water supply whether the preferred control strategy is remote control or automatic optimization of pressure.
- Constraints on how control is exercised in extreme circumstances can be set to ensure that the network is protected.

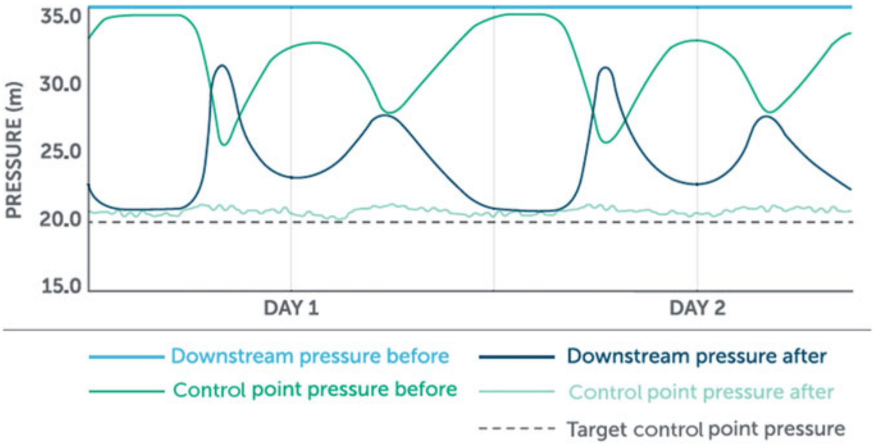

Fig. 12.14 Pressure curves before and after automatic optimization of pressure. *Courtesy* i2O Water Ltd. [29]

12.4 Data Management in Smart Water Systems

Without an effective management of the data provided by the network's sensors, it can be easy to get buried under an ever-growing mountain of information [30, 31]. Statistical tools and powerful algorithms are crucial to process that data efficiently. The firsts provide data quality control and reduce instances of "dark data" so the data that serve as input for the algorithms are more reliable. Meanwhile, algorithms can analyze computationally large data sets to reveal patterns and trends, and allow for more effective decision-making.

Statistical Treatment of data

Basic concepts of learning from data structure, inference and forecasts based the proposal of many methods that inspired statistical and machine learning disciplines. About 20–25 years ago, with the advent of powerful and user-friendly software, statistical and machine learning tools emerged focusing on supervised and unsupervised learning that started to be used not only by statisticians and computer scientists but also by a broader community [32]. Many of these methods started to be applied to residential water demand management relying on data generated by processes related to smart water data. As data-driven methods, the challenge is to transform the meter data into actionable insights that trigger decisions and measures.

With or without preconception of the data under study, exploratory data analysis (EDA) as the first step of any learning can reveal a fundamental understanding of the data and its structure allowing, for instance, the identification of water consumption patterns and variations over time, and outliers that can be identified as excessive water users or leaking. An outlier can occur due to extreme variation or incorrect measurement caused, for instance, by corruption of sensor installation or operation or by the data gathering process. The unveiled information can be applied to empower the customers for changing their habits and for a real-time action, and to build an integrated decision support system that allows smarter building management and a smarter water service. Based on a diverse quantity of published papers, a comprehensive discussion evolving data gathering, water end uses characterization, user modeling, leakage detection and pipe bursts, water distribution sectorization is presented by Britton et al. [33], Cominola et al. [34], Gurung et al. [35] and Nguyen et al. [36].

Database can be subject to a diverse graphical analysis to find probabilities of fixture use, peak hours of use, fixture flow rates and efficiency levels, and per capita correlations per number of bedrooms and bathrooms using various sample selections. The dynamics of water consumption data on different time scales can be evaluated by using time series plots. Box plots can be used to understand data distribution and spread and to represent location statistics (minimum, maximum, median, 1st and 3rd quartiles, interquartile range—IQR, and whiskers). They can also be used to identify outliers. However, when data are skewed, the inclusion of a measure of skewness in the determination of the whiskers can avoid that erroneous data are declared as outliers [37].

Supervised, semi-supervised and unsupervised techniques can also be used to outlier detection, as presented in Table 12.3. They consider the knowledge of normal and anomaly classes, the knowledge of normal class for labored instances and no information of classes in the training data set, respectively.

The missing values treatment is a key step in the interpretation and modeling of data from water metering systems. Their causes can range from configurations in measuring equipment (e.g. calibration, measuring range), data transmission, or even equipment maintenance.

Missing-data imputation, removal of missing observations or even maintenance of missing values will depend on the limitations of the techniques to be applied for the system modeling. While artificial neural networks for the classification of residential end-uses and ARIMA models for water demand prediction require complete data, models based on decision trees (e.g. random forest, boosted trees) or generalized linearized models can handle missing values as a separate category in the estimation of its parameters. An important framework about missing-value imputation methods is presented in Bertsimas et al. (2018) [39], where different datasets and percentage of missing values are treated and compared as optimization problems.

The analysis of the missing values distribution, such as time of day, days of the week or even the values that precede the missing values may reveal undesirable patterns in the application of missing data imputation algorithms for missing data not being missing at random (MAR) or missing completely at random [39], that is, not being independent of the observed values.

Pattern Recognition and Analytics

An early example of a modeling technique to predict leakage rates from the network data is the Background and Bursts Estimates (BABE) model, developed in 1993 [2]. BABE is a statistical component analysis model that estimates the current leakage conditions (real losses and minimum night flows) and shows how much leakage savings the utility can achieve if they improve their active leakage control activities.

A number of mathematical and statistical techniques have been used to develop models for predicting water consumption, pressure, leakages, or pipe bursts and components failures. Patterns of change over time in some variables like flow and pressure are predictable, as Fig. 12.15 shows. Therefore, the comparison between the current values measured by sensors and the ones that would be expected by the historic dataset, or a statistical or mathematical model, can reveal possible failures and malfunctions in a monitored area of the network.

A trend topic nowadays is how to convert the large database generated by the smart systems in tools to solve the efficiency and sustainability concerns. Wang et al. [40] present a comprehensive review about this problem where it was identified three key application areas for the database provided by smart meters: load analysis, load forecasting, and load management. One more item could be added to

Table 12.3 Summary of outlier detection approaches (based on Lhango et al. [38])

Approach	Assumptions	Strength and weakness	Methods/ algorithms
Statistical tests	Outliers do not follow the statistical model assumed for the normal data	+ Use statistical modeling techniques – Parametric assumptions often do not hold for real data sets – High dimensional distributions difficult to estimate and no tests are available	Parametric versus nonparametric
Depth-based approaches	Outliers are located at the border of the data space, independent of statistical distributions	+ No need to fit to a data distribution – Inefficient for large data set with high dimensionality	Isodepth, Minimum volume, Ellipsoid and convex peeling
Distance-based approaches	Distance-based outliers relies on the notion of the neighborhood of a point	+ Do not requires excessive computation – Suffer from detecting local outliers in a data set with diverse densities	Index-based, nested loop based, grid-based
Density-based approaches	Outliers are located in low density regions	+ Detect outliers that would be missed by techniques with single, global criterion – Parameter selection for upper bound and lower bound is difficult	k-distance, k-distance neighborhood, Local outlier factor
Cluster based approaches	Cluster represent related objects and there is a large distance between the outliers and its closest cluster	+ Do not requires labeled data – Effectiveness depends highly on the clustering method used – High computational cost	
Dimensionality reduction techniques	Data variability can be explained by few dimensions	+ No need to fit to a data distribution + Do not requires excessive computation – Inefficient for data set with high dimensionality	Principal components analysis, factor analysis

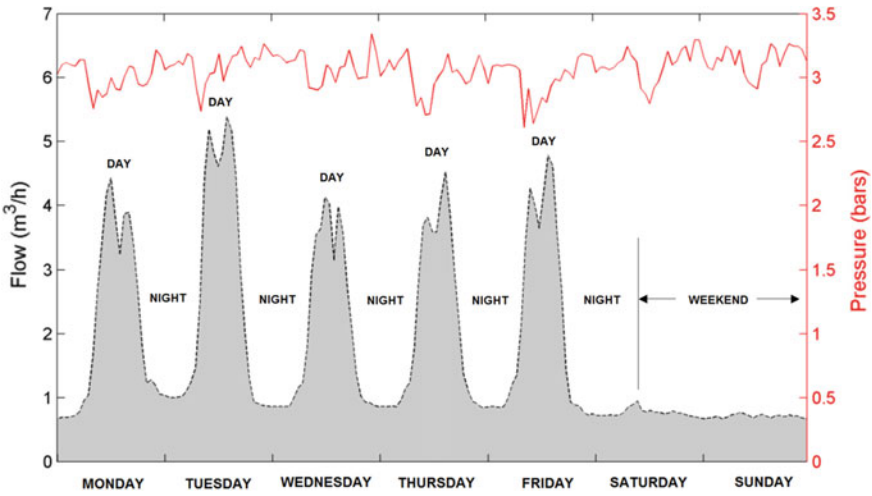

Fig. 12.15 Weekly profiles of flow and pressure values in a monitored node [16]

Wang 's list, the fault detection, which applies the historical data in order to improve the smart system itself. In order to provide an overview about this topic, Table 12.4 presents a list of works published in the two last decades addressing each one of the mentioned four points.

12.5 Conclusion

Smart water technologies are capable of significantly reduce water losses, improve the asset managing of water infrastructure and increase resilience against extreme climate events. This set of technologies are mature and ready to help water utilities to operate more efficiently. They are also crucial for urban areas to better preserve their limited water resources.

Rural areas and small villages are also prone to implement smart water infrastructure. The initial costs are higher than a traditional water network, but it is possible to implement a smart network with a limited set of features at an affordable cost. A rural water supply or irrigation system with smart online metering and automated pumping, for instance, won't be much more expensive than a traditional one, and the increase in the initial costs could be recovered in a few months with the reduction in leakages, pipe bursts and energy waste. Another characteristic of a smart water system is scalability, which means that, as the network grows, the system can be easily adapted to a wider user base than originally intended. Thus, a smart water system that was initially deployed with a limited set of features could later be upgraded with more automation, or with the capacity of monitoring more parameters. Also, as the water network expands, an increasingly large area can be

Table 12.4 A brief review of data management of smart water systems by application area

Author	Topic	Method	Year
Load analysis			
[30]	Data capture and analysis for sustainable water management	Extensive review about the topic	2018
[40]	Review of smart meter data analytics	Extensive review about the topic	2018
[41]	Water management in urban area	Exploratory data analysis	2017
Load forecasting			
[42]	Short-term water demand forecast	Machine learning methodologies/ artificial neural networks	2018
[43]	Domestic water consumption	Statistical analysis and artificial neural networks	2015
[44]	Demand forecasting for water distribution systems	Time series forecasting framework	2014
[45]	Urban water demand	Machine learning methodologies/ artificial neural networks	2008
[46]	Short-term water demand forecast	Artificial neural networks	2001
Load management			
[47]	Improve efficiency of water distribution systems	Artificial neural networks/kalman filter/ particle swarm optimization	2018
[48]	Optimal design of water supply systems	Particle swarm optimization	2010
[49]	Design of water distribution networks	Particle swarm optimization	2008
[50]	Optimal design of water distribution	Shuffled complex evolution	2004
Fault detection			
[51]	Water pipeline failure detection	Leak detection algorithms based on absolute pressure and flow measurements	2018
[52]	Detecting and locating leaks for long distance pipelines	Leak detection and localization algorithms/efficient wireless sensor node system on chip	2016
[53]	Leakage management	Mathematical modelling and statistical analysis	2013
[54]	Leakage fault detection in district metered areas of water distribution systems	Cumulative sum algorithm	2012
[55]	Leakage detection	Bayesian probabilistic	2003

monitored without varying the core architecture of the system. A higher initial cost could be a setback for many smart water projects in rural areas. Other typical obstacles are the lack of internet access and the lack of local IT specialists. The latter can be mitigated by investing in capacity building among the local population. Mobile collaboration, in which experts assist remotely to the workers that are on field, could also be very useful for solving maintenance issues in rural water systems. Besides higher cost and technological complexity, the benefits and functionalities of smart water systems make the challenge worthwhile for cities of all size, from large urban areas to small villages.

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Chapter 13
Rainwater Harvesting: A Challenging Strategy to Relieve Water Scarcity in Rural Areas

Faissal Aziz, Mounir El Achaby, Naaila Ouazzani, Jauad El-Kharraz and Laila Mandi

Abstract In recent decades water demand around the world has increased due to the scarcity of water. In the arid countries, water resources are characterized by a very high sensitivity to climatic fluctuations, an irregularity in time and an imbalance of spatial distribution in addition to vulnerability to drought and pollution. In most developing countries, there is frequently a shortage of drinking water supplies infrastructure, especially in rural areas. Consequently, interest has been rising in the use of rainwater harvesting which is considered as a climate adaptation strategy and was applied by many civilizations in the history of humanity. The populations of these areas resort on this method in order to have a continuous source of water for their own use by storing water in traditional reservoirs or small individual sized systems. In fact, it's one of the major drinking water supplies in rural areas that ensures a sustainable resource of water that is at least sufficient especially during drought periods. These reservoirs are fed from rainwater and/or directly from surface water of rivers after rainfall, and this water is generally consumed by the surrounding population without any treatment. Uncontrolled water storage in itself brings deterioration of its quality.

Keywords Rainwater harvesting · Rural areas · Reservoir · Drinking water

F. Aziz (✉) · N. Ouazzani · L. Mandi
Laboratory of Hydrobiology, Ecotoxicology, Sanitation and Global Change (LHEAGC, URAC 33), Semlalia Faculty of Sciences, Marrakech, Morocco
e-mail: faziz@kth.se

F. Aziz · N. Ouazzani · L. Mandi
National Centre for Research and Study on Water and Energy (CNEREE), Cadi Ayyad University, Marrakech, Morocco

M. El Achaby
Materials Science and Nanoengineering (MSN) Department, Mohammed 6 Polytechnic University (UM6P), Benguerir, Morocco

J. El-Kharraz
Middle East Desalination Research Center (MEDRC) Water Research, P.C. 133, Al Khuwair, Oman

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13.1 Introduction

Getting enough water is a daily struggle that takes a lot of time and energy, especially for women and children [14, 15]. The extent of this problem is growing as a result of population growth, armed conflict, urbanization and the projected effects of climate change [46, 74, 83, 111]. Indeed, a WHO report dealing with the situation in 2008, notes that while 30% of the population of the African region lives in rural areas, only 16% is served by public water distribution networks and the rest population uses individual facilities. Currently, it can be said that a significant improvement has been recorded for urban environment, while rural populations, which are often the majority in developing countries, are experiencing a less brilliant situation in their drinking water supply [105]. Taking the living conditions of these communities into consideration, surface and rainwater storage can be a suitable alternative solution to the lack of water [1, 45, 54, 101]. With water harvesting and storage, reliance on unreliable sources of water, such as backwaters can be significantly reduced.

13.2 The Popularity of Water Tanks: A Process Against Scarcity

Rainwater harvesting has been practiced for centuries; it is a simple and low-cost method [71]. In this method, Rainwater is collected from roofs or catchment areas and stored in different storage systems [38]. By its decentralized nature, the collection and storage of water allows people to manage their own water at the household and community levels [26]. Rainwater harvesting can be adequate solution to meet a large portion of water needs [31, 54, 101]. It also provides a good alternative during drought periods and when water levels drop and wells dry up [45, 54, 60, 101]. However, as precipitation is uncontrollable, it is of great importance to use the limited quantities of rainwater as efficiently as possible, especially in the climatic conditions of arid or semi-arid regions [55, 87]. The collected water is a valuable complement that would otherwise be lost due to surface flow or evaporation [62, 68].

The recovery of rainwater is considered a traditional practice in some countries. Their domestic use is a popular topic among researchers who aim to identify the key issues that need to be addressed to promote the return of worldwide to the historical evolution of the use of rainwater tanks [77]. Gould [47] refers to the first conference on the use of rainwater systems for domestic water supply in Honolulu, Hawaii in 1982 where 50 academics and practitioners were present. This was the beginning of a series of international conferences on rainwater or surface water collection where thousands of participants were present from a very wide cross section of countries, professions and advocacy organizations [77]. In addition, McAlister [72] stated that in many parts of Australia, the rain was the only source of water used simultaneously for domestic or other purposes. He also observed that Queensland residents were inclined to use rainwater in parallel with water from the network. They also used rainwater for drinking purposes.

Like other decentralized techniques, water storage is now reappearing in urban areas in a new and more sophisticated form, using modern technologies and knowledge that qualify it as retro-innovation [48], in the sense proposed by Poujol [84]. Gradually, the rainwater recovery and utilization facilities constitute a parallel water supply system, complementary to the centralized drinking water network [32, 54].

In this sense, the collection of rainwater and/or surface water is an excellent tool which, with proper use, could considerably reduce the continual pressure on watersheds [39, 87, 108]. In order to use resources and support farming practices, various technologies have been implemented to exploit rainwater. The techniques currently used are infiltration pits, ridges, and the use of runoff collection channels [66]. The collection of water is an old practice that goes back more than 3000 years. Worldwide, the popularity of rainwater harvesting is growing [33, 65, 81, 108, 111].

In Morocco, the use of domestic rainwater tanks is a well-established and relatively common practice, especially in rural and remote areas. Thousands of families in rural areas rely mostly on rainwater tanks for drinking water. However, in a new perspective aimed at solving the problem of water scarcity, especially in the South one, the Moroccan government is currently conducting studies aimed at the construction of a rainwater retention pond. Indeed, in Marrakech, the Drinking Water Supply Agency has already built a rainwater storage tank with a capacity of 20,000 m3 spread over an area of 4000 m^2.

13.3 Different Types of Storage Systems

13.3.1 Rainwater Storage Systems

Roose and Sabir report in 2002 [90], that the “magden” in Algeria, “matfya” in the Rif or “lavogne” in France are open ponds of a few tens of m3 that store the runoff of a track or a short impluvium (stony or encrusted and packed), to ensure livestock watering. With a pond of 80 m^3, it was possible in the region of Wadi Mina in Algeria to maintain 40 sheep and a family and irrigate a small fruit garden in marled hills receiving 300 mm of rain per year. The biggest problem is to reduce sediment input and maintain water quality by keeping livestock out of the pond.

Cement tanks; The Romans and Arabs have built a number of cisterns buried in the ground, capturing the waters of the roof (Mazets of Montpellier) or a rocky impluvium (Telman cistern studied by Bourges et al. [20] near Gabès in Tunisia). Van Wesemael et al. [109] studied 51 buried tanks (aljibes) in the province of Almeria (Spain). This system is still viable today provided that the tank and the runoff volume are sufficient to fill the tank (>60 m^3).

Ferrocement tank; The ferrocement tank is one of the types of storage built above ground, a technology that is 30 years old if not older. The combination of the mortar with steel is intended to provide a solid frame that supports the weight of the water as well as the effects of expansion or retraction due to changing climatic conditions. Ferrocement tanks under the RAIN Program for West Africa have a capacity of 10,000–14,000 L and are mostly built at the household level.

Tank in cut stones; This type of tank makes it possible to have a storage capacity close to 60 m^3 or more. This type of tank is made of large stones and cement which gives it a solid framework and is in most cases relatively easy to build. These tanks store water past the roof and are mainly built around community infrastructure such as schools or health centers.

13.3.2 Stormwater Storage Systems in the Valley

Construction of narrow terraces in the wadi; In semi-arid areas where it is difficult to cultivate the slopes, hedgerows are established along the wadi to slow down the speed of the current, capture the water and their sediment load to gradually build a dry season garden feeding a "seguia" (channel running along the hill to irrigate a terrace downstream). These hedges consist of Provence canes, various poplars, willows, ash trees, tamarisk, eucalyptus and oleander, sedge and rushes.

The Jessours; In the arid zones of southern Tunisia, earth embankments are built in series in the valleys to capture the runoff and its solid load in order to build a series of terraces gradually planted with fruit trees (palm, fig and olive trees), cereals and legumes [18].

Hill dams are built to harvest the runoff that will be redistributed for the irrigation of small terraces downstream or pumped around the edges [5].

13.3.3 Storage Tank Design

The water storage tank represents the biggest investment of a water collection system; thus, requiring careful consideration to ensure an optimal storage capacity and structural solidity while keeping low costs [119]. For the storage of water on a very small scale, in developing country, the people usually use plastic bowls and buckets, jerrycans, earthenware or ceramic pots, old barrels of oil or empty food cisterns.

To store large quantities of water, a tank placed on the ground or buried is needed. Its size can vary from one cubic meter (1000 litters) to one hundred cubic meters for larger tanks. For domestic systems at the household level, the size varies from 10 to 30 cubic meters and for systems at the community or school level, it ranges from 50 to 100 m^3, depending on the precipitation cycle [58]. Round tanks are generally stronger and require less material than square tanks, for the same storage capacity.

13.4 Water Storage Tanks in Morocco: A Typical Alternative for Rural Areas

Since its independence, Morocco has increased its annual production of drinking water by 10%, going from 80 million m^3 in 1956 to nearly 900 million m^3 currently. However, there is still a wide disparity between the urban and rural sectors in the country.

At the time of the last general census in 2018, the total population of the Kingdom of Morocco was 35.5 million, of whom 41.4% lived in rural areas [78]. The latter rate has steadily declined, since in 1960 it represented 70%, 65% in 1971 to reach 36% in 2030, according the Office of the High Commissioner for Planning. This decline usually accompanying the development of nations is also the same in Morocco with a strong rural exodus to the cities, with negative spinoff effects. As a result, the rural population of Morocco growing at an annual rate of 1.06% was distributed in 2000 to 1.86 million larger households in 2009 with 11.7 million inhabitants.

Surface water in Morocco is a significant contribution to the sustainable development of agriculture, livestock and industry in the country. It also allows, during normal rainfall, the recharge of certain aquifers and especially the preservation of the equilibrium of the ecosystem. In addition, they are likely to be used as drinking water and irrigation water. This is the case of the Assif El Mal River, which plays a very important role as the main source of storage water for the local population [9].

13.4.1 Difficulties in Rural Areas

13.4.1.1 Habitat Dispersion

In Morocco, the rural population is spread over almost 32,000 villages of less than 500 inhabitants. In some areas, the villages themselves are “split up” into several groups of dwellings, which can lead to total dispersal of the habitat. Under these conditions, any public water supply system could only be realized at the cost of major investments and high operating and maintenance costs.

13.4.1.2 Difficulties of Management and Maintenance

Frequent maladjustment of equipment, lack of organization and structures able to properly perform the tasks of management and maintenance are causing significant difficulties. It must also be remembered that the concept of free water, which fundamentally differentiates the rural world from the urban world, is still too often an obstacle, at the individual level, to the management and maintenance of equipment as soon as their technological level requires it.

13.4.1.3 Uneven Distribution of Water Resources

As 85% of the country's water resources are located on 1/3 of its territory, the water supply of rural populations in deficit regions would require the use of long-distance water transfers and consequently the realization of water resources projects that are expensive and difficult to manage by local authorities. On the other hand, areas without sufficient groundwater recharge rely only on temporary sources, even if the annual rainfall is relatively abundant, as in the Rif for example.

13.4.1.4 Organizational Difficulties

The multiplicity of stakeholders and the lack of coordination do not favor rational development of the sector. This is most often results in a low valuation of the actions undertaken and even a loss of effort.

13.4.1.5 Weakness of Investments

The per capita expenditure for the 1981–1995 plan for drinking water is of the order of 100 DH/year (9$/year) for a city dweller while it is at least 10 times lower for a rural inhabitant.

Faced with these difficulties, the majority of rural populations store rainwater and/or surface water in reservoirs named by these populations "Matfia", they use these waters for different uses.

13.4.2 Water Storage Tanks or "Matfia"; an Ancient Resource

13.4.2.1 Definition of "Matfia"

According to the French in Morocco dictionary "MATFIA, MATFYA or METFIA. Water: a red matfia water dust. It boils, it makes it drinkable to our taste. (The Opinion, 14/04/92)". A reservoir, either natural or man-made, contains water and has earth bunds (Photo-13.1). Rivers, rainwater from the watersheds or rainwater that accumulates in the areas to be flushed (Photo-13.2), flow into the reservoir. The threshing-floors are stone or clay surfaces (in Arabic, we use the word *nader* or *anrar* (in Amazigh)), it can take a circular shape but it can be also rectangular. It is a place where local farmers separate and treat their crops; they separate the cereal seeds (wheat, barley, oats…) from their straws traditionally (by the donkey). The threshing-floor is established, most often, near homes in a place where they are well exposed to the wind. In addition, these threshing-floors play an important role in the

Photo-13.1 Detail of a traditional reservoir (matfia) and its compones

Photo-13.2 Feeding matfias with rainwater falling on the threshing-floor in the Haut Atlas [121]

collection of rainwater due to their well-developed form. As a result the population connects them to their storage tank to feed it.

Single tanks, with an area of less than 40 m^3, are fed by precipitation and have low storage capacity. Complex reservoirs are fed by river water and rainwater runoff through diversion dams, supply channels and surface flows [11]. They can be connected in cascades where water from an upper reservoir flows into a lower reservoir.

13.4.2.2 Tank Configuration

According to Joliffe [59], there are many ways in which water tanks could be configured (corrugated sheets, concrete). The material and design of the walls of a tank must allow it to withstand the external pressure of soil and groundwater when the tank is empty. Tree roots can also damage it. It is therefore very important to choose the location of the tank. By installing it partly above ground level and well above the groundwater level, problems caused by rising groundwater and the passage of trucks, which could damage the underground construction. Local materials such as wood, bamboo and wicker could replace steel to reinforce concrete tanks. An underground tank must be equipped with a device to draw water: a pump or a bucket and a rope. To prevent contamination of the stored water, the device must be healthy, maintained, and cleaned regularly [115].

There are two categories of reservoirs: the surface tanks and the underground ones (tanks), the former being more often used for the collection of roof water. Surface tanks are usually made of metal, wood, plastic, fiberglass, bricks, interlocking blocks, blocks of earth or compressed rubble, cement, or reinforced concrete. The choice of material depends on its availability locally and the budget available. In most countries, there plastic tanks of varying volumes are usually available. Surface tanks are generally more expensive than cisterns, but they are more durable; they must also be equipped with a tap allowing to be used in water.

13.5 Quality of Stored Waters

Traditional water sources are often located at a distance from the community. When water harvesting and storage is near residential areas, water supplies are more accessible and convenient to use, with positive health impacts [116]. This system also reinforces the sense of ownership. One of the major concerns of rainwater harvesting is the alleged fear of the quality of water stored in the reservoir. Aziz et al. [12] indicated that improved quality of harvested water could be achieved through integrated system treatment that includes solar disinfection technique, resulting in high water quality consistent with the Moroccan Drinking Water Guidelines. Several methods are used to make this water drinkable [31, 100].

Numerous studies on the pollution of storage water, carried out since 1970, have confirmed pollution impact on aquatic environments [22, 50, 91]. A common concern is the purity of the rainwater harvested from the surface or the reservoir water [120]. Harvesting and using rainwater is considered very attractive in the absence of contaminants and pollution. Various sources of external pollution (for example, pathogenic microorganisms or chemical contaminants) have the potential to influence the quality of rainwater [7, 9, 13, 24, 94, 98, 120]. The impacts of (1) tank cleanliness and age, storage tank, pipelines and (2) weather conditions contribute and impact the quality of water harvested [13, 24, 92, 98, 120].

The quality of harvested water can be affected by several factors mainly the location, climate, and the nature of the storage system [11, 9, 13, 67, 92]. The location influences quality of the rain water, for example if the area is prone to acid rain or if there is a large amount of pollution in the local watershed. The quality of harvested rainwater is also affected by roof equipment. For residential and commercial rainwater customers, roofing materials can become a serious source of diffuse pollution [13, 24]. Water quality is also affected by air pollution and potential contamination of roof water by plants or animals [67]. In the state of Virginia, there have been some studies that describe the quality of rainwater. A survey of tanks showed that only fifty percent of the tanks sampled meet federal drinking water standards [117]. Most of these tanks failed with respect to total coliform contamination. These tanks were also analyzed for possible contamination with more than 30% within 200 m of a septic system. When properly maintained, it is expected that tank contamination may be much lower than that observed in the study.

The quality of harvested water can be improved if rainwater collection systems including roofs, gutters, pipe networks and storage tanks are cleaned regularly and are made from non-toxic materials. Pollutants deposited on roofs can contaminate stored water and cause sediment accumulation in the storage tank [75, 76, 92]. The general perception is that poor maintenance of rainwater harvesting systems can lead to microbial contamination by bacteria, viruses and protozoa, as well as chemical contamination. In general, any pond on the roof will be contaminated with excreta of dust, organic matter, birds and animals, and pollutants from human activities [75, 98]. This diversifies the risks of contamination of these water resources that can be either chemical and/or microbial.

13.5.1 Chemical Contamination of Reservoirs

The sources of chemical risks can be divided into two types:

- Off-site sources beyond owner/resident control, including urban traffic, industrial emissions and poor agricultural practices (e.g. pesticides, spray mist). In urban areas, potential contamination with lead has attracted more concern, due to its relatively frequent use, while in rural areas contamination by pesticides has been the major problem [56].
- Those coming from on-site sources in the immediate vicinity of the tank, and controllable by the owner/resident. These sources include the characteristics of the collector, the materials used in the construction of the tanks, etc. [4, 7–9, 11, 13, 28, 70].

13.5.2 Microbial Contamination of Reservoirs

Rainwater collected and stored in indoor reservoirs will contain a series of microorganisms of one or more origins [2, 7–9, 13]. While most will be harmless, the safety of rainwater will depend on exclusion or minimizing the presence of enteric pathogens [8, 9, 116]. Enteric pathogens include different types of bacteria, viruses and protozoa. These organisms do not grow or survive indefinitely in water environments and are introduced into faecal contamination in drinking water. Thus, water reservoirs may contain organisms called opportunistic pathogens such as Aeromonas spp. and Pseudomonas aeruginosa. Except for severely immunocompromised individuals, these organisms are not considered to represent a significant risk through normal uses of drinking water supplies [12, 114].

The tanks are installed above the ground and accumulate roof runoff via gutters. In this case, the probable sources of enteric pathogens include:

– Feces (excrement) deposited by birds, lizards, mice, rats, opossums, etc.
– Dead animals and insects, either in the gutters or in the tank itself.

According to Aziz et al. [12], Abbott et al. [2] and Bae et al. [13] inadequate maintenance facilities, inadequate water purification, inadequate delivery systems, and inability to take physical measures to protect water from microbiological contamination are the main reasons for the occurrence of any faecal contamination possible in rainwater. On the contrary, Coombes [29] demonstrated that the presence of all coliforms cannot be used as a vital sign of contamination in rainwater. The study argues that coliforms can occur very naturally in the environment. The main sources of fecal contamination are feces from birds, frogs, dead animals and insects, whether on rooftops or in the water reservoir itself [35].

Less frequently, the collected water is stored in underground reservoirs or tanks. If these tanks are not fully sealed or runoff protected, microorganisms associated with human and animal excreta can also contaminate stored rainwater [9, 116]. The microbiological quality of drinking water is usually measured by tests for Escherichia coli or alternative thermo-tolerant coliforms (sometimes referred to as faecal coliforms, less precise term), as indicators of faecal contamination and thus the possible presence of enteric pathogens. In the past, the large total coliform group has also been used for this purpose. However, this group includes non-pathogenic organisms that can grow in aquatic environments and may be present in the absence of fecal contamination (as it can be found in soil or vegetation).

Thermotolerant coliforms or *E. coli* have been frequently identified in domestic tanks [8, 9, 37, 43, 98, 107, 110]. This implies that enteric pathogens can often be present in rainwater tanks. However, when studies included specific pathogen tests, the detection was not common. In Australia, Campylobacter was identified in six of the 47 cases in a survey [110] while other pathogens such as Salmonella, Shigella, Cryptosporidium and Giardia, were not detected in a number of surveys of domestic rainwater reservoirs [107], Victorian Department of Natural Resources and the Environment, [110].

In New Zealand, Campylobacter was identified in 9 out of 24 reservoirs, but maximum concentrations were less than 1 per 100 ml and it was concluded that the risk of illness from drinking this water was low [93]. Cryptosporidium oocysts of unknown species were detected in 2 of 50 reservoirs that contained at least 30 fecal coliforms or 60 enterococci per 100 mL [98]. Similarly, Savill et al. [93] reported that detection of fecal coliforms in 43 of the 156 samples from rainwater reservoirs in Thailand, but Salmonella was detected in only one sample and none of these samples contained Shigella.

Water reservoirs can provide excellent habitats for mosquito breeding. In addition to causing nuisance, certain types of mosquitoes can be vectors of arboviruses. In Queensland, it has long been suggested that rainwater reservoirs are associated with the reproduction of Aedes aegypti, the main vector of dengue virus [61]. This was confirmed during a dengue epidemic in the Torres Strait Islands in 1996–1997 [51]. In addition, a survey conducted in the Torres Strait Islands in 2002, adult mosquitoes were identified, including Aedes aegypti, in rainwater tanks with missing or defective nets [89].

13.5.3 Factors Leading to the Revival of Bacteria in a Water Reservoir

The hydraulic configuration is one of the most important parameters for the efficient management of treated water inside a reservoir. Inadequate management of water transit in a reservoir can cause dead zones formation [19, 49]. Indeed, Gauthier et al. [41] attribute the considerable decrease in chlorine residual in a drinking water reservoir of a large municipality, on a time scale ranging between 5.6 and 7.9 days. A modification of the reservoir hydraulic configuration (closing a compartment and changing the pumping cycle) allowed reducing residence times and therefore obtaining a residual chlorine concentration greater than 0.1 mg/L in the reservoir and in the corresponding distribution area.

Sediments found at the bottom of reservoirs favor the growth of bacteria and it is mainly hydraulic conditions (low water velocity) that contribute to the accumulation of these sediments. Sediments are composed of organic, inorganic, and microorganisms [9, 42, 96]. Aluminum oxides, iron, manganese, and calcium are the main inorganic compounds found. The proportion of organic and mineral components in sediments is approximately 20 and 80% respectively [10, 42]. In addition, toxic metals such as zinc, copper, lead and cadmium can be found. Microorganisms have a high affinity for sediments because they find in them the food necessary for their development and, also, protection against oxidants. Schreiber and Schoenen [96] find that there are more than 9000 organisms per liter of sediment. In this study, the dominant group identified, in terms of number, is rotifers. In the same context, Douki [34] reveals the presence of aerobic heterotrophic bacteria (BHA) and in some cases coliforms in the sediments present in the bottom of reservoirs in Montreal city. Total coliforms were detected in two out of twelve cases and the BHA concentration was in the order of 106 CFU/mL.

The structure status, as well as the equipment attached (pumps and samplers) to the reservoir can, in some cases, increase the possibility of microorganisms intrusion and contribute to the degradation of water quality inside the reservoir. Although most reservoirs are in good condition, rainwater and groundwater can penetrate directly through roof openings or through walls with leaks. The development of recreational areas or parks above a reservoir can also contribute to the micro-organisms introduction in the water by the frequent presence of people and pets above the reservoir.

The use of certain products to protect the internal surface of the reservoir may be another source of contamination. Indeed, the use of a mineral protector on the surface of concrete walls in a drinking water reservoir in Germany, has contributed to the formation of microbial corrosion on the walls inside the reservoir [52]. Thus, the concentration of bacteria found in corrosion deposits was 106 cell/g with a free chlorine residual of 0.3 mg/L.

Oils used for the maintenance and lubrication of mechanical equipment in the reservoir, whose pumps may be a source of contamination. In fact, the contact of certain oils with drinking water can allow the development and growth of heterotrophic microorganisms given the biodegradability of certain lubricating oils [113].

Gauthier et al. [41] and Aziz et al. [9] has shown that water storage reservoirs are areas that can cause a water quality degradation since the sources of contamination are diverse and many hypotheses can be used to explain the presence of microorganisms at the outlet of the reservoir.

13.5.4 Risks Related to Reservoir Sediments

Sediments accumulated below rainfall can contain high concentrations of chemicals, including lead [29, 43, 86] and zinc [10]. In a survey of sediment samples from water reservoirs and along the Assif ElMal valley (rural area of Morocco), very high concentrations of zinc and lead were detected in sediment, while most water samples contained more than 3,5 mg/kg for zinc and 46 mg/kg for lead [10]. This sediment becomes a source of metal pollution in water, because the heavy metals in the sediments might be released into the overlying waters again via various processes [57, 69, 86, 118]. Although Sioud [99], have shown that the experiences of metal sorption (Cd, Cs, Ma, Co, and Zn) on natural particles of the Rhone are almost completely reversible after 72 days, sediments could be particularly important in the absence of regular cleaning.

The documentation indicates that the majority of enteric bacteria in aquatic systems are associated with sediments and that these associations influence their survival and transport characteristics. Two kinds of bacterial adsorption have been identified: (i) low adsorption, which is due to van der Waals repulsive strengths, and (ii) high adsorption, which is due to cellular appendixes or extracellular polymers excreted by the cell [82]. Bacteria that are poorly adsorbed are not really fixed to the soil surface but only closely associated. Low adsorption is considered a reversible process, while the strong link mechanisms are designed to be irreversible [17].

13.5.5 Impact of Reservoir Condition on the Quality of Stored Water

Drinking water reservoirs have been considered as inert infrastructure wherein the water quality at the outlet was identical to that at the inlet. However, several studies [6, 40, 41, 95] demonstrate that the conditions found inside these reservoirs can affect the quality of the water distributed.

The main factors responsible for an increase in the bacterial population in closed reservoirs are:

The hydraulic configuration: The residence time of water is defined as the time it takes for a water molecule to flow from the drop source to the point of consumer use. High residence time is often associated with a decrease in water quality. Inadequate management of water transit through reservoirs leads to increased water residence times and formation of dead zones [19, 40, 49]. Dead zones are regions or areas in a reservoir wherein water does not circulate and where residence times can be relatively high. The water stagnation causes a considerable decrease which facilitates in the sedimentation of suspended particles in reservoir bottom. Sediments favor the proliferation of bacteria [42, 96] since they find there the necessary food for their development and also protection against oxidants.

Structure status: Contaminated water (especially runoff and groundwater) can penetrate into the reservoir through roofs openings or through walls with leaks [79, 95]. Animals, such as birds or insects, can also accidentally penetrate the reservoir and contaminate the water if the opening and ventilation are not properly gridded [19].

13.5.6 Organoleptic Quality: Tastes and Smells

Water resources are confronted with taste and odour problems [103]. The absence of distinctive tastes and smells is a characteristic of good storage water quality, but there are a number of factors and/or conditions that can cause a deterioration of these characteristics during harvesting, storage, and piping. Other than dead animals, the main sources of taste and smell are:

- Metabolic products of microorganisms [102] (Suffet et al 1999).
- Sediments and silts at the bottom of basins or in piping systems that may contain stagnant water.
- Decomposing soil and vegetation accumulating in gutters.
- Growth of seaweed in pipes or open cisterns [112].
- Pollen.

Sediment and silt smell are the most frequently reported. Sediments accumulate at the bottom of reservoirs that have not been cleaned often enough. In hot weather, anaerobic conditions may be developed, leading to the growth of microorganisms that produce sulphides having a distinctive smell [27, 85].

Piping (for example, underground piping in watersheds from the roof of reservoirs, between reservoirs or from cisterns to buildings) can also be a source of false tastes and smells, especially when standing water is stored between rain events [23, 63]. In these environments, sludge and biofilms can be formed in the same way as for the sediments in the reservoir, anaerobic growth can occur, leading to the production of sulphides.

Vegetation and sediment accumulated in decomposing gutters can also liberate taste and smell components into the water, especially if the gutters are not kept clean and are not fully drained between rain events.

Open cisterns are rare but exposing stored rainwater to the light can allow seaweed growth. Most seaweed is not a risk to human health, but growth can affect the taste, smell and appearance of rainwater. Piping that is not impermeable to light can also allow seaweed growth.

Some pollen has very distinctive tastes and smells and if allowed to accumulate on roof drainage basins or in gutters, they can affect the stored rainwater quality.

13.6 Diseases Related to Storage Water

The relatively frequent detection of bacteria indicative of fecal contamination is not surprising given that the watersheds, roofs and gutters are subject to contamination by small animal and bird droppings. However, despite the prevalence of indicator microorganisms, diseases reports associated with rainwater reservoirs are relatively rare. Although traditional under-reporting of gastrointestinal diseases has contributed to a lack of evidence, epidemiological surveys conducted in Morocco has also identified a real link [12].

Surveys conducted in a rural areas of Morocco compared gastrointestinal disease rates for children who drank rainwater collected in domestic reservoirs, compared to those who drank filtered and disinfect water that is tap water, which was completely compatible with Moroccan drinking water guidelines [12]. Overall, the surveys found a significant increase in disease associated with rainwater consumption. In the first part of the survey, a questionnaire was administered to parents of 272 children who undertake a general health check-up before enrolling in school for the first time. The incidence of gastrointestinal diseases, which is highly significant, had a higher rate for rural children who drank stored rainwater rather than tap water [12]. There was a high difference in disease rates between children who drink rainwater of reservoirs or tap water in urban areas.

The second part of the survey was extended to results for children in rural areas through the use of a newspaper study with the parents of about children in rural areas. The results were reversed and the study revealed a significant decrease in disease associated with storage water consumption compared to running water [12]. The surveys included questions on the maintenance of rainwater reservoirs. As in most surveys, the interview was generally mediocre.

There have been some reports of illness associated with Campylobacter and Salmonella in rainwater stored in reservoirs. In four of these reports, contaminating organisms were detected in both infected organisms and their rainwater sources [21, 97, 106]. Brodribb et al. [21] have reported a survey of recurrent infections by Campylobacter fetus, of an immunocompromised old woman wherein the body has also been isolated from the patient's rainwater reservoir, which was her only source of drinking water. New infections did not occur after the patient started boiling the water in the reservoir before consumption. It has been postulated that the occurrence of 23 cases of campylobacteriosis at Queensland Island was probably associated with the contamination of rainwater reservoirs, even if Campylobacter has not been isolated from rainwater samples [73]. A study of risk factors for campylobacteriosis in New Zealand showed that the associated consumption of rainwater is an increased source of risk in a small number of cases (23 cases, 11 witnesses, odds ratio 2.2) [36].

An investigation on occurrence of Salmonella infections in a group at the Trinity Church in Jamaica led to the detection of the pathogen in rainwater samples and food prepared using rainwater [64]. It was reported that the roof was covered with fresh and dry bird droppings. Similarly, Salmonella was isolated from a rainwater reservoir used by a family of four in New Zealand that had suffered from recurrent infections with the same pathogen [97]. In an investigation of 28 cases of gastroenteritis in 200 employees on a construction site in Queensland, Salmonella saintpaul was isolated from two cases and rainwater samples [106].

An explanation of the apparent disparity in the frequency of fecal contamination and the prevalence of the disease could be the probable source of contamination. For most rainwater reservoirs, especially those installed above ground, fecal contamination is limited to small animals and birds. While fecal contamination of these sources may include enteric pathogens, there is a specificity degree of host-pathogen group. Enteric viruses are the most specific; in general, human infectious species infect only humans.

Birds that live near human populations can also transport Salmonella [53, 88]. These limitations are important because enteric disease induced by hydric bacteria requires ingestion of a much larger number of organisms than mediation in the case of enteric disease by protozoa or viruses. The dosing investigation found that if ingestion between 1 and 10 viral particles or protozoan cysts can lead to infection, at least 1000 and often more than 105 bacteria are needed [44, 80].

13.7 Measures to Protect the Stored Water Quality

Rainwater is generally unpolluted and pure before it reaches the ground. Its contamination usually occurs after contact with the collection system. It is therefore very important to regularly clean and inspects the collection surface and gutters to ensure good water quality.

The first rains should be used to remove dust, bird droppings, leaves, etc. that my exist on the roof surface. In practice, the preparation and cleaning of the roof before the first rains almost never happens. To avoid pollutants and contaminants entering the reservoir, it is necessary to divert or evacuate the first rainwater containing the debris.

This is why many storage systems integrate the installation of a device allowing to divert this “first flow” of water in order to not get it into the reservoir. However, a filter can also be used, in nylon or fine grid, preferably, to retain dirt and debris before water enters the reservoir.

Common sources of storage water contamination:

- dirt and fecal matters (mainly from birds and small animals) on the roof surface
- leaf debris and organic material carried into the reservoir
- animals, insects and birds that have drowned in water
- insects in the reproductive period
- dirty pails and containers.

13.7.1 Use and Maintenance

It is important to regularly operate and maintain all water storage systems, but this aspect is very often neglected.

Maintenance operations of a simple and private system for collecting water from the roof of a household or community centre are limited to an annual roof inspection, gutters and screens, removing leaves, dirt or other materials and cleaning the reservoir. In seasonal climates, the roof surface is probably dirty and covered with the dust during the dry seasons, it is therefore recommended to clean and sweep the roof, gutters and reservoir before the first heavy rains.

When various components of a CEP system are not regularly cleaned, there is a risk that some problems may not be identified or not to carry out the necessary repairs, and the system will not provide a reliable and good quality water supply. The maintenance and management schedule provides a basis for monitoring controls [115]:

During the rainy season: examine the whole storage system (roof catchment area, gutters, pipes, filters, first flow and overflow diversion system) after each rainfall and clean it at least after each dry period of more than one month.

At the end of the dry season: clean the reservoir and remove all deposit and debris at the end of each dry season, just before the rains came. It is also recommended to carry out a complete revision of all tank components: replacement of damaged filters and maintenance of the water extraction point or water pump.

All year: check regularly for leaks or fractures to be fixed. Only small leaks occurring during the first filling of the tank do not require repair and usually clog themselves up. At the slightest doubt of the presence of organic contaminants in the water, you have to bleach the water. The taps must never leak: in addition to the caused water loss, this would allow seaweed to proliferate in the sink or drainage system and would lead to the development of bacteria, which would be a hygiene problem.

The following section presents a program of activities related to reservoir operation and maintenance as well as the roofs and gutters to which they are connected.

13.7.2 Regular Maintenance [115]

1. Remove bird droppings from the roof and gutters. Also regularly remove leaves and other dirt from gutters and incoming filters.
2. Regularly inspect the insect screen of the overflow during the rainy season and replace it if necessary.
3. In the absence of an automatic system for diverting the first flow, disconnect the inlet pipe of the reservoir during dry periods. Replace it after the rains begin, once the system has been washed, to allow water to flow into the reservoir.
4. Measure the water level in the reservoir once a week, with a graduated rod. During dry periods, the level decrease must correspond to consumption, otherwise, there is probably a leak.

13.8 Regulations for the Domestic Use of Rainfall

Each of the countries mentioned below has its own regulations concerning the authorized domestic uses of rainwater collected downstream of the roofs of buildings. However, all these regulations allow the use of rainwater outside the building, such as watering green spaces, washing vehicles, cleaning the floor, etc. However, in Morocco, the absence of such regulation will be in favor of this study.

For the uses of rainwater inside the building, we provide an overview of the authorized uses in countries where rainwater reuse systems are being developed:

- In Australia, the authorized uses inside buildings are: the supply of toilet flushes (WC), washing clothes, hot water (heating). These uses constitute about 80% of the water consumed in a residential building [29, 30, 62].

- In Taiwan, only the flushing of toilets is allowed as use of rainwater. This constitutes 24% of domestic water consumption (250 l /p /day) [25].
- In Jordan, soil cleaning and flushing are the two most common uses of rainwater in buildings. This represents about 19.7% of domestic water consumption (about 141 l /p /day) [3].
- In the USA, collected rainwater is generally used in toilet flushing, garden watering and air conditioning (air conditioning) [16].
- In Brazil, rainwater can replace drinking water for any use that does not require drinking-quality such as: the supply of toilet flushes (WC), washing machine, car washing. These uses represent about 42% of total drinking water consumption (consumption varies according to region) [45].

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Chapter 14
Building Smart Water Communities: Technology and Institutions Toward Better Water

Asavari Devadiga

Abstract This chapter focuses on water service in small communities in India and demonstrates how a combination of technological and institutional aspects can bring reliable service for a better quality of living that can be sustained in the long term. Based on analysis of field research, literature review, and interviews of professionals, researchers, and policymakers, this chapter argues that creative solutions can be developed to make improvements over key, urgent problems of basic water service. The unit of analysis is a community formed by a cluster of households that may be situated in urban, peri-urban or rural or remote areas. Through a study of specific mechanisms in such diverse communities in the states of Karnataka and Telangana, the chapter makes two arguments: one, how technology and institutional mechanisms can make for "smart water"; and two, how such mechanisms can help build "smart water communities". The chapter describes what "smart water" and "smart water communities" mean and offers insights into building such communities through innovative ways of diversifying water resources and forming effective institutions toward better quality of life.

Keywords Smart water · Smart communities · Water supply · Water service · Planning · Infrastructure

14.1 Introduction

> NextDrop serves as a conduit of information, between the water agency and the users, bringing certainty to the service, where the users receive information on the water schedule in advance that enables them to plan their day more productively than to rely on the vagaries of the changing water schedule.

Water is one of the several basic infrastructure services and essential needs and which is not met for millions in the world. In the above case, NextDrop, a

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A. Devadiga (✉)
University of California, Berkeley, USA
e-mail: asavari@berkeley.edu

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non-profit organization in India uses technology to improve local water service. Where “smart water” or the term “smart” for water service has been mostly associated with technology, is it all about technology? Is that the same as a “smart city” or a “smart village”? Can it be strictly about either a city or a village? How do we then create “smart water communities”? This chapter explores these questions by examining cases of water delivery mechanisms that have improved service levels in different ways and the potential of such mechanisms to build “smart water communities”.

The chapter first provides a background on the discourse on “smart water” and the relevant Indian context of rapid growth juxtaposed with increasingly poor water service. The chapter then lays out the framework for the study with the methodology and research goals. The next couple of sections focus on the key findings on water service improvements and how they lend to building “smart water communities”. The chapter then provides insights from the study and concludes with reflections and recommendations.

14.2 Background and the Context

The relevant background can be provided through the broader discourse on “smart” and understanding of the relevant institutional background including the existing and the emerging “smartness” in delivering reliable water. This study also necessitates an understanding of the rapid urbanizing and prevailing water service context in India.

14.2.1 What Is “Smart”?

What does “smart” mean? There is no clear or definite definition. A comprehensive review of initiatives and practices on Smart Villages by Zavratnik et al. [29] brings a holistic approach to “smart” and makes it about achieving higher levels of sustainability. The Smart Village Network for example, connects villages and associations across Europe enabling them the exchange of information and experiences and therefore making their voices louder and stronger [29].

Relevant to water infrastructure and service, “smart” refers mostly to smart meters or technologies used to improve the water management systems. Broadly, “smart” is used as a term to conceptualize a city such as a “smart city”, again mostly using technology as the main theme. The Smart Cities Council in the U.S. defines a “smart city” as a city that “uses information and communications technology to enhance its livability, workability and sustainability.” The European Commission [6] defines a “smart city” where technology may form only a part of it: as an urban living environment, built or upgraded/renovated to enable the best possible coordination for otherwise fragmented urban sub-systems, and to facilitate everyday lives of inhabitants, making cities more liveable and sustainable.

Fennell et al. [7] call out the growing attention toward creating “smart cities” when there is an urgent need to recognize that smart and sustainable solutions are more important for rural communities, that are often far away from the growth poles of urban-based industrial development, and disadvantaged in their access to education and health. The notion of “smart villages” is built around the notion of advancing economic and social development and regarding the provision of sustainable energy, healthcare, education, water and sanitation infrastructures as the key catalysts for ensuring improved livelihoods, increased incomes, human security, gender equality and democratic engagement [11].

A “smart village” enables its inhabitants to make use of the contemporary technological and social achievements, while its infrastructures are still being developed in line with Sustainable Development Goals [26],[1] and offers an opportunity to efficiently deal with future of energy security and issues of local and circular economies [29]. Shukla [24] defines a “smart village” as a village where technology should act as a means for development, enabling education and local business opportunities, improving health and welfare, enhancing democratic engagement and overall enhancement of rural village dwellers.

Cutting through the arguably divided or polarized sets of definitions and objectives and between the rural and urban, Srivatsa [25] finds it necessary for smart development to consider both spaces simultaneously with their mutual interconnections and take into account that significant changes in one will affect the other and vice versa. Further as the world population grows and urbanizes, there is a call for new research and greater conceptual and empirical integration of urban and rural scholarship, which remains disconnected and segregated institutionally [14]; rejuvenation of work on rural-urban linkages [28]; and reclaiming of research on small towns and arguing for multidisciplinary dialog between large-scale analysis of urbanisation and in-depth scrutiny of localized ones [30].

14.2.2 The Indian Context

14.2.2.1 The “Smart” Schemes

The launch of the ‘100 Smart Cities Mission’ in 2016 in India, was followed by the announcement of the Shyama Prasad Mukherji Rurban Mission (SPMRM) aimed at making villages smart and the future growth centres of the nation, and establishing a proposal for 2500 Smart Villages by 2019. To ensure a standard of development,

[1]Sustainable Development Goals are part of the 2030 Agenda for Sustainable Development adopted by all United Nations Member States in (2015), that provides a shared blueprint for peace and prosperity for people and the planet, now and into the future.

the mission covers a list of 14 parameters, which include piped water supply and sanitation [7]. Under the Saansad Adarsh Gram Yojna (Parliamentarian's Model Village Scheme), each parliamentarian is mandated to adopt three rural villages and ensure that these villages are transformed into "Smart Villages" by 2019. Villages will be backed up by the provision of basic amenities that are often only available in urban areas and a social security system. There have been programs on various areas such as employment, agriculture and nutritional health [24]. However, nearly half the projects in the adopted villages had not been completed as of March 2019, and work had not even started on more than a third of the projects under the program which had a deadline of March 2019, the central government has conceded [23].

The intention of building Smart Cities and Smart Villages in India lacks any mention of potential for explicit linkages between the urban and rural spheres [7]. Thus, the concept of Smart Cities or Smart Villages seem to miss the peri-urban communities or sometimes even the entire units or clusters of users that reflect both urban and rural characteristics. The idea of "smartness" must consequently be not only about the means and design for providing access to communities' infrastructure such as roads, water, power, education and healthcare facilities, but also about the local institutions and networks that can ensure sustainable growth and development in these cities, towns, villages, or regions.

14.2.2.2 Water Service

The water problem that millions in India face is dire—both within the context of rapid and exploding growth and as the multiple layers of the service itself that fail.

India is the second most populous country in the world, with a 2011 population of 1.21 billion [1]. An annual growth rate recorded at 5.5% during 1981–2001 was followed by further acceleration in the GDP growth to 7.7% during 2001–2011 [10]. Rapid economic growth has come with rapid and large-scale urbanization. However, there has been no corresponding improvement in infrastructure service and in turn, the quality of life.

Water service is one of the most essential infrastructure services that is lacking or is inadequate and remains looming at a massive scale. Piped water is only one way to get water access and just over half (approximately 52%) of India's population receives its drinking water through piped connections, which include both individual and public taps or standpipes [17]. Having a water connection alone does not ensure water service. Piped water is intermittent, sporadic, and the quality is questionable. Lack of reliable water service is therefore a problem with multiple layers embedded in the levels of service: access, quality, and availability in terms of time duration, quantity, pressure. The severity of the problem also reflects in how widespread the problem is [3, 18, 22].

Further, due to the rapid increase in population and development, the problem is not static; it continues to evolve as part of the changing heterogeneous landscape. Large swaths of land are being developed not just within cities but outside including the peri-urban areas, towns, and villages for housing, commercial, and industrial use with inadequate or no access to basic urban infrastructure services including water, sewage, solid waste, and roads [15]. Some are relatively easily served by piped water; for others, where there is no clear right-of-way for utilities, it is far more difficult to provide piped water to individual units. Heterogeneity is also evident in unplanned developments, growing subdivisions, and slums that have dwellings unfit for human habitation due to dilapidated structures and narrow streets [1]. The problem here is about urgency, how to deliver reliable water now, that can be sustained over time.

The focus of the water standards and the national water service level benchmarks has been on piped water service. The technical manuals and guidelines for water facilities [2, 16] also cater to centralised pipeline systems for delivering water from a distant surface water source continuously under pressure. However, at the local level, there are different water delivery mechanisms in play, whether it is a groundwater well or a storage tank (which is a different access point than a tap); a private tanker (which is different than the local utility); or using a filter at home (which is different than readily using centrally treated drinking water). Centralised systems emerge as the predominant and actively pursued mechanism at the national and state levels, albeit barely functioning, while other mechanisms although practiced commonly by the municipalities appear as marginal ways, evident through their limited recognition as a legitimate option to deliver water.

While water supply infrastructure is planned and built by the States, in most cases, it is the city municipality that operates and maintains the infrastructure and delivers water to the citizens. In the case of most villages, it is the State water agencies, and sometimes the local village councils or *zilla parishads* that operate and maintain water delivery systems. Private contractors are often involved, for example in advising on policy or constructing major infrastructure, or managing or operating certain facilities and processes of water delivery.

With the growing heterogenous landscape, increasing unreliability of water, and uneven grounds of programs on smart cities and villages, where do or can "smart water communities" reside? The rest of the chapter delves into this question and examines how they can be built around what the chapter calls "smart water" mechanisms.

14.3 Study Framework and Methodology

The unit of analysis for this research is a cluster of homes or a community of residents that form a neighborhood, may or may not be connected through a network or a grid and may form a part of urban, peri-urban, rural, or remote areas. A community may be (1) a neighbourhood (a place of cultural identity); (2) as part of a political jurisdiction (county, city, etc.); and (3) as approximated by data constructs (like zip code areas and census tracts) [27].

I use community as a unit of analysis such that it accounts for the heterogeneous physical user conditions that need to be served at a given time. What I attempt to capture are the living conditions (individual houses or multifamily building, other, or a combination) and water service conditions (access to piped service or no access to piped service, proximity to the nearest feasible water source, tank, or a pipeline network), which may also cover households with diverse socioeconomic status.

The communities here serve as cases to execute an empirical enquiry of how a delivery mechanism operates in improving water service. The empirical inquiry delves into what technological interventions or institutional mechanisms were used and how they addressed particular water service needs in those communities. Here, institutional mechanisms involve the political context, policies, processes such as monitoring and enforcement, and any measures within or outside the organisations that involve various actors including the policymakers or even the community itself.

The study goes further to understand whether and how the intervention can deliver "smart water" in a community (Fig. 14.1) and eventually help make it a "smart water community".

Here, smartness is about applying solutions that target the need of the hour and adapt to changing conditions such as population growth or changes in the water supply source (e.g., water scarcity or pollution), and that can be sustained over time through a combination of various aspects. To target the need of the hour, it is about service and all of its levels from adequate quantity, quality and availability to timing and certainty; any or all of which need to be met quickly to avoid long periods of waiting time for say, piped service to reach the communities. Achieving "smart water" can also lend to transferability of the delivery mechanisms to other communities in need and help build more such "smart water communities".

The research and analysis for this paper involved extensive literature review and analysis, and a detailed study including review of government documents, protocols, technical manuals. I also conducted field observations and structured and non-structured interviews of diverse professionals and researchers, which included planners, scientists, engineers, planning and water practitioners and researchers, and policymakers.

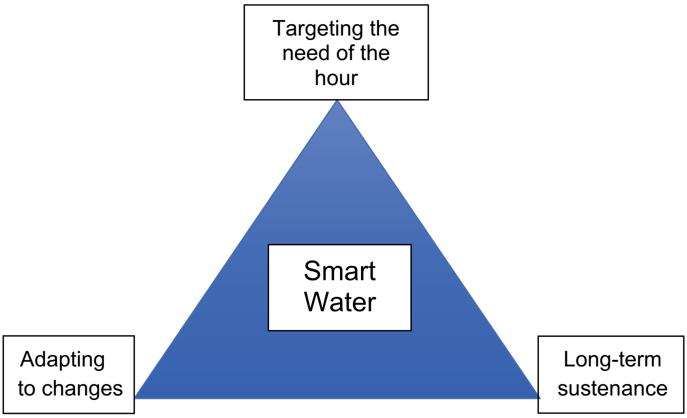

Fig. 14.1 "Smart water"

The communities researched here as cases and used for discussion purposes later in the chapter are located in the southern states of Karnataka and Telangana in and near growing regions and that are facing challenges in terms of one or more of the water service levels. The communities are located within the context of growing regions whether urban or rural or peri-urban, and that cut across the urban/rural dichotomy and exhibit different ways of achieving water reliability. Water is delivered to the households by a municipal corporation or municipal council if they are a part of the city or a town or by the State if they are a part of a village. For purposes of this study, the chapter refers to the water providers as local agencies. The mechanisms discussed here are used to cater to the water needs in those particular communities; this remains in the context of various technological and other water delivery mechanisms researched and implemented, which are not discussed in this chapter. This study does not claim that the mechanisms and communities studied are unique, in fact on the contrary, these are discussed precisely because of the diversity of service needs, mechanisms at play, and their potential of transferability to other communities in need. Hence this study provides valuable insights into how they operate and can be built upon to create "smart water communities".

14.4 Improved Water Service: Meeting the Need of the Hour

The study finds that "smart water" can incorporate delivery mechanisms not just through technological innovations for improved service but also through institutional mechanisms to ensure service reliability. The details of the technological set up, whether any particular software or modeling exercise is not the subject of this study; rather it is about how they make the water supply and demand meet in a timely manner for a community. This section thus discusses how smart water has been achieved in three communities through specific mechanisms. The mechanisms improve service, however their tremendous potential to form "smart water communities" remains untapped. The mechanisms can be used not only as a temporary measure but to sustain the reliability in the water service; the mechanisms may be used in the same ways or modified toward building smart water communities, which is discussed in the next section.

14.4.1 NextDrop and the Mobile Phone: Providing Certainty in Service

Community 1 includes households that reside both in single-family homes and one- or two-story apartment buildings that receive piped water service provided by the local agency. The service runs for approximately 2–3 hours a day for 3 or 5 days in a week. The water availability here depends on the user being at home when the water is on and for the duration the water is on. The time and the duration of the water service changes if there are emergency situations, such as water leaks, network breakdowns, or pipe bursts. Any notices or messages that are posted by the local agency do not reach the users in time and the users then have to cope with the sporadic nature of the piped water by forgoing work or other important tasks for the day incurring heavy costs.

Water is supplied to the communities for a specific number of hours in an effort to manage the water in the local reservoirs and guide its controlled distribution to the connected consumers. Water rationing is imminent to meet the water needs due to the inadequate and varying quantities of water stored in the reservoirs [5]. Water utilities in countries such as the U.S. identify water rationing as a water supply strategy during emergency conditions such as a drought or water scarcity or unanticipated infrastructure system breakdowns. In this case, water rationing is not an advanced planned strategy; rather it is an approach to work within the constraints of a malfunctioning infrastructure system and resources available and delivering water service at the same time. This in turn makes for uncertain, intermittent water service times for the users.

NextDrop, a nonprofit organisation was founded to apply innovative mobile technology. NextDrop identified the market and the need for addressing the uncertainty in the water service schedule and made a proposal to work with the local agency in resolving the issue. The local agency then entered into an agreement with NextDrop. Operating under a license, NextDrop provides a service of relaying in advance, the water schedule and duration of when the tap water would be available in the form of a text message on cellular phones of the residents [5].

The NextDrop staff works with the local agency engineers and valve men, who operate the water distribution network and are instrumental in scheduling and supplying the water as per schedule. NextDrop obtains direct information from the valve men and local agency staff concerning the different reservoirs and local tanks along with the water levels and quantities that change according to the weather, use, or other factors, which in turn affect the water supply schedule.

Based on regularly collected detailed data and calculations, the schedules of when the water might be supplied in different neighbourhoods are sent via text messages over the phone to subscribed customers. NextDrop serves as a conduit of information between the water agency and the users. It brings the much needed certainty to the service, where the users receive information on the water schedule in advance that enables them to plan their day more productively than to rely on the vagaries of the changing water schedule.

NextDrop retains the autonomous nature of decisionmaking related to its operations, and works collaboratively with the local agency staff toward a common goal of bringing certainty to the changing intermittent water service. The partnership entails an agreement of operation of NextDrop in the neighbourhoods with intermittent water service and where the users can receive the water schedule information and certainty in the piped water service at a nominal fee. At the time of this research, NextDrop provided this service for a fee of Rs. 10 per month to its subscribing customers and based on my interviews, had over 10,000 subscribers in the state. This technological intervention by an independent entity in collaboration with the local agency serves as a "smart water" mechanism, a timely improvement in a dire situation of long waits or sheer insufficient or unavailable water at the tap.

14.4.2 Tankers and GPS: Ensuring Water Is Delivered

Community 2 includes households that receive piped service and those that do not have access to piped service. Here, only a part of the community lies within the piped network, which delivers intermittent water service at arbitrary intervals. To cope with the poor water service, households contact independent private tankers infamous for charging exorbitant rates for water deliveries [4, 21]. This market is also characterized by malfunctions and unaffordable prices from lack of regulation and control. While the tanker companies are not registered, regulations on quality control are nil [19].

Here, I observed that the local agency used Geographic Information System (GIS) and Geographic Positioning System (GPS) technologies in spatially tracking the tractor- and tanker-operators.

We pay tankers to deliver water in peri-urban areas (19 tankers equipped with sensors) so (I) can track them via GPS. An IT firm administers billing of tankers.

– Interview with the local Chief Engineer

The engineer is able to monitor the travel routes of the vehicle so that the operator provides a true estimate of distance traveled in collecting and delivering the water. When the water is delivered as assigned to the community, the tanker operator obtains a sheet signed by the user confirming that the specified water quantity has indeed been delivered. The user pays for the delivered water at the local agency service centre and does not pay the tanker; this avoids any service compromises or overcharging of the customers [5].

The tanker operators are required to travel with a logbook provided by the local agency to ascertain quantities of water transported from the assigned reservoirs to the residents. The tanker operators collect the required quantity of water from the reservoir, enter a time in the log book, deliver water with a receipt, and get signatures from at least two users in the community at the delivery point. The operators log their time when they return to the local agency offices. A contract with an operator for daily tanker delivery service typically runs on a monthly basis. This provides an incentive to the tanker operators to maintain and improve their performance so that the contract continues to get renewed [5]. The payment to the operator is held back or retained until the entire work is completed. The contract is executed for a specific work task for a particular duration.

Being a public institution, providing service to the poor in particular—is one of the local agency's objectives. The water is delivered free of charge to the urban poor. The tariff for other users is Rupee (Rs.) 1 Per 10 kilolitres (kL) and for special/private functions and Rs. 23.20 per kL for private functions (hotel) and commercial use [5]. The "smart water" mechanism in action here is the institutional mechanism of using technology as well as specific contract management measures, to ensure the water is collected, transported, and delivered to the users.

14.4.3 RO and Water Kiosks: Safe Water Where There Is None

Community 3 covers households that have no access to piped service and are located at a considerable distance from the closest point of the piped network. In areas with no piped connections or no clean water supply source nearby, private vendors recruited by the local agency design, install, and operate kiosks that dispense ultraviolet (UV)-treated water at Rs. 1 for 10 litres. The kiosks treat the water drawn from reservoirs through processes that remove particulates and total dissolved solids and provide UV treatment. The kiosks are stationed within neighbourhoods, particularly in communities located outside the piped network, mostly in the peri-urban and remote areas that do not have ready access to water (Fig. 14.2).

The operators also design and build the UV-treatment units that are portable and can be easily installed at a particular location designated in a community where the residents collect water in bottles or cans. These kiosks serve as a "smart water" mechanism, a timely improvement in a desperate situation of no access to safe drinking water.

14.5 Toward Smart Water Communities

There are technologies and different means that serve specific water needs of households yet they seem to be operational only in some communities and serve mostly as a back up or a last resort. Such means also seem to be more of a reactive, rather than a proactive measure to meet the water needs [5], while there is still a vast majority of population that lacks basic water service.

Table 14.1 summarises the "smart water" mechanisms implemented in Communities 1, 2, and 3; the water service level they target to meet; and how they adapt or are tailored to the users they serve. However, the mechanisms fall short; they are inadequate in ensuring that the service would stay improved over time. It is questionable whether NextDrop will still operate successfully if, say the local Chief Engineer whom it had partnered with no longer works at that location. It is unclear whether the location-tracking mechanism will be successfully operated in the future for tankers or other means, or if there would be an assessment and proactive and

Fig. 14.2 Examples of water kiosks

proper vetting of several options before selecting a mechanism, rather than using a mechanism in an ad hoc manner.

As described in Sect. 14.4 and outlined in Table 14.1, the "smart water" mechanisms target specific on-the-ground water needs in each of these communities, adapt to the user conditions by connecting the supply and demand ends effectively, and deliver water quickly when the users otherwise would have had to suffer through a long wait to meet their basic water needs. However, sustaining the service takes more than only applying technology or implementing a measure at one point of time. "Smart water communities" as I define it here are the ones that

Table 14.1 "Smart water" mechanisms

	"Smart water" mechanism	Aspect of water service met	Adapt to changes?	Sustain over time?
Community 1	Text message re: water supply schedule	Certainty, availability	Yes, can be expanded to larger number of users	Not clear
Community 2	GPS on tankers and reporting mechanisms	Certainty, availability	Yes, tracking and monitoring is transferable	Not clear
Community 3	RO water kiosks	Water quality, availability	Yes, the number of kiosks can be increased to serve larger user size	Not clear

receive reliable water service in a sustained manner over time. What follows is a discussion of how that can happen and how the "smart water mechanisms" can be used to build "smart water communities".

Communities 1, 2, and 3 exhibit promising mechanisms that improve the water service fast and cater to the local user conditions, however they lack elements that would help them sustain the service in the long term and do not fare as "smart water communities". Such mechanisms may need continual enforcement, regulation of staff and contractor practices through specific role descriptions or contract provisions, regular monitoring, and other such additional mechanisms that can help maintain the operations of water delivery. The mechanisms may vary and need to be modified for specific contexts or unique characteristics of a community.

It is not definite if NextDrop will continue sending text messages about the water supply schedule to its customers. It is not certain if the RO kiosk operators dispatched by the local agency will indeed continue to operate in the areas that desperately need safe drinking water. Similarly, whether the private tankers will continue to be tracked to deliver water is unknown. Despite the promise that such mechanisms offer, they are not sufficient for reliable water delivery. "Smart water communities" can be created by sustaining them and ensuring that "smart water" continues to be delivered. This can happen in different ways, sometimes through a combination of them, which would also have their own downsides that are discussed collectively later in the chapter.

14.5.1 Policy Framework

One way to sustain the engagement with private independent operators or use of technology can be through legislative or a policy framework that keeps the user needs in check. Policy support can be provided through the right incentives to government agencies to evaluate different options and allow for selecting not only the least-cost option but that is appropriate for the water service needs in the long run. Mechanisms may be built into account for any malpractice; for example authorising specific agencies with requirements of documenting accountability of service and awarding contracts to private operators; and community policing or auditing and reporting mechanisms on a regular basis for ensuring the water service objectives are indeed achieved.

Policies may also be designed to help disburse resources from say, the Central Government's mission for "smart cities" and "smart villages" incumbent on the performance of the "smart water communities". This may involve phasing of projects so that the funds are not only used to upgrade or apply technologies but to ensure that the funds are indeed used to create "smart water communities" whether urban or rural.

14.5.2 Local Capacity: Institutions and Communities

Making "smart water communities" would involve more than one-time deployment of a technological or another solution. Whether it is a public agency, a private entity, or community-led effort, regular training and management of the individuals involved along with monitoring of the overall performance is critical for ensuring that the mechanism used continues to achieve reliable water. For example, in Community 2, when the local agency implemented GPS to track the tankers, there were additional measures to administer billing of the tankers as per the contract provisions and their performance, so the service continued to be delivered through the course of the contract. Tankers may be incentivised through say, awarding bi-annual contracts. Such practices can endure only by ongoing institutional support, which may be through the State or the local authority in question. If it is a community group, it may involve training and management of select individuals to ensure service delivery; coordination and decision making in case of any malfunctions or accounting issues form a part of it.

In the case of Community 3 that has no piped service, tankers or kiosks may be helpful in delivering water urgently, over a short term and also as planned back-up option in case of emergencies. However, in the long term, "smart water communities" may be formed by say, building community-led water systems that may involve technologies and designs to harvest rainwater or a local water supply source and collect, store, and treat the water at say a locally built facility and deliver it [5].

Water may be picked up from the facility in say, 10-liter pre-washed polythene cans or home delivered. A cart that can carry multiple containers at a time can be used to reduce the delivery trips. In similar such example in the state of Telangana [5], there is no direct cash transaction; rather a booklet of ten coupons, each coupon for sale at Rs. 1 is available at the facility. Drinking water is available for users at the rate of Rs. 1 for 10 litres (subject to adjustment for inflation) as against the baseline of no service available. Users buy coupons from the operator and exchange coupons for water on a regular basis. Local individuals are recruited for maintaining the water service. A moderate salary package as well as a respectable local employment opportunity help avoid any foul play.

To ensure water service is delivered as planned, the local public agency can regular audit the operations. This can be achieved by recruiting private entrepreneurs to design and build or design, build and operate such plants where the State would provide access to the supply source accompanied with regular audit and monitoring of the quantity of water drawn and delivered. There could be a State-approved list of certified or licensed engineers and contractors with quality performance standards where the work quality could be regulated through close monitoring and enforcement of those standards. There could be an arrangement made with the community where local human resources could be utilized in operating the plant. The operations of the plant in some cases have involved home delivery of water cans similar to the commercial water providers for offices in countries such as the U.S. The water is of drinking water quality and no additional water treatment is necessary. This mechanism would need to be combined with regular source water monitoring of both its quantity and quality to inform on its usage as well as any changes in treatment that may be necessary. The licensing and certification may cover bore well drilling or similar such professions that cover other water supply sources, and with the intent of an understanding of the water resource in its context, whether a larger watershed or an aquifer (discussed in Sect. 14.5.3).

14.5.3 Understanding Barriers

It is important to recognise that there can be barriers to best of the solutions implemented urgently to serve the water needs. Some planning can go a long way than incrementally using the back-up options as they come up. Delivering water by tankers over a long time may not be a sustainable option given the number of daily trips the tankers have to make in between the reservoir or the well to the users (if there is no communal storage option available and/or it is not possible to use large tankers) as well as the time taken for each tanker trip, which may vary with traffic, distance, and/or the weather. Further, this delivery option say, still assumes availability of an existing centralised surface water source. It may be that a local water source can be harnessed and with the involvement of the local dwellers, a community-led water service system may be built. Similarly, say for an institutional mechanism—whether local monitoring or setting up a policy framework—careful planning and designing of the different aspects of a measure can set up a path to achieve the water service objectives.

14.5.4 Situating Within the Larger Context

A “smart water community” can operate effectively by recognising the environmental and institutional contexts it is situated in. For example, while identifying and using a local source it is essential to understand and incorporate the water quantity and quality of the surrounding watershed or groundwater aquifer. Aligning with the previous institutional capacity discussion, say, in the cases of Communities 1 and 3, community water systems (or community-led water systems as cited in literature and experiences around the world) can effectively provide for the water service needed, when they are systematically planned for the users. More than selecting only what the market offers, an evaluation of different alternatives can help not just apply cost-effective but service-oriented and environmentally protective mechanisms. The alternatives may vary from maintaining the status quo of poor piped water or investing in repairing centralised infrastructure to providing the NextDrop-service along with pursuing other long-term solutions such as a community-based water system described above.

Beyond physical planning, it is critical that such systems and their management reside within the local or regional governing unit – whether the system is led by the local agency or is independent yet in communication with the local agencies. Coordination can involve sharing of best practices about identifying and addressing risks such as lower groundwater levels, and new research among multiple stakeholders on say, saltwater intrusion or algal blooms in a local pond that is used as a water source. It can also enable training, whether it is public education, community participation along with local and regional schools and universities, government or nongovernment organisations, or who may have access to funds and resources to support the communities.

A combination of technology and institutional mechanisms thus can provide reliable water service over the long term. As also argued by Zavratnik et al. [29], it is necessary to learn and draw on good practices from other countries, but meanwhile it is also necessary to consider local and regional frameworks within which the implementation of the Smart Village concept will take place.

14.6 Some Insights Forward

Creative solutions can be developed to make improvements over critical, urgent problems of basic water service. The "smartness" of the solutions comes not only from the technology used but from identifying the target needs of the community and urgently addressing them through different means—whether technology or institutional.

14.6.1 Smart Water

Being "smart", whether a city or a village, has different meanings in different regions of the world. Some of the early adopters of the term in water have seen it as use of technology for better lives, e.g., "smart water meter" where the meter informs the consumer about their water consumption and water charges at different times of the day. However, we cannot lose sight of the part that basic infrastructure is already established in several regions of the world, whereas, in some others, such as India it is yet to be established in many parts, therefore the "smartness" needs to be contextualised especially within the widely varying conditions on the ground.

14.6.2 Communities as a Unit of Analysis

Communities are not uniform [29]. With the large heterogenous user base in India and the rapidly growing water demand, communities offer a helpful unit of analysis where the population size might vary and what forms then are the characteristics conducive for certain type of water deliveries. Having a centralised water system with a single, uniform design template for a heterogenous landscape is like trying to fit a round peg in a square. For example, in communities with no piped service, bringing safe water may not mean only extending a pipeline connection because it is available for other communities; rather it would depend on whether there is a water network nearby and how far that is, or whether it is even a feasible option while the residents wait for basic drinking water. Each community may need a different way for meeting their water needs; a systematic look at the different communities can make for a more effective planning process to use resources efficiently.

14.6.3 Institutions

Creating "smart water communities" offers a scalable approach. For example, Nextdrop was able to scale it up to over 10,000 subscribers within months not only because of its technological expertise but applying it smartly for bridging the gap in the piped service through close coordination with the local agency. Here, both the authority and the decision to partner between the two entities and also the work with the local community are critical. While the tankers usually run by private enterprises charge exorbitant fees, recruiting tankers by the local agency for Community 2 coupled with the tracking and monitoring mechanisms provide for a promising institutional mechanism. Further, the water is delivered and the charges are determined by the local authority, which is responsible for safe water provision; this makes it affordable and even free for low-income communities.

Such insights may form a place and play a role in the schemes on smart cities or villages where large investments are being made by the Central Government. Area-based or citywide schemes have been approved for cities whereas in villages, the schemes have been barely able to take off [12].

14.7 Conclusion

This chapter examines water deliveries, termed as "smart water" mechanisms in small communities, and demonstrates how a combination of technology and institutional aspects can make for "smart water communities". The examination provides insights into what "smart water" can be.

Smart water communities understand their water needs and meet them on time. The institutional mechanisms are in place to ensure that the water needs continue to be met over time, in a sustained manner. They understand risks and adapt to the changing conditions, may it be growing population size or a drought.

Keeping apprised of new scientific research and incorporating local knowledge would help design measures for community involvement such as public education, develop information on State or Central regulations or supporting local ordinances for diversifying water sources while keeping adverse impacts in check. For example, water recycling could be encouraged by also mandating safe water use and discharge of clean water or developing local groundwater monitoring and protection measures for groundwater levels and quality that informs the pumping schedules for agriculture or other uses. Here, the inextricable link with power supply or energy to draw groundwater cannot be ignored [20]. Can solar pumps be used? Can energy from wastewater and sludge be harnessed for powering up households or treating water? Such intersectoral connectivity say, between water, wastewater, and power can be "smart" only when it is used in a way that can serve the basic needs of the households. Small water communities hence could be a part of not only residential neighbourhoods but broadened to mixed-use developments or estates with clustered industries or institutions such as a university campus or a hospital.

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Chapter 15
Stormwater Best Management Practices: Green Infra-structure in Rural Communities

Monica Aspacher and Bhuiyan Alam

Abstract Drainage systems in the US are largely characterized by complex systems of underground pipes, like combined sewage systems designed to collect both stormwater runoff and domestic waste products, and other structural features. Not only have such systems been demonstrated to be economically inefficient, combined sewage overflows significantly jeopardize the ecological integrity of the surrounding environments. As climate change catalyzes more frequent extreme weather events, periods of heavy rainfall will continue to overwhelm rural drainage systems, thus compromising water quality. Since the passing of the National Pollutant Discharge Elimination System in 1972, rural areas across the US have been taking a more integrated approach to the stormwater problem: best management practices. When utilized in combination with structural features, green infrastructure, a method that integrates the natural and built environments, is a promising alternative to current strategies. The goal of this paper is to synthesize the extant literature into a comprehensive reference for those interested in sustainable, smart solutions to widespread stormwater issues throughout the US.

Keywords Stormwater management · Rural communities · Sustainability · Water quality · Green infrastructure

15.1 Introduction

Not only are traditional stormwater management methods structurally inefficient, they also place an enormous economic burden on cities through costs of maintenance and extending infrastructure to sprawling areas, as well as resulting flood damage [1]. Stormwater has historically been considered a simple problem of quantity, or too much water. While cities across the country have invested in retrofitting infrastructure to hold more water, those efforts have proven to be only

M. Aspacher (✉) · B. Alam
University of Toledo, Toledo, USA
e-mail: monica.ra1024@gmail.com

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mildly successful and widely unsustainable for the long-term. The cause of the substantial increase in stormwater is multidimensional. Both urbanization and climate change have and will continue to exacerbate the stormwater issue [3]. Rapid urban- and suburbanization that has occurred over the last several decades has both deteriorated natural landscapes that absorb excess water and significantly increased impervious surface area that causes stormwater to run off. On the flipside, climate change has subjected communities across the country and the world to more frequent erratic and severe weather patterns that bring unprecedented surges of stormwater. Both of these factors have significantly altered the natural hydrologic cycle that has more or less remained consistent throughout earth's history prior to human development.

While stormwater management efforts have focused primarily on water quantity, another pressing issue has long been ignored: water quality. With increased urbanization also comes higher rates of pollutants travelling to nearby water sources via stormwater runoff. An early effort to minimize pollutant runoff, the preeminent Clean Water Act (CWA) was passed in 1972 and included a program focused on reducing point source pollution, or direct discharges to surface waters, but non-point sources like stormwater runoff from agricultural practices and impervious surfaces associated with suburban and urbanization were neglected [4]. Rural and suburban areas throughout the country experience severe water quality issues as a result of agricultural runoff that has largely been left unmonitored.

Fortunately, there may be an answer to the dire question of how communities can mitigate the destructive impacts of stormwater runoff: green infrastructure. While traditional or "gray" infrastructure is designed to carry stormwater away from cities to avoid flooding, green infrastructure incorporates the natural landscape to absorb water where it falls so that it may be reused throughout the natural hydrologic cycle [5]. In other words, green infrastructure ultimately restores (parts of) the built environment back to its natural condition. Green infrastructure is often utilized in conjunction with existing gray infrastructure to maximize management efficiency [5].

The objective of this paper is to synthesize the extant literature regarding stormwater management, with an emphasis on green infrastructure as new and improved best management practices. First, readers are introduced to the general history of stormwater issues and management in the US to accurately understand the root of the problem. Then, various types of green infrastructure are explored; this paper focuses on rural stormwater management, but the techniques are also applicable to urban areas. Additionally, a case study of communities in rural Ohio will provide some insight as to how green infrastructure as best management practices is an effective method to manage stormwater. Finally, because stormwater management is critical for resilient communities both now and in the future, aspects of policy and planning are discussed as tools going forward. While this paper does not involve primary data analysis, it is our goal to provide a comprehensive resource for those interested in stormwater management that is sustainable both environmentally and economically.

15.2 Preconditions

To preface, it is important to recall the role of urban sprawl as a precondition for modern stormwater issues. The definition of urban sprawl is the outward spreading of urban developments (such as houses and shopping centers) on undeveloped, rural land [1]. Fundamentally, that is all sprawl is—the outward expansion of urban development. What this simple definition neglects are the many implications of sprawl, like the degradation of water quality and economic burden that stormwater overflows or floods place on communities. Declining water quality and more frequent flooding is strongly associated with impervious surfaces as a product of suburban and urbanization. Impervious surfaces can be defined as "human-created land cover that reduces or eliminates the capacity of the underlying soil to percolate water" [1, p. 27], which significantly degrades the natural cycle of infiltration.

As much as 65% of total impervious cover in the US consists of streets, parking lots, and driveways to accommodate low-density, sprawling development [6]. Runoff from impervious surfaces carry an abundance of pollutants to nearby waterways: particulate matter from the atmosphere, nitrogen oxides from automobile exhaust pipes, debris from automobiles, phosphates from residential and agricultural fertilizers, and many others. Nonpoint source pollution, or pollution that comes from many points, jeopardizes water quality more than any other cause, particularly in rural areas where agriculture is predominant [1].

It is important to also understand the natural mechanics of water flow and how they are altered by conventional stormwater management methods. *Storm runoff* is defined as precipitation (rain or snow) that falls on the ground before being transported to a body of water [1]; the water literally "runs off" of the pavement or ground elsewhere, a process known as *overland flow*. Water can also move below the surface through the soil, a process called the *subsurface flow regime*, typically in lush, densely vegetated lands like the coastal regions of the Pacific Northwest [1]. As a storm persists, flow patterns and runoff quantities change rapidly where *overland flow* (flow of water over the surface rather than through the subsurface) is predominant. Where overland flow is naturally occurring, the paths that water may travel are naturally predetermined; this cycle has remained more or less consistent throughout earth's history. A stream's *base flow* is the naturally occurring flow via water consistently percolating through the soil, while *peak discharge* is the highest flow in the channel. After *peak discharge*, the *base flow* will naturally return. When a stream is overwhelmed and can no longer accommodate increased discharge, flooding occurs [1].

Impervious surfaces significantly alter the natural routes that surface runoff may travel, as well as the quality of the water, by decreasing the volume that percolates into the ground and increasing the volume of surface runoff (California Water and Land Use Partnership [7]. In other words, higher impervious surface area decreases the natural ability of the ground to not only absorb and infiltrate water but to also filter pollutants. *Infiltration* decreases as more natural groundcover is replaced by impervious surfaces, causing runoff to increase. The *peak discharge* of a body of water is dramatically increased as impervious surface area increases and *infiltration* decreases. When a stream or an area of land is overwhelmed with water faster than can be infiltrated, flooding occurs [7]. It is this continuous cycle of flooding that creates enormous issues for communities all across the country.

In addition to impervious surface area, rural agricultural practices significantly compromise both the ecological and economic integrity of rural communities. According to the EPA [9], the US consists of more than 330 million acres of agricultural land; the National Water Quality Assessment (2017) states that non-point source pollution is the largest contributor to decreased water quality in surveyed rivers and streams, third largest for lakes, second largest "source of impairments" to wetlands, and a significant polluter of groundwater EPA [9].

While impervious surfaces hinder natural absorption and infiltration processes, agricultural runoff is rich in nutrients like phosphorous and nitrogen that alter the delicate natural balances that sustain aquatic ecosystems [10]. Together, nitrogen and phosphorous support the growth of algae and aquatic plants that are then consumed and used as habitats by fish and other aquatic life. When nitrogen and phosphorous exist in excess, the aquatic environment becomes overwhelmed by algae growth that interferes with oxygen levels in the water that supports all aquatic life. Algal blooms occur when there is significant algae growth and some produce toxins that can render drinking water unsafe for human use and consumption [10]. Rural northwest Ohio, for example, experienced a "water crisis" in August 2014 when massive algae blooms in Lake Erie produced unsafe levels of toxins that rendered water unusable for almost four days [11]. Algae blooms currently plague rural communities throughout the country. The Environmental Working Group [8] provides an interactive map illustrating algae blooms in all 50 states from 2010 to 2019. Rural areas of Kansas, Iowa, New York, and Wisconsin, for example, have consistently dealt with algae blooms that compromise water quality, a trend that will continue if policies and public action do not support alternatives.

15.3 Overview of Stormwater Management Methods

Even though stormwater was not considered an actual problem requiring attention until the last few decades, stormwater infrastructure has always existed. Upon the birth of modern urban drainage systems following WWII, classic management methods involved a highly complex system of catch basins and pipes to transport water from urban areas away to local waterbodies [4]. This particular system is called a *combined sewage system*.

It was not long after the construction of these drainage pipe networks were the consequences of rerouting runoff flow realized. Receiving waters downstream grew severely overwhelmed and inundated with excess water, causing ban erosion and flooding [4]. A cost-effective solution to this issue was, and still is today, channelization, or modification of river or stream channels to improve drainage, reduce bank erosion, and increase holding capacity. Methods include straightening, widening, dredging (removing bottom sediment to add depth), or relocating stream channels [12]. Any activity that otherwise modifies a stream channel is considered channelization. While these methods may be cost-effective in the short term, long-term effects can be more costly. Hydrologic systems and aquatic environments have remained more or less constant throughout earth's history, experiencing only naturally occurring changes absent of human intervention.

Channelization is designed specifically to alter stream and river channels, without much consideration of the impacts. The most conspicuous impact of channelization is turbulent flooding of downstream channels. In technical terms, channelized streams experience heightened turbulence and reach *peak discharge* more quickly, and sometimes frequently during a single storm event, than do natural streams, resulting in rapid overflowing or flooding [13]. In general, channelization can, and oftentimes does, disturb stream equilibrium, disrupt riffle habitats, alter the base level of a stream and increase erosion from heightened turbulence and velocity [13]. To limit downstream turbidity, flooding, and erosion, cities began in the early 1970s requiring developers to reduce the *peak discharge* of storms of various magnitudes. On-site detention basins became the go-to infrastructure to accomplish this. Detention basins can control *peak flows* immediately below the discharge point and along the property boundary [4]. Because detention basins were installed on an individual basis without regard for other basins throughout the local stream network, total discharge volume was not reduced and downstream areas continued to experience damaging flooding [4].

Other methods of stormwater/flood control have also been constructed throughout the last several decades. Levees, also called embankments or dykes, have been the most commonly utilized form of flood control infrastructure. Levees are built up to a certain height that is designed to withstand storms predicted to cause severe flooding conditions and are relatively cheap to construct [14]. Levees can and have failed for multiple reasons: poor design, breaching (when waters flood over top of a structure), or inadequate construction. Typically, the predicted time frame for severe floods that would warrant such robust infrastructure is imprecise; some are designed to withstand severe floods that may occur every 100 or 500 years, or small floods that occur in 50 year intervals [14]. Flooding experienced in New Orleans, Louisiana, is a shining example of levee failure. Not only did flood waters breach the levees, the structures were poorly constructed and maintained. The flooding would have been bad regardless of infrastructure conditions, but levee failure certainly exacerbated it [15].

A dam is another form of infrastructure that has traditionally been used to control flooding and for other purposes like irrigation, hydroelectricity, recreation, and navigation [14]. Flood-control dams are constructed upstream of a developed area to protect downstream areas from floods. In a given year, as much as 60% of flow in all rivers and streams in the US can be stored behind a dam [14]. Perhaps the most famous dam is the Hoover Dam on the Colorado River located 30 miles southeast of Las Vegas, Nevada. Storing all of that water, though, has immense consequences.

Like channelization, dams significantly alter the natural character of streams. Water released from behind a dam, for example, varies in temperature from that of native waters and have been proven to be highly detrimental to the aquatic ecosystem of the Colorado River basin. Downstream river flow, for example, is impeded to such an extent that the water fails to reach lowlands for many months of the year, sometimes for the entire year [16], depriving aquatic life of sustenance. Another detrimental impact the Hoover Dam has had on the Colorado River is reduced sediment accumulation that provides nourishment for growing plants as well as wildlife and fish habitats. Downstream water quality has also significantly been impaired via low stream flows, changes in sediment and chemical accumulation, and warmer water temperatures that jeopardize aquatic life [16].

15.4 Regulatory Framework

Thus far the discussion has focused on traditional *structural* attempts to control widespread stormwater issues. But to understand how and why the spectrum of issues related to stormwater is in fact a flaw in *policy*, it is critical to also understand the regulatory framework for stormwater. While stormwater has been considered a sizeable issue and there have been extensive structural efforts to mitigate it, it is only since the 1970s that policymakers have been active in the process. The creation of the Environmental Protection Agency (EPA) in 1970 by President Nixon set in motion an ongoing series of legislation aimed at protecting the natural integrity of the environment. A landmark piece of federal legislation, the Clean Water Act of 1972 (CWA), was passed generally to eliminate pollution discharge to surface waters [4]; the efforts were primarily to improve waterways for recreational purposes, not environmental protection. Its parent legislation, the Federal Water Pollution Control Act of 1948, was amended to lend more robust water quality-focused regulatory capabilities to the federal government, thus the birth of the Clean Water Act (CWA). The scope of the CWA was expanded to deal with more diffuse sources of pollution, such as stormwater, through amendments in 1987 [4]. Regulatory efforts have largely focused on *point source* pollution, or pollution that can be traced back to its source(s). The specific language of the CWA presents immediate problems: "all *discharges* into the nation's waters are unlawful, unless specifically authorized by a permit" ([42 U.S.C. S 1342(a)] [4]). Discharges in this language are narrowly defined as "point sources" of pollution only from sources that "flow through a discrete conveyance, like a pipe or ditch, into a lake or stream" ([33 U.S.C. SS 1362(12) and (14)] [4]). This ambiguity allowed for nonpoint sources like stormwater runoff to go unnoticed unless individual states provided specific regulation.

To formally regulate point source pollution, within the Clean Water Act (CWA) operated the National Pollutant Discharge Elimination System (NPDES) that requires a permit to discharge pollutants with the overarching goal of decreasing pollutant loads and increasing water quality. The drafters of the

Environmental Protection Agency (EPA) were ill-prepared to regulate the hundreds of thousands of “point sources.” Other ambiguous language within the CWA that allowed the neglect of stormwater is the definition of “pollution”, as any conscionable substance that could be unnaturally released into waterways, including heat ([33 U.S.C. S 1362(6)] [4]). In other words, the original premise of the CWA was to improve water *quality*; absent is language concerning water *quantity*, or stormwater. Amendments to the CWA made in 1987 effectively broadened the scope of National Pollutant Discharge Elimination System (NPDES) to govern large sources of stormwater discharge like industrial facilities, municipal storm sewers, and construction sites. Although Congress directed the EPA to enforce stormwater regulations through the 1987 amendments, the EPA instead diverted responsibility down to the states, giving them discretion to approve, amend, or reject the plans. The EPA also granted regulated parties significant discretion to self-monitor, a marked difference from the mandated requirement applied to industrial wastewater (not stormwater) [4]. Again, blatant ambiguity in legislative language has opened windows for regulated parties to continue leaving stormwater discharge largely unchecked. Therein lies the conundrum: if the legislative language does not explicitly include or enforce language to regulate stormwater pollution discharge, the desired outcome of improving water quality simply cannot be achieved to the degree necessary to mitigate decades of pollution. For a comprehensive list of water-related legislation from the late 1800s to 2007, see chapter two of *Urban Stormwater Management in the United States* (47–128; National Research Council: Committee on Reducing Stormwater Discharge Contributions to Water Pollution, Water Science and Technology Board, Division on Earth and Life Studies 2009).

15.5 Existing Stormwater Sewage Systems

Now that we have discussed the historic context of stormwater management methods, it is important to know of the sewage systems currently in use, of which there are two: combined sewer systems (CSS’s) and municipal separate storm sewer systems (MS4s). Combined sewer systems currently serve citizens in 32 states, most of which are found in Maine, New York, Pennsylvania, West Virginia, Ohio, Indiana, Michigan, and Illinois [17]. First introduced in 1855, combined sewer systems (CSS’s) replaced ditches that lined city streets and spilled raw sewage waste into the streets during storm events. The complex underground pipe networks were designed to collect rainwater runoff, domestic sewage from newly invented flush toilets, and industrial waste all in the same pipe that had a single outlet destination: local waterways. In the early 1900s sewage treatment plants were constructed to treat wastewater before reaching streams [17]. Combined sewer systems (CSS’s) work well in dry weather when an area’s wastewater can travel to a treatment plant without overflowing, but sewer systems fill up quickly during wet periods. Although CSS’s were originally designed with escape overflow pipes to prevent sewage backup into buildings and homes, there was seemingly no consideration that wastewater would overflow directly into lakes, rivers, and coastal waters, a phenomenon called combined sewage overflow (CSO). It was not until 1994 that the EPA instituted the Combined Sewage Overflow Control Policy through the National Pollutant Discharge Elimination System (NPDES) permitting program that mandated a significant reduction in CSO occurrences, as well as provided guidance to communities to achieve this goal outlined in the Clean Water Act [17]. The EPA [9] has estimated that approximately 850 billion gallons of untreated wastewater and stormwater is discharged into US waterways every year, down from 1.3 trillion gallons per year prior to the CSO Control Policy. Combined sewer overflow events release contaminants like microbial pathogens, suspended solids, chemicals, trash, and oxygen-depleting nutrients into waterways that humans depend on for both recreation and general health. While it is difficult to precisely estimate the exact impact on human health due to many outbreaks that go unreported, the EPA and reports like the *Morbidity and Mortality Weekly Report* have estimated that microbial pathogens in US public drinking water supplies sicken hundreds of thousands of people annually, outbreaks that are correlated with rainfall and overflow events [17].

The EPA’s mandate to control CSOs has led most communities to install separate underground pipes for sewage and stormwater, systems called municipal separate storm sewer systems (MS4’s). Municipal separate storm sewer systems (MS4’s) are designed with separate pipes that collect domestic wastewater intended to travel to treatment facilities and stormwater that is released in waterways. The overall goal of MS4’s is to reduce the total maximum daily (pollutant) loads by catching and transporting wastewater and stormwater separately [17]. Polluted stormwater runoff, however, still contains contaminants from automobiles and other sources like agriculture that does not go to treatment facilities, so this pollution is still being released into waterways. It is not a perfect system, but it has significantly reduced total maximum daily loads.

A substantial hurdle to converting combined systems to separate systems is cost: the EPA [17] estimates that reducing CSO volume by 85% by 2020 will cost communities upwards of $50 billion [17]. There is some ambiguity within the National Pollutant Discharge Elimination System (NPDES) that distinguishes between rural and urban development regarding conversion of combined sewer systems to municipal separate storm sewer systems. According to the NPDES, “rural” areas are those that contain 0–10% impervious surface area, while “urban” is 25–60% and “ultra-urban” is greater than 60%; only areas that are considered “urban” to “ultra-urban” are required by statute to convert from a CSS to MS4 [18]. This implies that because there is less impervious surface area, rural communities experience less-severe issues related to stormwater, which is simply untrue. As opposed to urban areas that are largely concerned with redirecting excess water flow, rural communities are more concerned with sediment control, land use practices exempt from regulations (like agriculture), and non-point source pollution [18]. Rural communities struggle with stormwater-related issues just as much as urban communities, and because of the lack of federal requirements many municipalities have begun drafting their own ordinances for land not covered by an MS4 (such as agricultural land), a phenomenon known as “self-imposed stormwater management” [18].

15.6 New Promises for Stormwater Management: Green Infrastructure as Best Management Practices

Thus far we have discussed the historical context of stormwater management in the US, which has involved conventional management methods also referred to as “gray” infrastructure. It is evident that traditional gray infrastructure is inefficient both economically and structurally. Thankfully, an innovative alternative to hard, “gray” structures has emerged in cities both around the world and in the US: green infrastructure (GI), or low impact development (LID). Green infrastructure, as opposed to gray infrastructure, is identified as the “interconnected network of open spaces and natural areas—greenways, wetlands, parks, forest preserves, and native plant vegetation—that naturally manages stormwater, reduces the risk of floods by reducing *peak discharge*, captures pollution and improves water quality” [19]. Put more simply, green infrastructure incorporates the natural environment to restore parts of the built environment (human development) back to its riparian state to improve infiltration. More broadly, green infrastructure is just one aspect of communities’ overarching goals to achieve both environmental and economic sustainability, which ultimately improve community *resiliency*, or the ability of a community to bounce back from storm events [5]. An alternative name for green infrastructure is *low impact development* (*LID*) and is defined the same: to use or mimic natural processes that improve infiltration, evapotranspiration, or use of stormwater in order to protect water quality and associated aquatic habitats (EPA). Principles of both green infrastructure and low impact development include preserving and recreating natural landscapes and minimizing imperviousness to create functional and appealing site drainage that treats stormwater as a resource rather than a waste byproduct [5].

15.7 Types of Green Infrastructure

There are many ways to implement green infrastructure, like eco-roofs, permeable pavement, green alleys and streets, urban forestry and others. To start, eco-roofs are designed to respond to both extreme precipitation and extreme temperature. As opposed to traditional black roofs that only provide shelter, eco-roofs may serve three different but interrelated purposes: green (vegetated), white (cooling), and blue (water management) [5]. Green rooftops, or rooftops covered with natural vegetation, are the primary choice for stormwater management purposes.

Green rooftop vegetation should be appropriate to the local climate conditions and grow in 3–15 in. of soil, sand, or gravel planted atop a waterproof membrane; vegetation may also include additional layers of root barriers, drainage nets, or irrigation systems [5]. Green roofs can be either intensive (80–100 lbs. per square foot) that employ deeper soil and more robust plants that are able to tolerate diverse wet conditions, or extensive (15–50 lbs. per square foot) that are more focused on aesthetics or shallow infiltration. In addition, green rooftops protect underlying roofing material from environmental damage, thus lowering maintenance costs and enhancing roof life-span by two to three times [5]. In technical terms, green rooftop vegetation can reduce annual stormwater runoff by an average of 50–60% (including *peak* runoff), control between 30 and 90% of the volume and rate of runoff, detain 90% of volume for small storms and at least 30% for larger storms [5]. In addition to stormwater runoff control, green rooftops also have the capability to filter air pollutants, like particulate matter, and gaseous pollutants, like nitrogen oxide, sulfur dioxide, carbon monoxide, and ground-level ozone. According to the [5], it is estimated that a 1000 square feet of rooftop vegetation can remove approximately 40 points of particulate matter from the air per year, an equivalent to annual emissions of 15 automobiles, while simultaneously producing oxygen and removing carbon dioxide from the atmosphere.

Aside from environmental improvements, green rooftops are also economically sustainable. While vegetated rooftops are more expensive per square foot to install, the array of benefits deem them a cost-effective alternative to traditional black rooftops, especially when aggregated at a holistic watershed level (versus singular sites scattered throughout a community). Expected costs of a 21,000 traditional black roof is about $335,000 (in 2006 dollars), versus a green roof costing $464,000 (in 2006 dollars). Over the course of the lifetime of the roof, though, green vegetation would save about $200,000, primarily through energy-cost savings for the buildings [5]. Blue rooftops also provide benefits similar to those of green rooftops in that they slow or store storm runoff, but instead of utilizing vegetation they utilize various technologies like downspout valves, gutter storage systems, and cisterns. The main benefit that blue rooftops provide over green rooftops is rainwater harvesting, or repurposing collected/stored water for activities like direct groundwater recharge, landscape or garden irrigation, or significantly reducing *peak flow* drainage into sewer systems so as to reduce combined sewer overflows [5].

Another form of green infrastructure is green or permeable alleys and streets. Traditional permeable alleys and streets collect excess stormwater that ultimately runs off into and overwhelms local waterways, causing local and downstream flooding. Green alleys are an excellent alternative that address issues of stormwater management, heat reduction, and energy conservation that impact the entire watershed. Green alley practices include permeable and reflective pavements, rain-gardens (vegetation installed in depressions to capture and filter rainwater), downspout connections and rain-barrels, tree-planting, bioswales (artificially contained vegetation), and cisterns (to collect water for repurposing) [5]. Permeable pavements in particular have become a choice alternative to conventional impermeable/impervious surfaces. Made of material that allow water to soak back into the ground, permeable pavement aims to mimic runoff characteristics of riparian vegetation and is designed with a capacity to manage a 10-year rain event within a 24-h period (this standard can and will need to be adjusted for more frequent severe storm events). According to the [5], permeable pavement has the capability to infiltrate 3 in. of rainwater from a 1-h storm and has a life expectancy of 30–35 years. In addition to environmental improvements, permeable pavement can reduce the need for winter salt application by as much as 75%; increasing pavement reflectivity worldwide by 35–39% may also produce a global reduction in carbon dioxide worth approximately $400 billion (in 2007 dollars) [5].

Downspout disconnection and rainwater collection are other methods to control rainwater for homes and commercial buildings. Disconnecting downspouts that typically channel water directly into sewer systems and reconnecting to a collection (cistern) or slow dispersion (rain-garden) system significantly reduce the potential for combined sewer overflows and provides water conservation benefits to the community [5]. Professionally disconnecting downspouts cost around $2000 per household, while rain barrels can be purchased for as little as $15. According to the [5], one study noted that if 80% of a neighborhood participated in downspout disconnections, there would be a 30% reduction in runoff from the *peak flow* of a “1-year” storm; rain-garden installation could achieve an additional 4–7% reduction. Together, downspout disconnections and rain-gardens/harvesting could produce a reduction in local peak combined sewer overflow volume of around 20% [5].

Bioswales are another form of green infrastructure. Like rain gardens, bioswales slow and filter stormwater but are specifically designed to manage a predetermined amount of runoff from an adjacent impervious area like a parking lot or roadway [20]. Because bioswales are typically located directly adjacent to a parking lot, roadway, or other large impervious area, they often require soils that are engineered to slow, infiltrate, and retain larger volumes of water, as well as filter high levels of pollutants like phosphorous and nitrogen. Due to larger holding capacity, bioswales are deeper than rain gardens, and are linear systems as opposed to rounder rain gardens and are longer than they are wide [20].

In rural areas it is perhaps most common to see detention or retention ponds, also referred to as stormwater ponds. According to the [21] a stormwater pond is a permanent pool or shallow marsh that is designed to store runoff and filter pollutants; a detention pond slowly infiltrates water while retention ponds permanently hold water. Stormwater ponds are often considered purely aesthetic, but instead they are critical tools to managing stormwater. Stormwater management ponds can: control erosion that is caused by accumulated runoff that erodes slopes and encourage sedimentation, filter pollutants through slow infiltration and plant uptake, and control flooding by slowing storm surges or rates of flow [22]. Maintenance of stormwater ponds is critical to ensuring proper long-term function. If sediment accumulates, for example, the overall storage volume of a pond will decrease [21]. To reduce maintenance costs and improve the overall function of stormwater ponds, native plant species may be planted around the pond perimeter. As opposed to non-native plants, native species have longer, more robust root systems that enhance ecosystem health and are already adapted to local climate conditions and pests [23].

15.8 Case Study: Rural Ohio

The US state of Ohio has been realizing the value of green infrastructure as a promising alternative to traditional stormwater and water quality management methods. There are currently multiple programs being utilized to improve both water quality and stormwater management in rural and urban/suburban communities.

Through the Ohio Balanced Growth Program [24], a voluntary, incentive-based program, the state has been working toward improving the quality of Lake Erie, the Ohio River, and other vital state watersheds. The Program includes recommendations and resources for local governments who wish to implement Best Local Land Use Practices. The Ohio Balanced Growth Strategy, prepared by the Ohio Lake Erie Commission in 2011, created within it the Watershed Planning Partnership to promote and monitor balanced growth within state watersheds. The state of Ohio is rich in natural water resources, being that 2/3 of state borders are water (Lake Erie and Ohio River). Ohio also enjoys more than 61,000 miles of rivers and streams, has more than 265,000 acres of lakes, reservoirs, and ponds, and approximately 480,000 acres of wetlands [24]. Additionally, at least 60% of all Ohioans depend on surface water for drinking while the remainder rely on groundwater. Like virtually every other state, poorly maintained septic systems, pesticide runoff, and physical alteration of streams are now among the greatest threats to Ohio's water quality [24]. Prior to the Ohio Balanced Growth Strategy, the Ohio Lake Erie Commission released the Lake Erie Protection and Restoration Plan (2000) which provided a comprehensive set of recommendations for the state and its partners to improve the quality of Lake Erie as a critical local resource. A crucial conclusion of the Plan was that land-use trends within the Lake Erie basin are a major hurdle to achieving full restoration of the lake, and consequently appointed a Balanced Growth Blue Ribbon Task Force involving a range of actors including property owners, government officials, business leaders, conservationists, academia, agriculture, and other stakeholders. The Task Force was created in late 2001 and was delegated responsibilities of: recommending strategies to holistically protect the Lake Erie watershed while fostering economic growth, identifying ways the state can integrate balanced growth principals into its decision-making processes, researching best practices from around the country as a framework for Ohio innovations, developing a voluntary, incentive-based program versus a new regulatory program that would preserve property rights and local discretion for land use decisions, and make recommendations that are practical, realistic, and can utilize existing funding sources [24]. The resulting voluntary, incentive-based program was the Lake Erie Balanced Growth Program (2004) to adapt a regional focus on land use and development planning in the Lake Erie basin, create local Watershed Planning

Partnerships, align state policies, funding, and other resources to support implementation, and implement recommended regulations to aid in the promotion of best local land use practices [24].

On the stormwater side of things, the State of Ohio and the Ohio Environmental Protection Agency employs a permitting program as mandated in the Clean Water Act and part of the National Pollutant Discharge Elimination System Permitting Program, with parallel rules and regulations for both point source pollution and nonpoint (stormwater) discharges. The goals of Ohio's Stormwater Permitting Program are to eliminate the addition of pollutants, especially sediment, in rainwater runoff and to make long-term land use changes that restore natural hydrology and reduce pollutant loading of state rivers, lakes, and streams [25].

An example of local efforts to manage stormwater using green infrastructure methods comes from the Toledo Metropolitan Area Council of Governments (TMACOG) in the northwest city of Toledo, located in the western basin of Lake Erie. The City of Toledo employs a diverse set of stormwater best management practices (BMPs, green infrastructure) including biofilters, bioswales and detention basins. Funding provided by the US EPA and Ohio EPA has allowed the City to install several demonstration projects along City streets and on City properties. Currently, with the guidance of TMACOG's *Agenda for Lake Erie*, the City of Toledo is expanding its goals to increase the level of green infrastructure implementation during private and public construction, road projects, and brownfield remediation (TMACOG, 2015). As outlined by TMACOG, Toledo's level of green infrastructure implementation is measured in two ways: the amount of land area that drains to and is treated by BMPs and the amount of stormwater runoff designed to be captured by BMPs in order to remove a majority of stormwater pollutants. While Toledo comprises a metropolitan region, the region itself is largely rural and part of a unique ecosystem directly bordering Lake Erie, an area that has been significantly impacted by stormwater runoff particularly from agricultural practices that have fostered growth of toxic algae blooms. Now, the City of Toledo has implemented even more forms of green infrastructure. For a full map of where these best management practices are being utilized, see TMACOG website's "Water Quality" page (link in bibliography). Because Toledo is surrounded by suburban and rural communities that are heavily involved in the region's agricultural industry, farmers from these communities partner with water quality experts of TMACOG to approach the problems from a holistic standpoint to accommodate the needs of the entire watershed. The Ohio Farm Bureau created the Water Quality Action Plan to achieve improved water quality throughout the watershed. Demonstration farms are one method to raise overall awareness and improve conservation techniques. Rural Hancock and Hardin counties have designated three farms as demonstration farms to help farmers strike a balance between ecological concerns and economic well-being of farmers. Thus far, three best management practices have been identified as being most effective in improving water quality from an agricultural standpoint: the 4R approach (applying fertilizer or manure from the right source, at the right rate, right time and right place); developing a water management plan that includes practices like phosphorous removal beds, two-stage ditches, and inlet valves; and reducing soil erosion through cover crops, filter strips, grassed waterways, no-till and other practices [26]. These demonstration farms are open to the public to raise awareness of not only the problems presented by agriculture runoff but also of the ecological uniqueness of the area.

15.9 Policy Challenges

When examining existing stormwater programs and policies it is evident that ambiguous language has encouraged the manifestation of the issues communities currently face. The Clean Water Act, for example, initially neglected nonpoint source pollution as a significant source of water quality impairment. Significant barriers to innovative, more effective stormwater management alternatives are also present at the local level. Municipal codes and ordinances, for instance, often favor traditional infrastructure over green infrastructure due to differences in costs and a general lack of information regarding the true value of green infrastructure [27]. Conflicts of property rights at the local level also hinder the implementation of green infrastructure strategies; projects are often installed on private properties, making it challenging for public agencies to ensure proper long-term maintenance. At the state level, water and land-use policies and property rights are challenges. While state governments tend to devolve regulating authority to local municipalities, not all states provide robust state-wide guidelines for local implementation. Many states do not encourage the creation of organizational partnerships to address watershed-wide issues [27]. Another type of barrier is financial: lack of funding to implement projects and uncertainty over costs and cost-effectiveness. Locally it can be difficult to develop, increase, and enforce stormwater fees that can serve as an internal source of funding for implementing green infrastructure. Oftentimes there is no external funding for the design, development, and testing of large-scale projects, which greatly discourages municipalities from investing in green infrastructure [27].

15.10 Recommendations Going Forward

Flooding and water quality issues are not isolated to one specific geographic area or community. Instead they impact the entire *watershed*, or area-wide network of rivers and streams that all drain into larger outlets. The ambiguities within the legislative language demonstrates the need for robust regulations that close loopholes and use clear definitions, as well as encouraging partnerships at all levels of administration, which can be assumed for all cities and municipalities throughout the US. Following are recommendations for federal, state, and local governments to consider for moving green infrastructure initiatives forward.

Federal policies in the US ought to fully fund the Clean Water State Revolving Fund and incentivize green infrastructure projects through prioritization, interest rate reduction, and extension of funding eligibility for qualified projects. Federal policy in the US ought to also establish minimum performance-based standards to address runoff volume and water quality, and regulatory programs should support local watershed conditions through science-based approaches that address both local and watershed-wide challenges. Another policy recommendation is that the US federal government ought to coordinate with state and local governments to promote the integration of green infrastructure into permitting, planning, research, technical assistance, and funding programs.

On a state level, states ought to require incorporation of green infrastructure methods to meet overall best management practices and public education requirements in accordance with the National Pollutant Discharge Elimination System; states should also develop and enforce performance-based runoff control standards that align with watershed needs and goals. Finally, to secure these physical efforts, states ought to create a designated funding source for green infrastructure planning, implementation, and research and design. Where funding is a barrier, states should amend legislation to explicitly allow municipalities to establish stormwater utilities and/or levy fees.

In the absence of state or federal assistance, local municipalities may provide tax incentives to both homeowners and developers for new and existing development. For homeowners, incentives may come in the form of cash rebates, discounts, tax credits, and grants. For developers, vital incentives include cost reductions and streamlined permitting and inspection process. Local governments ought also to work towards establish a network between organizations and municipalities so that efforts may be streamlined. It is critical that local organizations and governments work closely with state and federal programs and follow overarching guidelines (all recommendations come from the Great Lakes Commission [28]).

15.11 Concluding Remarks

For decades, traditional stormwater management infrastructure and legislation have encouraged the manifestation of widespread water quality and quantity issues. Combined sewage systems, for example, collect both stormwater and domestic waste in a singular system and oftentimes leads to overflows that release large amounts of pollutants into waterways. In addition to traditional stormwater infrastructure, impervious surface area as a result of urban- and suburbanization have altered landscapes to such an extent that the natural capacity to infiltrate and filter runoff has been significantly reduced. In rural communities, nonpoint source pollution from agricultural practices is perhaps the most significant source of water quality degradation that persists across entire regions and watersheds. Green infrastructure is a promising and innovative alternative to traditional stormwater management methods that have proven to be inefficient.

It is the pervasive, widespread character of stormwater issues that demands a collective, holistic effort from all levels of government. Federal policies like the Clean Water Act (1972) and programs through the Environmental Protection Agency provide an overarching framework for mitigating stormwater issues. State programs like the Ohio Balanced Growth program provide guidelines for local municipalities and governments to follow regarding stormwater management and green infrastructure initiatives. Local government organizations like the Toledo Metropolitan Council of Governments in Ohio may serve to coordinate local efforts to holistically manage stormwater and implement green infrastructure initiatives. It is imperative that entities at the federal, state, and local levels coordinate efforts to mitigate stormwater issues to foster resilient communities for the future.

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Part III
Smart Renewable Energy Management

Chapter 16
Solar Electrification and Zero Energy Rural Communities

Muhammad Mujahid Rafique and Shafiqur Rehman

Abstract Worldwide primary energy demand has increased by more than 50% since 1980 because of rapid increase in the global population and subsequent economic development of developing nations. Furthermore, the developing nations will be responsible for more than 70% of this growth due to continuous and faster population and economic growth. In this regard, it is very timely to utilize alternative sources of energy to fulfill energy demands of individual nations. The focus of this book chapter is to encourage people and government institutions to develop zero energy communities which will greatly help to achieve sustainable energy infrastructure in developing countries. The concept of zero energy communities is to install solar microgrid electrical systems according to the power requirements of individual facilities. During the peak sunshine hours the electricity can be distributed to the consumers and any excess power could be stored as backup.

Keywords Renewable energy · Solar electrification · Zero energy communities · Sustainable development · Developing countries

16.1 Introduction

In this age, one of the major challenges of a country is how to access and maintain sustainable economy that allows human life to enjoy high standards of living without destroying its natural and biological sources. Energy jointly with suitable technologies and infrastructure provide the services demanded by modern societies such as transportation, lighting, air conditioning, information exchange, etc. Energy is considered as indispensable for many human actions and always plays a crucial

M. M. Rafique (✉)
King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia
e-mail: mujahidrafique89@aol.com

S. Rehman
Center for Engineering Research, Research Institute, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia

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role in economic and socio-political upbringing of any nation. For all socio-economic areas of a nation, energy is regarded as the engine for the providing goods and services. It also plays a vital role to fulfil fundamental community services in education, health care, clean water availability, and wealth generation. Not having enough energy availability is a causative aspect responsible for the scarcity of individuals, communities, nations and regions. In short, there is a clear relation between energy demand and economic growth of a country.

The demand supply gap of energy sector in developing countries is increasing due to rapid population growth, adopting luxurious ways of life and improving infrastructure in all the fields. Similar to other developing countries; Pakistan's energy demand is increasing while energy supply side has shown growth at snail's pace. The slow growth in supply side is due to poor energy infrastructure, huge capital involved to build supply resources and delayed policies on implementation level. The demand supply gap of electricity was noted as 31.6 TWh in 2010, which resulted in 2.5% GDP loss and unemployment of more than half million workers of Industrial sector [1, 2].

The energy shortage issues and challenges have led to an increasing gap of supply and demand. The demand for electricity has set aside the current generation capability thus developing gaps of up to 4500–5500 MW [3, 4]. This continuously increasing gap between supply and demand has continuously grown over the past 5 years thus getting to the present levels. This huge supply-demand gap is responsible for a load-shedding of 10–12 h across the whole state of Pakistan. Other than this high supply-demand gap, another major factor contributing in power crisis is exceedingly costly production of electric power. Due to dependence on costly fuel, the electricity is being generated at a tariff that is beyond the affordability of the nation and its general public.

There is a strong need to re-structure this energy mix in such a way that maximum reliability along with minimum cost of generation could be achieved. Thus, better analysis and modeling techniques are necessary for the selection of optimum supply scenarios of electricity generation.

As there is a crisis in energy sector of Pakistan and is deteriorating continuously. In Pakistan, there is not enough know how in the field of energy policy planning and management. At academic level energy policy is little known in Pakistan therefore opens new horizons of research in the country. The focus of this book chapter is to encourage people and government institutions to develop zero energy communities which will greatly help to achieve sustainable energy infrastructure in developing countries. Policy makers in Pakistan are mostly non-technical people; therefore this research work will be beneficial for policymakers.

16.2 Energy Profile of Pakistan

The current political regime has given high concern to energy sector right from the beginning. The current political leadership of the country has compensated the circular debt of Rs. 480 billion suddenly after being elected. This heavy payment of circular debt led to an increase of 1752 MW of power into the system. In fiscal year 2015, the existing circular balance was around Rs. 250 billion. Other than this Pakistan's National Power Policy 2013 strongly realized to provide the current and future energy demands of the nation. This initiative is to put the country on a path of fast paced social and economic maturity. There are three pillars of the term "sustainability". These are better management on the demand side, low cost primary energy supplies, and level playing field. Changing the fuel mix to less costly fuel options will lead to low priced energy. Expenditures essential for the low-priced fuels options will demand electricity duty to be rationalized. Provision of power to all industrial users ensures and is termed as level playing field. Effective management at the demand side includes developing new policies, effective pricing mechanisms and regulatory instruments. A monitoring report on Pakistan energy reform was offered to the Economic Coordination Committee (ECC) of the cabinet in December 2014. Its aim was to examine the developments in energy sector of the country. This report was then released to the public as per ECC judgment [5].

Reduced tax to GDP ratio in Pakistan is responsible for restricting the political leadership in providing financial support for energy projects exclusively. This enables the private sector to play its role in an optimistic way. This phenomenon indicates that energy sector is always considered as a key constituent of discourse between the governing bodies and other multilateral cohorts. A Transaction Advisory Services Agreement (TASA) has been signed by all the participating countries with Asian Development Bank (ADB) to uncover a principal, technically and financially viable corporation that could be able to generate enough financial resources for this mega-project [6].

Pakistan and China has signed a number of memorandums of understanding (MoU) to deter the energy crises of Pakistan. In latest visit of Chinese president to Pakistan, leadership from both countries initiated a debate on series of energy projects. The Government of Pakistan intends to expand its energy blend in order to ensure energy security. In this context alternative and renewable energy sector is a strong player in the new diversified energy mix. A number of measures have been taken by Alternative Energy Development Board (AEDB) in order to promote alternative and renewable energy (ARE) technologies. This is being done to draw attention of private sector investments in renewables. All efforts are being made by the government at all ends to get a long term solution to end power crisis in the country. This energy crisis is not only slowing economic development but also causing social annoyance.

16.3 Materials and Method

16.3.1 Domestic Household Load Requirements

The typical household appliances used in Pakistan and other developing countries are lamp, fan, television, refrigerator, washing machine, water pump, and electric iron. The community under study has total 100 houses with electric appliances listed above. The operating schedules, ratings of appliances are illustrated in Table 16.1.

16.3.2 Solar Resource Assessment

The geographic location of Pakistan, its topography, and climatic conditions are favorable for solar energy exploitation and utilization on national level [4]. South East part of Punjab, South West province of Baluchistan, and North East part of Sindh are the sunniest parts in the country. One of the richest provinces in terms of solar energy is Baluchistan which receives about 20 MJ/m^2 daily global solar radiation intensities. These conditions are ideal for different solar energy applications such as solar PV and solar thermal. Average solar insolation data for the major cities of Pakistan is shown in Fig. 16.1 [7] whereas mean monthly climatic data for Pakistan is shown in Fig. 16.2 [8]. The average daily sunshine duration for Pakistan is about 7 h. A high resolution annual solar resource map of Pakistan and potential

Table 16.1 Estimated load requirements for the community

Appliances	No. of units	Operating time (hours)	Wattage per unit (W)	Total daily load of a single house (kWh/day)	Total daily load of the community (kWh/day)
Lighting lamp	5	12	25	1.0	100
Washing machine	1	1	250	0.25	25
Refrigerator	1	13	180	2.3	230
Water pump	1	3	120	0.36	36
TV	1	7	80	0.56	56
Fan	3	8	60	1.26	126
Electric iron	1	0.5	1500	0.75	75
Total load				6.48	648

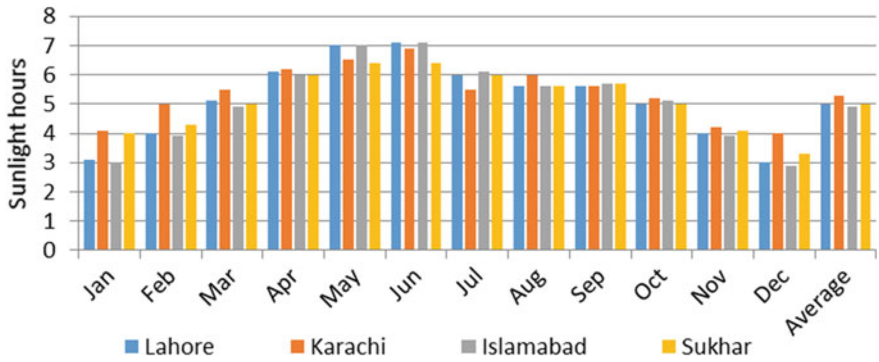

Fig. 16.1 Monthly average solar insolation for major cities [7]

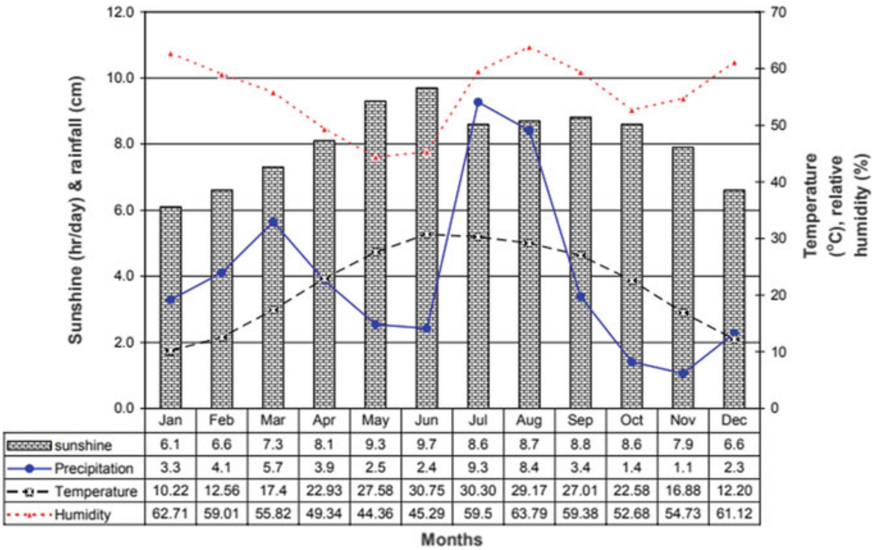

Fig. 16.2 Mean monthly climatic data for Pakistan [8]

of PV power output across different parts of the country is shown in Figs. 16.3 and 16.4. It can be observed that, solar potential is high in all parts of the country. The solar PV output potential is high throughout the country.

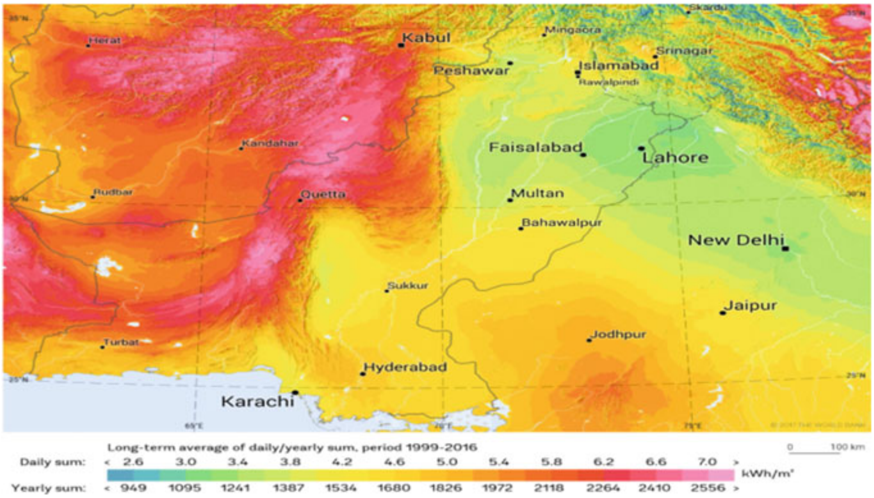

Fig. 16.3 Solar map of Pakistan. *Source* World Bank

16.4 Design Results and Discussion

The basic off-grid PV system consists of PV modules, inverter, power back up storage system, and a charge controller. The correct sizing and configuration of PV system for household electrification is very important for a predefined load demands. Depending upon the daily load requirements, the peak power of the PV module (P_{PV}) can be obtained using following relationship [8]:

$$P_{PV} = \frac{L_{daily}}{\eta_{overall} \times PSSH} \times SF \tag{16.1}$$

The estimated value of daily load demand (L_{daily}) for a single house is around 6.48 kWh whereas total daily load demand of the community accumulates to 648 kWh. The annual average daily peak sunshine hours (*PSSH*) in Pakistan is 7 [7]. The values of overall system efficiency ($\eta_{overall}$) and safety factor (*SF*) for compensation of resistive and temperature losses are taken as 80% and 1.15, respectively. The overall system efficiency accounts for connection losses, dust factor, inverter efficiency, and charging efficiency.

Using the above mentioned values, the required peak power of solar PV system is found to be 133.07 kW. Based on load, a solar module, mono-crystalline PV module type mono-Si-STP180S-24 from Suntech with a module peak power of 180 W_p is selected. The frame area of a module is 1.28 m^2. The required number of modules with selected specification is 739 and installation of all these modules will require a total area of 946.28 m^2. Based on the designed PV system a total capacity of 146.38 kW is required for an inverter with an efficiency of 90%. The detailed specifications of the selected PV module are presented in Table 16.2.

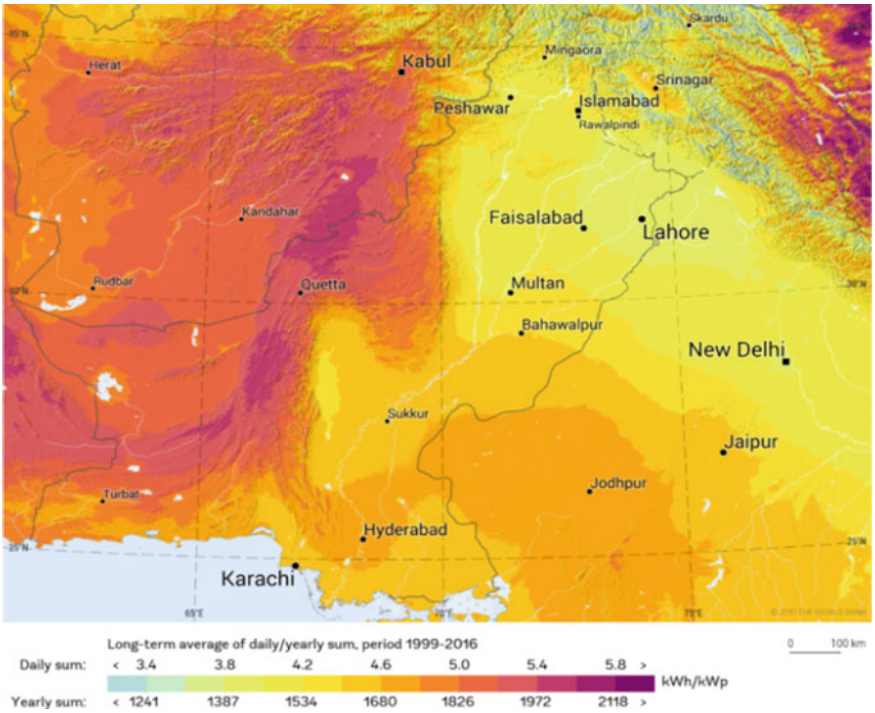

Fig. 16.4 Mapping of PV power potential across different parts of Pakistan. *Source* World Bank

Table 16.2 PV module specifications

	Unit	Specification
Type of module	–	mono-Si
Peak capacity per module	W	180
Manufacturer	–	Suntech
Model	–	mono-Si-STP180S-24
Module efficiency	%	14.1%
Nominal operating cell temperature	°C	45
Temperature coefficient	%/°C	0.40%
Solar collector area per module	m^2	1.28

The intermittent nature of solar power requires the correct sizing of the backup storage system. The correct size of the battery can be determined using Eq. (16.2). The ampere-hour capacity (C_{Ah}) and watt-hour capacity (C_{Wh}) of the battery block, with a maximum of 1 continuous day without sun can be determined using Eqs. (16.2) and (16.3), respectively.

$$C_{Ah} = \left(\frac{L_{daily}}{V_B \times \eta_B \times DOD}\right) \tag{16.2}$$

$$C_{Wh} = C_{Ah} \times V_B \tag{16.3}$$

where, values of battery bank voltage (V_B) and efficiency (η_B) are taken as 85% and 24 V, respectively while permissible depth of discharge (DOD) for the battery is assumed to be 0.80. Using these values, a battery with a capacity of 39,705 Ah/953 kWh is required for continuous electricity supply to the facility under study. The size of the charge controller can be obtained by dividing the maximum capacity of PV array with battery bank design voltage. The required size of the charge controller for this study is found to be 5541 A. The designed values of all the components needed to fulfill required load demands are summarized in Table 16.3.

The determination of life cycle cost and unit rate of electricity is an important aspect in order to assess the financial viability of the installed power system. The acquisition costs of an off grid PV system include costs of PV array, inverter, battery banks, and charge controller and are determined from the unit costs available in the country. Whereas, as operating and installation costs are normally taken as the percentage of PV modules cost. The detailed procedure and description of relationships used for life cycle cost analysis are presented in Fig. 16.5. In Fig. 16.5, the terms C_{PVi}, C_{Bi}, C_{Ii}, and C_{cci} represents unit cost of PV array, battery, inverter, and charge controller, reactively. The lifetime (N) of the installed PV system is taken as 25 years except batteries for which 5 years of life cycle are considered. For the assessment of life cycle costs an inflation rate (i) of 8% and a discount rate (d) of 10% is considered depending upon the data for Pakistan. The other costs associated with solar PV system such as cabling etc. are counted as miscellaneous costs and are taken as 2% of initial cost of PV system.

The associated unit costs of system components based on market prices in Pakistan and other factors for financial analysis are presented in Table 16.4. In this research the value of US dollar (US$) to Pakistani Rupees (PKR) has been taken as 110 (1 US$ = 110 PKR). The obtained results are illustrated in Table 16.5. The cost of above designed PV array, inverter, and charge controller is found to be 119,763 US$, 52,695 US$, and 4544 US$, respectively. The total cost of initial group of batteries and replacement set of batteries with above designed capacity is found to be 158,278 US$. Finally, the total life cycle cost of the off-grid PV system is found to be 348,453 US$. This cost also includes system installation, maintenance and miscellaneous costs. With a discount and inflation rate of 10% and 8%,

Table 16.3 Designed system components for an average value sunshine

Component	Capacity
PV module	133.07 kW
Inverter	146.38 kW
Battery	39,705 Ah/953 kWh
Charge controller	5541 A

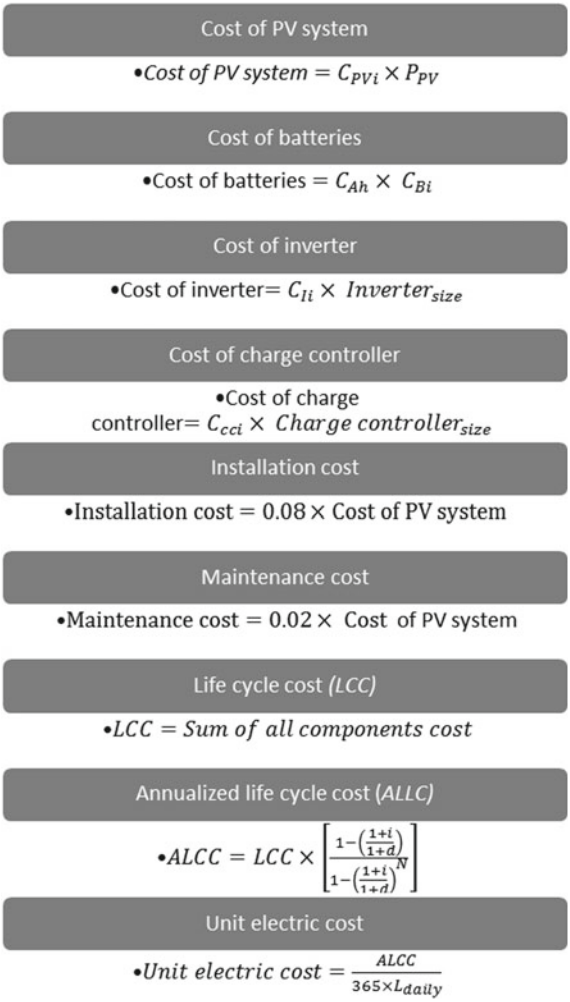

Fig. 16.5 Process and description of relationships used for life cycle cost analysis

Table 16.4 Unit costs of individual components

Item	Value of one unit in PKR	Value of one unit in US$
PV module	100 PKR/W	0.90 US$/W
Battery	105 PKR/Ah	0.95 US$/Ah
Charge controller	90 PKR/A	0.82 US$/A
Inverter	40 PKR/W	0.36 US$/W

respectively, the annualized cost of the system over a lifetime of 25 years is estimated to be 17,224 US$/year. As, the total daily load demand of the community is 648 kWh, the calculated cost of electricity for one unit is 0.072 US$/kWh.

Table 16.5 Life cost analysis results

Item	Value
Cost of PV system	119,763 US$
Total cost of batteries	158,278 US$
Cost of charge controller	4544 US$
Cost of inverter	52,695 US$
Cost of maintenance	2395 US$
Cost of installation	9581 US$
Miscellaneous costs	1198 US$
Total life cycle cost (LCC)	348,453 US$
Annualized LCC (*ALCC*)	17,224 US$/year
Unit electrical cost	0.072 US$/kWh

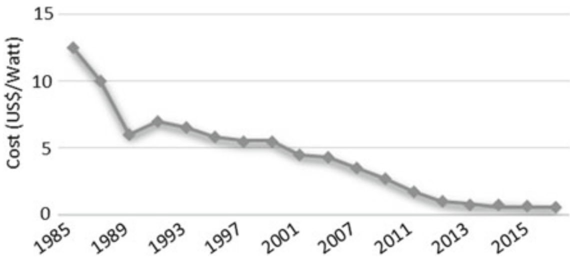

Fig. 16.6 The cost of solar energy generated through PV cells. *Source* IRENA

The current unit cost of conventional electric supply in Pakistan ranges from 0.13–0.18 US$/kWh (15–20 PKR/kWh) which means that produced electricity from installed off-grid PV system is 45–58% cheaper as compared to conventional grid supplied electricity. The initial cost of PV modules is decreasing with time as shown in Fig. 16.6. This will result a decrease in cost of power generation from solar PV technology in the coming time. Furthermore, the subsidies and support provided by the government of Pakistan will further decrease the unit cost of electricity from the PV system.

The integration of solar based electrification technology in the country will help to achieve a sustainable energy mix in the country as this will help to overcome increasing emission of greenhouse gases.

16.5 Conclusions

The implementation of renewable based technologies for household electrification is a need of the day in developing countries like Pakistan. In this chapter, a simplified design procedure is presented to size an off grid PV system to fulfill the load demands of a household in particular and a group of houses in general. The life cycle cost analysis of the PV system for single household application has also been estimated based on the market available prices in the country and inflation rate. The obtained results from the present study indicate that development and implementation of off grid PV system to fulfill load demands of a household is beneficial and suitable for long-term investments. The achieved electricity rate from off grid PV system is found to be 50–55% cheaper as compared to conventional electricity supplied in Pakistan. Apart from that, the prices associated with solar technology are decreasing which will further reduce the associated costs for development of solar assisted power plants. Also, the efficiency of the solar cells is increasing with time which will make it further economical. That is why; solar PV power plants are most promising energy source for climatic conditions of Pakistan and would be the better option for household electrification in the country.

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Muhammad Mujahid Rafique is a graduate with strong communication and organizational skills; trained as a mechanical engineer and researcher. His scholarly area of research is thermal science with major focus on the development of clean and energy efficient mechanical systems. His main areas of interest are energy conversion and management, desalination, sorption, solar air conditioning, desiccant cooling, heat and mass transfer, and development of renewable energy technologies. His updated research profile can be accessed through: http://orcid.org/0000-0003-4366-6198.

Shafiqur Rehman is a Research Engineer-II (Associate Professor) at the Center for Engineering Research at the Research Institute of King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia. Dr. Shafiqur Rehman was honored with 'Best Researchers Awards in 2007 and 2012' by the university and a national "Almarai Scientific Innovation Prize—2017."

He has been mainly involved in wind and solar power resources assessment, wind speed and related parameter measurements using 40 m tall towers, design of wind farms and PV power plants for isolated and grid connected applications, design and optimization of hybrid power systems (Wind-Diesel, PV-Diesel, Wind-PV-Diesel), corrosion measurements and data analysis, the mathematical modeling of planetary boundary layer, upper air meteorological data measurements using radiosonde, establishment of baseline environmental data for new upcoming industrial zones in Saudi Arabia, LiDAR based wind speed and direction measurements up to 200 m. Dr. Rehman has hands on experience on state of the art wind data analysis tool "WindoGrapher" and windfarm design tool WindFarmer, and hybrid power system design and optimization too HOMER.

Dr. Shafiqur Rehman is the author of more than 200 technical papers published in refereed technical ISI journals and refereed conference proceedings, a book, and three book chapters. He has participated in the writing of more than 75 technical reports and more than 45 research proposals. Last but not the least Dr. Rehman has around 3880 citations on SCOPUS with an h-index of 30 excluding the citations by all authors. He has 6469 citations with h-index of 39 on Google Scholar and a RG score of 39.64 and more than 5300 citations on research gate with an h-index of 34. He has also received best paper awards and has been invited as keynote speaker at international refereed conferences.

Chapter 17
Review on Cow Manure as Renewable Energy

Anas Tallou, Ayoub Haouas, Mohammed Yasser Jamali, Khadija Atif, Soumia Amir and Faissal Aziz

Abstract The world now is looking for alternative resources of energy instead of using fossil fuels that contribute to the greenhouse gases and that are in depletion. This energy must be renewable and environment eco-friendly. The huge amounts of organic waste produced every year imposes to seek for a new approach and new methods to manage these tremendous quantities of organic waste dumped illegally into natural resources. Cow manure is considered one of the most abundant organic waste threating our world, especially that it produces greenhouse gases, malodours and destroy water and agricultural resources. From the other side, cow manure presents many properties that can be useful as renewable energy and soil organic natural amendment. Regarding the amount of cow manure produced, there is a significant possibility and opportunity for all researchers to work on this organic waste. One of the best biochemical methods used to manage cow manure is an-aerobic digestion. It is considered an attractive approach especially in terms of renewable energy (producing biogas and bio-fertilizers). This review article presents an overview of cow manure used as substrate and co-substrate in the anaerobic digestion process from different perspectives.

Keywords Cow manure · Anaerobic digestion · Biogas · Waste

A. Tallou · A. Haouas · M. Y. Jamali · K. Atif · S. Amir
Interdisciplinary Laboratory of Research and Development, Sultan Moulay Slimane University of Beni Mellal, Beni-Mellal, Morocco

F. Aziz (✉)
Laboratory of Hydrobiology, Sanitation and Global Change (LHEAC, URAC 33), Semlalia Faculty of Sciences, Marrakech, Morocco
e-mail: faissalaziz@gmail.com; faziz@kth.se

F. Aziz
National Centre for Research and Study on Water and Energy (CNEREE), University Cadi Ayyad, Marrakech, Morocco

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17.1 Introduction

The biggest challenge today is the environmental, economic and health equilibrium named circular economy concept. It aims to create a sustainable system that produces goods, manage different waste and ensure human health in order to achieve sustainable development goals [31].

Animal manure is considered very attractive when it comes to renewable energy, it is a natural resource that can replace industrial fertilizers and enhance soil fertility. Nevertheless, this organic waste has several disadvantages if not treated such as malodours, water, and soil depletion and greenhouse gases emission [7]. Cow manure presents several advantages and benefits, such as in-creasing methane production when used as co-substrate in anaerobic co-digestion process, it balances low substrate parameters as well as pH, C/N ratio and nutrients content [33]. Cow manure management is considered as one of the important challenges nowadays, it is necessary to elaborate appropriate approaches and treatments to manage cow manure problems. Therefore, biogas plants technology is a suitable solution for producing renewable energy and reducing greenhouse gases emission [14, 29].

Ruiz et al. [25], reported a total amount of animal manure produced annually, where sewage sludge is on the top with 7200 t/yr followed by pig and cow manure with 6500 t/yr. Manure quantity generated is about 2.7 million tonnes dry weight per year, where cow manure has the majority with 76%, horse manure, pig and poultry represent respectively 10, 6, and 2%. From these data, it can be seen clearly the huge quantity of cow manure that can be transformed into renewable energy instead of being discarded [7].

Anaerobic digestion process (AD) can be defined as the biodegradation of different organic wastes in anaerobic conditions [6]. Cow manure is a suitable substrate for anaerobic digestion because of its properties. Alt-hough the common use of cow manure is the land spreading, and in terms of quantity, there is a surplus, which can be elaborated in anaerobic digestion. This technology can lead to an adequate digestat after the process, which is rich in important nutrients for plants (C/K/N/P). On another hand, the microbial community consumes organic matter at soluble form. Therefore, solubility and the humidity percentage is crucial in anaerobic digestion [18, 27].

The AD is an efficient technology for organic wastes treatment, which has several advantages as malodorous emissions control and biomass stabilization. The majority of researchers nowadays use different organic waste in mixtures as a substrate for anaerobic co-digestion due to the high performances and results obtained compared with mono anaerobic digestion. Nutrients imbalance, volatile fatty acids, acidification, and toxic compounds are common problems in anaerobic digestion that can be tackled with mixing different type of organic waste. Anaerobic digestion is favorable when it comes to energy ratio (28.8 MJ/MJ) [6, 16, 21].

The AD is a process that needs exact parameters to succeed. It is reported that any slight fluctuation in parameters leads to process deficiency. Temperature is the most effective parameters where the optimal temperature range is [35–40 °C] [18, 30].

pH is also very important and need to be monitored between [6.5–8], Increase or decrease in pH value influence on the biochemical process of the anaerobic digestion and consequently low biogas production. Other parameters such as C/N ratio, hydraulic retention time, Volatile Fatty Acids (VFA), stirring and also particle size can also affect the whole process [18, 27].

Anaerobic digestion technology has many advantages including economy, health, environment and social: The biogas resulted can be used for electricity and heating, and it is considered clean in terms of energy burned and gas emissions during combustion. The by-product resulted from this process called digestat is also very rich in nutrient suitable for agriculture [18, 21]. Overuse of chemical fertilizers in the last century resulted in many dangerous problems affecting the ecosystem and human health. Therefore, bio-fertilizers is-sued from organic waste is now a world strategy [13].

In 2010, a number of biogas plants reached 5800 unit and generate 2300 MW of electricity. The United States of America with 160 biogas plants generates 57.1 MW of electricity. Biogas production in Europe is about 10.9 Mt where Germany have 61% as the first country in producing renewable energy, while the United Kingdom has a part of about 16.5%. It is expected that Germany will reach 43,000-biogas plant by 2020. China is also considered one of the top countries implementing biogas plants with about 4700 biogas plant and production rate of 4 billion m^3 of biogas annually. In growing countries such as Ethiopia, 14,000 domestic biogas digesters are implemented which means that all the world now is looking for an alternative resource of energy and in the same time must be an eco-friendly technology as anaerobic digestion [21].

17.2 Cow Manure as a Substrate in AD Process

Javed et al. [14] investigated the large quantity of organic waste produced every year in rural areas of Bangladesh, where cow manure is on the top by 102.6 million tons/year. They indicated the great economic value of this organic waste to produce renewable energy (biogas and bio-fertilizers) in order to reach the environmental, industrial and health balance. Authors linked different renewable energy technologies available to manage organic waste produced every year to cover the energy needs of rural areas, this strategy called life cycle analysis (LCA). Data were collected from 20 biogas plant and 20 solars photovoltaic to evaluate the factors affecting the efficiency of this system. It was highlighted that poultry waste is more productive in terms of biogas than cow manure and the Life Cycle Analysis (LCA) confirm that photovoltaic systems and biogas plants using cow manure and other organic waste is economically feasible.

There are few research papers that treat tea waste, where tea is considered one of the most important products in daily life. Khayum et al. [16] reported that India, China, Srilanka, and Kenya are the leading producer of tea where India is the second producer of tea with 900,000 tones/year and about 70% is consumed only in

India. Therefore, the organic waste generated can be used as a substrate in the anaerobic digestion process. Authors of this work co-digested tea waste with cow manure in different percentages (50/50, 60/40, 70/30, 80/20, and 100/0).They obtain a maximum biogas (0.82 ml/g VS) and maximum methane (14.40 ml CH_4/kg) from the (70 (tea waste)/30 (cow manure)) combination. This result was confirmed also by the pH, C/N ratio and spectroscopic analysis using FTIR and X-ray diffraction [16].

Dias et al. [11] worked on anaerobic co-digestion of cow manure with pear waste, under mesophilic and anaerobic conditions using a completely mixed stir-ring tank reactor (CSTR). This study aimed to evaluate the influence of substrate type on biogas production. Pre-treated dairy cow dung was co-digested with pear residue in different mixtures (0, 25, 75, and 100%). The authors showed that addition of co-substrate enhances clearly the biogas yield in comparison with mono-digestion. Synergetic effect and high performance were observed in the mixture (75% PLF + 25% LCM) resulting in methane production of 390 ± 2 ml g-1 and a volatile solid removal of 60%. Storage of pear residue did not show any effect on the anaerobic digestion process. This research paper showed that pear waste can be an interesting candidate to be co-digested with cow manure and can complement each other for energy production and waste management [11].

Dareioti et al. [10] exanimated the anaerobic co-digestion of treating olive mill wastewater with cow manure under mesophilic conditions (35 °C). Acidogenesis and methanogenesis process was monitored and controlled separately using two continuously stirred tank reactors (CSTRs) for hydraulic retention time (HRT) of 19 days. The importance of using cow manure appears in balancing alkalinity, nitrogen content, and dilution of phenolic compounds and fatty acids [18]. They prove that AD of olive mill wastewater with cow manure is a stable system. The presence of cow manure enhances the biogas yield, increase resistance to acidification and biodegradation of phenols present in olive mill wastewater [10]. Mahmoodi-Eshkaftaki et al. [20] Assess two type of mixers (pneu-mechanical and mechanical) in order to increase microbial activity and enhance biogas yield. Highest biogas yield was obtained when using an initial bioreactor composition (42% of cow manure, 56% of municipal wastewater and 2% of kitchen waste) stirred with pneu-mechanical mixer.

Torrellas et al. [29], elaborated different approaches to characterize gas emissions from anaerobic co-digestion of cow manure with industrial food waste (normal measurement, theoretical estimation, and the IPPC adopted guidelines). Evaluation of biogas production from cow manure (CM) at pilot scale was done using ultrasonic pre-treatment and co-digested with crude glycerine which is considered, and appropriate candidate that balance the cow manure nutrients. The highest biogas yield (0.59 m^3 CH4/kg VS added) was obtained when the mixture of cow manure and crude glycerine was pre-treated by ultrasound. The paper shows clearly that biogas production enhanced when the mixture was treated by ultrasound. When comparing the results from laboratory and semi plant scale, it has been concluded that scaling of the anaerobic co-digestion and pre-treatment with US is feasible. Morphological changes in cow manure after pre-treatment and/or co-digested with crude glycerine was analyzed using Scanning Electron Microscopy (SEM), which, confirmed the results obtained by the researchers. From im-ages of Scanning Electron Microscopy, ultrasound pre-treatment and addition of crude glycerine as a co-substrate increase the surface accessibility of cow manure [24, 28].

In order to enhance the biogas plant performance, [32] used an adaptive neuro-fuzzy interference system called ANFIS during AD of cow manure with maize straw. This system is considered successful to elaborate models in order to measure and evaluate biogas produced during AD process. The main idea of this model is to compare and evaluate the scatter between theoretical and experimental biogas yield through the coefficient of determination.

The results collected during the anaerobic co-digestion of cow manure with maize straw were biogas yield with different total solid, C/N ratio and stirring within 17 days of hydraulic time retention. Based on the ANFIS model, the coefficient of determination 0.99 was obtained from the data analyzed and compared between theoretical and experimental biogas production. Therefore, authors of this paper confirmed that ANFIS model can provide high measurement and certitude to forecast biogas production. In order to reach the maximum biogas yield, ANFIS model recommends an exact anaerobic co-digestion parameter (Total Solid of 9%, C/N ratio of 27.9 and stirring of 60 rpm). The maximum biogas obtained in this case was 194 L/Kg TS [32].

Corro et al. [9] evaluated the use of coffee-pulp in anaerobic co-digestion process with cow manure and the influence of this mixture on biogas production under mesophilic conditions. Biogas obtained from the experiments was analyzed with FTIR in order to investigate the presence of hazardous compounds that can affect humans or animals health.

Three bioreactors were performed and monitored in this study. Bioreactor 1 contained (80% of cow manure and 20% of tap water). Bioreactor 2 was loaded with 80% of coffee-pulp and 20% of water and the bioreactor 3 was loaded with a mixture of 40, 40 and 20% of water. Biogas obtained from reactor 1 was low due to nutrient deficiency in cow manure even the presence of bacteria in the first month. For Bioreactor 2, authors observed also low biogas production rate but in this case, the problem is due to the presence of caffeine and phenolic compounds, which are considered toxic to bacterial community. In contrast, it was observed the highest biogas produced in reactor 3 where cow dung and coffee-pulp were mixed for a period of four months. It can be also concluded that this mixture is suitable for the anaerobic co-digestion process. This result is more confirmed with the optimum C/N ratio and balanced nutrient and presence of the microbial community during the process [9].

Biogas produced during the anaerobic co-digestion was analyzed with Gas Chromatography (GC) and Infrared spectroscopy FTIR. The results showed the presence of toxic compounds such as hydrocarbons, isocyanic acid, bromomethane, and other toxic volatile compounds. Authors of this work present very important results that can limit the anaerobic digestion process or open other new thematic problem that need to be faced [12, 26].

Nordell et al. [23] used two bioreactors in order to study the influence of adding trace element (Cobalt and Nickel) during anaerobic co-digestion of manure in mixture with industrial waste. The initial substrate used in this work is highly concentrated in cobalt and nickel. In the bioreactor where trace elements were added, it was noticed that volatile fatty acids (VFA) were 89% inferior to the reference bio-reactor. In addition, biogas yield rate increased with 24% as a consequence of the presence of trace elements at high organic loading rates. These results showed the positive influence of adding trace elements to the anaerobic co-digestion process. Addition of nickel has shown a positive effect on the biogas production and the authors noticed that the influence was within hours (rapid effect). The production of biogas increased rapidly after the addition of nickel.

This research paper showed an important result of using trace elements such as nickel and cobalt in anaerobic co-digestion of manure with industrial waste. But the challenge now still in demonstrating and evaluating the digestat resulted from the anaerobic digestion process in order to determine the safety of this by-product that can be used as a bio-fertilizer, especially when it comes to tracing element which is considered phytotoxic for soils and plants and consequently on humans and animals.

Anaerobic digestion results were analyzed with CCA (canonical correlational analysis) and HCA (hierarchical clustering analysis), which demonstrate the impact of cow manure addition to anaerobic digestion of oat straw in different percentages on biogas production rate [33].

The addition of cow manure at a proportion below 2/3 enhanced the biogas yield. In addition, the highest cumulative biogas yield was 26.64% higher than oat straw digested alone. However, above a proportion of 2/3, cow manure is considered as an inhibitor [33]. It can be due to the unbalanced nutrient during the anaerobic co-digestion process, which means an increase in bacterial community and decrease in available nutrient, and therefore high ammonium concentration.

In comparison with wet anaerobic digestion, dry fermentation technology presents several advantages in terms of low energy need, wet digestion needs dilution with water, liquid inputs, and agitation. Chiumenti et al. [8] evaluate the biogas production and electric energy produced from start-up until full-scale period. First, dry fermentation plant produced thereabout 3,431,900 m^3 of biogas and electric energy of 6905.604 MWh. These results are comparable to the biogas yield resulted from a wet process for a retention time of 365 days. This recent paper [8] confirmed that the dry fermentation process could reach the same biogas production rate and electric energy to wet anaerobic digestion process. In addition, dry fermentation parameters (hydraulic retention time HRT, initial loading rate and recirculation of digestat) must be controlled in order to achieve the highest performances. Moreover, this process can avoid the wet anaerobic digestion problems but not much was done in literature in this field.

European Biogas Association EBA reported in 2013 that total biogas production is about 13.4 million tonnes of oil equivalent. The number is expected to be higher in the future. This paper reported a significant and an important potential for biogas plants [7].

Alvarez et al. [5] worked on the anaerobic digestion of llama manure and cow dung, but the exception of this study was the high altitude (Bolivian highland). Authors of this article report that no published studies were available for highlands above 3000 m over the sea level. The region where the experiments were conducted is situated in an altitude between 3000 and 4000 m over the sea level. This parameter of high altitude means that the process of anaerobic digestion and also cow manure contents are affected by temperature and pressure and consequently by hydraulic retention time. Alvarez et al. [5] used a factorial design in order to optimize the process. They report that the nitrogen content in Bolivian cow manure is less than the minimum requirement (0.6%) for microbial community, which can affect negatively the biogas production. It was the case in the result when they observed low biogas production from lama and cow dung.

A research paper published by Alfa et al. [4] was done in Sub-Saharan Africa, place where energy and natural resources are very important especially that 36% of people who can benefit from sanitation facilities and 58% have access to clean water. In terms of renewable energy, anaerobic digestion is considered the best method to provide energy and to protect environmental resources. As reported in this study, biogas technology is an alternative opportunity for an energy resource that is environmentally friendly economically inexpensive. It can also preserve the green forest in order to achieve the SDG (Sustainable Development Goals) on environment protection and sustainability. The first objective of SDG is to solve extreme poverty and hunger problems. Therefore, using the digestat produced from the anaerobic digestion, to fertilize soils and improve the agriculture is certainly recommended to achieve circular economy [4, 31]. Alfa et al. [4] evaluated the efficiency of the anaerobic digestion process of cow manure with poultry manure. Microbiological analysis of the digestat showed an-aerobic and aerobic microorganisms, as well as Clostridium, Pseudomonas, Bacillus, Penicillium, Bacteroides. *Shigella spp*. and *E. coli* were discarded after the an-aerobic process. It was noticed that Salmonella and Klebsiella still present after the AD process. Therefore, digestat needed to be treated in order to confirm its safety and can be used as bio-fertilizer. Nutrients in digestat after anaerobic digestion is higher than in substrate before the process. For example, they noticed that digestat has 25% more accessible nutrient as nitrogen than untreated cow manure. Another important aspect presented in this work is that Bacillus species solubilized silicates and zinc, which are toxic trace element and this species, can influence positively the plant growth. Udomonas spp. Can solubilize phosphate bio-fertilizers, Pseudomonas species can also help the plant growth by boosting rhizobacteria. They showed also that Penicillium and Aspergillus could solubilize phosphate fungi. All these organisms make the digestat an excellent bio-fertilizer [4].

Achinas et al. [3] studied the influence of digesting sheep manure as a co-substrate with cow manure in anaerobic conditions. Methanogenic communities were determined in this experiment to study their effect during the AD process. Authors reported that the mono-digestion of cow manure reaches the maximum biogas volume (104 Nml biogas g-1 V, while AD of cow manure with sterilized sheep manure results in low biogas volume (0.89 Nml biogas g-1 VS). Low nutrient content in cow and sheep manure results in low methane yield. Therefore, sheep manure had a negative effect on the anaerobic process of cow manure digestion. This research paper showed that anaerobic digestion still a complicated process that needs to be studied in order to reach high performances, especially the microbial community responsible for degrading organic matter.

Another research paper of Aboudi et al. [2] treated dried pellet of sugar beet in anaerobic mono and co-digestion system using cow manure as co-substrate in a mesophilic semi-continuous bioreactor. Mono-digestion experiment showed stable biogas production rate during the hydraulic retention time of 20 days (OLR: 3026 gVS/L reactor d). On the other hand, authors reported that the addition of cow manure permit to decrease the HRT hydraulic retention time to 15 days (OLR:4.97 gVS/L reactor d) and increased the biogas production by 32%. This research paper investigated also the type of volatile compounds present in the experiments. For the mono-digestion, propionic acid was observed while in co-digestion acetic acid was predominant. The role of cow manure in this research paper was clear and acted positively when used as a co-substrate for the anaerobic digestion process.

Khairuddin et al. [15] used cow manure in their experiments as a co-substrate with household organic waste (HOW) in anaerobic co-digestion conditions. The objective of this paper was the investigation of synergistic effect resulted from the mixture of these two organic waste in four reactors, where two reactors were used for mono-digestion and the other ones for co-digestion. Authors showed clearly that the synergistic effect was significant in the co-digestion where the results were analyzed following this equation below:

$$\alpha = \frac{Co-digestion\ methane\ yield}{Mono-digestion\ methane\ yield}$$

If $\alpha > 1 \Rightarrow$ digestat has synergistic effect.
if $\alpha = 1 \Rightarrow$ substrate work independently from the mixture.
if $\alpha < 1 \Rightarrow$ competitive effect in the digestates.

The highest methane yield 247 mL/g VS and 243 mL/g VS were obtained from R_3 and R_4 respectively. These results confirmed the importance of using co-digestion which is a more stable process instead of mono-digestion.

Essential elements (N, P, and K) were measured in order to valorize the digestates after AD process. Nitrogen content enhanced by 5–30% in all bioreactors, but no significant effect of AD was observed on phosphorus (P). In addition, 33% of potassium (K) was noticed as the highest value in digestates from R2 [15].

Cow manure was used also as a source of the microbial community in AD of different organic waste (castor cake, maize cob, mixed vegetable waste, etc.). In this work [19], 10 ml of digested slurry from cow manure was added to each bioreactor. The maximum biogas production rate, degradation of hemicellulose and microorganisms activity were recorded in T7 reactor where there are no fluctuations in pH [T7: 25 g of cow manure (CM); 25 g of castor cake (CC) and 40 g of mixed vegetable wastes (MVW)]. This old paper [19] reported that the successful management of different organic waste can be effective and can provide renewable energy, bio-fertilizers and reduce the impact of organic waste on the environment, which is now accepted and revised by the European Commission in order to start producing bio-fertilizers from organic waste.

The use of bio-fertilizers as an amendment for soil instead of synthetic fertilizers is a promising approach nowadays, that can help to reduce phytotoxicity of heavy metal present in agricultural soils. The presence of these toxic elements is very dangerous for animals and humans. [17] studied the influence of cow manure (CM) and cow manure biochar (CMB) on cadmium present *in Brassica chinensis L.* planted in a specific soil. Cow manure and Cow manure biochar were added in different percentages (0, 3 and 6%) to acidic red soil contaminated with cadmium. The results showed that cow manure biochar was more effective than cow manure in terms of reducing the cadmium availability in acidic red soil, where the presence of Cd in soil reduced by 34.3–69.9%. This original work confirms also that the addition of cow manure biochar rises the extractability of trace elements (Cu, Zn, Fe, and Mn) and accumulation in plants. The application of Cow manure biochar in reducing phytotoxicity of agricultural soil by Cd caption is a new approach that improves sustainability and contributes to decrease soil pollution. Cow manure was used as a bio-fertilizer to increase the fertility of agricultural soils. Because of its high nutrient content especially ammonium, cow manure biochar (CMB) contains essential nutrient for plants. The surface area of CMB used in this work is about 8.55 m^2g^{-1}. This property assists in the Cd sorption pre-sent in contaminated soil. Authors of this work present an opportunity for researchers to work on this theme. They reported the rare bibliography of using organic waste properties as well as cation exchange capacity (CEC) in reducing soil phytotoxicity and heavy metals contamination.

Abdelsalam et al. [1] worked also on nanoparticles effect on anaerobic digestion of cow manure in mesophilic conditions. They found that the addition of nano-particles of trace metals (Ni, Co, Fe, and Fe_3O_4) influence positively on the process where Ni increase the biogas production more than Cobalt and Iron. It was observed that the time to reach maximum biogas was reduced.

Cow manure is a biodegradable organic waste that should not be stored in landfills because of high levels of nutrients and pathogens. It is reported, according to Neshat et al. [22], that cow manure can contain about 10 lb/t of potash, 5 lb/t of phosphate and also 10 lb/t of nitrogen. In many countries, this organic waste is discharged into the water resources, which can be bio-decomposed and create eutrophication and heavy metals contamination of water resources and consequently several environmental and health problems. This review article presents many studies already done on anaerobic co-digestion of animal manure (especially cow manure) and lignocellulosic biomass waste in order to produce biogas energy.

Many biomass wastes were reported in this review [22] that are considered to be a suitable candidate to be co-digested with cow manure. Kitchen wastes when co-digested with cow manure produced biogas yield higher than the mono-digestion. Wheat straw, which is a very abundant agricultural waste, is an interesting organic waste that can balance the low nutrient content of cow manure. Switch grass, corn Stover, cotton stalk and palm pressed fiber were co-digested by several researchers with cow manure and improved the biogas production rate and digestates important properties.

17.3 Conclusion

This review article is on cow manure and its importance in anaerobic digestion as a method of biological treatment of different organic waste in order to obtain biogas and bio-fertilizers. All research papers presented in this work reported the positive contribution of cow manure and confirmed the usefulness of this organic waste from different researcher's perspectives. Biogas plants are rising in all over the world, which can be a sustainable solution in order to protect our natural resources and can afford a renewable, clean and cheap energy. The anaerobic digestion process still complicated because of the different parameters that control this process, and especially when adding different organic waste with different composition, parameters, and properties. Now, it is time to be aware of the major environmental problems, and seeking for new technologies, new approaches and new strategies in order to reach the environmental, industrial and health balance.

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Chapter 18
Algae-Powered Buildings: A Strategy to Mitigate Climate Change and Move Toward Circular Economy

Ahmad Farhad Talebi, Meisam Tabatabaei, Mortaza Aghbashlo, Soha Movahed, Masoumeh Hajjari and Mahmoud Golabchi

Abstract By 2050, the global urban population is expected to raise by 2.5 billion. Equivalently, the required building space in square footage is projected to be doubled. Thus, the importance of emerging sustainable architecture as a new approach to energy conservation is increasingly highlighted. Algae are well known for their high capacity to simultaneously sequestrate carbon dioxide and produce clean energy carriers. Such unique characteristics of algal communities put them among the most qualified candidates to be used in bioinspired architectural designs. They could be utilized whenever energy and water saving is a matter of concern or an efficient management of liquid and solid waste is needed. Today, algal cells are considered in the design of solar thermal collectors, improved indoor air conditioning systems, lighting systems, shading, etc. Algal photobioreactors as part of

A. F. Talebi
Genetic Department, Faculty of Biotechnology, Semnan University,
35131-19111 Semnan, Iran

M. Tabatabaei
Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA (UiTM),
40450 Shah Alam, Selangor, Malaysia

M. Tabatabaei · M. Hajjari
Biofuel Research Team (BRTeam), Karaj, Iran

M. Tabatabaei (✉)
Microbial Biotechnology Department, Agricultural Biotechnology Research Institute of Iran (ABRII), Agricultural Research, Extension, and Education Organization (AREEO),
Karaj, Iran
e-mail: meisam_tabatabaei@uitm.edu.my

M. Aghbashlo (✉)
Department of Mechanical Engineering of Agricultural Machinery, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources,
University of Tehran, Karaj, Iran
e-mail: maghbashlo@ut.ac.ir

S. Movahed
Pars Art and Architecture University, Tehran, Iran

M. Golabchi
School of Architecture, University of Tehran, Tehran, Iran

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building compartments have also been considered as a nature-based alternative to large glass surfaces. However, since the technology is still in its infancy, it has not been yet included in green building regulations. The present chapter reviews the current-state of the microalgae-based bioinspired designs in the development of green architecture. It also briefly covers the systems in which sunlight energy is converted into value-added products such as biomass, biogas, and biodiesel through microalgal photosynthesis. A strong synergy between biologists and civil engineers would be needed to progress towards more economic, sustainable, and cleaner algal-based architecture.

Keywords Algae · Algae-powered buildings · Photobioreactor · Renewable energy · Sustainable architecture · Green buildings · CO_2 sequestration · Energy harvesting · Smart village · Circular economy · Climate change mitigation

18.1 Introduction

One fifth of the global energy demands is consumed in the domestic sector and mostly in the residential and commercial parts. According to the International Energy Outlook 2016 [23], total energy consumption in the domestic sector will increase by about 1.5% per year beginning from 2012 till 2040. In light of that, policies already implemented in the EU region in compliance with the 7th Environment Action Program are aimed at reducing the overall environmental impacts associated with the production and consumption of energy in the housing sector.

Historically, coal was the first and only fossil source until the 1860s when The Great Smog of London in 1952 killed 4000 people as a direct result of the smog mostly arising from the use of coal in power stations located in the area of Greater London [8]. Subsequently, efforts were put into introducing more sustainable sources of energy carriers such as wind power, solar energy, etc. to various sectors including the household sector. In fact, if buildings are capable of generating their own energy sustainably, a large favorable impact on the total energy consumption will be expected. Consequently, this could also substantially reduce the air pollutants emitted by the housing sector. It is worth quoting that although the aforementioned technologies can sustainably generate electricity, they are incapable of taking up the existing CO_2 to further support the goal of environmental protection.

One of the novel approaches to the sustainable energy production is utilization of solar energy through the action of photosynthesizing unicellular/multicellular plant species whose biomass could be converted into renewable energy carriers. Among these species, microalgae are advantageous given their highest efficiency in utilizing solar energy. These unique microorganisms could be effectively cultivated in advanced platforms called photobioreactors [13]. The application of algal photobioreactors implemented in buildings as building compartments could not only reduce the external energy demands but could also simultaneously assist with CO_2 mitigation. Algal photobioreactors act as closed bioreactors driven by light energy and might appear in different shapes. They have to meet specific requirements for algal growth; i.e., conditions such as sunlight, nutrients, pH, CO_2 supply, and temperature directly determine the final productivity of these algal systems [19] and therefore, should be taken into account during buildings design and construction. In fact, within photobioreactors, suitable conditions for algal photosynthesis is provided in which cells could produce chemical energy by converting light energy. Valuable products such as biomass and bio-oil could be produced through microalgae photosynthesis, coupled by CO_2 sequestration as a major advantage.

In spite of the benefits considered for the integration of algal photobioreactors into buildings, lack of sufficient knowledge and know-how has limited such applications. Moreover, most of the documented results available in the literature are of laboratory scale. On the other hand, the completely multidisciplinary nature of the works; i.e., construction and algal biology has further made the task of show-how challenging. Hence, it will be essential to try to redesign new architecture models based on the very principles of sustainable development such as zero waste/zero emission, self-sustainability, environmental preservation, etc. Self-sustainability is also important in rural areas and development of smart villages, i.e., to make these platforms independent of the extended networks such as water and wastewater network as well as national electricity grid [24]. This would also help with maintaining the integrity of the rural areas causing minimal interferences while providing them with modern technologies and the favorable welfare consequences. In accordance with that, the present chapter is aimed at providing insights into the current algae production technologies while looking into the possibilities of using algal cultivation systems in architectural designs as a promising way for sustainable green energy generation and environmental amelioration. Furthermore, the utilization of algae-powered buildings in smart villages is discussed at the end of the chapter.

18.2 Green Buildings Regulations

To guide the nations toward a more sustainable and economically vibrant future, building codes and standards should play an integral role in shaping the cities and towns. These standards could substantially contribute to public health. In recent decades, they have focused on the issue of energy efficiency and have tried to reduce buildings' energy consumption by up to 70% compared with a similar base-case building. These regulations include both the design and construction of buildings and are dependent on a number of factors such as climatic, local, and economic conditions.

There is a consensus among the latest approaches in sustainable design regulations concerning the green buildings concept. The US Green Building Council (USGBC) and Leadership in Energy and Environmental Design (LEED) standards are two examples of the leading institutions in green design. LEED standards are implemented in all the levels of regulations from federal to local level, making it the superior green designs standard. To pass the hard process of obtaining LEED certification, a building has to gain qualification in all the aspects of design and construction involving water and energy conservation, waste recycling, materials, sitting and indoor environmental quality. Based on the points a building can earn in these areas, a certain LEED level will be gained. Four certification levels could be earned in LEED certification system: Certified (26 points), Silver (33 points), Gold (39 points), and Platinum (52 or more points) [4].

To obtain a LEED certification, a project has to be first submitted by the U.S. Green Building Council (USGBC) and the project documents will be pursued through the rating steps in the certification system. Upon the completion of this stage, the building has to be registered to the USGBC for the technical review process [5]. The USGBC will then assess whether the building features such as location and proximity to public transport, parking space, bike racks, water reusability and efficiency, energy saving, eco-friendly materials utilized in the building, etc. are in compliance with the requirements of each level. Then a LEED rating certification will be given based on the total points, the building has collected during the assessment [1]. The LEED checklist also involves a wide range of sustainability aspects and sustainable construction features to be checked in the interior design of the buildings such as recyclable materials or local products used in the painting, carpeting, decorating, flooring and roofing. The energy consumption optimization shortcuts posed in LEED are weatherizing, insulating, windows installation, ventilation ducts sealing, heating and cooling systems upgraded to more green ones with automatic controls, and finally lighting.

18.3 Algae-Powered Building

Energy demands and the issue of environmental protection are at the core of the present century's concerns. More than 30% of the global energy usage and about 50% of the urban greenhouse gas (GHG) emissions are associated with buildings. A major proportion of GHGs (such as CO_2) are in fact generated through anthropogenic activities like factories and farms. These gases hold high thermal capacities and are responsible for global warming (www.greenbiz.com). Therefore, in order to construct a more sustainable multifunctional city area, the issues of regeneration, reutilization and rehabilitation of the existing urban texture should be targeted [15]. Within such a framework, green buildings will be capable of onsite energy generation and a self-sustaining household could be established.

The application of living species as construction material is quite new in the world of architecture. The idea was first suggested by CENIT VIDA by combining the effort of 14 outstanding multinational companies and up to 24 public Spanish researchers to overcome the limitations of the current technology of microalgae production in architecture. The program was set to last for 4 years and funded by a budget of 19 million Euros, trying to explore the potential of microalgae as raw material to establish a bio self-sufficient city using "Living Architecture" [15].

Algal cells could efficiently convert sunlight, CO_2, and inexpensive nutrients into value added products of photosynthesis such as carbohydrates, proteins, lipids, etc. These products could serve as raw materials for the production of bioenergy, biofertilizers, etc. Microalgae have a relatively high surface area-to-volume ratio, allowing them to absorb nutrients and CO_2 much faster than agricultural plants [22]. Microalgae carry out about one third of the carbon fixation in the world while they produce about 70% of the oxygen content of the earth atmosphere [6]. Smart green buildings integrated with microalgal cultivation systems can not only create clean renewable fuels, but also remediate wastewater [6]. Input parameters include natural luminosity and artificial luminosity, temperatures, O_2 and CO_2 available in air inside buildings and these factors determine the final productivity of the systems.

Flat plate photo-bioreactor panels installed on buildings surfaces could efficiently absorb the UV light and other thermal light rays and generate heat the same way a solar thermal unit does. The captured energy is either directly used for hot water supplementation or stored in the ground using boreholes. Sunlight energy could also be fixed within biochemical compounds accumulated in algal biomass. For instance, it has been reported that the harvested biomass in façade elements showed a productivity of on average 15 g/d. This was equivalent to 150 kWh/m^2 thermal energy (equal to 30 kWh/m^2 biomass) and caused the building CO_2 emission to reduce by 6 tons annually [26]. In addition, the buildings equipped with algal photobioreactors are cooler on sunny days due to the provided shade. This green background also creates a visually interesting view for buildings. The new subject of green-roof buildings is widely propounded recently. One of the benefits associated with green roofs, i.e., decreasing in energy consumption by 30% on average [17] could be mixed with energy production capability of algal cells if used as roof-plant instead of common roof-trees. This not only results in thermal isolation but could also provide a significant proportion of the building energy demands leading to self-sustainability.

Although, the maintenance of microalga cells depends on photobioreactor operation regimes, the total efficiency of the system is dependent on characteristics of the selected strain. Like any other crops, microalgae are categorized into several types emanating from different origins called “microalgae strains”. The chosen microalgae strain, the type of cultivation, and the source of energy input determine the final energy productivity of the system. The ideal microalgae species show the following characteristics. High oil productivity, potential to adsorb high light intensity, temperature tolerance, insensitive to high oxygen concentrations, large cells with thin membranes, resistant to infections, eco-friendly production by capability of continuous extracellular oil excretion as well as natural cell flocculation, simple life cycle, and facilitated large scale cultivation are among such characteristics [21]. It should be noted that although all these characteristics can be found in the nature but one strain is unlikely to carry all. Therefore, seeking new microalgae species through genetic modifications is widely regarded as necessary.

More specifically, if a microalgal strain has a high volumetric lipid productivity and a fast growth rate, the final productivity of the prospected bioenergy would enhance. If the cultured stain shows resistance to high concentrations of O_2, longer photobioreactors without degassing equipment could be employed. Larger cell sizes with thin membrane accelerate the procedure of oil extraction. All these parameters could lead to the ease of cultivation. In addition to the above, if a microalgal strain can grow efficiently in wastewater, providing fresh water and supplementation of nutrients could be eliminated. Moreover, microalgae as a biological material, could efficiently accumulate heavy metals from wastewater through a process known as biosorption, thereby could help with environmental protection and remediation purposes [14]. Further studies on the utilization of microalgae for fully self-sustainable buildings especially in rural areas, where there is no access to fresh water resources except for heavy metal contaminated water streams, could be instrumental in more efficient exploitation of microalga cells to treat wastewater and produce potable water on one hand and generate energy on the other hand [2]. Some characteristics of major algal species are summarized in Table 18.1.

It should be quoted that the discovered microalgal strains used for laboratorial or small-scale operations are only a small part of the known species. Species belonging to genius *Spirulina*, *Chlorella*, *Dunaliella*, and *Nannochloropsis* are among the most popular microalgal strains for biofuel production as well as wastewater treatment. However, there are still many undiscovered strains in their natural inhabitants. Therefore, non-stop investigations should be performed to explore and introduce new microalgal strains and modify them to produce bioenergy in a more economically feasible manner.

Table 18.1 Growth characteristics and biosorption capacity of major microalgae strains

Microalgal strain	Parameters			
	BP (g/L.d)	LC (%dwt.)	VLP (mg/L.d)	Max. metal biosorption capacity (mg/g algae)
Ankrystodesmus sp.	0.09	17.5 ± 1.8^{B}	15.07	
Chlamydomonas rehinhartii	0.05	18.9 ± 1.1^{B}	9.45	145 (Cd^{II})
Dunaliella sp. (Persian Gulf)	0.12	22 ± 2^{A}	25.66	45.5 (Cr^{VI})
D. salina (UTEX)	0.15	24 ± 1.3^{C}	36.48	58.3 (Cr^{VI})
Scenedeasmus sp.	0.10	16 ± 2.3^{B}	15.80	429.6 (Zn^{II})
Chlorella emersonii	0.29	18.6 ± 1.5^{B}	54.41	58.8 (Cr^{III})
Chlorella protothecoides	0.25	18 ± 2.2^{A}	45	–
Chlorella vulgaris	0.46	17.3 ± 2^{B}	79.08	86.6 (Cd^{II})
Amphora sp. (Persian Gulf)	0.16	24 ± 2.3^{C}	37.92	–

A, B, and C: ($p < 0.05$)

Source Adopted from Talebi et al. [21] and Zeraatkar et al. [28]

BP Biomass productivity, *LC* Lipid content, *VLP* Volumetric lipid productivity (dwt. × LC × 1000)

18.3.1 Operational Considerations

This section aims to introduce the effects of various parameters such as light intensity, temperature, wind velocity, and nutrient concentrations on algae growth and yield. In an algae cultivation, pH of the growth medium should be maintained in ranges suitable for the growth of the microalgal species under cultivation. CO_2 concentration has a direct impact on the pH of the bioreactor. Microalgae also needs CO_2 for growth and high productivity. CO_2 can be supplied by the atmospheric air but the concentration is too low to support high productivities [25]. Therefore, in an ideal situation, atmospheric air can be captured and CO_2 can be filtered and concentrated for use in photobioreactors. For instance, Hulatt and Thomas studied bubble column reactors with CO_2 concentrations of 0.04, 4, 12% (v/v) and noted increases in algal density at the end of the 10-d experimental study [11]. Temperature in reactors could also affect algal growth and needs to be maintained in an appropriate range for the algal species to be cultivated. Too high temperature values could cause cell death while too low temperature values could freeze cell growth. It is also known that the rate of photosynthesis depends on the amount of dissolved oxygen removed from reactors [7]. Therefore, it is recommended that the partial pressure of oxygen (pO_2) be maintained at less than 100% of air saturation. Algae growth is inhibited when the pO_2 rises beyond 400% of air saturation. Thus, measures should be taken to reduce the pO_2 without damaging the cells through the use of an excessive supply of volumetric power. The faster growing microalgae species and the consequent more concentrated biomass produced will block more sunlight from entering buildings and at the same time, more energy can be harvested per surface area.

It should be noted that all these parameters are usually predefined and running and operations are not usually performed based on real-time data and daily variations. To address this, application of the concept of Internet of Things (IoT) to monitor the algae growth could be beneficial. IoT is the smart technology of embedding machine learning, internet connectivity, electronics, automation technology of controllers and measuring devices such as sensors and transmitters to measure, control and report data over the internet to make a process smart monitor-able and controllable [12]. Measuring the amount of normal light, pH, and temperature of the cultivation medium and also the concentration of nutrients and residues using some sensors getting the data from the environment, one microcontroller collecting this data and sending it to a cloud database could be proposed. An internet connection makes it possible to read and analyze this data everywhere. In fact, non-stop monitoring of the influencing parameters would make desirable increases in the quality and quantity of microalgae biomass production possible. Moreover, such an accurate controlling systems could prevent critical conditions, which could negatively affect the overall productivity of the system. The collection and communication of real time data and control of the system using the IoT can increase the efficiency of algae growth yield and decrease labor costs.

The effective operation of photobioreactors in smart green buildings are performed using analysis of three sources of information: (1) Outdoor wireless sensor network (WSN) information providing direct information about weather parameters; (2) Weather forecast information obtained from the internet; and (3) Room WSN information describing climate parameters inside the buildings. The microcontroller operates the photobioreactor based on these three types of data and send proper commands to the control system, to maintain the operation regimes.

The light regime and intensity provide all the energy necessary for algae growth, but if present in excess, it can damage the cells. Building surfaces provide enough area in photobioreactors to harvest sunlight, but to achieve the best production with no light waste or damaging the cells, IoT could effectively control the amount of light that will reach the algal cells.

18.3.2 Cost and Long-Term Benefits

Green construction, low-carbon buildings, and zero-carbon cities act as a new economic driver expected to cause USD126 to be saved from reduced energy use in the United States from 2010 to 2040 while also accounting for millions of jobs simultaneously (www.greenciz.com). Overall real-life statistics about cost and energy usage in smart green buildings are becoming more accurate and more available with the increasing number of completed green buildings. In light of the progress at all levels in the green building industry, it became clear to us that new architecture technologies and progress in biotechnology have made simple and cost-effective processes/fabrications possible. It should be noted that a growing algae system also needs a well-designed biorefinery infrastructure to be a productive and cost-effective system. It should consider all the growth requirements of the species under cultivation like nutrients supplementation, water logistics, bioreactor design, efficient harvesting and extraction equipment as well as process control. To prevent transport energy loss, all the procedures should be on site. Recent advances in microbial fermentations, strain modifications, and technological improvements should also be employed to decrease the cost. Integrated biofuels production could enhance the overall productivity. Moreover, exploring new microalgae species or genetic modification of the existing strains might enhance the potential of harvesting solar light and consequently increase the efficiency and decrease the costs involved.

As a new technology, algae-powered structure technology requires a deep understanding of its benefits to be accepted and taken up by law makers, planners, managers, decision makers, surveyors, built environment professionals, contractors, owners, and end users. Being a strong interdisciplinary field of science, algae-powered building technology combines environmental design skills, structural engineering, materials science, simulation techniques, services, and control systems.

One of the controversial issues raised in utilization of new technologies is their cost that could be higher compared to established ones. On the other hand, the existence of deleterious neurotoxins and hepatotoxins materials in some algae species brings about concerns about probable leaks and contaminations in the algal-powered systems. These leakages could cause odors if not well controlled. These are some addressable but not insurmountable concerns of this new valuable technology that should be surmounted to benefit many environmental advantages of algal-powered systems.

Since there is only one completed green building, there is no sufficient reliable data to evaluate probable additional costs incurred in all steps of a green building construction including design step to construction and operation as well as maintenance steps. Only after several experienced constructions and many years of operation of such buildings, there will be enough appreciable data to make reliable conclusions about the expenses of an optimized building construction. Having insufficient reliable data could higher the risks associated with the cost management of the projects and cause refusal of the newly born technology by itself. Overall, as a unique technology, the value of algae buildings could be remarkable. However, the complexity and the unexpected expenses of the construction process may affect it negatively.

Algae panel design information and guidelines for all steps of the building development projects should be prepared and evolved. For example, in order to avoid odor and contaminations potentially releasing from leakages, it is mandatory to make the panels resistant to accidental or intentional damages. The other technical consideration is cleaning of the glazing pipes of the panels by implementation of shortcuts such as those considered in aquarium designs like magnetic scrubbers used to clean the interior glass-pipes walls. Another technology-related issue would be the fact that the manufacture of some components may occur overseas and lead-in times for projects could be affected. One other major consideration is the high cost of the algal panels that makes these systems significantly more expensive compared to the other renewables.

Another unknown is the optimal scale of installation in which the living algae building is economically viable. It should be noted that the geographical location of the building is a key factor to decide if the algae technology is viable. The geographical location will determine shade and daylight conditions that instantly switch the balance between algal and other energy systems. Totally, the drivers and challenges of developing this innovate technology are now partially known and we can consider it as an innovation that is more likely to bring viable outcomes. The algae technology needs to immigrate from being a “complex” to the credibility of stable systems in order to consistently succeed. Undoubtedly, it is a costly technology, but it is the pathway all the other innovations and technologies passed to be developed and on this basis, it could warranty the attempts done to stablish this technology.

18.4 Smart Bioenergy Solutions

As mentioned earlier, the combustion of fossil fuels leads to emission of atmospheric pollutants. Accumulation of the emitted GHGs is the leading cause of global climatic changes [3]. Supplying energy by using biofuels is an alternative strategy to decrease these emissions [21]. The algal cells can sequestrate CO_2 from the atmosphere or a concentrated source through photosynthesis while the energy harvested from biomass could serve as a feedstock to be converted to biofuels. Biofuels are nontoxic, biodegradable, and free of aromatics compounds [18]. Compared with fossil fuels, algal biofuels release no net carbon dioxide, if the biomass is grown sustainably. It means that during the combustion of biofuels such as biodiesel obtained from algal lipids, the same amount of CO_2 which has sequestrated during photosynthesis will release. Moreover, since the biofuels have higher oxygen content, less carbon monoxide is produced [10].

Small-scale cultivation of microalgae on building components such as static surface buildings as well as glass surfaces would turn them to living and dynamic ones. In situ production of energy, prevention of energy loss, recycling of wastewater and purification of the atmospheric air are among the major benefits which could be achieved by employing such new bioenergy strategies. From two major groups of algae, microalgae and macroalgae, biomass of microalgae are more potent to be converted to biofuels; high volumetric lipid productivity, fast growth rate, ease of cultivation, smaller cultivation area, temperature tolerance, and availability of facilities and other inputs required for cultivation have made microalgal strains a potent alternative for biofuel production [21]. Microalgae act like solar energy-driven factories sustainably sequestrating CO_2 and the adsorbed carbon would be converted into variety of hydrocarbons which could further be converted into different types of biofuels. The details of different processes and required facilities to convert algal biomass to biofuels are the subject of numerous patents and research papers which could be found in our previous report [20]. But in brief, they can be categorized into four different processes including: (a) extraction and transesterification of triglycerides to produce biodiesel, (b) fermentation of carbohydrates to produce bioalcohols, (c) anaerobic digestion to produce biogas, and (d) gasification or other thermochemical conversions of the biomass. Apart from serving as feedstock converted into liquid biofuels such as biodiesel and bioethanol, algal cells can also generate bioenergy carriers such as biohydrogen and bioelectricity directly.

18.5 Algae-Powered Buildings: The Key Solution for Smart Villages

The utilization of algae-powered buildings could serve as a multifunctional key to integrate Smart Villages with modern eco-friendly technologies and concepts such as renewable energy production, waste valorization, circular economy, zero discharge, etc. In line with that, in the Europe, integrated policies for economically-viable local energy utilization is already implemented to make villages self-sufficient in terms of their energy consumption [27].

Biomass is the most popular source of renewable energy traditionally used in rural areas as boilers' combustion matter for central heating or producing hot water for household applications. The traditional forms of biomass have many limitations such as seasonal availability, varying compositions, etc. making it hard to use them as smart energy sources. On the contrary, the new approach to utilize smart biomasses like microalgae biomass could overcome the intrinsic limitations of traditional biomass. This could be more feasible in coastal areas with vast amount of land, water, and sunlight using which microalgae can grow naturally. For the lands located far from coastal areas, specially the isolated or hardly accessible areas, virtual frameworks of microalgae cultivation, i.e., photobioreactors could be used. Besides being a potent renewable energy source, the tubular or sheet algal bio-cells installable on top of the roofs or as walls' covers of rural houses could also provide an eye catching unique sight, while insulating the buildings against direct heat and cold resulting in more than 30% energy savings.

Non-seasonal daily-harvestable nature of microalgae in line with its high yield, especially in the genetically modified species, as well as their compatibly with saline water, treated waste water, non-arable lands, and cheap fertilizers make them the smart choice to revolutionize rural areas [16]. Microalgae can also be used as a biosorption filter media to remove heavy metals from wastewaters to provide potable water especially in isolated or mountain villages. After all, the remaining by-product oil-extracted mass could yet be consumed as livestock feed thanks to its high protein content [9]. In better words, the off-grid algal power stations could be specially designed to produce smart village with electricity while supplying livestock with quality feed (local power plant by-product) during cold seasons.

18.6 Conclusions

With the rapid growth of population and construction costs due to limited resources and consumables, the demand for the use of new materials in the construction industry has increased. Paris Agreement form a growing global consensus on the need for change in existing habitat models by development of green architecture and finding renewable source of energy to support the global climate action summit. Architecture models and the issue of self-sustainable cities and villages are currently undergoing fast and transformational changes. Biomaterials, nanocomposites, biofuels, and productive algal strains are now emerging as common features of the today's complex green power systems. With the blessing of modern technologies, microalgae production plants running based on IoT could be integrated into architectural models. These developments are expected to revolutionize the traditional building construction models turning them into pieces of green smart city power plants.

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Part IV
IoT and Smart Application

Chapter 19
Scheduling Operations of Smart Appliances Using Demand Response

Nilima R. Das, S. C. Rai and Ajit K. Nayak

Abstract Nowadays, many countries are concerned about the environmental problems which are mainly caused due to insensible and careless use of energy. The ignorance of the people towards energy consumption is greatly affecting the environment. The contribution of electric sector in polluting the environment is the highest among all other sectors that work on energy. High demands of electricity during peak hours result in increased production of electricity using fossil fuel based plants which increases the level of CO_2 in the atmosphere. However improved performance of the grid system in reducing the peak loads and availability of electricity can reduce the green house gas emission which is considered as the main reason of climate change. The work in this chapter is mainly focused on optimal load scheduling for energy cost minimization and peak load reduction. The proposed model uses Time of Use (TOU) pricing tariff in the optimization process. The optimization problem has been solved with multiple optimization techniques including Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and a hybrid algorithm formed by combining GA and PSO. The proposed scheme has many applications like peak load reduction and energy cost minimization which can benefit consumers and utilities.

Keywords Smart home · DSM · Demand response · TOU pricing · GA · PSO

N. R. Das (✉) · A. K. Nayak
Faculty of Engineering and Technology, Siksha 'O' Anusandhan
(Deemed to be University), Bhubaneswar, India
e-mail: nilimadas@soa.ac.in

S. C. Rai
Department of IT, Silicon Institute of Technology, Bhubaneswar, India

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19.1 Introduction

With economic development and increased population, the electricity demand has increased to a great extent and is expected to grow further resulting in high demand during peak hours. To safeguard the reliability and robustness of the grid system it is required to reproduce and supply adequate amount of electricity to fulfil the demands of the consumers that in turn needs extension of the existing grid infrastructure. This expansion of the grid structure may increase the price of electricity because the operational cost is increased in installing more number of power generating factories and transmission lines in order to increase the availability of electricity. These power plants may enhance the level of carbon dioxide gas in the environment. Expanded grid system may also incorporate more faults and complexities which reduces the efficiency and reliability of the system. However not meeting the demands might result in the failure of the grid system leading to blackouts. So there is a need to control the demands of the consumers and upgrade the existing grid structure instead of installing new power plants and distribution systems. For reliable operation of the grid a balance needs to be maintained between supply and demand which becomes possible by using intelligent and efficient energy management programs that can be applied during generation, distribution and consumption of energy. The energy management at user side can be more effective to maintain the balance between demand and supply. Controlling and managing demand can help to have an efficient grid system with increased availability of energy. Implementation of energy management techniques at the user side is called as demand side management (DSM). Furthermore the demand response (DR) which is a special category of DSM technique encourages the users to reduce their consumption during peak hours that results in a stable and reliable grid system. The grid system also has to be smart enough to handle such high demands. A grid equipped with advanced information technologies can communicate with the consumers and motivate them to reduce or manage their demand in such a way that the peak hour energy consumption can be reduced. Reducing peak hour demand can avoid installation of new power plants and distribution systems that helps to reduce environmental degradation and stabilize the cost of electricity. Therefore DR programs are required to be implemented at the demand side to help both the consumers and the utility providers to have a robust grid system with improved quality of service and reduced energy costs.

The rest of the chapter is organized as follows. Section 19.2 provides a brief introduction about smart grid. Section 19.3 provides a detailed discussion on DSM. Section 19.4 presents a comprehensive description on DR. Section 19.5 presents recent research works on DR. Section 19.6 describes the proposed DR model. Section 19.7 describes the optimization algorithms used for the system. Section 19.8 provides the simulation results and compares the results obtained from Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and GAPSOH (Hybrid of GA and PSO). Section 19.9 presents the conclusion and Sect. 19.10 states the future scope of the work.

19.2 Smart Grid

Smart Grid is an up-and-coming concept in electrical grid systems. It maintains the upgrading of technology and information system with highly advanced electrical infrastructures to increase the reliability, security and efficiency. Reliability is one of the most important challenges for smart grid. Reliable operation of smart grid requires an absolute balance between supply and demand [1]. However maintaining balance is a very challenging task as it is difficult to control the demand of the consumers. This can be possible with the implementation of smart grid. The smart grid can implement energy efficient methods during production and distribution of electricity. It can induce the consumers to use energy efficient techniques during consumption also. Smart meter is an imperative constituent in the smart grid system that can help utility companies control the demand, reduce expensive peak power usage and provide a better deal for consumers by allowing them to see and respond to time varying prices. To meet high demands the utility companies generally depend on more fossil fuel based plants, but uncertainty in generation forces them to keep higher surplus of resources which increases the cost of electricity. The better way is to use intelligent and innovative methods that emphasize consumer participation. The standard approach maintaining a balance is to fulfil all the demands of the consumers, but these new methods try to encourage the consumers to manage their demand in a response to the current capacity of the grid. In order to maintain a proper balance between the demand and supply the smart grid requires the integration of DSM techniques. DSM incorporates energy conservation and energy efficiency programs, DR programs, and residential or commercial demand management programs [2]. DSM programs are accomplished by utility providers to guide and regulate the energy consumption behaviour of the users [3]. These programs when implemented increases the efficient use of the available energy instead of building new production and transmission framework or infrastructures. The motivation behind the implementation of these programs is to make the users aware of the actual market energy prices so that they can change their usage pattern and use more energy efficient appliances to save energy. Along with this the users can also shift some of their consumption to low peak periods as a result of which the peak time demand can be reduced which is very much required for a stable grid system. The main objective of the DSM programs is to reduce or change the time of consumption [4]. DSM programs make the consumers able to know and understand the actual electricity market scenario which helps them manage their consumption efficiently in order to maintain a balance between the demand and the available supply.

An important feature of the grid system is to provide more electricity to satisfy the global demand. With DSM programs it is easy for the utilities to handle or manage the consumer loads. The utility implements load control and management programs by following bill saving schemes or incentives for the consumers.

19.3 Demand Side Energy Management

The DSM techniques are used to keep a control on the demand which helps to maintain a balance between the demand and the supply. DSM programs motivate the consumers to adopt more energy efficiency in their usage by including improved lighting system and automated buildings with smart and energy efficient appliances. According to the www.ieasdm.org, "DSM refers to all changes that originate from the demand side of the market in order to achieve large scale energy efficiency improvements by deployment and use of improved technologies and changes in end user behaviour or energy practices". The DSM techniques are broadly classified into two categories.

Energy Efficiency programs Energy efficiency programs encourage the consumers to use energy efficient appliances which can avoid wastage of energy and help in conserving more energy. Energy efficiency programs can either be public purpose programs or utility programs. The public purpose programs are controlled by utilities, state agencies or other third parties and are paid for by utility ratepayers. The utility programs are coordinated by the local utility and paid for by utility ratepayers through their bundled rates.

Demand Response programs The most important activity in DSM is DR. DR motivates the consumers to change their consumption pattern so that it can match with the available supply. The DR scheme employs intelligent techniques to increase the efficient use of energy at the demand side. It provides phenomenal opportunities for the forthcoming efficient electricity markets. There are different approaches of DR. Some are price based and some are incentive based. The utilities follow different DR schemes based on the consumers' demands. DR can effectively maintain a balance between the demand and available supply. Using the DR schemes the consumers can get awareness of efficient energy usage patterns resulting in electricity cost savings. The DR schemes can help to have a more efficient smart grid system. Many challenging issues like increased number of consumers' participation, developing decision making tools and using time varying pricing tariffs instead of flat pricing can make demand response a powerful and productive part of the smart grid [5]. DR programs are used to scale down the energy demand during peak hours which can turn down the risk of blackouts and voltage fluctuations and prevents further expenditure on new power plants.

19.4 Demand Response

DR programs are devised with a purpose to motivate consumers to reduce electricity consumption or shift it from peak to off-peak periods based on their comfort and priorities. When there is an imbalance between demand and supply it is difficult to pressurize the supply side, because some sources may take more time to operate fully, some sources may be very expensive and sometimes the demand can be larger than the available power supply. So in place of increasing the supply the DR tries to control and modify the demand so that demand can never be more than the current supply. This may reduce the cost of electricity in wholesale markets which in turn, results in reduced or stabilized electricity costs in retail markets. DR is a technique to reduce the peak demand to avoid system emergencies. It encourages the consumers to change their pattern of energy utilization in a response to the current price. The main objective is to manage user consumption dynamically according to the current energy price which reflects the current supply conditions. DR includes dynamic demand management mechanisms to be used by the consumers to regulate or reduce the use of electricity in acknowledgement to supply conditions. Utilities encourage the consumers to use smart meters with different pricing techniques to implement DR. These techniques include time of use pricing (TOUP), real-time pricing (RTP) and critical peak pricing (CPP) tariffs. These are also referred to as time-based rate programs in which different rates are used for different hours in a day. The consumers may adjust their demand by delaying the operations of some appliances, or may choose to pay a higher price for their electricity use. Some consumers may shift part of their consumption to off peak hours of the day or may use other power sources (renewable energy sources). This voluntary control is practised by giving some kind of monetary benefits to the consumers. For example utilities can offer lower rate per unit of consumption when the consumers reduce their consumption during peak periods. The main purpose of DR is to actively involve consumers in altering their consumption pattern in response to pricing signals. The goal is to reflect supply expectations through consumer price signals or controls and enable dynamic changes in consumption relative to price [6]. Now-a-days DR programs are used in commercial as well as residential area. The programs may apply load shedding being influenced by the wholesale market prices. Services (lights, machines, air conditioning) may also be reduced during emergencies.

19.4.1 Need of DR

The utilities employ DR to avoid the higher costs of energy production by preventing building of new power plants to meet the increasing demand of the consumers. Consumers can also make some savings in their electricity bills by reducing their use during peak periods [1, 3, 5]. As there is a reduction in overall demand due to demand response activities the dependency on expensive and additional sources is also reduced which again decreases the overall electricity price. There are several benefits of DR which can be summarized below:

Financial benefits In order to get financial benefits and incentives the consumers can control their electricity usage in high pricing hours. The electricity bill of the consumer is reduced due to less energy usage during those periods. The consumers being a part of the DR program may also be given some financial incentives by the utilities for adjusting or reducing their usage.

Increased reliability of the Grid Along with monetary benefits the users may also get reliability benefits when they become part of the DR programs. When demand becomes higher than available resources then there are possibilities of blackouts and outages. But DR can avoid such situations by reducing demand during those critical periods. It results in increased reliability of the grid system. Reliability reduces the risk of being deprived of the service provided by the grid. The more the consumers adjust their load the more they get financial and reliability benefits.

Reduced wholesale and retail market prices Demand response programs have a great effect on the supply costs of electricity and system reliability which motivates the utilities to implement DR programs. Since the consumers adjust their energy usage during high pricing periods the utilities do not have to supply additional electricity to the consumers and not have to buy more electricity from the sources. As a result the supply costs of electricity and the wholesale market prices are reduced. It further avoids investment for additional generation, transmission or distribution capacity infrastructure. As a result there can be a significant saving in the costs which the utilities would have to bear in such investments.

Increased flexibility of the consumers It can provide more options to the consumers to manage their electricity usage and cost in varying pricing environment.

Reduced power play of the suppliers The utility providers may reduce the supply with a motive to increase the prices. But price-responsive demand can avoid this possibility because the consumers can reduce their demand during high prices which may increase the risk for the suppliers to be priced out of the market. As a result the suppliers cannot exercise power in the market which again results in less manipulation of the suppliers in the market.

Reduced green house gas emissions Use of DR programs motivate the consumers to manage their energy usage in such a way that the peak hour consumptions are reduced that reduces the pressure on the grid and increases the availability of energy during peak hours. It helps in avoiding construction of new power plants which could have resulted in more CO_2 emissions and resources utilisation.

19.4.2 Categories of DR Programs

DR programs are categorised mainly into 2 different types based on the consumer incitement and the conditions responsible for activating load reduction programs. Table 19.1 summarizes the possible categories of DR programs.

Load-Response Programs When the utility providers provide some incentives to the consumers for reducing demand during system's peak periods, the method is called load response. In emergency periods the utilities use load response to induce

Table 19.1 Types of DR

Load response	Price response
Direct load control	Time of use pricing
Curtailable load	Real time pricing
Interruptible load	Critical peak pricing
Scheduled load	Extreme day pricing
	Extreme day critical peak pricing

consumers reduce their load to alleviate the limitations of generation or transmission of the required amount of energy. This is termed as emergency DR. Load-response programs can be divided into following categories.

Direct Load Control Direct-load-control (DLC) programs are usually implemented for small commercial and residential consumers. Consumers give their consent for the program so that the utility can control predetermined load usage of the consumer. The air conditioning loads are the commonly controlled loads in residential area and lighting loads are controlled in commercial area. Water heating and pool pumps also come under residential load control programs. The consumers taking part in DLC programs get fixed monthly payments and one-time participation payment added to their electricity bill. Some utility providers give some remittance for the load reduction. The utility sets up agreements with consumers that states the maximum number of load control programs to be held during a year (e.g. up to 30) and the maximum time span of a program (between 2 and 8 hours, but normally 4) [7]. Most of the DLC programs empower the consumers to ignore an event when they face any problem, but some programs charge fines for not following the agreement. These programs make the utilities assured of the fact that they can reduce the loads when it is essential to do so. The technologies used in these programs like control switches and smart thermostats are generally not so expensive and also extremely dependable and competent of bringing up to 60% load reduction for small consumers.

Curtailable Load Curtailable load programs involve medium and large consumers. The consumers who want to be part of the program give their consent to reduce or turn off a part of their load for a particular time period after getting information from the utility. They can do it manually or automatically, depending on the agreement and availability of control technologies. Generally utilities provide advance notification to the consumers regarding the upcoming event. Like direct-load-control programs, the utility provides information regarding the number of such programs and period of each program to be held during the current year. After agreement the consumers are severely penalised if they override the agreement.

Interruptible Load Consumers taking part in interruptible load programs remain in agreement to shut off larger portions or if possible all of their loads for particular time period. Only some largest consumers can participate in interruptible load programs. The consumers use backup generators during an interruptible event.

The program is implemented through two-sided agreements between a utility and a consumer. Severe penalties are charged for not following the contract.

Scheduled Load Scheduled load reductions are decided with mutual agreement between the utility and consumers. The electricity bill for the consumers taking part in these programs gets reduced. The users can reduce their loads according to their convenience on the pre-decided days. However, on these days the utilities may not need any load control and when they actually need it they may not be able to implement it with short notice.

Price-Response Programs When consumers willingly reduce or change their demand in response to the market prices, the program is called price response. Consumers try to decrease load during those periods when the cost of reducing load is lower than the cost of generating it. Utilities may use communication signals (telephone or Internet) to inform participants regarding the upcoming events that need load response for which the utilities can make some extra payments to the consumers. Alternately they may encourage consumers to implement DR at their side by using different pricing tariffs. The pricing tariffs used by the utilities reflect the actual cost of providing electricity. In price response, utilities design the prices in such a way that they remain high during hours of either peak demand and supply constraint. Price remains lower at off peak periods. In real-time pricing, utilities reveal the fact regarding the actual situation of the wholesale markets and the resulting unstable price structures to the consumers. These programs allow consumers to voluntarily reduce their demand in response to pricing signals. DR programs are mainly categorised by pricing mechanisms and the amount of advance notification. Advanced communication technologies and smart meters are required to implement price response programs.

Various pricing techniques can be used by the utilities, for example fixed pricing rate and dynamic pricing rate [8, 9, 42]. Flat pricing schemes are used in systems where the consumer understands the possible target of achieving reduction of bills by using low electricity for the entire day. But in varying pricing methods the users get flexibility in using their loads. They do not have to reduce their consumption for the whole day; rather they have to reduce it during some specific periods of the day in order to reduce their bill. Different variable pricing techniques that can be used by the utilities are described below:

Time-of-use (TOU) pricing TOU pricing program uses variable pricing tariff based on the time of the day or days of the week. It incorporates a peak time price, an off-peak time price and occasionally a shoulder-peak rate for predetermined blocks of time decided by the utility [10]. A TOU tariff may impose consumers 5.5 cents per kilowatt-hour (kWh) consumed on weekends and weekdays from 9:30 PM to 8:30 AM, 8 cents/kWh on weekdays from 8:30 AM to noon, and 6:00 PM to 9:30 PM, and 12 cents/kWh on weekdays from noon to 6:00 PM [7]. TOU rates do not reflect fluctuating costs of the wholesale markets in emergency periods; rather they represent the prices used in normal market conditions. The consumers receive some incentives for shifting their load to off peak periods. It results in bill savings for the consumers. It also induces the users to invest in new smart home appliances. TOU rates can attain moderate load shifting on a daily basis, involving a reduction of energy usage from 4 to 17%.

Critical peak pricing (CPP) CPP is a variation of TOU tariffs that tries to represent the unpredictability and instability of market costs incurred due to increased production and supply of electricity. In Critical Peak Pricing (CPP) [11], at a particular period of time in a day or a week, there is a substantial increase in the prices because of unavailability of the resource according to the current demand. Accordingly the consumers are informed about the sudden increase in the price, generally one day before. The CPP tariff sets a time-dependent rate which is higher than regular rates. A critical peak event can be called before some hours of their actual execution. For example, an agreement can be made that a critical peak rate of 24 cents per kWh can be charged for 4 h up to 30 days every year [7]. CPP programs can be implemented for both small and large consumers. In case of non-availability of the consumers at home, automated load control can be implemented using smart appliances and advanced communication technologies.

Real-time pricing (RTP) RTP pricing tariffs reflect the uncertainty and instability of the wholesale power market costs. The electricity price represents the actual supply costs borne by the utility for each hour of the day [12]. The prices are declared to the consumers before every hour or before some hours of actual execution. The main challenge in RTP is that it needs a continual monitoring of real time data which depends on two way communication of the smart grid with the development of smart controller in practice. Maximal involvement of the consumers is required in this scheme to make it effective. Consumers manage their consumption in response to higher or lower price information. Implementation of RTP program requires advanced price prediction and notification techniques and improved communication and billing systems. In practice, only a small group of the largest industrial and commercial consumers can participate in these programs. These consumers who have backup generation or separate production units can take part in this program. Automated control technologies for consumers can be used to maximize performance and savings. Load management technology or energy management systems, are generally not able to respond automatically to the signals sent by utilities. Most of the consumers require technical and financial support from the utility so that they can install automated systems to implement DR. RTP based DR can be used to switch off the building loads which are not so important for the consumers.

Extreme Day Pricing (EDP) EDP is nearly similar to CPP. But high price is used for all 24 hours during critical days and TOU price for other days. The critical days are more than that in CPP.

Extreme Day CPP (ED-CPP) ED-CPP is a variation of CPP in which the critical peak price is applied during critical peak days but there is no TOU pricing on other days.

With each of these tariffs the consumers experience different price variances and can reduce their expected price by taking more risks.

Technical Feasibility of DR Programs Due to economical and technological infeasibility it has not been possible to apply DR worldwide. It is difficult to implement price-based demand response for all consumers because ordinary meters and billing systems which are used with fixed prices cannot be deployed directly to charge the consumers based on the rates that vary over time and most of the users are not able to make decisions regarding electricity consumption on a daily or hourly basis. So it will take time to use time-varying tariffs in place of fixed tariffs. For this purpose smart meters are needed. The technology is also needed to be advanced to actually have a grid system which can apply DR properly. The cost measures acquired by the utility providers like incentives, bill savings and the users need of technology up-gradation by acquiring smart appliances has to be addressed. Further the technology expansion can be done at all levels by successful installation of smart meters at every user premises. Smart meters are required to have faster two way communications between the market provider and the consumer. Some significant challenges in the implementation of DR are discussed in [8]. It says a lot of investment is needed for advanced metering. All time-varying rates require meters that can store the details of the electricity consumption of the consumer based on time of the day and can calculate the prices based on different time-varying rates stored in it, but the conventional meters cannot perform these tasks. The advanced meters also need some extra cost for their installation and maintenance which finally has to be borne by the consumers. After using advanced meters the system becomes somewhat complicated. But many of the consumers cannot handle complicated systems. For this they need to be educated on the usage of advanced meters and convinced about the benefits of the DR programs which in turn motivate them to participate in the programs. After understanding the benefits the consumers have to shift or reduce their consumption to make the program a success. Whereas some of the consumers are resistant to these ideas there can be many consumers who try to shift their demand in response to the electricity price to non-peak hours, creating a peak during non-peak hours which can create problems for the grid to maintain reliability and availability.

Even in the presence of these challenges the DR and DSM techniques are very beneficial. Although it takes time to involve consumers for these programs, a well-defined pricing design can motivate the consumers to save cost and reduce peak time demands. It can be possible by training the consumers on the benefits of advanced metering and communications technologies. The communication need in this plan depends on some components like quality of service, flexibility and interoperability. For implementing a smooth DR program, service providers have to maintain the highest quality. Information has to be shared among the network providers, utility and the users in a quick and efficient manner. For flexible communication structure cloud based domain is needed where the user's domains are big and many users communicate under a utility provider. This structure is used when there are large users and the communication is made data centric at the utility side. It is necessary to create appropriate standards of communication for DR to provide seamless information flow.

Demand Response Costs The costs of accomplishing DR can be represented as participant and system costs.

Participant Costs Individual consumers are subjected to participant costs. Costs obtained by DR program administrators are denoted as system costs. System cost is incurred in building a proper infrastructure for the grid system that can support the DR. It can include monetary incentives given to consumers in incentive-based DR and price-based DR programs. Consumers may incur cost in using advanced technologies to manage their schedule in response to current pricing tariff. For example smart meters, well designed communication system and energy management systems have to be used by the consumers to be a part of the DR. The consumers may take some education to make themselves aware of the DR system for which they have to incur some cost. Some consumers may use renewable energies to satisfy their needs which again lead to some monetary investments. When consumers try to reduce their demand during peak periods they may have to face some inconvenience and discomfort which decreases the value of energy for them.

System Costs System costs may also arise from communication costs. Communications costs is incurred from using dedicated communication lines hired from a telecommunications provider to transfer information between utilities and the consumers, as well as between the utilities and the suppliers. Time-varying tariffs require regular measurement of energy usage, which is possible by using advanced metering systems (AMS). The AMS can estimate and store energy consumption made during each time interval. The installation of AMS can add to system costs. It also needs upgraded billing system which is required for implementation of these dynamic tariffs. Other system costs may include program administration, operation, marketing, evaluation, and recruitment costs.

Achieving the Objectives of DR Programs In general, for any DR model the primary goal is to minimize the power consumption and maximizing the social welfare. Through optimization the goals of DR can be achieved. The optimization model for DR includes one or more objective functions, some variables and some constraints for the values of the variables. The possible objectives for the optimization are (i) minimizing the energy cost (ii) maximizing the comfort (social welfare) (iii) minimizing total power consumption (iv) minimizing peak to average demand ratio (v) minimizing peak hour load (vi) combined effect of all the functions (social welfare, cost, power). However, the first five categories involve a single objective function, and the combined effect involves optimizing multiple objective functions.

The main purpose of DR programs is to have proper load scheduling for each consumer. The DR schemes can be represented as optimization models that include uncertainties in load demand and prices. The optimization depends on the advanced communication technologies. Before formulating the optimization problem one has to understand the actual need and priorities of the consumers, the type of every load they are using and the expected behaviour of the consumers at particular situations. In literature there are various optimization models to minimize the cost, maximize welfare, minimize power consumption, to have minimum cost and minimum power and finally maximization of social welfare with minimization of power consumption.

Goal of optimization As the classification of DR optimization methods are based on decision variables, pricing schemes and control strategy, the optimization is solved using both centralized and distributed approach. The research on Demand response modelling involves the proper analysis of load shaping objectives. Mainly there are six different load shape objectives for DR management problems, which are termed as peak clipping effect, Valley filling effect, Strategic Conservation effect, Load Shifting, Flexible load shape and Strategic Load Growth.

Peak clipping effect is implemented in DR model in order to reduce the total peak demand, that is, to prevent the load from exceeding the supply capacity at the distribution side. Moreover this effect helps the consumers to gain their own satisfaction in reducing peak of their individual demand. This effect is also important for the kind of utility providers who do not have sufficient generation capacity for maximizing the demand at peak hours. It mainly targets on single objective function of maximizing the load factor by involving DLC method directly on users participating in DR.

Valley Filling effect is to build up off peak hours energy consumption schedule by using storage devices like electric vehicles, battery backup etc. This effect is most desirable when the incremental cost at a long run situation is found to be less than the nominal average electricity price. In this effect maximizing the load factor objective is arrived at by creating a matrix of new set of off peak loads.

Load shifting effect is the traditional one of load shaping which combines the effect of valley filling and peak clipping. It involves the shifting of loads from the peak hours to off peak hours in such a way that the user total consumption in a day is not reduced. Using this objective in DR model the main target is to maximize the load factor using TOU pricing schemes and energy storage devices.

Strategic Conservation effect is the advanced level of load shaping objective. It reduces the total load demand in a day and also tries to decrease the load not only during peak hours but also in other hours of the day. These effects increase the energy efficiency and defer the need of utility driven capacity addition in the near future.

Strategic Load Growth effect indulges the utility to encourage the users to involve in new electro technology methods to handle for DR model.

Flexible load shape uses specific rates to flexibly control the consumption of the consumers.

In general DR techniques help in maximizing the load factor and minimizing the cost which is done by efficient scheduling of the operation time of the appliances.

For designing DR models with different objectives the constraints are grouped based on the appliances which are either fixed or shiftable, and then constraints of local energy generators and energy storage systems are included based on DR scenarios.

Demand Response in Global Markets Demand Response in the electricity market is becoming a salient component. As all the countries want to have a low-carbon economy they try to encourage the DR activities in their countries. Reduction in electricity cost and carbon dioxide emissions motivate the users to become active participants in DR programs. In this situation developing new power plants can be reduced introducing more economy. All these factors increase the DR participation level in the global market.

Different DR programs are implemented in US and the use of smart meters has been started in many residential and commercial areas. At present smart meters are mostly used by residential consumers who actively participate in the DR programs [13]. The Australian Ministry council of energy has implemented Demand Response programs to improve the energy usage of the consumers. The council has done many investigations and prepared a report [14], according to which there would be a substantial load reduction in many areas of the country after being a part of the DR programs. In Europe, the use of smart meters has been increased as the consumers' participation in the DR programs has also been increased. The percentage of DR levels increase at different states in European Market [8].

In the following paragraphs some recent research reports on DR activities in the global market are described:

According to the reports made by Future Market Insights (Market Research and Consulting), the global market for demand response is trending on a large scale as it is considered as the most ideal program that helps in adjusting the demand for power rather than adjusting the supply.

According to the reports prepared by Transparency Market Research for the forecast period 2014–2025 [15], as the power demand grows worldwide the demand response market is also expected to grow significantly. According to the report electricity markets are gradually admitting that the use of demand response programs can help in managing the electricity demand and supply efficiently in emergency periods. In North America the utilities are convinced that the demand response programs can reduce higher wholesale prices which results in reducing overall grid costs. It further mentions that with regulatory support if some changes can be brought in the demand response policies then it can help in the growth of the Europe's smart demand response capacity market. Asia Pacific is expected to grow in demand response capacity market due to its enhanced use of demand response programs.

The report 'Smart Demand Response Market Analysis By Application (Residential, Commercial, Industrial) And Segment Forecasts To 2022' [16] says that the global smart demand response market size was estimated at USD 5.57 billion in 2014 which confirms that advancements in technology in utilities are expected to increase smart grid deployment, which is estimated to drive industry growth. The report again says that growing smart grid tries to enhance consumer energy management systems with integration of renewable energy sources and automated transmission and distribution systems.

According to the investigations made on the Global Automated Demand Response Management Systems Market for the forecast period 2018–2023, Segmented by Geography—Growth, Trends and Forecast (2018–2023) [17]: the global automated demand response management systems (ADRMS) is expected to witness robust growth during 2018–2023. Due to the growing fall-back rates of traditional fuel-based power plants there is a need of energy efficient management systems which increases the demand for automated DR management system during the forecast period and the use of DR programs will help in maintaining a balance between electricity demand and supply in the future and try to create attractive opportunities for the companies associated with the ADRMS market.

As the use of natural gas and renewable energies can help in increasing energy efficiency and environmental advantages almost all the countries in the world are trying to replace the conventional fuel such as coal and nuclear-based power generation with renewable energies. The global smart demand response market players are adopting a strategy of mergers and acquisitions to pursue growth in the market. The strategic alliances allow companies to enhance its smart demand response offerings to their residential/commercial/industrial consumers.

Energy Demand and DR in India Rapid growth in population and increased per capita income in India has resulted in high demand in electricity in all the sectors.

According to the report 'Demand Response System Market: Global Industry Analysis and Forecast 2016–2024' [18], the Demand Response System market across the globe is expected to show a substantial growth by the year 2019. The report says that the DR market will provide greater opportunities in residential markets of Asia Pacific countries such as India, Australia and New Zealand in the upcoming periods. It further says that India's utilities are paying very high prices for peak power and struggling to keep up with growing electricity demand that greatly affects the country's power generation capacity. They are also trying to reduce the energy loss made due to inefficiency and theft and maintain the reliability of the grid system in the presence of maximum power outages. In such a situation the DR activities can reduce the peak demand to avoid blackouts which in turn reduces the overall energy cost due to overall decrease in costly peak-power purchases. Indian IT giants like Infosys, Wipro and Tata are going to be involved with 14 regional smart grid projects launched in 2013.

Increasing internet access, improved communication technologies and increased artificial intelligence embedded in the electricity using devices have made the use of automated DR cheaper and user-friendly than the conventional manual methods. Now-a-days most of the appliances being sold are smart appliances. The examples of such appliances are smart TV, smart fridge, smart AC, smart mobiles and smart microwave ovens etc. The smart appliances are normally equipped with sensors, operating softwares and processors which help them to be operated in an automated fashion. Their operation can be controlled by a controller from inside the house or from a remote location. Generally smart meters embedded with scheduling software are used to generate optimal operation schedule for the smart household appliances. As a result the peak hour consumptions are reduced which is the main purpose of a DR system. In a developing country like India, the use of smart grid technology can lead substantial improvement in both residential and in industrial sectors. Starting from the small scale to large scale industries there can be complete change in the power use as a proper outcome of the DSM programs. But there is a need to educate the consumers about the requirement of electricity pricing and methods of cost reduction which motivate them to be a part of the DR programs.

DR and smart villages The notion of Smart villages is a global modern approach for off-grid communities. The intension behind this idea is to support the rule makers, contributors and socio-economic designers for rural electrification worldwide mostly for Asian and African countries. The term Smart villages refers to the attempts that are made to make electricity available to the people of rural areas mainly in developing countries by using technological, financial and educational methods. Off-grid systems have the ability to fulfil the electricity demand using local power generation. The off-grid systems are generally based on renewable energy resources [41]. Microgrids, powered by renewable energy resources, are considered to be an ideal technological solution to supply energy to remote rural sites [19, 20]. One of the main challenges facing distributed energy microgrid (DEM) designers is the intermittent nature and characteristic unpredictability of renewable sources [21, 22]. This problem is intensified by unpredictability of the demand, particularly inconsistencies in energy consumption behaviour of the household consumers which disturbs the balance maintained between demand and supply. Various energy management techniques involving computational intelligence can be used to maintain the balance. In addition to the challenges of optimising the scheduling of supply and demand, most rural energy consumers have a very volatile day-to-day energy budget [21, 23]. This requires careful consideration during the project planning to ensure that the energy consumers have the ability to stay within their daily budget (flexibility in payment) [21, 23]. As there is a lack of advanced communication systems in the villages the energy management programs may not use centralized controllers. However machine learning techniques can be used in a distributed fashion to make demand forecasts of the household energy expenditure for the next day which can then be optimised to avoid overload situations and maintain a balance between user demands and the financial condition of the family.

19.5 Topical Research Articles on DR

Recently a lot of research has been made on different scheduling methods applied in DSM programs for residential grid networks. Even if they are different in their methodologies their main aim is to reduce the consumers' expense of energy and demand during peak hours, because increase in peak load leads to higher production costs and reduced supply of electricity. The scheduling methods provide schedules that help to guide the consumption pattern of the users so that the peak load and consumption during peak hours can be reduced. Various DR techniques have been proposed by different authors. Some the methods are discussed here. A dynamic programming based method is presented by Hsu and Su in [24] to reduce the peak load by cycling off consumers' air conditioners. The consumers are divided into some groups. The air-conditioners for a particular group are held off for a fixed time period with their acceptance. When the control period is over their demands are restored and for some other group the loads are held off for the same time span. This procedure is repeated for all the groups for the whole day. Kurucz et al. [25] have proposed a Linear Programming (LP) model to control the peak load by controlling the loads in commercial, industrial and residential area. By offering lower prices for electricity the utility tries to control the load during different periods. The residential load control is done for some particular appliances such as pool pumps, air conditioners and water heaters. In [26] the authors Zhu, Tang, Lambotharan, Chin and Fan have described an Integer Linear Programming (ILP) based optimization method which reduces the peak time load and calculates optimal power and operation time for user appliances. The technique tries to reduce the peak hourly load of the consumers. Every house is connected with a smart meter that produces an optimal schedule for all the connected appliances in the household. The system also supports multiple users where many smart meters are connected together in order to achieve a cooperative scheduling. There is a central control node that takes the information about the appliances belonging to individual houses from their respective meters and tries to optimize the operation schedules for all the appliances connected to the system. The authors have also proposed a consumption scheduling mechanism using a combination of integer linear programming (ILP) and game theory approach to minimize the peak time load in [27]. The authors H. K. Nguyen et al. 2012 follow a game theory approach in [28] for generating optimized schedule for the consumers. In this work the game is played between the users and each user tries to minimize its cost. Samadi et al. have proposed a Vickrey-Clarke-Groves (VCG) mechanism in [4] which implements the utilitarian welfare function for implementing DSM programs. It encourages efficient energy consumption among users so that social welfare may be maximized. An optimization problem has been formulated to maximize the aggregate utility and minimize the total cost for all the users. The utility function of each user is derived from its preferences and energy consumption patterns. The optimization process is based on the assumption that every user possesses a smart meter containing an energy consumption controller (ECC) unit in it. The ECC unit tries to control the user's energy consumption and maintain coordination between the user and the energy provider. All the smart meters are connected to the energy provider through a local area network. Using this network each user can share its demand information with the energy provider. By executing a centralized mechanism, the energy provider determines the optimal energy consumption level for each user, and broadcasts a specific electricity payment for the user. Bu, S. and Yu, F. R. have used a real-time pricing tariff in [29].

A real-time demand response scheme is used to manage the load demand of the consumers so that the cost of electricity can be reduced and the usefulness from the consumption of electricity can be maximized. The model is described with the help of a Stackelberg game. The initial stages of the game analyze how the retailer should make decisions regarding the selection of sources of electricity, the amount of electricity to be bought and the optimal retail price for the consumers, in order to get maximum profit. Then the consumers adjust their demand based on the current price to reduce the cost to be paid and maximize the utility they get from the energy consumption. In [30] a demand-side energy consumption scheduling scheme for both the time-shiftable and the power-shiftable appliances has been proposed by Liu et al. It tries to maintain a uniform load demand during the day time. In addition, the schedule generated by the optimization process takes the consumers preferred usage requirements into consideration while finding optimal energy consumption and operation time for the appliances. The authors have proposed a quadratic convex programming method to determine the optimal operation time for the appliances for cost minimization. The authors Z. Md. Fadlullah et al. have described a game theory based optimization procedure where the game is played between the users and the utility provider in the article [31]. In the game the user's strategy is to minimize its electricity payment and the strategy of utility provider is to adjust the energy price parameter to reduce users' consumption. Hazem M. Soliman and Alberto Leon-Garcia have used a non cooperative game theoretic method in [32] to optimize the energy consumption of the users so that the peak to average load is reduced. A novel cost function has been introduced that can handle the scenario where the users can sell their accumulated energy back to the utility providers and the energy accumulation is done using storage devices. H. Chen et al. followed a game-theoretic method to find optimize schedule for the appliances in [33]. They have used a distributed approach to guide the energy consumption of the individual users. Raj et al. used a real-time based energy management system in [34] that depends on the real time consumption information of the users which is communicated to the grid through smart meter. Using this information the grid is able to predict the next demand which can help to avoid overload situations. In [35] a home area energy management system (HEMS) for smart homes has been proposed by Zhao et al. It can manage different load types with photovoltaic generation with energy storage. The HEMS optimizes the utilization of local renewable and reduces energy wastage due to AC and DC conversions and storage charging and discharging. The objective of the system is to minimize the total daily energy cost for all the consumers. A fully distributed DSM method presented by Barbatoa et al. The article [36] is based on a game theoretic approach which minimizes the peak demand of a group of residential users. It uses a real time pricing tariff. The authors have considered two practical scenarios. In the Single-Appliance DSM case each appliance decides autonomously its scheduling time in a distributed fashion, so each appliance is a player in the game which can make independent decision regarding the starting time of its execution and the time appropriate to buy energy from the grid so that its contribution towards the overall electricity payment is minimized. In the Multiple-Appliance DSM case each user has to find schedules for all his home appliances. The householder is the player in this game who chooses the schedule of all its appliances according to its preferences with an aim to minimize its electricity payment.

19.5.1 Limitations in the Existing Works

Most of the works in literature use both linear and non-linear programming method to solve the DSM problem. However these programming techniques cannot handle a large number of controllable devices which have several computation patterns and heuristics [37]. The Linear programming methods may not find a feasible solution for NP-hard problems. The computational time is also very large for the problems that belong to NP-hard, non convex programming or Mixed Integer non linear programming. However heuristic-based evolutionary algorithm can provide a near optimal solution in polynomial time [38]. The heuristic based methods like genetic algorithm, Ant Colony Optimization and Particle Swarm Optimization (PSO) can search very large spaces of candidate solutions and find globally optimal solution in polynomial time. The author in [39] has given importance on advanced computational techniques which are needed for optimization and better control of grid systems. As distributed and coordinated intelligence is required at all levels of the electric grid like generation, transmission and distribution, the author has emphasized on the computational intelligence mechanisms that include artificial and bio-inspired intelligence paradigms exhibiting an ability to learn and adjust to new situation, generalize and abstract the existing situations and find association between different situations which in turn help to develop effective and robust algorithms for grid management. Motivated by these facts some heuristic-based optimization techniques have been used to solve the DR problem in this chapter. The proposed techniques try to find optimal operation schedule for the smart appliances present in a household. The appliances are connected with a smart meter which is connected to the grid. The power is received by the appliances through the smart meter. The smart appliances are embedded with some control units. The control unit controls the operation of the appliances. The smart meter contains the scheduler that calculates the schedule for the appliances and sends signals to the control units of the appliances so that they can operate at scheduled time. When the appliances operate at the scheduled time the electricity bill of the consumer can be reduced. It also reduces the peak demands and peak hour demand of the consumer.

19.6 Proposed System Model

A smart home plays a very significant job to implement DR in household sectors. A smart home consists of some smart appliances which are connected with each other through some communication link. Every appliance is embedded with some

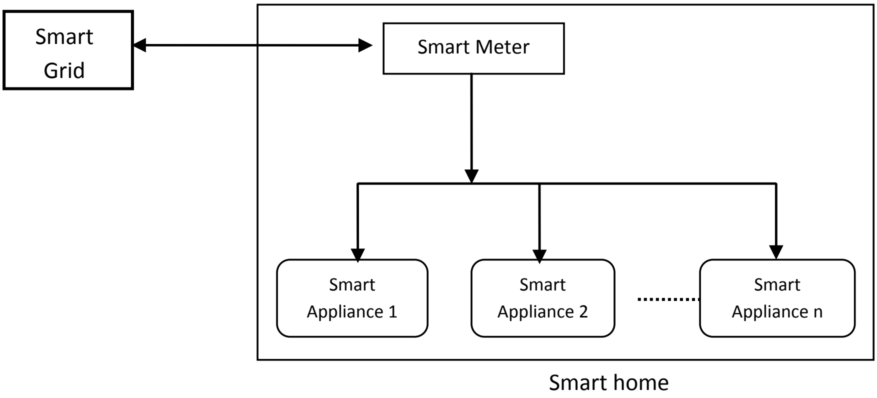

Fig. 19.1 Smart meter controlling smart appliances in smart home

operating system that can control the operation of the appliance. DR also needs smart meter for each house which is connected to all the appliances present in the house. The smart meter is also connected to the grid from which it receives information regarding the price and the upcoming events. Generally there is a two way communication link between the grid and smart meter. Required information from the user can also be sent to the utility through the link. The smart meter is embedded with a scheduling algorithm which when executed calculates the schedule for the operations for the appliances connected to it. When the appliances are operated based on the calculated schedule there is a significant saving of the electricity bill of the consumer and along with this the user demand during peak hours is also reduced. It is the responsibility of the smart meter to send start and stop signals to the appliances for their operation according to the schedule generated. Figure 19.1 shows the structure of a DR system where there is a smart meter connected to the appliances and controls their execution.

19.6.1 Daily Energy Consumption

The schedule is calculated for an entire day before the day starts. The time horizon taken for simulation is a complete day which can be divided into 24 slots. Every appliance has a specific time period during which it can operate. The total energy consumed in a whole day is calculated as the sum of the amounts of energy used by all the appliances during the day. It is denoted as E_{tot} and defined as:

$$E_{tot} = \sum_{t=1}^{24} e_t \tag{19.1}$$

where e_t is the amount of energy required by all appliances during time slot t.

$$e_t = \sum_{a \in A} e_t^a \tag{19.2}$$

e_t^a is the energy consumed by the appliance a during time slot t. A is the set of appliances. Every appliance has a minimum power level ($a^{\min}$) and maximum power level ($a^{\max}$) which is defined as:

$$a^{\min} \leq e_t^a \leq a^{\max} \tag{19.3}$$

The energy consumed at a particular time slot is bounded by a maximum consumption amount $e^{\max}$ *which has* been used to avoid high peaks.

$$0 \leq e_t \leq e^{\max} \tag{19.4}$$

19.6.2 Energy Cost Function

The cost of energy for a complete day denoted as C is calculated as the sum of the hourly costs of the day. It is defined as:

$$C = \sum_{t=1}^{24} c_t \tag{19.5}$$

where c_t is the total cost of energy during a time slot t and it is calculated using a logarithmic function.

$$c_t = p \times e_t \times \log(e_t + 1) \tag{19.6}$$

The energy cost during a time slot is assumed to be proportional to the energy consumed during that slot. When the amount of energy consumption is increased the cost calculated by the scheduler is also increased. p is the cost parameter that helps to control the consumption of the user during a particular time slot because its value is more during the peak hours of the system and less during the low peak hours similar to TOU pricing.

19.6.3 Objective Function

The objective of the system is to minimize the daily energy cost incurred by the user which is possible by shifting a fraction of the daily load to off peak hours. The cost minimization function is defined as:

$$minimize \sum_{t=1}^{24} c_t \tag{19.7}$$

19.7 Heuristic Optimization

Heuristic optimization algorithms like Genetic algorithm (GA) and Particle swarm optimization (PSO) have been used in this work to find the optimal schedule for the appliances. GA is an evolutionary algorithm that follows natural selection of fittest individuals from a random population and applies repeated modification of the individual solutions until a satisfactory solution is reached. PSO is another evolutionary optimization technique. However it is motivated by the social behaviour of birds forming a group, fish schooling and swarm theory. Another technique has also been used here which is an amalgamation of GA and PSO. It can be called as a hybrid of GA and PSO denoted as GAPSOH (GA and PSO Hybrid).

19.7.1 GA (Genetic Algorithm) Based Optimization

GA is a meta-heuristic optimization algorithm which is a special type of heuristic algorithm depending on bio-inspired methods like mutation, crossover and selection to find good quality solutions within polynomial time. In GA a population of candidate solutions is evolved toward better solutions. It is an iterative process. In each iteration more fit individuals are selected. From the current population and they are recombined and randomly mutated to form new individuals for the next iteration. The algorithm terminates after some prefixed number of iterations or when some satisfactory solution is found. The hourly load matrix is taken as the population on which the optimization is applied. A set of randomly initialized individuals satisfying the constraints 2, 3 and 4 form the population and act as the input for the GA. Figure 19.2 shows an example of a load matrix that can be treated as a population to be optimized by the algorithm. Every row in the matrix represents an appliance and every column represents a time slot. Every element in the matrix represents an amount of energy consumption made by a particular appliance (denoted by the row number) during a particular time slot (denoted by the column number). Every row in the matrix represents a chromosome in the population.

Times Slots

Appliances	1	2	3	4	5	6	....	....	....	24
a_1	0	0	0	0	500	500	....	....	...	0
a_2	1000	1000	0	0	0	0	...	...	...	0
a_3	0	0	0	0	0	1000	...	...	...	0
..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..
a_n	0	0	400	400	0	0	..	..	..	0

Fig. 19.2 Hourly load matrix

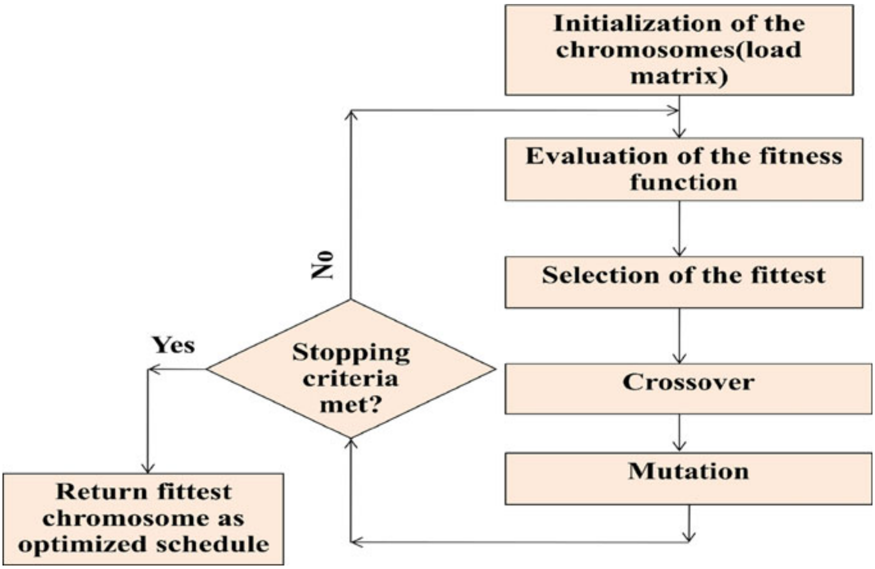

Fig. 19.3 Steps followed in GA

Every individual (chromosome) in the population represents a possible candidate solution. The cost minimization function (Eq. 19.7) is considered to be the fitness function with the objective to reduce the consumer's daily energy cost, reduce the peak hour demand and increase the utility of the consumed energy for the user. The flowchart for the algorithm is given in Fig. 19.3.

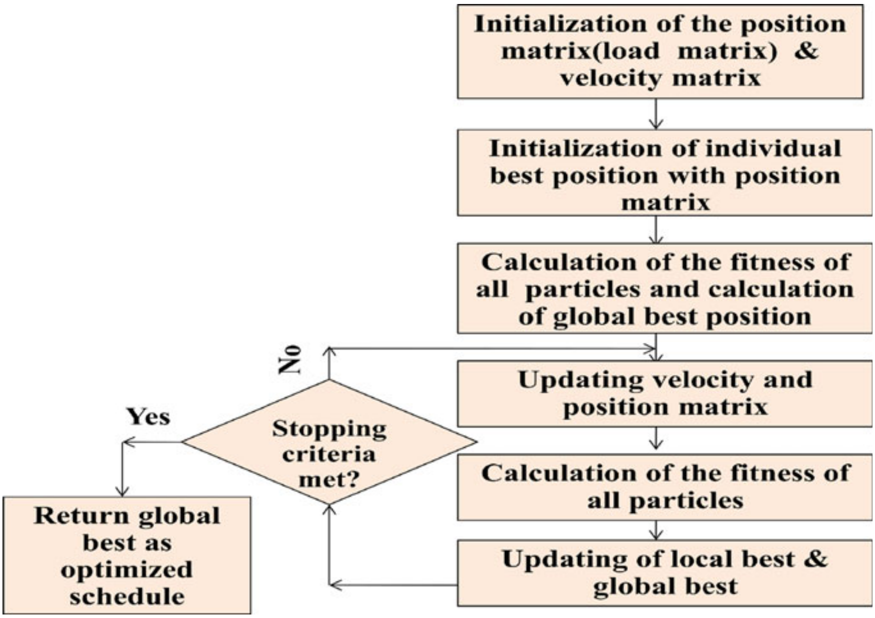

Fig. 19.4 Steps followed in PSO

19.7.2 Particle Swarm Optimization (PSO) Based Optimization

PSO is an evolutionary optimization technique which is inspired by the social behaviour of bird flocking, fish schooling and swarm theory. Like GA, the hourly load matrix is taken as the population on which the optimization is applied. The population representing the positions of the individuals is initialized with random values based on the defined constraints (2, 3, 4) and the algorithm is executed for some fixed number of times or until some satisfactory solution is achieved. In every iteration the population is updated based upon some formulae. The best individual from all the populations from all the iterations is the final solution to the problem at hand. The potential solutions called particles fly through the problem space by following the current optimum particles. The flowchart for PSO is depicted in Fig. 19.4.

19.7.3 Combination of GA and PSO

In GAPSOH the steps of genetic algorithm are combined with the steps of PSO to escape premature convergence and local minimum. At the beginning the position

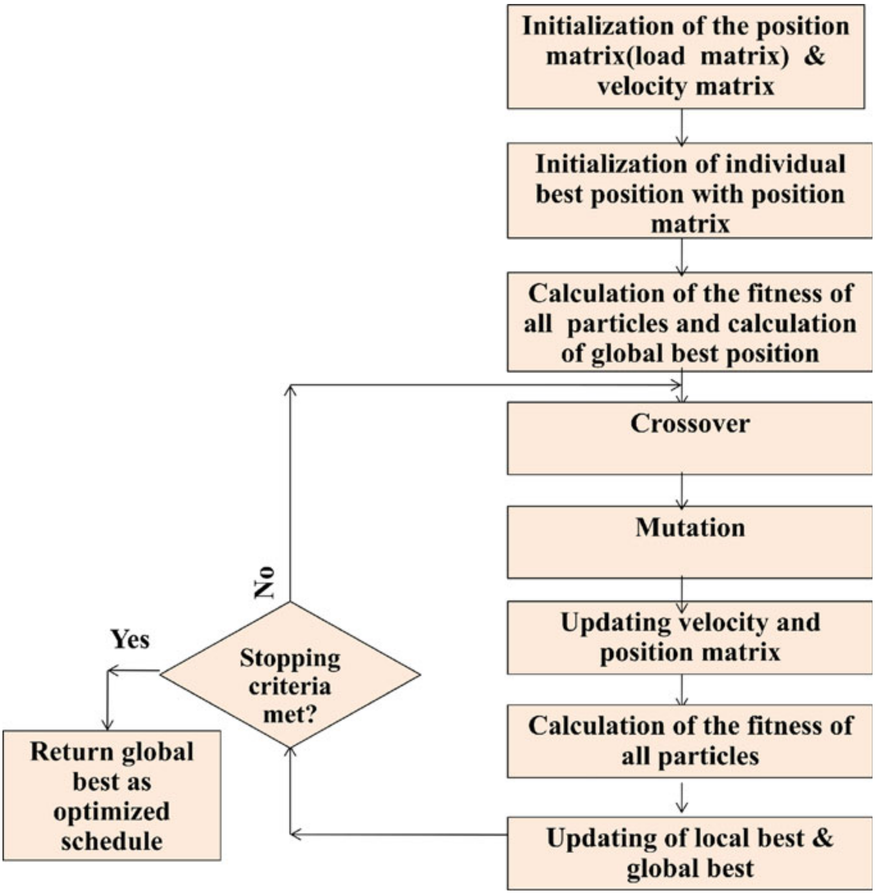

Fig. 19.5 Steps followed in GAPSOH

matrix and the velocity matrix are initialized with random values based on the constraints defined by the system. Then the local best and global best positions are calculated. To expand the search space and enhance the diversity of particles the crossover and mutation operators are applied on the velocity matrix and position matrix and then the resultant population becomes the input for the rest part of the PSO algorithm. The flowchart for GAPSOH is described in Fig. 19.5. As the crossover operator can generate a new population assuring that the offspring inherits good qualities from their parents, this has been used with PSO.

19.8 Simulation Results

The performances of the algorithms are compared based on the simulation results. Figure 19.6 provides a comparison made between the energy usage pattern of the user without optimization and with optimization. The daily consumption graph (without optimization) in the figure is similar to the graph used in [40]. It is clear from the figure that when optimization is not used the maximum energy is consumed during peak hours and when optimization is followed the demand during peak hours becomes low by shifting a part of the consumption to non peak hours (before 8 am and after 8 pm). Figure 19.7 shows the convergence behaviour of the three algorithms. It can be seen from the figure that the GA algorithm converges faster than the other two algorithms. However the function values calculated by the hybrid algorithm are lower than the values calculated by GA and PSO. Figure 19.8 compares the algorithms based on the cost values calculated by each of them for a consecutive 25 number of days. The cost values are the highest when there is no optimization. It indicates that when optimization is not followed the daily electricity payments are very high. When optimization is used the cost values generated by the hybrid algorithm are the lowest among cost values calculated by all the algorithms. It proves that the performance of the hybrid algorithm is the best among the algorithms being considered for optimization. Hence this can be used for implementing the proposed system to minimize the peak hour consumptions and the daily electricity payments.

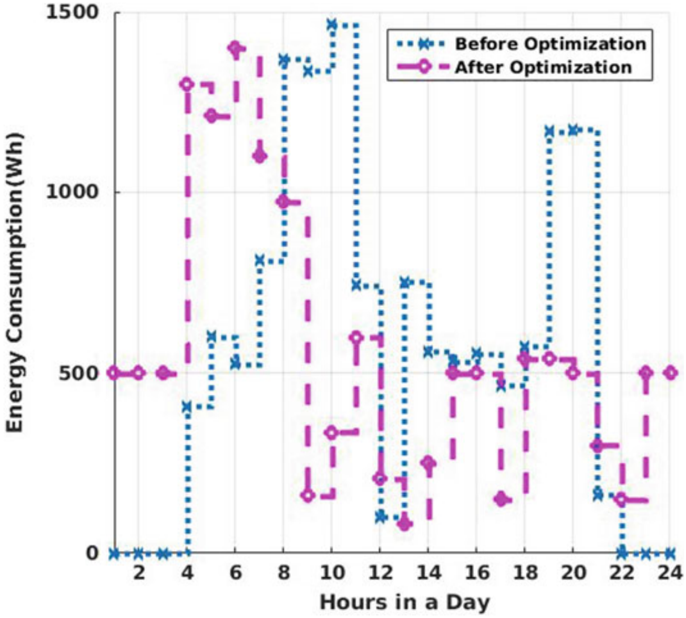

Fig. 19.6 Energy consumption reduced during peak hours

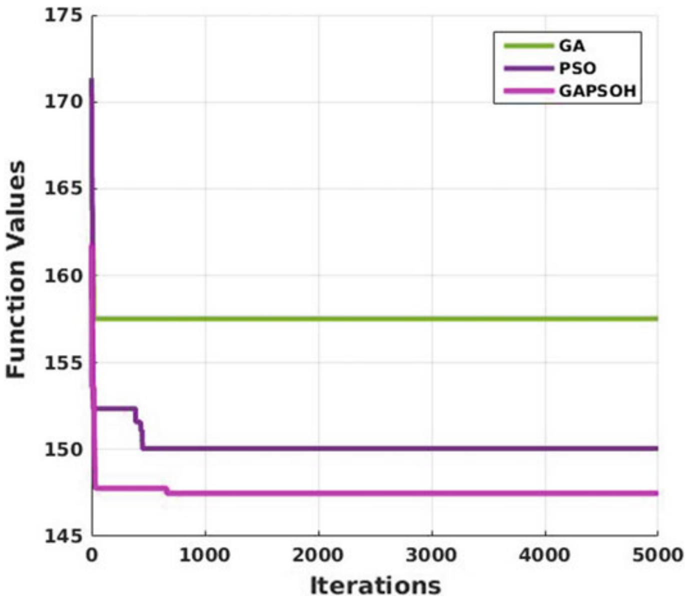

Fig. 19.7 Convergence of GA, PSO and GAPSOH

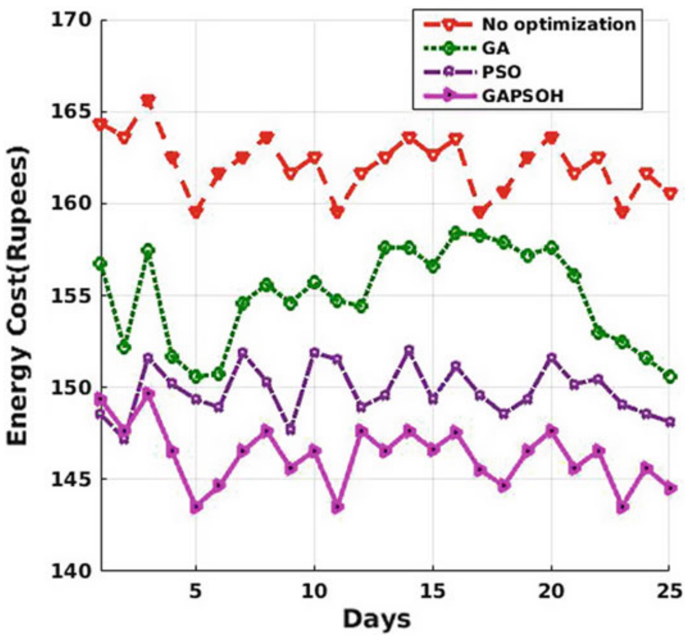

Fig. 19.8 Cost graphs for without optimization, GA, PSO and GAPSOH

19.9 Conclusion

The chapter includes a detailed discussion on the DR techniques used in smart grid. It has focused on several benefits of using DR, the possible obstacles in using the DR and the market scenario of several countries implementing DR and feasible DR approaches. Along with the detailed description of DR a model based on DR strategies has been developed in this chapter. This model makes use of optimization techniques to reduce the daily electricity payments and peak hour energy consumption by shifting a fraction of their demand from high pricing hours to low pricing hours. The optimization techniques have also been compared based on their performance. Among them the hybrid method seems to be more effective for the implementation of the DR problem.

19.10 Future Directives

A possible extension to the work has been outlined as follows:

Regarding DR strategies, results have been illustrated assuming a time horizon of 24 hours. The effect of considering wider time horizons has not been considered and it can be extended to handle the load curve for several days.

Scalability analysis of the proposed technique with respect to number of devices and users can be done. New pricing scheme for better DR in smart grid environment in context of appliance scheduling can be designed.

The proposed energy management strategy is not adaptive to the unexpected activities of the consumers in energy demand. A rule based expert system can be developed that can react to the changes in price and consumption behaviour of the users. The system can be extended to handle real time based energy consumption behaviour of the consumers.

It can also include the features to handle the energy production using renewable energy sources and selling of produced and stored energy back to the utility companies.

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Chapter 20
Smart Villages in Depopulated Areas

Angel Paniagua

Abstract The politics of smart village is an innovative area of the European rural policies that can have a remarkable usefulness in depopulated rural areas. It is necessary to distinguish the gap in the politics of smart villages between the core rural areas and peripheral rural areas in Europe and national scales. The implementation of smart villages is easier in the core rural areas and presents more problems in the peripheral rural areas. An integrated scalar vision is needed for/from Europe and a vision for/from each country with different problems, needs and expectations. In this context depopulated Spain is a double rural periphery: European and national. There are two roads around the smart villages: (a) horizontal connecting territories, and (b) firms that favor diversification. Depopulated areas are attractive locations for leisure, work and retirement. The problem is how it is possible develop a politics to smart and competitive areas in the whole of European rural areas and how is possible implement a smart and competitive policy and politics in depopulated areas. Some answers are detailed in this contribution focused mainly in depopulated Spain.

Keywords Smart · Town · Depopulation · Geography · Europe · Rural areas · Politics · Rural people · Innovation

20.1 Introduction

The rural Europe is complex space in constant evolution with multiple disparities. It maintains singular social and territorial inequalities across the continent, but also in each state. In any case the smart village is a new opportunity for European rural areas. An European countryside more inclusive in social and spatial terms, without traditional differences between urban and rural, core and peripheral, self and

A. Paniagua (✉)
Csic, Instituto de Políticas Y Bienes Públicos, Departamento de Economía y Política, Group: Geografía Rural (GGR), Madrid, Spain
e-mail: angel.paniagua@csic.es

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others… The final purpose is to generate a new countryside with connectivity for all people and not only for new rural businesses.

Some recent conferences confirm this trend. In the eleventh OECD rural development conference confirmed that the rural development—beyond agriculture—is essential to an inclusive rural areas. At the closing session of the Conference, the Edinburgh Policy Statement on Enhancing Rural Innovation was adopted. In this declaration it is recognized that rurality is not synonymous of decline. Place-based politics and multilevel governance are needed for inclusive rural areas. The rural areas are diverse. This conference identifies several key drivers of change in the 21st century, among other: digital connectivity, cloud computing and the internet of things, the future of health, the future of education. Place well-being across multiple dimensions, mainly: social, environmental and economic. Taking a place-based approach implies: implemented an integrated approach with the horizon of complementarities between territories and sectoral policies and the design of the policy instrument to promote coherence between rural, sectoral, regional and national goals political objectives [26]. In this context this conference suggest to develop urban-rural linkages for improve the quality of life of rural residents, the social innovation in local communities of contributing to climate change adaptation and finally incorporate the effect of demographic trends in rural areas on the design and implementation of rural public services [26]. All these international objectives and transferred to the European politics of smart villages.

In this contribution we want to show the evolution of smart village's politics in the framework of European rural policy, it's most recent evolution and the main national styles in the development of smart villages and its connection—and value—with the depopulated and remote rural areas. Also, show many local examples that already exist and their articulation with space.

20.2 Smart Village, People and Rural Spaces

Access to the internet makes it possible to match the living conditions of European regions. The digital divide between rural and urban communities and between peripheral areas and urban close is an element of social inequality among European rural citizens [29]. The importance of broadband in economic and social sustainability of remote and marginal rural communities has been repeatedly pointed out in recent years [28]. Connectivity conditions daily life and working terms in remote rural areas. Each remote rural area has its own singular characteristics, which condition the effectiveness of the connectivity process.

The lack of convergence between core and peripheral regions is usually pointed out as one of the difficulties—and one of the challenges—for the interpretation and application of the smart rural policies and the implementation of the smart villages [24]. How is it possible to translate to the regional and local rural contexts? The smart villages is not an issue yet resolved. Rural regions differ in terms of social structures and economic conditions, even in different European remote rural areas.

If knowledge and innovation are driving forces in the last processes of rural changes, place-based politics, are relevant in the implantation of smart villages. This makes the question of the definition of (adequate) place very relevant in the smart villages scale politics. The smart villages they need a fluid and porous place approach, with the rural spatial context, with others places and with the individual resident in each place.

In accordance with this approach, it is important to design an adequate smart village specialization that implies place-specific innovation policies based on the potential and vocation of each region. The design of a smart village in European rural context is a complicated purpose. Smart villages can be implemented in different roads, but in a multi scalar perspective. In the most peripheral regions, it will be difficult to implement a smart village's specialization strategy due to the lack of social capital and the inexistence of an adequate administration capacity [19]; the question is how is the most appropriate smart village's specialization policy for all regions of Europe.

20.3 The European Politics on Smart Villages

The background of the smart villages can be found in the European Strategy for technological innovation and improvements in technology. Innovation also includes new services, new marketing and new forms of business organization. In relation to access to external knowledge, rural regions are worse off than urban regions, this situation implies the need to improve ICT (Information and Communication Technology) infrastructure, such as high-speed internet [8, 9].

The European rural development program (2014–2020) includes various measures related to the creation of 'Intelligent and competitive rural areas' that included three priorities: (1) promote the transfer of knowledge and innovation to the agricultural, forestry and rural sectors; (2) improve the viability of agricultural holdings of all types of agriculture in all rural areas; (3) promote the organization of the food chain. So far the activity has focused on the sub-themes of food supply chains and rural enterprises [13]. Smart villages were a sub-theme within the 'Smart and competitive rural areas'. The smart villages in the field of rural development are understood as the 'initiatives around rural revitalization services through digital and social innovation. It looked at how rural services—such as health, social services, education, energy, transport, retail—can be improved and more sustainable through the deployment of information and communication technology (ICT) tools and through community-led actions and projects' [14]. In 2015, the first thematic meeting on smart villages in the ENRD is held and continues until today. In the years 2018 and 2019 with the practical orientation of how the available policies can help to smart villages emerge and develop.

These previous initiatives contribute to the emergence of the EU Action for Smart Villages from April 2017 [10], which aims to define smart villages and bring together sectoral policy efforts. Its philosophy is based on the document emanating from the Cork conference of September 2016 entitled ‘A better life in rural area’, in which attention is paid to digital divide between rural and urban areas and the integrated approaches and interaction between different policy fields. Smart villages cannot be done in isolation of the wider development strategies for rural territories. For many people’s, rural areas are places for live and rural communities need jobs, basic services, connectivity and smart transport solutions and adequate environment for entrepreneurship [10]. The EU action for smart villages indicates that the smart village is a relatively new concept within EU policy making. ‘The emerging concept of smart villages refers to rural areas and communities which build on their existing strengths and assets as well as developing new opportunities. In smart villages traditional and new networks and services are enhanced by means of digital, telecommunication technologies, innovations and the better use of knowledge, for the benefit of inhabitants and businesses. (…) The concept of smart villages does not propose to one-size-fits-all solution. It is territorially sensitive, based on the needs and potentials of the respective territory and strategy-led, supported by new or existing territorial strategies’ [10]. The approach of smart villages inserts its potential in the regional context.

Technology is important for community building. Good governance and rural citizens involvement is also relevant. Smart villages cover human settlement in rural areas as well as surrounding rural environment.

The development of smart villages combine initiatives of several EU policies: (1) Common Agricultural Policy- Rural Development provides some possibilities for development smart villages (rural business development, investment in small-scale local infrastructure and connectivity projects, village renewal, knowledge development and bottom-up initiatives—Leader). (2) EU Cohesion Policy, implemented through several programs at national, regional and local level. Specific instruments are smart specialisation strategies and integrated territorial investment (ITI). Notable opportunities exist to explore rural-urban linkages. Some specific new actions are the smart eco-social villages, which aims to link the best practices concept (in quality of life, education, energy, environment …) with the smart villages.

The ‘concept’ of smart village of the EU action is endowed with a dimension of ‘approach’ in the Bled declaration of April of 2018 [11]. ‘Smart villages have the potential to increase economic and social cohesion, and improve the social equality of our societies, which is especially visible between rural and urban areas’ [11]. A smart village is a compendium made up of people who take the initiative to mobilize local assets. These models of village offer the opportunity of human capacity to create synergy between some technological achievements: precision farming, digital platforms, shared economy, circular economy, rural tourism and social innovation in rural services.

In this way, the smart villages is a open approach ‘begin with local people coming together to develop a strategy around local assets and aspirations’ [21: 2]. The smart village’s functional cross sectoral approach has three axes [31]: (1) solve depopulation problems, (2) boost the provision of services, (3) realize opportunities for growth in rural areas. The smart village is an integrated approach of different policy fields to increase functional complementarily at different spatial scales. The smart village's policy should consolidate in the long term a range of territorially based intelligent instruments for the disparity of situations of the European Union. Also aims to reduce the gap between rural and urban areas, only 47% of rural households have access to fast broadband, compared with 80% of urban households [31]. In 2012, 90% of the European population that did not have a broadband internet connection resided in rural areas especially peripheral ones [30]. The smart villages is an opportunity for an equilibrate development of rural Europe.

The smart villages approach suggests multiple smart rural communities, not is a simply way. Smart villages are made up for rural people with practical solutions to new changes and opportunities. 'Smart villages are about the people' [15: 7]. Rural citizens take the initiative to find solutions. But need beyond individual or isolated experiences. Smart take place at village level, but involve the surrounding territory or groups of villages. Smart means alliances between rural actors and farmers. But, in definitive, no exists a standard initiative for smart villages.

The strategic drivers of smart villages are [15]: (1) depopulation, rural decline and demographic change. (2) Local solutions for a decentralization of public services in areas with lower population densities. (3) Exploiting linkages with small towns and cities, with a line of difference between the rural close to city and marginal depopulated areas. (4) The role of rural areas in the transition to a circular economy, through the smart specialization. (5) The digital transformation of rural areas. Digital technologies have the capacity to transform the traditional disadvantages of the rural areas in terms of distance and low population, and promote a digital place economy.

In definitive the smart village aims to break the decline circle of many marginal and depopulated rural areas. The initiative belongs to civil society.

20.4 National and Regional Styles for Smart Villages in Europe

National strategies or styles respond to three major processes of rural change [16]:

(1) Rural depopulation strategies, mainly address the depopulation and loss of population in some rural areas of Spain, Italy, France, Finland, Sweden, Scotland, Eastern and Baltic countries. Many actions combine the promotion to economic development with the support of service provision. An example is the Inner Areas Strategy in Italy, this strategy focuses on the most peripheral and marginal inner areas with problems of demographic decline and ageing of population. The strategy is based in investment in improving services, multi-level, multi-fund and participatory governance. At the end of 2017, this strategy covered 1066 municipalities, mainly through LEADER, through 71 pilot areas, but there are problems of integration with national and European scales.

(2) The rural-urban divide and the spatial conservation of services, for rural areas with stable populations, but with problems for maintain public and private

services: 'Focused investment in ICT can support quality of life; higher standard of living; ensure basic access to public services and infrastructure; better use of resources; lessen impact on the environment, and provide new opportunities for rural value chains in terms of products and improved and improved processes' [7]. An adequate example is the reciprocity contracts in France, with the finality of close the gap between urban and rural areas, through the promotion of common areas of interest. In the selected areas, we are currently working on four axes: regional/local economic development; social inclusion and health; culture and services; and finally environment and energy transition.

(3) Promoting a digital transformation of rural areas, based on the creation of broadband infrastructures and digital opportunities. An example is the smart countryside in Finland, with the purpose of improves digital innovation in rural services and familiarize to rural people with the digital technology. Since 2016 in Finland, the 'smart countryside' has been promoted [16], which investigates the processes of rural change and the opportunities for the digitalization of rural areas affected by restructuring processes. Its objective is to explore the diverse possibilities of diversification of rural services through its adequate digitalization. Its recommendations are adopted as principles and goals in the concrete actions of digitalization of health services and bulls in remote rural areas. It is intended in any case to reduce digital exclusion, find solutions adapted to local media and promote local experimentation: a digital and inclusive rural society for all people.

In any cases, people are the centre of discussion. In response the ongoing depopulation and loss of young people in marginal rural areas and the need to overcome the digital divide between urban and rural areas, these national strategies can be summarized in two broad orientations [12]: (1) Strategies aiming at broader rural development and improvement of the quality of life, (2) Strategies aimed at ICT—Information and Communication technology—development.

20.5 Local Level and Smart Villages

The multiple local approaches to smart villages can be organized in two main categories [12]: (1) forms of social and community innovation, with two perspectives: the approach service innovation from an environmental point of view and the social approach—care, education; (2) digital innovation with the approach of an adequate interrelationship between sectors in a given village or territory. The Leader can play a relevant role in bringing local actors together to identify smart needs, problems and solutions. But, decline regions need complex strategies at multiple scales, both horizontals and verticals: 'Efforts made at the local municipality level alone will not be sufficient and more consolidated and collective efforts at national/regional levels are essential' [7].

Local initiatives have different purposes: (1) social innovation through rural services: the loss or decline of a service or the identification of an opportunity is not enough, to initiate social innovation; certain conditions are required in the local community, such as leadership and social capital. There are three main scenarios of social innovation [17]: (a) rural areas with notable social capital, where there is a direct community investment in strategic local assets (energy, broadband, transport, elderly care…); (b) the initial initiative comes from innovative municipalities (municipal multiservice centers); (c) finally, the initiative is research-led (digital villages). (2) A new experience is the smart eco-social village that explores the main characteristics of smart eco-social villages and identifies the best practices upon which decision maker and rural communities can build development actions [10]. Climate change and environmental degradation is an important driver of this type of community. Recent estimates suggest there area around 15,000 eco villages, 2500 community energy initiatives and 1200 transition town initiatives [17].

20.6 Smart Villages, an Opportunity for Depopulated Areas

The politics of smart villages connect this approach with the solution of depopulation and rural decline. As suggest the ESPON [7] cooperation programme: 'Information and communication technology (ICT), digitalization and knowledge-intensive activities are fundamental to the restructuring of rural regions' in response to decline. Policy innovation in a region in decline is a complex task, particularly in rural areas with conservative structures, resistant to rural change and restructuring [7].

The demographic change does not affect all European regions in a uniform manner. The remote rural areas experiencing a decline [20], also brings development opportunities at a local level, thorough a smart territorial specialization strategy in marginal rural areas with an attractive innovation environment. Beyond the rural-urban divide, rural areas have a rupture between zones close urban areas and peripheral spaces. Broadband is essential for marginal rural areas, the improvement of broadband coverage could help a wide range of economic and labor activities, but also the quality of everyday live [22].

The main losses of rural population in Europe occur in [5]: (1) rural areas in the east and central of Europe with strong processes of rural restructuring: Bulgaria and Romania, Slovakia and Croatia, eastern German Lander; (2) the inner of the southern European countries: southern Italy, central part of the Iberian Peninsula, inner parts of France, affected with traditional process of rural decline; (3) the sparsely populated Nordic and Baltic countries: northern Scandinavia, Finland and Baltic States.

The decline in Central and Eastern Europe constitutes a new trend. In contrast, population decline has already been constant in northern Scandinavia, central regions of Iberian Peninsula and Central France since the 1960s. A new and old depopulation with different problems and contextual processes in each national and sub national scale: 'The key issue in these areas is the threshold population levels above which stabilization of population levels appears possible. These threshold levels vary from country to country…' [5].

20.7 The Smart Villages in Depopulated Spain

The depopulation is an European and Spanish problem, with different multi-scalar proposals and strategies for mitigate. At the national level, strategies around smart villages are diverse. The National Plan for Smart Territories of December 2017 was closely linked to the depopulation of rural territories [1] and the provision of public services. One solution is the application of technological advances through smart rural communities: 'Smart rural communities is a territory with a set of institutionalized actors, citizens, economic agents and public institutions transversally linked to rural development policies; generating a democratic governance that projects its cooperation and collaboration in a homogenous rural area, continent of a set of resources, with identity characteristics and with competitiveness assets of the territory, with public-private institutions with the capacity to excite and valorize, through the adoption of innovative actions and, especially, through the use of information and communication technologies (ITC)' [1]. In this perspective at the beginning of 2018, two important companies put into orbit a new satellite and activate a plan to facilitate access to the satellite network. The aim is to overcome the digital divide that in 2015 reflected the presence of high-speed networks in 70% of Spanish cities, while it did not reach 25% of the rural villages.

In addition, in recent years, measures have been taken to alleviate the problem of rural depopulation, which always includes smart villages approaches [18], through the development of digital innovation and the development of electronic administration and the extension of the ITC. In this same sense, the Agriculture Commission of the Spanish Congress approved a motion with a series of measures that included quality access to the Internet of all inhabited areas [4].

The current strategy to combat depopulation, currently under negotiation and development, also includes specific measures for broadband internet connection in the areas most affected by depopulation.

In the regional context, the initiatives carried out in Aragón stand out, the first European region with all its municipalities with access to broadband internet [6]. Through the Connect Aragon plan, it reaches 21,000 people in 700 small population centers through the main telecommunications companies in the country [2].

The smart initiatives at local scale that are developed in Spain can be grouped into five areas [25]: (1) promote a type of smart rural tourism, mainly through applications that can be installed on mobile phones that allow personalized visitor information or client (2) activities to develop an intelligent environment in a population center: automation of public lighting, automated systems of water management, optimization of garbage collection… (3) Solutions for intelligent mobility, by planning different types of transport to make them more effective for the rural citizen. (4) Develop and implement a more intelligent welfare state for its citizens, through electronic consultation services for the elderly. (5) Smart governance of municipalities, through the development of an electronic administration for the citizen inspired by the concepts of transparency and citizen participation.

Some singular examples of smart villages are [3]: (1) the smart village initiative of Villanueva de la Serena in Extremadura one of the most backward rural regions of Spain where an open data portal was put into operation at the disposal of the citizen, within the framework of a municipal transparency policy. It has also installed sensors on the floor of the parking spaces, to see the free spaces through a web application. (2) Valdepeñas, in the Castilla-La Mancha region, where an electronic administration system has been installed. In addition, a tourist web application has been put into operation. (3) Lepe, in the region of Andalusia, has focused its smart strategy on the development of a tourism website, as well as a corporate and transparency website of the municipal government. (4) Alcala la Real, in the region of Andalusia, has developed its smart strategy in the field of local tourism and energy efficiency (e.g. lighting control…). (5) Martos, in the region of Andalusia, has focused its smart strategy on energy efficiency through the control of street lighting and smart control of the traffic on foot of its citizens.

There are also many individual stories related to the (in) existence of smart villages: 'The producer of the most expensive ham in the world is forced to work almost without an internet connection. Five million Spaniards suffer the same problem' [23].

20.8 Conclusion

Rural Europe is a territory with multiple disparities in spatial and social terms. In this sense, the smart village aims to overcome the urban-urban rural gap that is different in each country. They are founded in place and in civil society (people), as the main drivers of their implementation. The smart villages policy born with the European action on smart villages, that aims to amalgamate all sectoral policies that influence their development: rural policies and cohesion policies. Although initially defined as a 'concept', it is immediately transformed into an 'approach' that aims to adapt to the multiple situations and European rural contexts. It is a flexible, open and inclusive approach that can be developed in multiple facets of the life of a community. Its current development in each member state offers different styles of implementation, associated with the main characteristics of the rural environment of each country. In some cases it is linked to the solution of demographic and social problems, while in others it focuses on the technical diffusion of digitalization. In each country, regional and local levels are important with different solutions to more localized problems. At the local level, smart villages are relevant to the solution of social/demographic problems or the solution of environmental problems.

The depopulation appears with continuity in the political documents that promote the smart villages to European scale. Smart village is a solution associated with decline, remote, marginal, depopulated… It has more relevance for the peripheral areas than for the rural close to city areas. In Spain, smart village is a key component in the national document for depopulated rural areas, and also in some relevant regional strategies (e.g. Aragon).

In any case, smart is an open perspective with three sides: functional, territorial and inclusive. Not is a closed concept is an adaptive and flexible approach, with an open perspective, associated with fluid and ductile multilevel governance. Rural areas and also peripheral rural areas can be places of opportunity beyond agriculture and other natural resource-based sectors [27]. This is a relevant issue, with the smart villages the beneficiaries are the residents in the rural areas, but they also want to be the protagonists. Each smart village project adapts to the specific conditions of the place. It is an action adapted to the place and the people who reside in it, but, also porous and fluid to the social context and territorial environment. It is not an individual option, on the contrary it is an orientation adapted to communities, where the protagonists are the people that make up the community.

The future of smart villages should delve into current trends and their generalization. But it will be necessary that each community has sufficient autonomy to adopt the best options in its development, adapted to the needs of the people who reside in each place. This will require a sufficient social capital in each community, but also an adequate connection with regional, national and European scales.

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