Jean-Claude Bolay · Magali Schmid
Gabriela Tejada · Eileen Hazboun *Editors*

Technologies and Innovations for Development

Scientific Cooperation for a Sustainable Future

United Nations Educational, Scientific and Cultural Organization

UNESCO Chair in technologies for development Lausanne (Switzerland)

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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Foreword

Science, technology, and innovation (STI) form essential pillars in our struggle to eradicate extreme poverty and promote sustainable development. However, despite some technological progress in developing countries, the technology gap between developed and emerging countries and developing countries is widening dramatically. We now realize that most developing countries will face serious challenges in meeting the Millennium Development Goals (MDGs) by 2015 unless they can build a solid STI base to address national needs and contribute to development effectively.

Indeed, according to the United Nations (UN) reports on progress in achieving the MDGs, many least developed countries, including 34 in Africa, could miss the boat unless there is significant investment in human resources and in STI, which are considered of crucial importance to stimulate sustained and inclusive development as a means of poverty alleviation. The Report of the Millennium Project's Task Force on Science, Technology, and Innovation, *Innovation: Applying Knowledge in Development*, is also very clear:

> Meeting the Goals will require a substantial reorientation of development policies to focus on key sources of economic growth, including those associated with the use of new and established scientific and technological knowledge and related institutional adjustments. Countries will need to recognize the benefits from advances in science and technology and develop policies and strategies to harness the explosion in new knowledge.

Strengthening national channels of technology dissemination, and research and innovation applications adapted to the various socioeconomic contexts are pressing challenges which are not only facing developing countries. They are facing us all as the world we live in is an interlinked and interdependent one. They are a global challenge which requires a global response. UNESCO, through the activities of its Natural Sciences Sector, has a vitally important role to play in mobilizing the international scientific community to more effectively address the global development of STI capacity, particularly in the developing world. This mobilization requires solid and concerted interaction and dialogue between all stakeholders at all levels: Universities and other institutions of higher education must play an increasing role in facing major global challenges such as climate change, freshwater management, biodiversity loss, and the use of renewable energy. What sets higher education apart from other institutions is not just its capacity to produce knowledge and human capital but, above all, its capacity to reason and work over the long term. This is not the case of political institutions that have often to work under short-term pressure. In an ever more complex world, it is crucial to rely on and give full place to higher education as higher education systems worldwide are at the heart of healthy STI ecosystems.

Universities are key sources of knowledge generation, yet in developing countries, faculty are often forced to take on a heavy teaching load to complement their modest income, leaving little time for research. As the *UNESCO Science Report 2010* demonstrates, this is the case in many Arab universities and in developing Asian countries like Nepal, for instance. Another hindrance to university research is the time faculties spend identifying funding for specific research projects. There is a general consensus that universities could overcome these handicaps by developing closer ties to the productive sector. However, the linear model prevails in many developing countries, leading to a science-push model rather than the demand-pull model that would be conducive to innovation. The report goes on to say that:

> 'the region [Latin America] demonstrates a paradox in that countries possess an acceptable scientific sector . . . which produces valuable knowledge that is potentially applicable to the productive sector, yet their economies demand very little local knowledge and are scarcely innovative.'

Even the prestigious Indian Institutes of Technology, for instance, tend to be extremely teaching-intensive institutions. The Report notes that it is estimated that the entire higher education sector in India contributes no more than 5% of India's gross expenditure on research and development.

Capacity development in higher education in developing countries is therefore crucial, and support to university and higher education institution networking is one strategy that UNESCO set up in the early 1990s through its UNESCO Chairs/UNITWIN Programme. It was conceived as a way to advance research, training, and program development by building university networks and encouraging inter-university cooperation through the transfer of knowledge across borders, notably North-South. The UNITWIN Programme now aims also to be forward-thinking and to impact socioeconomic development effectively, generating new ideas through research and reflection and facilitating the enrichment of existing university programs while respecting cultural diversity. A few years ago, emphasis was placed on transdisciplinary work and on the role of the Chairs as "bridge-builders" between academia, civil society, local communities, research, and policymaking.

The Chair in Technologies for Development, established in 2007 at the Ecole Polytechnique Fédérale de Lausanne (EPFL), belongs to this new generation of UNESCO Chairs which fully play the dual function of "think-tank" and "bridge-builder," aiming at promoting transdisciplinary research in STI adapted to the context of developing countries through partnerships with local institutions, in order to develop innovative solutions for the most vulnerable populations. As a

UNESCO academic partner, the EPFL Chair is a seminal international platform for dialogue and exchange in this key area. The last international conference organized by the Chair in 2010 with UNESCO support focused on technologies for the sustainable development of habitat and cities, ICTs for the environment, science and technology for disaster risk reduction and technologies for sustainable energy production. This publication reflects the main outcomes of the conference and provides significant orientations and criteria of success for the effective implementation and use of innovative technologies, notably on the importance of stakeholder ownership and the creation of entrepreneurial ecosystems which will enable their sustainability.

Gretchen Kalonji
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Foreword

Scientific Excellence and Appropriate Technology: A Global Challenge of Solidarity with Developing Countries

Knowledge is henceforth globalized: without borders, thanks to new means of communication and limitless thanks to constantly improving technological innovations. The challenges to be overcome are of major impact, whether in education, health, nutrition, or energy supply. And all of this is taking place against the backdrop of the Earth confronted with two fundamental issues: (1) climate change, which obliges us to review the foundations of our economic and industrial models to invent specific, sustainable solutions and (2) demographic growth resulting in a world population of some nine billion individuals by the year 2050, who need to be trained, fed, and housed to contribute to the development of new activities.

Science and technology thus have a major role to play in facing up to these challenges. We are all jointly responsible for ensuring that these innovations are as accessible as possible throughout the world. This is the very justification of scientific cooperation for development: to produce scientific excellence with positive significant impacts on sustainable development of less well-off countries.

The situation in the field remains of concern. Numerous studies demonstrate that economic growth is indispensable for the creation of wealth, but that it is not able to stamp out poverty on its own. Major disparities continue to exist. This is totally true in a number of African countries as is the case in certain Asian and Latin-American countries. According to the United Nations Conference on Trade and Development (UNCTAD) in 2005, 35% of the population of the least advanced countries was living in extreme poverty, and the number of persons living on less than a dollar a day had increased compared to the year 2000. Although there is positive integration of these countries in the world economy, interior and regional markets need to be developed and reoriented on satisfaction of the needs of their populations. When it is understood that emerging and developing countries currently group together 80% of the world's population, all these questions constitute important avenues of research. Furthermore, these countries, especially in Asia and Africa, are experiencing accelerated transition to increasingly more urban and technological societies.

Within this context, research and higher education play an essential role for international solidarity cooperation, even if application may sometimes seem arduous. Higher education is deemed useful to drive development, render public institutions more efficient, foster private enterprise, and ensure a nurturing environment. On the other hand, funding for both basic and applied reseach in African, Asian, and Latin American universities is all too often limited; public budgets are virtually inexistent, making countries and universities totally dependent on international aid. Young scientists emigrate and do not find an appropriate, stimulating environment should they ever return to their own country.

It is therefore imperative to found scientific cooperation on this training and research axiom and support academic institutions with their development initiatives. This is based on networks, as is the case of the RESCIF (Réseau d'excellence des sciences de l'ingénieur de la Francophonie),[1] with the setting up of joint laboratories and on postdisaster support for the two main universities in Port-au-Prince. Or alternatively it is based on scientific partnerships, such as the collaboration between the Edmond and Lily Safra International Institute of Neuroscience of Natal (ELS-IINN) and EPFL for the Blue Gene/L supercomputer and creation of the Brazilian "Brain Campus." Or it may be based on scientific collaboration agreements, as is the case for EPFL for more than 20 years with quality partners such as the Universidad del Valle, at Cali in Colombia, and the Institut International d'Ingénierie de l'Eau et de l'Environnement (2iE), in Burkina Faso, in the fields of water and energy.

The present publication highlights some concrete examples of North-South cooperation, leading to win-win partnerships for all parties concerned. For northern universities, this constitutes the opportunity for students and researchers to confront challenging contexts for which original technological solutions, tailored to these environments, must be provided. For southern universities, this constitutes the opportunity to directly enter the world of international research, enabling their Ph.D. students and young researchers to be trained in laboratories in western countries and write theses on priority subjects for their countries and their regions. All these facets thus contribute to the knowledge sharing strategy.

Faced with the extent of needs and the type of aims, the agenda is no longer simply to transfer technologies from the north to the south, even if that can sometimes be deemed an excellent progress vector in emerging and developing countries. Henceforth, this involves considering technical and social innovations, appropriate to physical, environmental, cultural, and economic conditions of receiving countries, and which can be appropriated by their potential users and are thus revealed as real technologies for fostering development.

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[1] Network of Excellence in Engineering Sciences of the French-speaking Community.

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Abbreviations

2IE	Institut International de l'Eau et de l'Environnement, Burkina Faso
AAS	African Academy of Sciences
ACCFP	African Climate Change Fellowship Program
ACCI	Agencia Presidencial para la Acción Social y la Cooperación Internacional
ADB	Asian Development Bank
ADPC	Asian Disaster Preparedness Center
AFIS	Advanced Fire Information System
AIACC	Assessments of Impacts and Adaptations to Climate Change
AIDS	Acquired Immune Deficiency Syndrome
AMS	African Maize Stress
ANN	Artificial Neural Networks
APEC	Asia-Pacific Economic Cooperation
ARCSSTE-E	African Regional Centre for Space Science and Technology Education in English
ARTP	Autorité de Régulation des Télécommunications et des Postes
ASPI	Australian Strategic Policy Institute
ATPS	African Technology Policy Studies
AVHRR	Advanced Very High Resolution Radiometer
CAU	Clay Activation Unit
CBD	Central Business District
CCAA	Climate Change Adaptation in Africa
CCB	Cement Concrete Blocks
CCFSC	Central Committee for Flood and Storm Control
CCIS	Comprehensive Crop Insurance Scheme
CDM	Clean Development Mechanism

CDRR	Certificate of Advanced Studies in Disaster Risk Reduction
CEDT	Centre for Electronics Design and Technology
CEEPA	Centre for Environmental Economics and Policy in Africa
CEPT	Center for Environmental Planning and Technology University
CFA	Franc de la Communauté Financière Africaine
CfRR	External Evaluation Report on the Cash for Repair and Reconstruction Project
CG06	Conseil Général des Alpes-Maritimes
CH_4	Methane
CIAT	International Center for Tropical Agriculture
CICDA	Centre International de Coopération pour le Développement Agricole
CIDEM	Centro de Investigación y Desarrollo de Estructuras y Materiales (Center for Research and Development of Materials and Structures)
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo
CLTS	Community-Led Total Sanitation
CNAM	Conservatoire National des Arts et Métiers
CND	National Committee for Decentralization
CNIG	Conseil National de l'Information Géographique
CNRS	Centre National de la Recherche Scientifique
CO_2	Carbon Dioxide
CODEV	Cooperation & Development Center
COLCIENCIAS	Departamento Administrativo de Ciencia, Tecnología e Innovación
COPE	Cooperative Orthotic and Prosthetic Enterprise
COPSOP	Country Strategic Opportunities Paper
CORPOICA	Corporación Colombiana de Investigación Agropecuaria
CoV	Coefficient of Variation
CPI	Consumer Price Index
CSEB	Compressed Stabilized Earth Block
CSERGE	Centre of Social and Economic Research on the Global Environment
CSI-CGIAR	Consortium for Spatial Information of the Consultative Group for International Agriculture Research
CSIR	Council for Scientific and Industrial Research
DDC	Direction du Développement et de la Coopération Suisse
DFID	UK Department for International Development

DfT	Department for Transport
DGIS	Distributed Geographic Information Systems
DRR	Disaster Risk Reduction
DTA	Differential Thermal Analysis
EACH-FOR	Environmental Change and Forced Migration Scenarios
EcoSur	Latin American Network for an Ecologically and Economically Sustainable Habitat
ECOWAS	Economic Community of West African States
EdL	Electricité du Laos
EFLUM	Environmental Fluid Mechanics and Hydrology Laboratory
ELS-IINN	Edmond and Lily Safra International Institute of Neuroscience of Natal
EM-DAT Database	The International Disaster Data Base
ENAC	School of Architecture, Civil and Environmental Engineering
EPCD	Commune Public Associations for Development
EPFL	Ecole Polytechnique Fédérale de Lausanne
ERACTION	Environmental Rights Action
ESRC STEPS	Social, Technological and Environmental Pathways to Sustainability Centre
ETM	Enhanced Thematic Mapper
FADEC	Support Fund for the Development of the Commune
FAO	Food and Agriculture Organization of the United Nations
FCT	Federal Capital Territory
FICCDC	Federal Interagency Coordinating Committee on Digital Cartography
FU	Functional Unit
GAMS	General Algebraic Modeling System
GDP	Gross Domestic Product
GHSOM	Growing Hierarchical Self-Organizing Map
GIMMS	Global Inventory Modeling and Mapping Studies
GIS	Geographical Information System
GLASOD	Global Assessment of the Status of Human-Induced Soil Degradation
GLC	Global Land Cover
GLCF	Global Land Cover Facility
GNG	Growing Neural Gas
GNI	Gross National Income
GOP	Government of Pondicherry
GOTN	Government of Tamil Nadu
GPRS	General Packet Radio Service
GPS	Global Positioning System

GRET	Groupe de Recherche et d'Echanges Technologiques
GSDMA	Gujarat State Disaster Management Authority
GSM	Global System for Mobile Communications, originally Groupe Spéciale Mobile
GSMA	GSM Association
GWP	Global Warming Potential
HCMC	Ho Chi Minh City
HDI	Human Development Index
HEC	Hautes Etudes Commerciales
HEIG-VD	Haute École d'Ingénierie et de Gestion du canton de Vaud
HEKS	Hilfswerk der Evangelischen Kirchen Schweiz
HIV	Human Immunodeficiency Virus
IAV	Institut Agronomique Vétérinaire Hassan II
IB	Index of Brilliance
IBGE	Brazilian Institute of Geography and Statistics
IBRD	International Bank for Reconstruction and Development
IC	School of Computer and Communication Sciences
ICT	Information and Communication Technology
ICTs	Information and Communication Technologies
IDB	International Data Base
IDNDR	International Decade for Natural Disaster Reduction
IDRC	International Development Research Centre
IDS	Institute of Development Studies
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IES	Institute for Environmental Sustainability
IFAD	International Fund for Agricultural Development
IFEU	Institute for Energy and Environmental Research
IFPRI	International Food Policy Research Institute
IHDP	International Human Dimensions Programme on Global Environmental Change
IICT	Institute for Information & Comunication Technologies
IIE	Environmental Engineering Institute
IIED	International Institute for Environment and Development
IISc	Indian Institute of Science
IMX	Institute of Materials
INFOSOLO	Mercado informal e o acesso dos pobres ao solo
INTER	Institute of Urban Studies
IPCC	Intergovernmental Panel on Climate Change
IRA	Institute for Resource Assessment
IRD	Institut de Recherche pour le Développement

ISDR	International Strategy for Disaster Reduction
ISIM	Institute of Computing and Multimedia Systems
ISO	International Organization for Standardization
ISODATA	Iterative Self-Organizing Data
ISRIC	International Soil Reference and Information Centre
ITU	International Telecommunication Union
IUCN	International Union for Conservation of Nature
KFH	Swiss Universities of Applied Sciences
kW	Kilowatt
LAO PDR	Lao People's Democratic Republic
LASUR	Urban Sociology Laboratory
LBL	Lawrence Berkeley National Laboratory
LCA	Life Cycle Assessment
LDCs	Least Developed Countries
LDM	Media and Design Laboratory
LED	Light-Emitting Diode
LIRE	Lao Institute for Renewable Energy
LMC	Laboratory of Construction Materials
LME	Electrical Machines Laboratory
MaDePro	Certificate of Advanced Studies in Management of Development Projects
MADR	Ministerio de Agricultura y Desarrollo Rural
MAP	Maximum A Prior Probability
MCM	Multicriteria Mapping
MDGs	Millennium Development Goals
MEERP	Maharashtra Emergency Earthquake Rehabilitation Programme
MGIS	Mobile Geographic Information Systems
MJ	Megajoule
MK	Metakaolin
ML	Maximum Likelihood
MLP	Multilayer Perceptron
MOFA	Ministry of Food and Agriculture
NAIS	National Agricultural Insurance Scheme
NASA	National Aeronautics and Space Administration
NCCR	National Centers of Competence in Research
NDVI	Normalized Differential Vegetation Index
NGOs	Non-Governmental Organizations
NIAS	Nordic Institute of Asian Studies
NICTs	New Information and Communication Technologies
NMR	Nuclear Magnetic Resonance
NOAA	US National Oceanic and Atmospheric Administration
NPP	Net Primary Productivity

NRE	Non Renewable Energy
OCA	Observatoire de Côte d'Azur
OCHA	Office for the Coordination of Humanitarian Affairs
ODIHPN	Overseas Development Institute Humanitarian Practice Network
OECD	Organisation for Economic Co-Operation and Development
ONE	Office National d'Electricité
ORNL	Oak Ridge National Library
OST	Observatoire des Sciences et des Techniques
PCA	Principal Component Analysis
PCIS	Pilot Crop Insurance Scheme
PDVM	Development Program for Medium-sized Towns
PNUD	Programme des Nations Unies pour le développement
PPP	Purchasing Power Parity
PR	Public Relations
PU	Pastoral Unit
PV	Solar Photovoltaic
R&D	Research and Development
RAND	National Defense Research Institute
RASTA	Rapid Soil and Terrain Assessment
RCC	Reinforced Cement Concrete
RCMRD	Regional Center for the Mapping of Resources for Development
RE	Renewable Energy
RESCIF	Réseau d'excellence des sciences de l'ingénieur de la Francophonie
RESTREND	Residual Trend of RUE
RHA	Rice Husk Ash
RUE	Rain Use Efficiency
S&T	Science and Technology
SAGMO	Independent Ouahigouya Market Management Service
SCBA	Sugar Cane Bagasse Ash
SCMs	Supplementary Cementitious Materials
SCSA	Sugar Cane Straw Ash
SCU	System Control Unit
SDC	Swiss Agency for Development and Cooperation
SECTRA	Secretaría Nacional de Transporte
SER	State Secretariat for Education and Research
SEU	Social Exclusion Unit
SFB	Solid Fuel Block
SHS	Solar Home Systems
SLRS	Solar Lantern Rental System

SMS	Short Message Service
SNSF	Swiss National Science Foundation
SOM	Self-Organizing Map
SRTM	Shuttle Radar Topography Mission
STD	Standard Deviation
STI	Science, Technology and Innovation
STI	School of Engineering
SUPSI	University of Applied Sciences of Southern Switzerland
SVG	Scalable Vector Graphics
TERI	The Energy and Resource Institute
TERP	Tsunami Emergency Reconstruction Programme
TGA	Thermogravimetric Analysis
TM	Thematic Mapper
TOD	Decentralization Guidelines
TRMM	Tropical Rainfall Measuring Mission
UCLV	Universidad Central de las Villas
UCR	Uncoursed Random Masonry
UKCDS	UK Collaborative on Development Sciences
UMR	Unité Mixte de Recherche
UN	United Nations
UN DESA	United Nations Department of Economic and Social Affairs
UNCCD	Nations Convention to Combat Desertification
UNCED	United Nations Conference on Environment and Development
UNCHS	United Nations Centre for Human Settlements – Habitat
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNECA	United Nations Economic Commission for Africa
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCO GREET	UNESCO's Global Renewable Energy Education and Training Programme
UNFCC	United Nations Framework Convention on Climate Change
UN-Habitat	United Nations Centre for Human Settlements – Habitat
UNISDR	United Nations International Strategy for Disaster Reduction
UNITWIN	University Twinning and Networking Programme
UNS	Université de Nice – Sophia Antipolis

UNU-EHS	United Nations University – Institute for Environment and Human Security
UPS	Uninterrupted Power Supply
USB	Universal Serial Bus
UTM	Universal Transverse Mercator
VAC	Volts Alternating Current
VEC	Village Energy Committee
VSBK	Vertical Shaft Brick Kiln Project
VT	Village Technician
W3C	World Wide Web Consortium
WARDA	Africa Rice Center
WB	World Bank
WHO	World Health Organization
WSN	Wireless Sensor Network
XRD	X-ray Diffraction
YSME	Yobe State Ministry of Environment

Part I
Introduction

Chapter 1
Appropriate Technologies for Sustainable Development

Jean-Claude Bolay

1.1 Introduction

Technological innovation – combined with scientific research – has always constituted a driving force of transformation in our societies. From the moment it turns into an industrial and economic tool, any form of societal innovation involves change in production processes: the creation and development of new lines of business, increased marketing of new products, and therefore the set-up of new organizational modes of social interaction, as much within as between societies across the world.

But technology is also a process, a social mechanism which becomes inclusive over time and brings individuals together, or drives some away; it creates special-interest groups, impacts the natural or developed environments in which these individuals evolve, and alters cultural patterns, the way we think and act, and the way we see the world and understand it, whether we have taken ownership of these technologies or are marginalized by their development.

Technologies – their emergence, dissemination, transformation, development, and even disappearance for the benefit of more sophisticated ones – are, and increasingly rapidly so, catalysts for change within and between contemporary human societies. They are the fundamental constituents of what will determine the future, and the reference points outlining the present.

We live in a world in which technologies play a prevalent role in the globalization of exchanges (not only of information but also of people and culture) and in the creation of new living patterns (settling down, moving around, working, eating and staying healthy, communicating, enjoying ourselves, interacting, etc.), as well as the geographical distribution of the assets, knowledge, and products that are driven by growth. In fact, the world is no longer divided into self-contained hegemonic blocks,

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be they political or economic groupings. The world has turned into a throng of countries and regions constantly competing with each other. They have all adopted a similar vision of what progress means, both economic and material as well as cultural and social, teetering between aggressive behavior and cooperation, between living and working patterns that are either site specific – and yet similar worldwide – or mixed.

In the future, developing and emerging countries, given their demographic and geographical weight as well as the potential for growth that some of them have unlocked, will face the major challenges that humankind is currently grappling with but will do so much more effectively than the old industrialized powers by offering the most fitting responses to solve them – provided they have the resources necessary and the capacity to do so.

In this light, generally speaking but for developing countries in particular, scientific and technological breakthroughs may not only create wonderful opportunities but may also convey risks that should not be overlooked (James 2002a).

In the future, only high-level human skills will provide the means of seizing these opportunities and forging them into development tools; this is in sectors that international organizations consider to be key points for improving living standards in countries of the South, for example, agriculture, health, access to water, the fight against the deterioration of the environment, and energy (Watson et al. 2003). It is therefore necessary to implement public policies that promote science and technology, most notably in favor of information and communication technologies (ICTs) – which clearly provide better access to knowledge – as well as educational policies that are in line with these priorities.

A study of the links between technologies and development should first address the contribution of modern technologies to sustainable development in all its environmental, social, and economic aspects, in order to cover the basis of this concept (Brundtland 1987).[1] Secondly, it is necessary to examine the relationship formed by individuals – and more globally, by contemporary societies – with present and future technologies.

This is a universal issue since technological innovation has been an evolutionary process through an increasingly widespread, complex, and sophisticated use of such technologies and their ever-growing dissemination across the planet. There is almost always a deep belief that technologies will improve the life of individuals, whoever they are and wherever they live. However, it has also been proven many times that technologies have unfortunately only partially succeeded in eradicating socioeconomic disparities, both within and between societies.

The North-South relationship has long been a matter of debate, first in economic and then in political terms, and from a sociocultural standpoint. From this point forward, the relationships between regions of the world, between nations, and

[1] Besides, sustainable development, in its quest for balance, cannot overlook the spatial dimension, through fair territorial distribution of development, or the cultural dimension – development models must be designed to adapt to the socio-spatial contexts upon which they bear their imprint.

between the populations of these countries must also be perceived in terms of technology. And here, several lines of thought can be explored:

- Is technological innovation universal in nature or, conversely, is it specifically intended for particular sectors? Does it fulfill the particular needs of certain societies in conditions inherent to each context, with particular reference to developing countries? If the universal nature of technological innovations is undisputed, their effects can be sharply contrasting, depending on the development of individual countries, public policies applied, and the social configuration in place. As Anton et al. (2001) put it: "Those not willing or able to retrain and adapt to new business opportunities may fall further behind."
- Focusing as a priority on developing countries, scientists and technologists of the North and South, as well as public and private decision-makers, are faced with great social, economic, and environmental needs that are not entirely or are only partially met and for which technological solutions must be created, implemented, and adapted to conditions prevailing in societies of the South. The issue of investing in priority sectors to guarantee more sustainable development for the benefit of all is paramount, as much on a political as on a financial, economic, and societal level.
- With this is mind, the issue of appropriate technologies and technological transfer opens up a vast debate on the choices to be made and their defining criteria. Although intrinsically there are no "poor" technologies designed for poor countries or innovating technologies designed for rich countries, societal contexts vary widely and so do human and financial resources. And these specific environments will impact on technological creation, as well as its ability to offer solutions that fit the needs, and the extent to which additional advantages can be drawn from this technology for the benefit of all. Decision-making criteria related to future technological choices are therefore crucial and should (a) meet the priority needs of the countries and regions concerned, (b) concentrate on the nature of the innovations that are put forward, (c) adapt to the specificities of users in all societies, and (d) promote the full inclusion of these countries in international exchanges (Murphy et al. 2009). The implementation of a technological innovation strategy raises the following question regarding the stakeholders involved directly or indirectly in this scientific, technological, and socioeconomic development process, as much in the Southern countries concerned as within international scientific cooperation projects and programs: who are the decision-makers, how are decisions made, and in favor of whom?
- The last vital issue to address concerns access to technologies. It is clear that the development of research is generally very costly, as are transferring and implementing this research and then managing and maintaining it. But those in charge of managing technologies will also have to be watchful and ensure their development and sustainability, all the while guaranteeing the profitability of each innovation. Whatever their socioeconomic status, users will inevitably have to pay for this service, either fully or partially, with the risk – often demonstrated – that *technologies adapted to a territorial and societal context can lead to segregation* in

society, as a majority of disadvantaged sections of the population cannot afford access to these innovations. It is therefore essential to identify pathways and means of fighting against these new forms of inequality (SDC 1999) and to commit to scientific cooperation projects addressing these problems.

As James (2002b) quite rightly says, "for the majority of developing countries, the goal of policy should be to promote universal access, as opposed to individual ownership of information and communication technologies."

These fundamental issues will guide our reflection and ensuing proposals in order to address a de facto situation which is relentlessly deteriorating the terms of economic and technological exchange between industrialized or emerging countries on the one hand, and the vast majority of developing countries on the other hand.

1.2 The Role of Innovation and Technology in the World

The world has been undergoing radical transformation over the last two to three decades. From now on, the globalization of trade is setting the course for a fully globalized economy. On the subject, Cohen (2004) recalls that from 1950 to 2000, the share of trade in Gross Domestic Product (GDP) has more than doubled.

Yet the opening of external trade is one of the three key factors in the dissemination of technological advances, along with direct overseas investments and contacts established between emigrated populations and their families of origin, in particular through financial remittances (World Bank 2008).

Technological advances have therefore led to the implementation of telecommunications and information system networks that are continuously linking up, in real time, all the inhabited areas of the world.

This technological revolution and the globalization of economic exchanges on an international level have not, however, significantly reduced the poverty that is still rife in many regions of the world (Bolay 2004; Stern et al. 2002). Whether at an international level or more narrowly, within each country's own internal structure, globalization does not concur with a widespread reduction of inequalities. On the contrary, as highlighted by Williamson (1998), there are growing disparities between countries and between individuals.

Technological progress also contributes to these disparities. Thus, the technological gap between rich and poor countries remains significant, on the one hand because rich countries own resources that less advantaged countries do not possess and on the other hand because rich countries have more individuals and companies with the skills needed to make the most of available technologies. However, developing countries have achieved remarkable technological advances, sometimes even twice as fast as developed countries. Such progress was notably rapid in lower-income countries, with some catching up with high-income countries: for example, in Chile, Hungary, and Poland, the level of technological development increased by more than 125% during the 1990s. During the 2000s, a coalition of 132 developing countries stressed the need for developing countries to build scientific capacity and close the technological gap between them and industrialized nations. According to Arunachalam (2005), such a perspective will depend on increased scientific cooperation, including setting up networks of researchers and a consortium on science and technology.[2] And a key proposal is to share information on scientific results and technological innovations through institutional open-access archives in developing countries (UNESCO 2007).

Alongside the expansion of international trade and the globalization of economies, the pace of technological dissemination has also increased dramatically over the last two centuries. At the onset of the nineteenth century, an average of 84 years were necessary to introduce new technologies in all developing countries; in the 1950s, the delay was reduced to 26 years, and in 1975, it dropped to 18 years (Arunachalam 2005).

Technological progress is dividing fast-growing economies (Southeast Asia and developing European countries) and slow-growing economies (Latin America, Middle East and Africa). The measurement of technological progress remains flawed: it is based entirely on total factor productivity, namely the efficacy with which an economy produces goods and services, given a particular level of manpower and capital, and attributes to technology that portion of revenue growth which cannot be attributed to investment or available manpower. Nevertheless, in absolute terms, it is now widely recognized that technological progress has largely contributed to reducing poverty in developing countries.[3]

The first determining component of technological dynamics – chosen directions and spawned innovations – relates to the promotion and definition of "human capital," that is, education and advanced training (Acemoglu 2002). This is in addition to investment in Research and Development (R&D) which extends its effects (Afonso and Aguaiar 2004). Also, in both areas, we can clearly distinguish great discrepancies between countries, as well as between regions in today's world.

Although there seems to be an established link between information technologies and economic productivity, the more complex relationship between these technologies and social development has attracted less attention (Corea 2005). Several studies have pointed to a positive correlation in the most industrialized countries between new information and communication technologies (NICTs) and socioeconomic development. However, this link is not so straightforward in developing countries, thereby encouraging them to invest in both material and human resources, as they lack the skills to embrace these new technologies.

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[2] In this regard, UNESCO Chairs and UNITWIN networks are unique models that encourage knowledge circulation and the reinforcement of capacities through innovative ways of North-South and South-South cooperation.

[3] The poverty rate has dropped from 29% in 1990 to 18% in 2004, according to the World Bank (2008).

Indeed, public authorities can take various measures to promote technological progress, most importantly: openness to trade, continuous improvement of the investment climate to enable businesses to flourish, reinforcement of infrastructures, improvements in the quality and quantity of education, and enhancement of R&D guidelines and delivery programs.

Yet investment in R&D – the driving force of innovation – remains highly clustered (Mustar and Esterle 2006). The United States is in the lead with close to a third of the world's total investment, followed by the European Union (25%), Japan (13%), and China (9%). Other countries around the world – all regions combined – account for only 18% of R&D expenditure. This is a very low figure. As a result, the most disadvantaged regions of the world fully depend on innovations produced elsewhere, a situation which turns them into consumers of high value-added products. Similar discrepancies can also be observed in the number of researchers involved in the scientific sector, be it public or private. For 2002, the same study forecasts the equivalent of 5.3 million (full time) jobs in the field of research across the world: 23.7% in the United States, 21.4% in the European Union, 15.2% in China, 12.1% in Japan, and 9.2% in Russia, meaning that other countries, including emerging and developing countries, share the remaining 18%.

The UNESCO Science Report (2006) highlighted once more the great divisions in our world: 77.8% of R&D investment takes place in developed countries, which bring together 70.8% of world researchers, while developing countries – with 69.5% of the world's population and 39.1% of the world's GDP – allocate 22.1% of investment to the scientific field and account for 29.1% of researchers. As regards less-developed countries – that is 11.1% of the world's population and 1.5% of the world's GDP – funding of R&D amounts to 0.1% of the total world figure, for a corresponding 0.1% of world researchers. These figures signal a total and alarming marginalization of the poorest countries in the face of the technological changes dominating our modern economies, where education, science, and technology serve as drivers in societies that are increasingly fed by information and knowledge as significant factors of production.

Africa is probably the continent that is the most symptomatic of such socio-spatial disparities. For the nations on this continent, R&D amounts on average to 0.3% of GDP, though South Africa alone represents 90% of the 3.5 billion dollars invested every year in this sector across Africa. The remaining African countries share a tiny fraction of research funding (OECD 2007).

This is a dramatic situation since many international experts recognize that science and technology are prime drivers of development (PNUD 2001). Whatever the region, the modern world is now plugged into and driven by the information and knowledge economy, a "virtual" world which is nonetheless an integral part of our daily lives. Since global economic growth and the underlying technological explosion do not fuel social equality and a fair distribution of the fruits of growth, the only remaining way to manage the "challenges of globalization" described by Thimonier (2005) is through cooperation.

Considering priority sectors for the development of countries of the South and possible cooperation strategies, we can identify four fields which open up possibilities for international cooperation, representing both real challenges for the scientific community and significant issues for public and private decision-makers, at national and international levels.

These essential components, although not exhaustive, establish a link between scientific and technological skills and strategic areas of development; they represent a first-rate potential for research and a genuine tool for development cooperation – both key elements for long-term sustainable development.

They are the following:

- Technologies for sustainable habitat and cities
- Information and communication technologies for the environment
- Science and technology for disaster risk reduction
- Technologies for sustainable energy production

In this fashion, and with the aim of promoting research for technologies and innovations that are appropriate for developing countries and which enable solutions for the key significant challenges faced by the most vulnerable populations, the EPFL UNESCO Chair International Scientific Conference on Technologies for Development was held from 8 to 10 February 2010 in Lausanne, Switzerland, offering a platform for discussion and scientific exchange. The conference addressed the aforementioned priority sectors in different interdisciplinary workshops.

1.3 Technologies for Sustainable Habitat and Cities

In 2008, a symbolic milestone was reached when, for the first time in the history of mankind, over half of the world's 6.8 billion total population was living in an urban environment. This growth primarily concerns developing countries: according to the United Nations (UN), in 2030, 81% of the world's urban population will be living in developing countries, with 70% of this population living in Africa and Asia. In fact, the poorest populations will be the first to contribute to this phenomenon. The struggle against social and spatial segregation will thus add to the many challenges already confronting Southern cities, such as demographic transformation, access to community infrastructures and services, mobility needs, globalization of economic exchanges, environmental degradation and climate change. Yet, despite these deficiencies, the city is already acting as the prime driving force behind progress: a concentration of persons, resources, power, and knowledge. In this context, technological innovation is both the cause and effect of urban development, not only playing a decisive role in the structuring of cities but also representing a means of fulfilling the new needs being expressed. In view of this, the international community has for several years been urging the transfer of urban technologies to developing countries and the joint creation of technologies adapted to the major problems confronting public authorities, economic actors and users. There are five particularly suitable domains for this transfer in the urban environment: water, energy, transport, sanitation, and habitat. The aim of this workshop was to examine the link between technology and development in an urban environment by:

- Questioning the contribution of contemporary technologies to the sustainability of development in its environmental, social, and economic aspects
- Analyzing individual perception of technologies according to sectors, needs, and access

1.4 Information and Communication Technologies for the Environment

ICTs offer promising potential for the environment in developing countries: mobile information and communication systems are used to build wireless sensor networks and produce complete sets of data on the environment, Global Systems for Mobile communications (GSM) applications can support data transfer for various applications, and cell phone networks and many Internet applications contribute to a better understanding or governance of the environment. Although new technologies are available, enabling of ICTs in developing countries remains a challenge in the form of obstacles to technology transfer, closing of numeric gaps, and contributions to ensure environmental sustainability. The latter is a major objective worldwide and one of the UN Millennium Development Goals (MDGs) in the fight against poverty. Closing the numeric gap is also a concern on the international agenda (Gerster and Zimmerman 2003). Part of the environmental challenge is directly linked to economy and governance: although resources may be sufficient, poverty, competition, and poor choices make sustainability rare. Adequate information and communication are essential to obtain data, monitor and manage the use of resources, and inform. When environmental management fails, ICTs can provide innovative solutions that will encourage sustainability. The idea of this workshop was to generate discussion of new technology, examples of applications, and innovative uses, which will enable ICTs to be used for environmental management in developing countries. The workshop aimed to exchange ideas and pilot experiences involving mobile information and communication systems, GSM applications, cell-phone networks, the Internet, and other ICTs. The objective of the workshop was to review emerging ICTs, discuss innovative applications of ICTs and the conditions for successful implementation, such as the importance of tackling challenges relating to development.

1.5 Science and Technology for Disaster Risk Reduction

Over the past few decades, the number of major disasters and persons affected by them throughout the world has steadily increased. This particularly applies to natural disasters involving hydrometeorological phenomena. According to work carried out by the Intergovernmental Panel on Climate Change (IPCC 2007), this trend can be expected to continue due to the possible impacts of global warming, including the likely – even very likely – increase in the number of extreme phenomena. Not all countries are equally equipped to cope with these risks, however, since a community's adaptive ability is closely linked to its level of development. Poverty and unequal access to resources are both factors that are likely to increase vulnerability in the face of natural hazards and climate change. Science and technological innovations are essential components of "Disaster Risk Reduction." They play a role at every stage of the process right through to the actual crisis: from risk analysis (identification of hazards and vulnerabilities) to mitigation measures (impact mitigation in case of unavoidable hazards) and preparedness (early warning systems in particular). The aim of this workshop was to reflect on the following questions: which technologies for what sort of development in the field of natural disaster reduction, and how can their effectiveness in coping with these disasters be improved and better adapted to local environments and their populations?

1.6 Technologies for Sustainable Energy Production

Strong demographic growth, the rapid industrialization of large countries emerging on the international economic scene, and the environmental impact of industrial, agricultural, and urban activities mean that energy choices made over recent decades have to be rethought. In view of the anticipated depletion of fossil fuels (oil, gas, coal) and their proven contribution to the deteriorating living conditions on the Earth (pollution, climate change), it is essential that dependence on these inherently nonrenewable energy resources be reduced. The energy crisis is however not just linked to a problem of resource supply and shrewd effluent management – it also involves economic and social aspects: the extremely volatile nature of fuel prices, large disparities in access to energy sources, and ambivalent public policies regarding consumer prices. These questions, if posed on a global basis for the planet as a whole, entail especially serious consequences for developing countries. The precariousness of populations, whether rural or urban, also has energy implications: although the changes observed in ways of life in developing countries result in an overall increase in energy consumption, one quarter of the human race is entirely reliant on "noncommercial" biomass fuels (particularly firewood), while 1.6 billion people still have no access to electricity. Developing countries are confronted with a dual challenge: gaining access to alternative and renewable energies with low environmental impact, adapted to their geographical and climatic conditions, and encouraging the use of local primary energies, produced at reasonable cost and efficiently transformable into energies accessible to the vast majority of low-income inhabitants. The aim of this workshop was to reflect on the links that exist between energies, appropriate technologies, and socioeconomic development in Southern countries by:

- Evaluating the potential of contemporary technologies for sustainable development relating to energy and the environment
- Focusing workshop participants' attention on the major innovations in the energy sector and the necessary conditions for adapting these to the context of developing countries
- Examining individual perception of technologies according to sectors, needs, and access possibilities

1.7 Conclusions

In conclusion, the issue of "Technologies for Development," as addressed during the EPFL UNESCO Chair International Scientific Conference on Technologies for Development in February 2010, leads us to define the specific technologies we are discussing, their aims, their particular contexts in relation to countries of the South, their accessibility for users, and their appropriation by producers and stakeholders in the field of development both in the North and South. These questions have been the main guidelines for the various chapters and contributions to the present publication.

Analyzing the four technological areas chosen for the occasion, presentations were illustrated by case studies and theoretical considerations. The resulting observations were developed from fundamental issues, both aiming at sustainable development which benefits the whole population of the regions concerned and taking into consideration their historical and cultural diversities:

What are the characteristics of technologies exported or created in emerging and developing countries?

The question of appropriation clearly emerges from the identification of technologies implemented in developing countries. The vast majority of technologies, emerging within a context of globalized trade and heightened economic competition, are there not only to solve practical development issues but also to act as weapons in a ruthless "economic war" between producers of goods and services, promoters, and users. However, the questions of adaptability to a context, to a society, and to management and maintenance capacities, or the question of natural resources conservation, do not appear to be essential criteria in the choice of technologies and the practical aspects of their transfer.

What are the societal needs aimed at through these technologies?
Opening up toward so-called "appropriate" technologies brings us closer to the guiding principles of sustainable development, in the sense that whether imported or indigenous, old or newly created, their aim is to respond to the demands of a society which is focusing not only on economic profitability but also on social and environmental issues. This also brings into question the stakeholders involved in designing and implementing these technologies, in an attempt to determine who defines the idea of "need" and its content, in the face of "social demand" – another less discussed notion – thereby confronting scientists and technologists with users' renewed necessities.

How unique and innovative are they in relation to contemporary sciences and technologies?
There have been, over the last decades, outstanding and recognized breakthroughs in technology, increasingly focusing on confirmed links between theoretical research, its experimental applications, and the development of new prototypes and products. Despite this, technologies used in developing countries are characterized by their great diversity: created through the use of ancient traditions, "turnkey" imported products from highly industrialized countries as well as mixed solutions which are socially and technologically more innovative. It remains to be seen what part of the scientific and commercial market will be occupied by these appropriate technologies, and to what extent they will be viable in the context of global trends which influence both production and social and institutional demand.

Can these technologies be adapted to the geopolitical context into which they are being integrated?
The evaluation of technologies – their relevance, their adaptability, and the solutions they bring to known problems – must also focus on the context into which these technologies will be deployed, both the geophysical and climatic context on the one hand and the social and political context on the other hand. Taking into account the environment into which these technologies are incorporated will affect both their actions and results. And, we have a duty to not limit their evaluation simply to their technical performance, partly because this context has varying levels: local, because attention is focused on the characteristics of their location; regional and national, because a technology is always connected to other technical and social networks; and global, because technologies today are for the most part completely dependent on global trends and markets. These levels of intervention, the individuals determining their orientation, the conflicts and negotiations leading to their implementation, and the resources available to enhance their functionality, will be the criteria used to judge the impact and appropriation of technologies at a specific time in history and in a chosen territory.

How do they contribute to sustainable development through their environmental, social and economic compatibilities?
Despite all the potential they embody for the development of both industrialized and developing contemporary societies, technologies remain an instrument, a tool, an often highly sophisticated means of scientific innovation, and the result of

advanced research, all of this with the aim of improving the performance of the priority sectors of society. This can apply to energy systems and their networks, construction materials and their impact on the expansion of cities, or communication methods and their role in technological exchanges. To play their part, these technological means must be sustainable – not as such (innovations evolve and are continuously transformed), but in their function, which must answer to societal demands, taking into consideration not only the necessity of economic profitability but also that of social cohesion and inclusion and respect for natural resources.

What is the role of technologies in the context of scientific cooperation for development?
Those participating in the creation, development, and expansion of technologies, first-hand players of this endless progress, are known and recognized by all: academic researchers, industries, public and private companies, and indirect instigators such as governments and public authorities and national and international organizations supporting innovation and research. Bi- and multilateral agencies for cooperation and development remain somewhat lagging compared to the other stakeholders identified here. Although aware of the effects of science and technology, they seem intimidated by the complexity of situations and by short-, medium-, and long-term commitments. All the while, these same authorities recognize the positive role of technologies in a sustainable and global development. It is worthwhile to capture the position held by international cooperation and the role it hopes to play in the future among other incumbent stakeholders: that of promoter like other official entities, of intermediary between technologists and users, or of leader in favor of disadvantaged sectors of the world population and areas neglected by key research and industry players. The question remains open.

With the contributions of the various authors of this publication, and within a spirit of sharing and exchange encouraged by UNESCO Chairs' UNITWIN Network, we should be able to set out guidelines for the establishment of future North-South scientific cooperation projects. These will aim at scientific and technological innovation in favor of an equitable development tackling disparities in emerging and developing countries, promoting the reinforcement of human capital capacities through fairer knowledge sharing between developed and developing countries, and supporting a growth respectful of human beings and their natural and built environment, both today and in the future.

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Part II
Key Note Speakers - UNESCO Chair International Scientific Conference on Technologies for Development

Chapter 2
Sustainability, Development, Social Justice: Towards a New Politics of Innovation

Melissa Leach

2.1 Introduction

We live in a time of unprecedented advance in science and technology, with global annual spending on research and development (R&D) now exceeding a trillion dollars. Yet development challenges have also grown. For many people and places, poverty is deepening, and the environment is in crisis. Thousands of children die daily from waterborne diseases, and more than a billion people go hungry. Meeting the interlinked global challenges of poverty reduction, social justice and environmental sustainability is the great moral and political imperative of our age, and moreover, one that must be pursued in an increasingly complex and interconnected world. Science, technology and innovation of many kinds have essential roles to play. However, in this chapter, the author argues that this imperative can only be fulfilled if there is a radical shift in how we think about and perform innovation – amounting to a new politics.

Debates about the relationship between science, technology and development have a long history, with formal discussions in the United Nations (UN) circles going back more than 40 years. With the late 1960s witnessing the moon landing, the burgeoning Green Revolution and a global smallpox eradication program, this was a time of great interest in the potential for science and technology to address development challenges. Yet science and technology were overwhelmingly steered by the interests of the global rich rather than the poor. At that time, however, some began to argue that research agendas needed to focus much more strongly on the world's 'developing' countries and their needs. In some quarters – for instance, in a study commissioned by the UN in 1969 which became known as the 'Sussex Manifesto' (Sussex Group 1970), published in 1970 – calls were made for large increases in investment and funding, as well as the building up of institutions and

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infrastructure – to support science and technology in, and for the interests of, developing countries. This document, along with a number of other related initiatives during this period, did help to advance broadly progressive aims for building science and technology geared to development goals and capabilities in developing countries to realize these. Indeed, since then, there have been significant achievements. The share of global research and development expenditure in 'developing' countries has increased from 2% in 1970 to roughly a fifth, whilst expenditure on research and development across 'developing' countries has risen to approximately 1% of aggregate gross domestic product. The scale of science and technology for development has therefore undoubtedly increased. However, this chapter argues that scale is not enough. By examining current patterns and debates about how to link science, technology and development, and drawing on arguments developed in a New Manifesto (STEPS Centre 2010), this chapter argues that much more attention should be given to the *direction, distribution* and *diversity* of scientific, technological and innovative activities, illustrating the practical and political implications of this '3D' agenda.

2.2 Scientific and Technological Promise: For Whom?

Today, we are witnessing a range of coordinated international efforts to solve global problems using science and technology. Modern advances appear to offer more promise than ever, and private sector and philanthropic foundation involvement has added significantly to the potentials.

Two main arguments are now put forward in favour of science and technology as the core solution to development challenges (Leach and Scoones 2006). In the first, scientific and technological innovations are seen as routes to national economic growth in a highly competitive global economy. The emphasis is on fostering scientific and technological infrastructure, connectivity, markets and capacity through 'centres of excellence' towards an increase in growth-focused technological activity. This is held also to lead indirectly to poverty reduction and capacities to deal with environmental protection – in line with general 'trickle-down' models of economic development. Yet, whilst scientific and technological advance has undoubtedly contributed to growth in particular areas, the benefits – and sometimes risks – have been very unevenly distributed. For instance, China and India have experienced rapid economic growth assisted by hi-tech knowledge industries, yet the poor peri-urban populations of these countries' new 'shining cities' must struggle for livelihood and health, often amidst polluted land, air and wastewater. Or take Africa, where the development of continent-wide network connectivity with fibre-optic cables promises a new era of opportunity and investment for some, but will not directly help the poorest, those who remain isolated, or those who do not speak a global language. This route and its consequences therefore follow and support a 'lock-in' to particular growth-focused styles of technological activity – from which other people and problems are excluded or lose out.

The second argument responds to this problem through focusing more directly on particular poverty and environmental challenges. The emphasis here is on targeted scientific and technological solutions – 'silver bullets' – that can be rolled out and applied at scale. In particular, new philanthropic and public-private investments have massively expanded the scope to address challenges that were once neglected because addressing them was seen as unprofitable. Again, this has yielded many successes and much promise. Thus in 2010, for example, the Bill & Melinda Gates Foundation committed an unprecedented £6.24 billion investment in vaccines for children, geared to saving eight million lives by 2020. But often, hoped-for technological successes founder amidst particular local contexts, with their diverse realities, perspectives, priorities and socio-cultural understandings. Thus, for example, the biotechnology-led 'Green Revolution for Africa', as manifested in the scientific search for drought-tolerant maize in East Africa, is proving inappropriate to the needs of dryland small farmers in Kenya who see their resilience amidst climate change better built through cropping and livelihood diversification, moving in and out of maize (Brooks et al. 2009). The vaccine-led Global Polio Eradication Initiative foundered in Northern Nigeria where local priorities focused on other diseases and basic health care and socio-political contexts associated highly resourced external technology interventions with political terror in a post-9/11 world (Yahya 2007). The roll-out of bednets – at least partly responsible for massive declines in child mortality from malaria in Africa in the last decade – foundered in Western Kenya because they were the colour of the shrouds used to wrap the dead. Such problems and missed targets arise, again, because of concentration and lock-in, this time around big-win, scaleable technologies that are seen to meet grand challenges. However, context matters, and technologies that work in one place will evidently carry quite different meanings and implications in others.

2.3 A '3D' Agenda for the Politics of Innovation

Neither these successes nor the generic importance of either of these routes to technology and development progress should be denied. They need political commitment and investment. However, this needs to be oriented in new ways, in line with what can be termed a '3D agenda' (STEPS Centre 2010). This aims to foster far more *diverse* and more *distributed* forms of – and *directions* for – innovation, in turn requiring far more attention to deliberative, democratic politics.

Before elaborating this '3D agenda', it is important to acknowledge that this refers not just to science and technology but also to innovation – and innovation systems. Amongst many possible definitions, *science* can be defined as the process of generating knowledge, whilst *technology* refers to the application of scientific knowledge, frequently involving invention – the creation of a novel object, process or technique. *Innovation*, however, refers to developing new ways of doing things in a place or by people where they have not been used before. This may involve the bringing together of new ideas and technology or finding novel applications of existing technologies (Conway and Waage with Delaney 2010). Innovation therefore can make use of science and technology, but goes beyond it. We also need to move our conceptualization beyond a linear model, in which research leads to translational research, product development and then to application or consumption, to recognize innovative activity and innovation systems as involving multiple interactions between a wide array of actors – from laboratories and firms to funders, civil society organizations and users. These interactions often involve interplay, feedback, experimentation and embedded learning in multiple directions. They encompass not just research and development but also design and engineering; not just technologies and applications but also social meanings and arrangements. These interactions, in turn, take place in wider institutional environments – involving policies, regulations, property rights and finance – extending across local and global scales. This broad conceptualization of an innovation system, in which creativity and learning are dispersed throughout, is an essential basis for a 3D agenda.

Whichever link with development is the focus – competing in a global economy, or meeting challenges directly – current mainstream discourses focus quite narrowly on science and technology, rather than broader innovation systems. Equally, they emphasize the scale and pace of innovative activity, over its direction, distribution or diversity. When thought about in relation to any given challenge (dealing with a disease, addressing hunger amidst drought, building low-carbon energy systems), the image is that there is an optimum pathway to be followed. But if we look more closely, it becomes clear that for most challenges, innovation pathways are chosen; particular directions are promoted over others and gain momentum and lock-in. This is a political process involving power, markets and the interests of incumbent institutions.

A 3D agenda involves making such questions of *direction* far more explicit, asking 'what is innovation for?'; 'which kinds of innovation, along which pathways?' and 'towards what goals?' This includes – but goes beyond – prioritization across different sectors, such as military, health or energy, to address the particular directions of change supported in any given sector. For instance, even quite a narrow field such as low-carbon electricity production presents a host of alternative directions for innovation pathways: such as those emphasizing small-scale distributed renewable energy; large-scale, centralized renewables in continent-spanning infrastructures and nuclear fission or fossil fuels with carbon capture and storage. None of these strategies can be pursued to their full potential without detracting from support for others. This inevitably involves political choices.

Direction matters because it shapes the *distribution* of benefits, costs and risks from innovation. As we have seen, marginal people and places are often the ones to lose out. So turning to the second D, for any given problem, we need to ask: 'who is innovation for?'; 'whose innovation counts?' and 'who gains and who loses?' This means deliberating, explicitly and inclusively, what different innovation pathways imply for equity and justice – across rich and poor, place and circumstance, gender and generation, and ethnicity and identity. It also means, I argue, enabling poorer and vulnerable women and men to be far more central to choosing amongst and promoting different innovation pathways and to be valued as innovators themselves.

In turn, this raises further questions about *diversity*: 'what – and how many – kinds of innovation do we need to address any particular challenge?' To take direction and distribution seriously means deliberately pursuing a diversity of innovation pathways. This is important to resist the processes of concentration and lock-in that close down directions and crowd out the paths that would bring justice to more marginal groups. Greater diversity also brings other advantages. It enables sensitivity to varied ecological, economic and cultural settings. And it fosters resilience – hedging against our uncertainty and ignorance about the future. However, an argument for diversity does not mean that 'anything goes'. Diversity must be linked to questions of direction and distribution; with a *politics* of technological diversity addressing which options present the best ways to address poverty alleviation, social justice and environmental sustainability.

These three Ds – direction, distribution and diversity – are therefore mutually complementary. Together – and as envisioned in our New Manifesto (STEPS Centre 2010) – pursuing them could help to shape a world where science, technology and innovation work far more effectively for social justice, poverty alleviation and the environment, across diverse contexts, unleashing and supporting the energy, creativity and ingenuity not only of scientists but also of users, workers, consumers, citizens, activists, farmers and small businesses.

2.4 3D Innovation in Practice

There are many worldwide who share this kind of vision, and numerous practical examples are emerging where, in different ways, elements of these 3Ds are being pursued – towards innovations that work for particular, poor people and their environments.

One such example highlights the role of bottom-up innovation in addressing local challenges. Sanitation, previously neglected in much development funding, is now enjoying increased support. In contrast to many top-down sanitation projects, community-led total sanitation (CLTS) is an example of an alternative approach that takes communities themselves as the point of departure (Kar 2003; Mehta and Movik 2011). This originally began in South Asia and involves the facilitation of a participatory process in rural communities whereby residents come to analyze and reflect on their defecation practices and their consequences in terms of hygiene and health. In numerous cases, this has triggered a change in mindset in which villagers embrace the desire to eliminate open defecation completely. Thereafter, they have developed an array of locally appropriate, innovative, social and technological arrangements for sanitation to achieve this goal – for instance, combining low-cost, self-built latrines with peer pressure to ensure that people use them. CLTS has now spread throughout large areas of Asia and Africa, with varying degrees of success. A massive diversity of technological designs has emerged, adapted to local conditions. Widespread sharing of local innovations and experiences, and ongoing research, are paving the way for further improvement geared towards greater sustainability. This emerging second ‘wave’ of CLTS emphasizes greater diversity of CLTS pathways adapted to particular climatic, ecological and cultural settings and greater attention to distribution within as well as between communities (Kar and Pasteur 2005; Movik and Mehta 2009).

A second example highlights the role of innovative marketing arrangements in meeting particular technology distribution challenges Bloom (2009). The social enterprise Scojo designs and produces low-cost eyeglasses for people with age-related vision problems. In the vibrant markets of South Asia, it has established distribution systems or linked with other organizations that have a local distribution network. In Bangladesh, Scojo is working with BRAC, a very large non-governmental organization (NGO) with a major health program, which has trained an extensive network of village health volunteers. To motivate continuing involvement, BRAC also identified a need to ensure that this volunteering helps to maintain a livelihood in a context where there are increasingly other opportunities for the volunteers to earn a living. Thus, Scojo is filling an important need in rural populations for the distribution of low-cost eyeglasses whilst also providing income to BRAC’s health volunteers, effectively linking need and demand through an innovative organizational arrangement.

The example of participatory plant breeding in marginal environments highlights the value of bringing technology users centre stage in shaping innovations Millstone et al. (2009). In contrast with the convention of breeding for optimal environments, the innovative CIMMYT[1]-led African Maize Stress (AMS) project, for instance, developed new methodologies for diverse ‘managed stress’ conditions. The research team employed a participatory varietal-evaluation methodology popularly known as ‘mother and baby’ trials and went on to instigate a second stage of farmer participatory field research. As ‘Farmer First’ approaches have long advocated and illustrated (Scoones and Thompson 2009), starting with the concerns of the most routinely marginalized groups such as women and resource-poor farmers, involving them centrally in designing and implementing the selection and testing of different plant varieties, can enable context-sensitive adaptation and shaping of technologies – paying attention to their social as well as technical dimensions.

Methodologies also have roles to play in contributing to a 3D agenda, in ‘opening up’ processes of technology appraisal to appreciate a wider diversity of possible innovation pathways and their distributional implications (Stirling 2008). For instance, ‘Multicriteria Mapping (MCM)’[2] is an interactive, multi-criteria appraisal method for exploring contrasting perspectives on complex strategic and

[1] Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT).

[2] http://www.multicriteriamapping.org

policy issues. An MCM exercise usually involves a series of one-to-one interviews with stakeholders, using a dedicated software tool and making special efforts to include all relevant perspectives. These involve (a) developing a set of options, or alternative ways to achieve a particular aim; (b) characterizing a range of ‘criteria’, or issues that are seen to be relevant in appraising the options; (c) ‘scoring’ each option under each criterion and (d) assigning a ‘weight’ to each criterion. One end product of these four steps is the calculation of an overall ‘rank’, expressing – for the viewpoint in question – the relative performance of each option under all the criteria taken together. MCM thus helps to ‘open up’ technical assessment by systematically ‘mapping’ the practical implications of alternative options, knowledges, framings and values and allowing non-quantifiable factors to be explored on a par with quantitative measures. MCM exercises can thus provide policymakers with information that attends to issues of distribution and diverse values, as a route to more democratically accountable decisions. The STEPS Centre’s project ‘Environmental change and maize innovation pathways in Kenya’ is providing MCM-based outputs for decision-makers that identify alternative pathways in and out of maize in risk-prone environments. Participatory methods with farmers, with scientists and with decision-makers explore alternative innovation pathways and distributional implications.[3]

Funding allocations also have roles to play. An example of where these have been ‘opened up’ to help foster elements of a 3D agenda is provided by the African Technology Policy Studies (ATPS) Network. This is a network of researchers, policymakers, private sector and civil society representatives that serves to link producers and users of science, technology and innovation policy research from across the African continent. The network has begun to adopt an innovation in its resource allocation process that invites quantitative assessment and qualitative comments on proposals presented at its annual meeting. These inputs from different stakeholders are fed to the ATPS science, technology and innovation committee as it decides on a list of funded projects. Whilst some administrative challenges still remain, this represents a step towards opening up and democratizing the process of research funding around innovation, sustainability and development in Africa.[4]

2.5 Moving Ahead

This is only a small selection of many possible examples. Indeed, taking direction, distribution and diversity seriously both endorses and builds on many shifts and exemplars in thinking and practice around innovation in recent years, recognizing

[3] http://www.steps-centre.org/ourresearch/crops,%20kenya.html; www.multicriteriamapping.org

[4] http://stepscentre-thecrossing.blogspot.com/2009/12/opening-up-research-funding-at-atps.html

and paying greater attention to the significance of things that are already happening and that people are already doing. The crucial question is: how can such efforts be more widely recognized and supported? The STEPS Centre's New Manifesto proposes five broad areas of recommendation, targeted to different dimensions and hence actors in innovation systems, which are intended to catalyse, provoke and support specific concrete actions in different places and which are reproduced below. These address *agenda setting*, *funding*, *capacity building*, *organizational arrangements* and *monitoring*, *evaluation and accountability*.

2.5.1 Funding

The funding of science, technology and innovation – whether from public, private or philanthropic sources – needs to be geared much more strongly to the challenges of poverty alleviation, social justice and environmental sustainability. This requires that the needs and demands of poorer and marginalized women and men as potential users of technologies, as well as the outcomes of innovation, are addressed in funding allocations. Therefore, all science and technology funding agencies should regularly review their portfolios to ensure that a significant and increasing proportion of their investments are directly focused on these challenges. Such agencies should also progressively improve the balance in investments across basic science, technology, engineering, design and science services. Moreover, transparent accounts linked to these criteria should be produced and made available to public scrutiny.

In order to encourage diversity in innovation pathways, funding allocations to support experimentation in niches, and networking and learning across these, involving the private sector, community groups and individual entrepreneurs should be promoted. In order to help democratize the process of innovation, procedures should be established directly to involve end users of science and technology – including poorer and marginalized people – in the allocation of funding. Also, incentives for the private sector to invest in forms of innovation geared to poverty alleviation, environmental sustainability and social justice should be enhanced.

2.5.2 Capacity Building

Capacity building for science, technology and innovation must move beyond a focus on elite science and so-called centres of excellence to support science that works more directly for diverse social and environmental needs. As a vital complement to training scientists and technology experts, this means extending the scope of capacity building to other players in the innovation system, including local entrepreneurs, citizen groups, small businesses and others. A key challenge in improving innovation processes is linking between groups and facilitating inclusion of otherwise excluded people. Therefore, an extension of capacity-building support towards ‘bridging professionals’ who are able to link technical expertise with particular social, ecological and economic contexts should be enhanced. Further, the support of civil society networks and social movements should be encouraged to facilitate the sharing of technologies, practices and wider experiences and learning. Capacity support should further enable such groups to engage with national and international political debates about science, technology and innovation.

This, in turn, will involve investment in new priorities for training, including key reforms to tertiary, further and higher education in the area of science, technology and development. These will require new institutions (or refashioned old ones) that actively link science and technology to located needs and demands, and the building of new learning platforms, virtual and face to face. They will also include greater provision for local community engagement in tertiary, further and higher education as well as wiki spaces for innovation support of a kind that enable more inclusive, networked and distributed forms of innovation.

2.5.3 Organizing

Organizing for innovation requires identifying and supporting social and institutional arrangements that enable technologies to work in particular contexts and to meet the needs of poorer and marginalized women and men. Firms, public and philanthropic organizations developing specific technological innovations should invest in concrete plans to ensure that these social, cultural and institutional aspects of application are addressed. Further, local experiences with these organizational aspects of innovation need to be shared and learned from more widely. This requires an open, distributed and networked approach, with active investment in linkages between public, private and civil society groups. Therefore, future investments – by the public and private sectors – should especially highlight bridging functions, connecting formerly separate organizations and linking upstream and downstream research and development activity. Overall, investment should extend its focus from basic science to emphasizing other aspects of the innovation system, including engineering, design, science services and social entrepreneurship. Further, support needs to be increased for open source innovation platforms, with limits placed on narrowly defined property-based systems which impede competition and constrain innovative activity.

At national level, and led by Strategic Innovation Fora, a broad framework for science and innovation policy should be developed, putting poverty alleviation, social justice and environmental sustainability at its core.

2.5.4 Monitoring, Evaluation and Accountability

Increased accountability and full transparency must be at the centre of democratized innovation systems – across public and private sectors and at local, national and international levels. This requires active engagement by citizens in priority setting, monitoring and evaluating innovation activities. Benchmark criteria, relating to the priorities of poverty alleviation, social justice and environmental sustainability, should be set in all countries and so become the basis of indicators for monitoring innovation systems. At the international level, overseen by the Global Innovation Commission, similar criteria should be established for monitoring and annual reporting. Further, data collection systems and methodologies need to be improved, switching the focus from indicators such as publications, patents and aggregate levels of expenditure to assessments of the wider development outcomes of innovation efforts. All organizations – whether government departments, philanthropic foundations, non-governmental organizations and private sector firms registered in a particular country – investing in research and development above a certain amount should be required to report on expenditures in relation to these criteria. Such data should be freely available and open to public scrutiny. Finally, the Strategic Innovation Fora (or similar bodies) should have a statutory obligation to report publicly both to national parliaments and the Global Innovation Commission on a regular basis concerning innovation direction, distribution and diversity, presenting full data from all research and development organizations.

Only in such ways may the promise of more diverse and equally distributed directions for innovation be fully realized.

2.6 Conclusions

Networks are already building around the 3D vision and agenda. The task ahead is to take the key messages to national governments, international organizations and civil society groups in an effort to affect long-term change at multiple levels.

It is clear that a vigorous new critical global politics of innovation is needed. This will mean moving beyond narrow conceptions of science, technology and development, to embrace innovation more broadly as 'new ways of doing things' that also involve changes in social arrangements and institutions. It also means addressing innovation not as merely a technical matter but as part of a political process, with its directions, distributive implications and required levels of diversity a matter for democratic debate and political argument. It will also mean harnessing the energy, creativity and commitment of marginalized groups, small business and civil society – as well as existing organized innovation systems. No single prescriptive set of actions will be sufficient, or universally appropriate, to achieve this. The potential value of practices and actions like those highlighted in this chapter, and the new networks forged around them, is their capacity to help catalyse and enable this new politics so that people's creativity may genuinely rise to the environment and development challenges ahead.

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Chapter 3
Renewable Energy for Development and Climate Change Mitigation

Osman Benchikh

3.1 Renewable Energy for People's Basic Needs

The world population is growing by almost 216,000 individuals per day – or in 1 year by 79 million (US Census Bureau 2011). By 2050, the global population will increase by about one third to surpass 9 billion. Most of the additional 2.3 billion people will enlarge the population of developing countries, which is expected to rise to 7.9 billion in 2050 (UN DESA 2009). By this time, Africa's population will double with a growth of about 24 million per year while Asia's share of world population may continue to cover around 60% (Population Reference Bureau 2009). Who will provide this new population with energy? How will the urban and rural poor pay even for the minimum energy services they require? What will be done to relieve the inevitable stress on the environment? These are very difficult questions to answer. What is clear is that population growth and rising expectations of living standards represents colossal challenges for the world energy sector.

Energy is seen as an essential component in any economic and social development processes, and the capacity to meet the basic energy needs of all citizens should be a key objective. Besides, it constitutes a prerequisite to reaching the Millennium Development Goals (MDGs); energy being one of the major multipliers of these goals and few, if any of them, can be achieved without it. In most of the developing countries, public electric utility grids and improved infrastructure for energy supply exist mainly in urban and peri-urban areas. This could be explained by the fact that the cost for extension of energy supply infrastructure (public grid, fuel supply, etc.) is justified economically, only if the energy flows is high enough. This is not the case for the vast majority of rural areas. Four out of five people lacking access to electricity live in rural areas in developing countries.

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Access to electricity constitutes nowadays a real social inequality in needs for correction. At present, approximately 1.4 billion people representing over 20% of the global population in the world lack access to electricity services, and some 85% of them leave in rural areas of developing countries (IEA 2010). In sub-Saharan Africa, they represent approximately 72% of the population, and this figure rises up to 88% for the rural areas (IEA 2010). In this region, households may spend as much as 30% of their disposable income on fuel-based lighting, and women devote at least a quarter of total household labor to wood collection, while those consumers receive poor services in return (G8 Energy Ministers Meeting 2009).

3.2 Energy and Human Development

The quest for long-term sustainable energy supplies and the imperative for environmentally responsible energy use are the two main interrelated aspects of the vital energy component that underpins today's global agenda. Energy considerations are of paramount importance to key global concerns such as climate change, sustainable development, poverty reduction, and economic growth. In this regard, climate change has, over the last decades, evolved into an issue of global concern. Human understanding of the relation between emission levels, concentrations of greenhouse gases in the atmosphere, and changes to the global climatic system is improving, and there is increasing consensus in both the scientific and political communities that significant reductions in emissions are necessary in order to limit climate changes to manageable levels. Modern energy is seen as one of the major multipliers of the eight goals of the United Nations Millennium Declaration (UN General Assembly [55/2] 2000), as few, if any of them, can be achieved without it. At the local and household levels, energy services provide the basis for cooking, lighting, water pumping, refrigeration, transport, and communication (Fig. 3.1).

Assessment of energy-sustainable development nexus could be made through the analysis of the impact of energy on the human development index (HDI) set to define the level of sustainable development.[1] The wide set of indicators which describe the different aspects of human development for each country will allow the qualitative analysis on the energy contribution to meet the MDGs. The following indicators for energy and human development will be considered:

[1] The HDI measures the average achievements in a country in three basic dimensions of human development:

- A long and healthy life, as measured by life expectancy at birth.
- Knowledge, as measured by the adult literacy rate (with two-thirds weight) and the combined primary, secondary, and tertiary gross enrolment ratio (with one-third weight).
- A decent standard of living, as measured by the gross domestic product (GDP) per capita in purchasing power parity (PPP) in terms of US dollars.

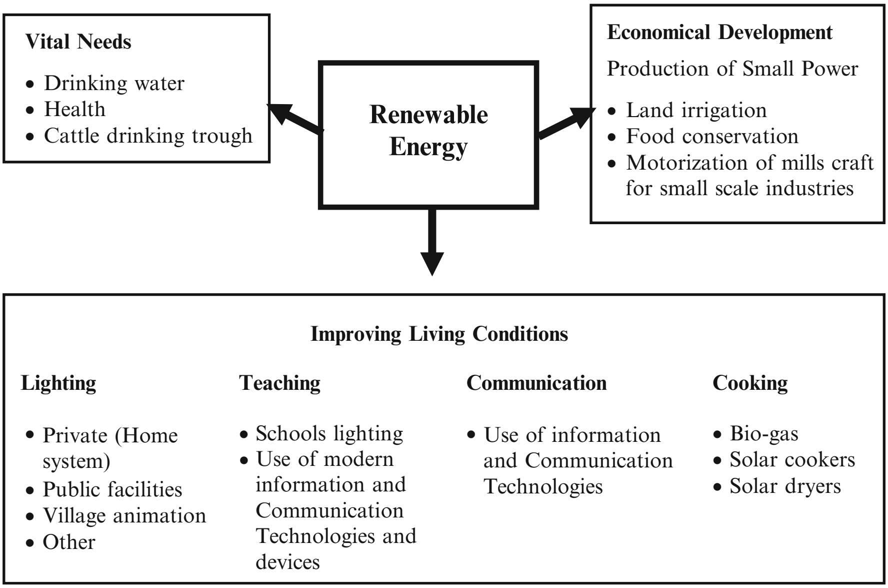

Fig. 3.1 Application of renewable energies

Energy indicators

- Energy per capita consumption (tep/inhab)
- Electricity per capita consumption (MWh/inhab)
- Access to electrical services (%)
- Rural population rate

Indicators selected for human development

- Human development index (HDI)
- Life expectancy at birth (years)
- Adult literacy rate (%)
- GDP per capita (US$/inhab)
- Total fertility rate (per woman)

Evaluation of *energy* influence on the HDI (Benchikh and Courvello 2004) shows the direct dependence of energy on the HDI, which highlights the strong correlation between energy and *development*. The life expectancy has an evident correlation with the energy indicators and the rural population. For countries having better indicators, the influence is not so strong. It could mean that when there is a certain level of access to energy services, some other factors start influencing the life expectancy. The *electricity* consumption as well as the access to electricity services also has a strong emphasis on the literacy rate, which depends on the life conditions, gender component, and social development. While progress will occur and the number of people with access to modern energy services will increase, population growth will erase most of these gains, meaning that it is unlikely that the goals of the Millennium Declaration can be met by 2015, if no appropriate measures are taken.

Influence of some selected energy indicators on HDI components highlights the strong impact of energy on sustainable development. More specifically, the role of the access to electricity services and the electricity consumption per capita constitutes the key factors that have a stronger positive influence on the sustainable development and the achievement of the MDGs.

Drawing conclusions from experience and in order to better address the energy paradigm, the following observations can be made:

1. The energy development currently applied to evaluate the goals, ways to meet these goals, and performance indicators appeared in fact two centuries ago with the industrial revolution.
2. The main target was the development of energy sources and technologies to replace the renewable energy technologies used until that time due to their very low energy power. This energy technology process has seen the following phases: at the beginning, there was steam engine using coal for fuel, then electricity; internal combustion engines fueled with gas, gas oil, diesel oil, and at the end of this path were developed nuclear power plants.
3. The energy development that allowed a rapid economic development and has structured our way of living is, however, at the origin of important global changes that deeply affect our natural environment.

The process of moving from the concept of energy development focusing on economic growth to a new one, centered on global sustainable development including environment protection, will be made possible only if the current energy development paradigm is changed. This process could be conducted only if the following criteria are met:

1. A full understanding to the need to address energy issues as a key instrument for sustainable development and climate change mitigation
2. A global approach towards the conservation of the human natural capital
3. A decision-making process guided by a global approach and driven by concerns about a whole range of intertwined issues taking into consideration evolving global priorities such as climate change, poverty, and sustainable development
4. A wide awareness about the need to better address the challenge of making those structural changes – economic, social, technological, and environmental – required by the transition to a new era of multiple energy resources

3.3 Role of Education and Training

The use of renewable energy sources implies a general knowledge of the various technologies and their adaptation to different contexts and fields of applications. It should also include an outstanding knowledge on various aspects of the energy sectors, covering both energy demand/supply and economic aspects in general. The development of sustainable energy will only be possible if the efforts to meet the education of technicians and information needs of end users are successfully completed. The task of providing the relevant education and training activities goes to those institutions capable of delivering this type of specific knowledge. In general, efforts to meet educational and training needs must target the following different but complementary areas:

- Advanced theoretical and practical training for researchers, planners, and designers
- Practical training and some elementary theoretical knowledge targeting technicians
- General knowledge adapted to decision makers needs
- Specific training covering general and practical knowledge addressing trainers, operatives in the field, entrepreneurs, and end users.

The various renewable energy technologies are a considerable opportunity for new jobs. Hundreds of thousands of jobs have already been created in few years. The locations and nature of these jobs, as well as their number, are in a progressive evolution. It is, therefore, a sector to which appropriate training policy seems to be an absolute necessity.

Renewable energy requires diversified components for the construction of systems. These components should be improved by intensive research and development activities and by more efficient industrial production. However, it is not the fundamental research that presents the principal barrier to their development but the lack of trained personnel to design, install, and maintain the complete systems.

All these workers need training sessions based upon their original educational background. For instance, engineers, designers, and architects would have sufficient basic technical knowledge but need a radical change in their usual behavior to address renewable energies. They are used to working with conventional systems, which can be used anywhere, and for any environment. However, the renewable energy technologies are influenced by the sites as well as the interaction with consumers. They do not offer universal solutions (except for some applications, such as calculators), and this is one of the principal barriers to their widespread use. In general, they require more work than conventional systems for their design, adaptation, and commissioning. This implies the creation of more jobs in order to get durable and efficient systems.

In conclusion, addressing the challenge of a new global sustainable energy system involves an increased use of alternative and renewable energy sources and requires the availability of local competencies as well as endogenous scientific capacity as a foundation for increased knowledge of the various related technologies and their adaptation to different contexts and needs. This will call for the development of energy strategies and policies, disseminating relevant scientific knowledge and technology and ensuring local capacities and competencies for the use and better management of locally available energy resources. These are objectives of UNESCO's Global Renewable Energy Education and Training (GREET) Programme.

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Part III
Urban Planning and Cities: The Conditions for an Effective Ownership of Technologies in Urban Areas

Abigaïl-Laure Kern and Jean-Claude Bolay

Urban development in developing countries has become a major challenge for the international community as witnessed by the United Nations Millennium Development Goal 7, Target 11 (adopted by the UN General Assembly in 2000), which aims at significantly improving the life of at least 100 million slum dwellers by 2020.

Since 2007, for the first time in history, more than half of the planet's population, over three billion people, lives in urban areas. This increase relates primarily to developing countries. According to the United Nations (UN), in 2030, 81% of the world's urban population will live in these countries, with 70% in Africa and Asia.

Given both its structural nature and its contribution to the country's economic, social, and cultural development, it is now widely agreed that the global urbanization process should be supported rather than fought.

At the same time, the absolute growth rate of urban population in many developing countries is also reaching record highs (5% on average per year). Over the next few years, urbanization will result more from the natural growth of urban populations than from migration or the movement of small rural communities to the urban centers, as well as their absorption when located on the outskirts of expanding cities.

The pace of such urbanization raises the question of the sustainability of these cities, as much as the impact technology will have on their social, economic, and environmental dimensions. *Consequently, what role could technology possibly assume in the face of the new challenges that must be met by the cities of the South, and how far can technology effectively contribute to the sustainable development of said cities?*

Technological innovation characterizes our society today. In the wake of significant technological advances in developing countries, the proportion of people

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living in poverty fell from 29% in 1990 to 18% in 2004. Yet the city plays a major role in the dissemination of these technologies. Technological innovation is both a cause and a consequence of urban development, playing a leading role in the structuring of cities but also embodying the response to new emerging needs.

The UNESCO Chair in Technologies for Development has thus defined science and technologies for towns and sustainable housing as one of its four priority fields.

One of the main transversal issues guiding studies conducted within this field focuses on the relationship built by individuals to urban technologies according to sectors, needs, and access, a relationship which does, or not, allow ownership for and by everyone. The analysis of the social, economic, and environmental impact of these technologies and what they imply in the long term and at various levels – the slum, the city, and even the agglomerations – must therefore constantly underpin thought reflections.

The actions of the Chair are therefore guided by the issues relating to local knowledge in the identification and development of technologies, the interaction between technologies and social and organizational structures, as well as reflections on the appropriation and distribution of these technologies throughout the urban area. Furthermore, within the context of new emerging technologies (micro-generation, photovoltaic energy, etc.) stretching beyond the need for major infrastructures, the Chair's activities seek to explore and foster different experiences in the use of these technologies and their potential to improve current urban living conditions in order to contribute to reducing mass poverty.

The three following chapters have been selected to illustrate two of the main conditions required to achieve these objectives. Interdisciplinarity thus seems to be a fundamental prerequisite to enable technological research to improve the living conditions of city dwellers in the South in a sustainable manner.

The importance of social sciences in particular can be highlighted in attempting to better understand and improve the public transport planning process in Latin America, as demonstrated by the authors Witter and Hernández in their chapter.

Equally, this interdisciplinarity enables Lonardoni to describe and explain the changes in land and real-estate dynamics in the Brazilian *Favelas* where the increase in rental housing radically alters the lives of the inhabitants of these slums. Beyond this interdisciplinarity, this chapter depicts another conditionality for the ownership of technologies by everyone in urban setting: the need to contextualize this research by, for example, taking federal or state policies into consideration.

A condition also identified by Lieberherr-Gardiol, who demonstrates that besides the national level, this contextualization must also focus on the local level. In short, it would seem that working directly with the communities and local authorities can guarantee a real process of transfer and acquisition of technologies for the populations.

Chapter 4
Santiago de Chile and the Transantiago: Social Impact

Regina Witter and Diego Hernández

4.1 Introduction

The purpose of this chapter is to identify the requirements of public transport modernization and resulting impacts on people's daily life and social inequalities, with specific regard to the case of Santiago de Chile. The public transport policy developed from a period of deregulation in the 1980s to reregulation since the late 1990s, which seems to have had significant impact on users' travel habits and competences. During the period of deregulation, the service was characterized by an uncoordinated, oversupply of private buses, complementary to the efficient but rather small public metro network. In order to eliminate the stigmatization attached to public transport as the "mode of the poor," the period of reregulation finally culminated in the establishment of the "sophisticated Transantiago" system in February 2007. The Transantiago project envisaged total modernization of the transport industry by reorganizing the bus network under private operation, renewing the fleet and bus infrastructure, establishing advanced public regulation and monitoring tools, and introducing a tariff union with the metro and new electronic tickets. However, the design and implementation process of this ambitious project failed, and in its first 2 years of existence, the Transantiago was increasingly rejected by parts of the population.

This chapter consists of four basic parts. The first part presents the concept of *motility*, within the theoretical framework, and provides an appropriate explanatory approach to the Transantiago rejection. Moreover, methodological implications for

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public transport planning and public responsibility for the provision of adequate transport services are highlighted. The second part of this chapter presents the basic data for Santiago de Chile and, more specifically, the Transantiago project. In this context, a brief overview of the technical and planning failures of the Transantiago is provided. The third part focuses on the results of our own empirical works and is made up of two segments. The first one consists of a case study on block level, including spatial analysis supported by a Geographical Information System (GIS) and a short survey of 50 residents. The second one considers individual attributes backed up by 40 in-depth qualitative interviews in five different boroughs. The last part provides some final remarks, highlighting the lessons learned concerning transport planning and related social drawbacks.

4.2 Motility as Public Planning Interest

To understand the cause of user-related problems stemming from adoption of the new public transport system in Santiago de Chile, the term motility defined by Kaufmann (2008) forms a convenient theoretical construct. Motility can be understood as the conglomerate of conditions and possibilities of an individual to be mobile, that is, to move within space or society (Kaufmann 2008). The following three dimensions can be identified: (1) spatial and temporal accessibility, (2) competences, and (3) individual appropriation. All three dimensions run the risk of differing among the populations and, thus, of contributing to social inequalities and problems.

Firstly, there is the question of *spatial and temporal accessibility*, particularly in relation to availability and affordability of transport infrastructure and services as well as related land prices and values (Preston and Rajé 2007). A lot of research has been carried out in the context of spatial assignments on the deprived periphery of urban agglomerations, pointing out that the fact many inhabitants would prefer to live elsewhere, that is, in more easily accessible areas (González et al. 2006; Pancs and Vriend 2007). The term "social exclusion" is often used in this context to describe coexistence of a set of social problems associated with fragmentation of traditional social structures, decline in participation in normal processes of society, as well as increasing deprivation among particular social groups.

In addition, there is the second dimension of motility, which refers to the traveler's need of *specific competences* in order to be able to program the trip, and as the case may be, to improvise within the given framework of spatial and temporal activities. Being inventive and knowing the *rules of the game* is part of the human and social capital that has become more and more important in order to be mobile and to travel within space (De Certeau 1990; Hofmeister 2005). Certain mobility practices are required, including the use of maps, planning and tracking of routes, as well as gaining access to information based more and more on advanced technology (automatic phone hotlines, Internet platforms, etc.). These practices both require and develop specific competences in favor of programming and improvising one's own activities in space and time. If these competences are not available, the ensuing inappropriate travel choices may incur stress or additional financial burdens. On the other hand, better travel competences may form a tool for deprived households to compensate for limited access to communication and affordable transport systems with better organization. Placing emphasis on emerging economies, several researchers have identified remarkable potentials of *creativity*, especially among deprived households, which helps to overcome mobility bottlenecks via some collective practices, such as the private organization of carpooling or the setting up of a family-owned taxi business (Pedrazzini 2007).

Finally, the third aspect of mobility deals with individual *interpretation and appropriation* of travel outcomes. Understanding transport as a derived demand, trip-making means carrying out a personal project and requires physical movement (Kaufmann et al. 2001). Several surveys in deprived areas have identified the difficulties that certain people have in *pushing themselves* to leave their residential area in order to carry out nonobliged activities, for example, of a social and recreational nature (Le Breton 2005). Even if a good public transport system bears high potential to enhance people's integration into societal life, it is not the sole condition. Adoption of a new transport system requires reorganization of people's daily activity patterns and travel habits. These habits are strongly influenced by previous travel experiences, such as individual preferences, values, and attitudes, which together are often described as people's lifestyles (Ohnmacht et al. 2009).

It is rather obvious that *motility potential* varies among the population, with it being more and or less prevalent within some groups (Geurs and Van Wee 2004; Geurs et al. 2009). Groups that are more likely to have problems are, for instance, lower-educated, older, or handicapped people, as well as lower-income households living in less accessible areas on the urban periphery or in rural areas. In addition, in more traditional societies, some women may experience motility problems since they often do not have access to a private car, are less integrated into the formal labor market, and have less access to stable income opportunities. In general, lack of a private car or ability to drive forms a crucial criterion for possible mobility problems. The so-called captive riders without any alternative to public transport have a strong need for efficient and reliable, but affordable transportation services in order to reach daily activity locations (Fotel 2006).

Thus, unequal mobility conditions may affect or exacerbate *social inequalities*, if participation in societal life is impaired (Grieco 2006). The issue of social exclusion risks incurred by transport has attracted increasing interest in the past few years (for further details, see Rajé 2003; Dobbs 2005; Le Breton 2005; Stanley and Lucas 2008). An outstanding example is the Social Exclusion Unit (SEU) in Great Britain, which has developed analysis tools in order to identify and combat social exclusion, requiring some kind of "social impact assessment" to be incorporated in all types of urban development plans at local level. In this context, the SEU also compiled comprehensive spatially referenced datasets, which cover, for all municipalities, the locations of relevant destination categories (related to education, health care, employment opportunities, supermarkets, and convenience stores). As a result, this system has identified a number of concrete indicators combining socioeconomic characteristics, travel impedances, and normative mobility thresholds. Thus, a concrete example is the percentage of young people (aged between 16 and 19) as a target group, living 30 and 60 min from a further education college by the different travel modes (Department for Transport [DfT] 2009; SEU 2002).

In any case, the British authorities are one step ahead, and the social exclusion topic often remains an issue of academic research. The public authorities normally base their work on rather conventional planning approaches, which concentrate on general spatial and temporal accessibility of locations and include only basic socioeconomic criteria related to car ownership, age, and gender. Individual criteria related to the second and third aspects of people's motility, that is, their competences, skills, and cultural preferences are neglected. One of the central reasons is probably related to the difficulties of measuring these criteria at the macro-level, for instance, related to the whole city and not only to one single settlement. This results in in-depth anthropological studies, based on qualitative methods at settlement level, with high potential to detect possible problems, but quantifiable information at city level cannot be provided as important planning input for the authorities (see Hernández and Witter 2010). Moreover, the classical demand estimation models used in public planning rely on data from the national census, Origin–destination surveys, and traffic counts that are often not up-to-date. Lack of financial resources, especially in developing cities, might affect the use of outdated planning information, despite a very dynamic urban and demographic structure. Methodological drawbacks and imprecise, outdated, too general information are a serious issue within the framework of transport planning and modernization. Especially the failures of the Transantiago can be partly attributed to these problems.

Given these problems, we suggest that even with restricted resources, the combination of classical, spatial data with in-depth, detailed socioeconomic information, according to the SEU approach, is feasible. Technical progress related to user-friendly GIS greatly facilitates this work. The problem of outdated information calls for the compiling of specific "motility-indicator" datasets at local level, where all planning stakeholders have free access to and may upload and exchange recent information.[1] Establishment of "transparent governance practices," including civil participation, could also help to foster the population's acceptance of major transport projects (Schulz 2006) or, at least, to put this issue on the "social agenda." Furthermore, the integration of results of micro-level, qualitative studies can provide important hints on individual travel habits, preferences, and possible difficulties, which might require review in a wider spatial scope. It is essential to assess social impacts and to prepare the affected population ex ante, that is, before the planning, design, and implementation process of significant transportation changes. Otherwise, the projects may face eminent opposition from the users. Moreover, their lack of acceptance or *appropriation* not only forms an obstacle

[1] For further information on this idea, see Hernández and Witter (2010).

for the frictionless project but may also give birth to serious social conflicts, with strong negative externalities for society as a whole.

This chapter presents some features of this micro-level approach. We argue that the findings indicate *complexity of the mobility phenomenon* and the need to integrate alternative planning approaches. Thus, the findings might provide a hint as to future steps to be taken for transport planning and research.

4.3 Santiago de Chile and the Transantiago Project

The metropolitan area of Santiago de Chile comprises 37 boroughs or municipalities with approximately 5.5 million inhabitants (2002 census), spread over a surface of 76,000 ha. Morphologically, the city is characterized by a rather monocentric-radial structure with the traditional central business district (CBD) in the central (homonymous) municipality of Santiago-Centro and radial transport axes, connected by a privately run ring road highway. In addition, in the last decade, a second economical center emerged in the affluent *cone of wealth* in the eastern part of the city, which has gained increasing economic dominance over the traditional CBD. This area also concentrates the better-off households, while the residences of deprived households are mainly located on the western and southern periphery. Thus, social inequalities are also revealed over space, expressed in strongly manifested residential segregation patterns (Figueroa 2004).

4.4 The Transantiago Project

The idea to modernize and improve the public transport system in the capital of Chile was born almost a decade ago. Bus-based transport in Santiago had gone through a period of deregulation in the 1980s – according to the liberalization politics under Pinochet, resulting in its oversupply by a huge range of private micro-entrepreneurs who competed on 380 lines with over 8,000 buses (Muñoz et al. 2008). Despite incurring a wide range of environmental and safety problems due to deficient public regulation and control, this service was especially convenient for the deprived households located on the urban fringe and who did not benefit from direct access to the publicly owned metro system. Accordingly, the choice of motorized trip modes was strongly correlated to household incomes, with the affluent households mainly using private vehicles, the middle-income households mainly the metro, and the lower-income households predominantly the deficient bus system (SECTRA 2002; Jirón 2007). Socioeconomic status and mode choices were important determinants for people's daily activity locations and resulting trip rates (lower in motorized modes for the lower-income people), as well as daily travel time budgets (about double for the lower-income than the high-income people). Accordingly, residential segregation and spatial fragmentation were at the same time the cause and consequence of inequalities in accessibility conditions (Figueroa 2004).

In answer to the transport deficiencies, the idea of the subsequent Transantiago system was based on renewal of the bus services as the backbone of the sophisticated, public metro, which was efficient but underused. New licenses for a few regular operator companies and development of a dedicated bus infrastructure (proper bus lanes) were thus required. The new system called for total redesign of the network in the form of a trunk and feeder system, acquisition of new, high-capacity articulated buses, establishment of a tariff union between the bus and the metro, introduction of a contactless ticketing system, service monitoring, and a comprehensive user information system supported by Global Positioning System (GPS) and Internet-based technology. The single central objective of this ambitious project was to provide high-quality, cost-effective services, without requiring public subsidies in the long run.

After having been postponed several times, the Transantiago system was fully launched on February 10, 2007 (Muñoz et al. 2008). Due to the abrupt start and the chaos the new system immediately provoked, the event came to be known later on as the Big Bang. Today, more than 2 years down the road, a set of studies was published to try to understand all the errors that had been committed by the public authorities, private consultants, and operators.[2] To sum up, firstly, there was a series of technical failures incurred by the shortcomings of the GPS-based control and information system and the sophisticated electronic ticketing system. The latter was generally welcome, but teething problems adversely affected the level of confidence, and its use appeared to be particularly difficult for older people. Secondly, certain planning errors were committed, due to the use of outdated information and underestimation of the demand (interview with Jara-Díaz 2009). Thirdly, the strong lack of financial commitment resulted in deficiencies in the vehicle fleet and in inadequate infrastructure (bus lanes, stops enabling speedy boarding, etc.). Consequently, severe bottlenecks occurred, especially during rush hour. Finally, a weak regulation and coordination process between the different public and private stakeholders was observed, as well as the lack of civic participation and ongoing ignorance of user concerns (Ureta 2009). The latter aspect is directly related to our own research hypothesis presented above, concerning people's difficulties of appropriation and acceptance.

Aware of impacts of the Transantiago on political satisfaction, the government put all its efforts and resources into improving the system. By February 2009, the vehicle fleet had been extended by 42%, the amount of lines by 46%, and daily service kilometers offered had been increased by as much as 58%. Additionally, the number of segregated bus lanes was tripled, and many bus stops, often with off-board payment systems, were added. Thanks to these improvements, average waiting times have been reduced by half, and average travel times are today only slightly higher than before the Big Bang (Gschwender 2009; Albarrán 2009).

[2] The texts by Muñoz et al. (2008) and Quijada et al. (2007) are recommended for further details.

On the whole, the system does not perform perfectly but in an acceptable manner, and people seem to have got used to it. Nonetheless, one problem remains related to target profitability of the system. With current ticket prices that are slightly more expensive than the previous bus tickets (which did not enable transfers between different buses and to the metro), the financial deficit is immense, and recent permanent public subsidies have been introduced for the system (Muñoz et al. 2008).

4.5 The Transantiago and Social Impacts: Empirical Evidence

This part focuses on the social dimensions of transport, including impacts on people's welfare and individual perceptions and preferences. As mentioned above, we suggest that endorsement of conventional planning results from in-depth analysis on micro-level, focusing on deprived groups. Thus, the results of micro-level investigations of one deprived, peripheral area of Santiago de Chile (borough of San Bernardo; Fig. 4.1) are first of all presented. In this context, the results of a *spatial analysis* supported by a GIS are combined with the findings of a *mini-survey* of 450 inhabitants dealing with people's travel patterns and transport

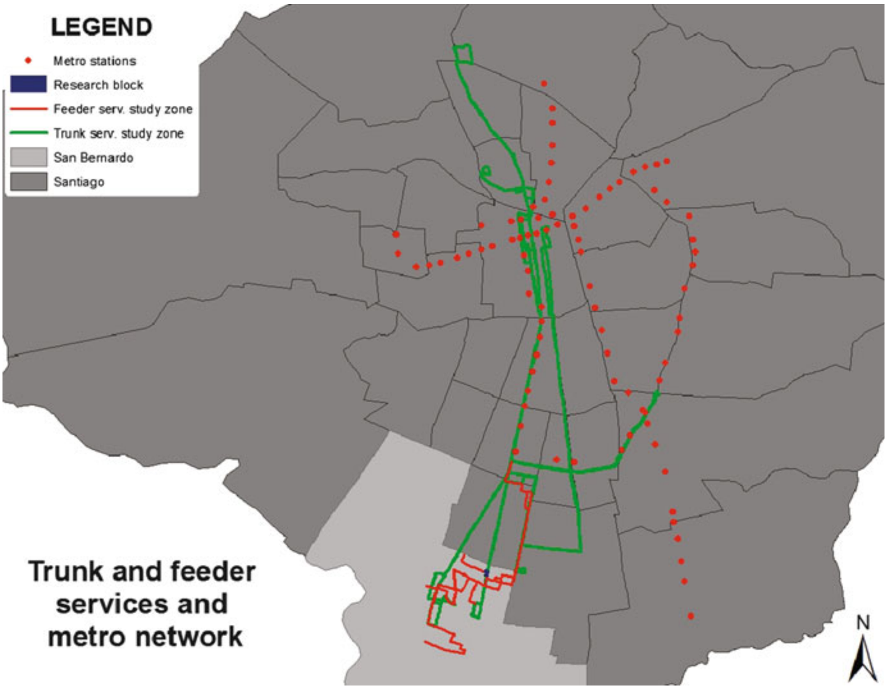

Fig. 4.1 Area in San Bernardo for spatial access analysis and mini-survey at block level (Source: Hernández 2009)

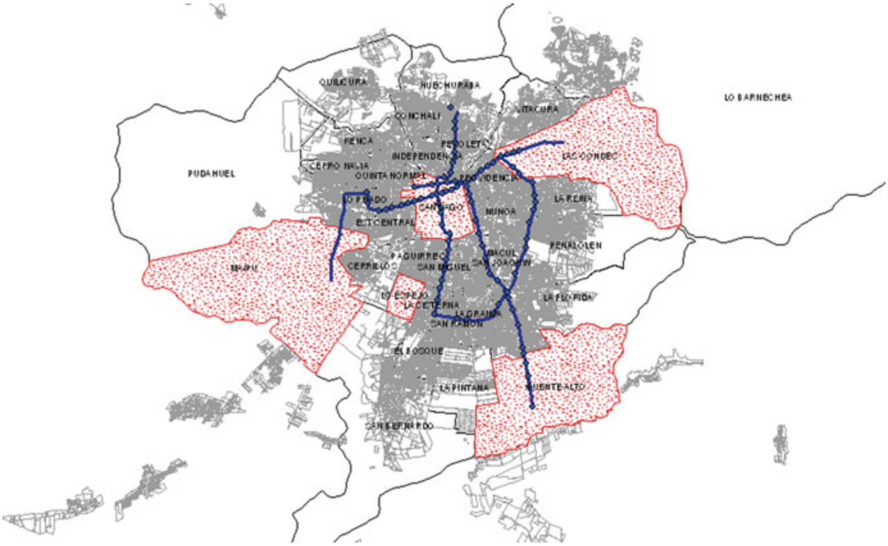

Fig. 4.2 Five areas for qualitative in-depth interviews with the residents (Source: Witter 2009)

affordability. Secondly, the results of 40 *qualitative in-depth interviews* with the residents of five boroughs in the metropolitan area of Santiago are summarized (Fig. 4.2) and discussed focusing on the term motility. Since these five boroughs differ a lot concerning access conditions, socioeconomic structure, and predominant mode use, the results provide at least a hint on general mobility inequality between the wealthy and deprived inhabitants in the metropolitan area.

4.5.1 Spatial Analysis and Mini-survey in the Borough of San Bernardo

To start with the analysis, it has to be considered that only 4% of the population in San Bernardo owns a car. The residents are therefore captive riders of public transport options. Thus, it is indispensable to analyze public transport networks with a regard to social compatibility.

At the beginning of the Transantiago service, there was only one new trunk line, which was located at an acceptable distance for the residents of the block studied. This line, number 301, connects the borough of San Bernardo with the borough of *Independencia*, passing through downtown Santiago. An advantage of this route is that it connects with *La Cisterna Multimodal Station*, which offers good connectivity to various parts of the city and provides for transfer to the metro network (line 2). Nevertheless, it is rather obvious that the population experiences larger mobility deficits due to the lack of direct services to many districts of the city.

Thus, they need to travel between 30 and 40 min for the first section of their trip, before transferring to their final destination. Moreover, even though line 301 has a good frequency both during and outside rush hour, it does not offer night services. In addition, three feeder services cover the block studied rather well. Two of these routes connect with various parts of the borough and also with the intermodal station *La Cisterna*, while the third one follows an internal itinerary through the whole borough of San Bernardo. In the same way as for route 301, two out of the three feeder lines did not run night services and displayed very irregular frequencies, which was a serious problem according to the residents.

Regarding individual attributes of the residents questioned in the brief survey, their daily destinations are of interest, particularly related to job opportunities. From the inhabitants' perspective, there are two relevant locations: the center of Santiago (63%) and the wealthy eastern district (63%). It can be stated that almost all the people interviewed identified the central-eastern corridor *Santiago*, *Providencia*, *Las Condes* as the most attractive in terms of labor. Nevertheless, 21% of respondents also mentioned the borough of San Bernardo as a suitable place to find a job. These results are on the one hand good news when they are compared to the actual public transport supply: the main line 301 seems to carry people where they need to go, at least for work purposes. On the other hand, other communes mentioned by the rest of the inhabitants are inaccessible by public transport. This is, among others, the case for the borough of San Bernardo itself, in which the offer of transit services (feeders) is relatively restricted, both in terms of quantity of lines/routes and frequency of services.

The mini-survey also showed that the residents allocate 9% of their income to transportation on average. It is remarkable that a quarter of the households spend at least 15% of their total income on transport purposes. Accordingly, these families probably spend a much higher percentage on transport than families with higher incomes. In addition, even if they assigned the same proportion, "competing goods" within the household budgets are different. Whereas in the area studied transport "competes" for resources from households with very basic needs (for instance, food), in better-off households, the items with which it competes are probably less urgent (for instance, electronic equipment). As described above, an important indicator of individual accessibility is whether they have stopped doing activities due to mobility problems. Two out of three interviewees confirmed that they had not done certain activities due to mobility issues. More than half of these activities are related to leisure, recreation, and participation in family networks. "Failed" trips for employment are very limited, indicating that, in those cases, people chose to pay for alternative travel (either in time or with personal belongings). It is interesting to consider the reasons behind these failed trips, given the fact that it is not absolutely certain that, had the conditions been more favorable, the trip would have been undertaken. Virtually all the reasons mentioned in the survey had to do with the deficient bus service, that is, its rather low quality of service and the need to carry out transfers. At the same time, 10% mentioned quality aspects, for instance, related to personal discomfort due to capacity problems or difficulties to travel with children.

Finally, asking people to compare the present system with the former one ("yellow buses"), almost three quarters of respondents evaluated the Transantiago as bad as or much worse than the "yellow buses" system. Almost half of the answers evaluated the Transantiago as "much worse." This confirms the idea that the Transantiago project has been a serious failure of public policy, misled by the objective of modernization and economic progress.

4.5.2 In-depth Interviews with Residents in Five Different Boroughs

The second part of qualitative works was based on the idea of comparing individual perception and evaluation of the system in different areas of the metropolitan area. Therefore, the five boroughs studied represent very different conditions of accessibility: three of them have direct metro access, two do not; one borough is centrally located, two boroughs are located in the second concentric ring, and two on the periphery. Moreover, the socioeconomic structure of the case study areas differs: one is a high-income area with predominant mode use, two are rather middle-income areas, and two boroughs are lower-income areas with a high share of captive ridership. Qualitative in-depth interviews, held 1 and 2 years after the Transantiago started up, made it possible to understand different individual learning and appropriation processes as regards the new public transport system.

Thus, at first glance, people's evaluation 1 year after the Big Bang showed a very *low satisfaction level* for all kinds of population groups. Criticism was commonly related to long travel times, low frequencies, overcrowded vehicles, deficient information, and difficult orientation, as well as the need for mode shifts requiring longer walks and greater discomfort. An important change seemed also to consist of people's travel habits in the vehicles. Many people criticized not being able to sleep anymore and relax during the trip, which before used to be longer but more comfortable and without any mode shifts (changing vehicles). In almost all cases, the previous system was evaluated as better, except for a normally positive attitude toward the new drivers, as well as toward the new tariff union. Acceptance of the electronic ticketing system varied, showing younger people as being more in favor than older ones. Furthermore, changes in daily travel patterns could be determined, especially for lower- and middle-income groups. In the lower-income areas, people stated that they use public transport for going to work during the week, but since the arrival of the Transantiago, they preferred to stay at home on the weekends (instead of carrying out recreational activities or social visits). In the middle-income areas, people mainly used to go to work by public transport, but due to problems with the Transantiago, they said that they now prefer to go by car. Use of the metro by the lower- and middle-income groups prevailed if the metro was readily available in their residential area. Otherwise, people consistently preferred to go by bus – preferably only one – often despite longer travel times. The main criticisms against the metro were lack of comfort and a general aversion, due to the lack of daylight, and the need to use escalators. In both the lower- and middle-income areas, the use of collective taxis and taxis had also increased due to a more reliable service and despite higher costs. Nevertheless, in the higher-income areas, people explained that they continue to use their cars for all kinds of purposes. As they did not have any firsthand experience, they evaluated the new transit system as even worse than the previous one. Especially, the metro was said to have "decayed" in quality since the arrival of the Transantiago. Their arguments against public transport were related to the lack of comfort, cleanliness, orientation, safety, and security.

On the contrary, in the *second round of interviews* (2 years after the Big Bang), the majority of interviewees suddenly expressed their satisfaction with the system. According to the significantly improved supply, most people in all the boroughs weighed up the different advantages and disadvantages of the new system and were now used to the need for trip organization based on formal information sources, carrying out mode shifts, queuing at the bus stop, and so forth. Improvements in safety and security, the convenience of the electronic ticket card, better access to and more frequent use of the metro, shorter travel times in areas with segregated bus lanes, and increased comfort at the stops were recognized. On the other hand, the remaining problems were identified as longer walking distances to the bus stops, lack of comfort due to mode shifts, irregular waiting times and frequencies, and capacity bottlenecks during rush hour, particularly in the metro.[3] Nonetheless, three groups continued to reject the Transantiago, preferring the previous deregulated system. Firstly, there were the inhabitants of the high-income areas. Despite rarely using public transport, they continued to describe the Transantiago system as dangerous, due to accidents and robberies, as well as being unreliable and very slow. Secondly, some women living in very deprived areas (mostly with low education levels and informal jobs) still feel challenged by the long walking distances to the next bus stop, long waiting times at the bus stop, lack of comfort due to transfers, as well as deficient information and orientation. They also stated that passenger mutual respect had decreased since the arrival of the Transantiago. It is important to take into account the fact that they declared that they travel less, especially for nonobliged trips, and particularly prefer to stay at home on weekends. The same was also stated by the third group, constituted by the elderly and mobility-restricted people in the peripheral boroughs.

With regard to this heterogeneous change in individual perception of the transport system, we can state that not everybody appreciates the technical progress and desired *modernization* of the transportation system in the same way.

By first of all considering the *accessibility* conditions, it is obvious that vulnerability to systematic changes significantly varies with the public transport need. The riders without any real alternative to public transport are more exposed to the

[3] This phenomenon was also confirmed by our own empirical works related to the measurement of bus frequencies and levels in several focus boroughs as well as by the experts interviewed (Gschwender 2009; Jara-Díaz 2009).

serious social impacts of transportation changes than occasional riders. Thus, impacts of the Transantiago were more prevalent in the peripheral areas where the metro is not available and where most of the deprived households live. Especially at the beginning of the Transantiago, the peripheral areas were more adversely affected by network gaps and lack of service control. Another problem refers to increased travel and waiting times. The researcher Jara-Díaz (2009) points out that the public budget restrictions have led to the preference of bigger vehicles with lower frequencies instead of smaller vehicles running with high frequencies. Even if lower-income groups may have more flexible travel time budgets, overall longer travel times require the reorganization of people's daily activity patterns and may indeed incur the risk of suppression of nonobliged activities, such as social visits. Furthermore, *economical accessibility*, that is, affordability of ticket prices, is also concerned. Thus, the only people who did not recognize the economic advantages of the tariff union were low-income people, who before used to go by one single bus, paying a lower fare than today. In addition, their residential location on the periphery may sometimes require more frequent use of (collective) taxis and informal "pirate" transport, which are far more expensive. Finally, in the motility concept, the term access also refers to the *availability of information*. As the previous system was based on informal information sources, such as mouth-to-mouth information, the new sophisticated information system of the Transantiago is officially based on network maps, a service hotline, and Internet. It can be assumed that official information channels constitute a significant barrier and a challenge for some users.

The second item of motility, the *competence* aspect, is thus involved. As low incomes in Chile are often closely correlated to lower education levels, the majority of the people interviewed in the poorer areas had finished only basic education and were working in informal or rather low-level jobs. They have been particularly challenged by the cognitive requirements related to travel organization, map reading, obtaining information about supply on the telephone or Internet, the electronic ticketing system, and so forth. The same can be stated for elderly people, whose travel difficulties have often been identified in other studies. In addition, the negative influence of the press and television media during the first year of the Transantiago existence might have manipulated the lower-educated groups to a much higher degree.

Following on from the motility concept, it is argued that the *appropriation* process of the new system is also more complicated for lower-income and lower-education people. Due to restricted access to financial and social capital, they are normally also socially less mobile, which results in life being more difficult in all kinds of ways. Despite an objectively lower quality of life in their living environments (concerning access to activities, quality of public services and public areas, security level, etc.), their *activity spaces* at least for social and recreational activities seem to be geographically restricted to their residential areas. This hypothesis was also analyzed in other studies (Schönfelder and Axhausen 2003). There remains the question of if the smaller geographical scope of activity spaces in Santiago is effectively due to lower mobility potentials, or of it might not be rather due to individual decisions and preferences for social segregation. Finally, it could be observed that especially women still complained about problems with the Transantiago system, probably also due to fears for security, when they have to wait at bus stops in deprived areas. Women's specific mobility problems and needs have been the subject of several research studies, in the Latin American context too (Lazo and Contreras 2009).

Lastly, in the context of appropriation and acceptance of transport changes, people's previous *experiences* with public transportation, individual habits, and preferences play a crucial role. Therefore, the lower-income groups had gained long-lasting experience with the previous deregulated system characterized by eminent oversupply, and found it very convenient to move virtually door-to-door with one bus. Previous travel habits are therefore firmly embedded and are more difficult to break. The amount of travel time spent inside the vehicles began to be much more flexible than that outside the vehicles. It is assumed that universal travel time (taken to be double outside the vehicle than that inside the vehicle, according to Jara-Díaz 2009) is even too low. The aversion against the metro especially of the lower-income and lower-education groups might be explained by the mode shifts its use often requires and some kind of *contact fear* due to the previous metro image as a modern and sophisticated mode, more for the rich. On the other hand, there are also the high-income groups as exclusive car users, who have a very bad perception of public transport, which is unjustified and hardly rationally grounded. The link between a negative perception of public transport and lack of one's own experiences has also been remarked upon in other studies (e.g., Kaufmann et al. 2004). Since in Chile social status is still closely linked to material property and residential exclusiveness, the inhabitants of very high-income areas freely expressed their aversion against other social groups, direct contact would be unavoidable within public transport vehicles.

4.6 Final Remarks

The empirical findings of the studies presented in this chapter show us that, with the radical transport reform of the so-called Transantiago in February 2007, the city of Santiago has radically changed. Unfortunately, the attempt to create the basis for a "world-class" bus system, which would replace the previous deregulated system, failed. As a matter of fact, this failure incurred accessibility problems in many districts of the city and adversely affected the daily life of many inhabitants.

What does that mean for public transport policy and, in the context of the present publication, for technological improvement? In short, how can a technologically oriented policy reform be so severely rejected by the people, although it came out of one of the top technocracies in the Latin American context? The Transantiago system was planned and advertised as a "state-of-the-art" technology in transportation. Nevertheless, its outcome was much more different from what was expected. Although it was designed in order to create better social inclusion, it actually lacks social legitimacy now. Part of the explanation arises from the information presented in this chapter: The Transantiago still fails today, 3 years after the Big Bang, to provide good and efficient services. Even when users are now less dependent on the market thanks to permanent public transit subsidies, the new system does not seem to reach the same level of acceptance yet as the previous deregulated system. This was insecure and little coordinated, but able to take people directly to the places they wanted to reach. The strengths yielded by the previous "yellow buses" system could also be questioned, but it was characterized by a remarkable adjustment to actual demand.

As we have seen, acceptance and appropriation of the Transantiago has been difficult for the first 2 years of its existence, especially for the captive riders living in less accessible areas and with lower income and education levels. Among them, the women and the elderly seem to be the most vulnerable groups. They hardly recognize and appreciate the advantages that the new Transantiago system may have provided. On the contrary, the new sophisticated system seems to have adversely affected their daily life, especially the organization of social and recreational activities. These impacts are partly relieved by strong social networks in the local neighborhood whereby traveling in a motorized transport mode is not necessary.

Based on the *motility* concept, the empirical evidence shown in this chapter suggests that changes of the urban transit system are problematic not only by exacerbating accessibility disadvantages for the deprived groups but also by requiring new mobility behavior that is totally unrelated to the previous public transport system. Thus, the more vulnerable people with an already lower mobility potential are the worse off. The need to organize daily trips beforehand with use of information and operation technology (reading network maps, charging the electronic ticketing card and passing it over the contact point, and getting information on the telephone or Internet about the best way to arrive), reductions in travel comfort (waiting and queuing at the bus stop and standing inside the bus or metro), and reduced travel choices (the metro should be used for most of the longer connections) constitutes crucial changes in the previous deregulated system. These changes cause significant discomfort and stress. Certain people announce that they react by traveling less or perceiving travel at the very least as a burden. Therefore, they have modified their daily travel time budgets and trip rates as well as the location of some activities. While formal jobs are tied to fixed locations, the location and frequency of informal jobs as well as nonobliged trips (mainly social and recreational trips) are more flexible. Nevertheless, these modifications require the reorganization of daily activity patterns and incur the risk of inclusion of people in their local neighborhood and exclusion from metropolitan life. Without having analyzed the planning and implementation failures in detail, the public authorities are somehow responsible for the accumulation of problems. They have shown a certain lack of political and financial commitment and willingness to cooperate with other public, private, and civic stakeholders.

To conclude, the evidence strongly suggests that (a) public transport is a key issue that should be taken into account when discussing urban sustainability, (b) the introduction of adequate technology in this field can and will help to overcome some of the future challenges for the cities, and (c) for effective use of development technologies, a serious planning process needs to be invested in. This process should be able to rely on adequate and comprehensive information regarding complex phenomena, such as accessibility of the population. To put it in a nutshell, sometimes it is not extremely sophisticated technology that is needed but high-quality information to tackle sustainability issues. Lastly, the research presented in this chapter helped to identify some mobility problems on a small scale. The undisputed challenge is to now obtain inspired information not just at block level or for a group of communes but for the entire city. At least in the Latin American context, reflection on the development of new techniques and the use of existing ones is still missing but highly recommended.

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Chapter 5
Informality of Housing Production: Rental Markets in *Favelas* and the Challenges for Land Regularization in Brazil

Fernanda Maria Lonardoni

5.1 An Overview of the Problematic

Access to serviced urban land and housing is a historical challenge for the poor. One of the Millennium Development Goals (MDGs) is to mitigate the growth of slums, thus ensuring access to housing and improving living conditions of slum dwellers. Hence, these areas are within the scope of global development agendas and have been the target of policies and actions that work in several directions, trying to produce solutions to the many socioeconomic constraints that affect the daily lives of slum residents and homeless people. Likewise, science and the production of technologies adapted to the various and very different contexts of poverty and deprivation have had a vital role in producing effective answers to the problem. However, initiatives of all kinds have had restricted achievement. The 2010 report on the MDGs recognizes that progress made with the slum target has not been sufficient to offset growth of informal settlements in the developing world[1] and "redoubled efforts will be needed to improve the lives of the growing numbers of urban poor in cities and metropolises across the developing world" (UN MDG Report 2010: 62).

Such ineptitude is partly due to the imbalance between the scale of the problem and the amount of investments allocated along with political intent to resolve the issue. The investments and actions intended to achieve equitable access to serviced land and basic shelter are still limited and local-based. In addition, the lack of thorough knowledge of the different realities of deprivation and the socioeconomic dynamics producing and transforming such realities—both at global and local

[1] The report shows that in absolute numbers, the proportion of urban populations living in slums increased from 33% to 46% between 1990 and 2010 (UN MDG Report 2010).

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level—minimizes the ability of the initiatives underway to produce proper solutions sustainable over time.

The basic question of how the poor have accessed land and housing, for example, is of major importance for any action whose aim is to mitigate the growth of slums and urban poverty. Yet, the answers are still surrounded by misinterpretations. Many governments still take it for granted that squatted land and self-help housing explain the production of informal settlements and rely on this fact to design policies and housing programs.

For many years, the literature regarding social housing and informal urbanization has been enthralled by the phenomenon of land occupation and self-help settlements, discussing and comparing its assets and limitations in providing shelter for the poor in urban areas. By focusing on the self-help process and assuming that virtually all the households were able to occupy a plot of land and build their shelters, the majority of studies and public policies neglected the important dynamics of access to housing in informal settlements, such as real estate and rental accommodation.

Theorists point to the expressive importance of rental housing within the lowest income sectors of the population (Gulyani and Talukdar 2008; Gilbert 2008; Kumar 2001). Already in the late 1990s, general estimates were that more than half of the population in Africa and Asia were tenants, and in Latin America at least one third rented homes (UNCHS 1996). Precise information on the number of tenants in the informal sector has always been limited—evidence of the neglect of the sector—but several analysts argued that this proportion should be higher within the low-income groups living in informal settlements throughout the world (UN-Habitat 2003).

The case of Brazil is emblematic. Scarcity of serviced urban land and increasing control over squatting processes significantly impacted the dynamics of access to land and housing over the last decades. Whereas, from the 1970s to the 1990s, access to housing for low-income migrant populations could be mostly attributed to the equation “land occupation + self-help housing,” at present, the gateway to medium-size cities and metropolitan areas is the informal housing market inside slums, with emphasis on rental housing. Faced with rising land prices, the poor, the newly arrived migrants, and young households virtually rule out the possibility of owning land and housing so that the alternative is to rent a shelter in one of the various informal settlements making up the urban landscape from north to south in Brazilian cities.

This scenario makes renting a shelter in a slum one of the main alternatives for the poor nowadays. Landlords and tenants already comprise a significant part of slum dwellers, and it is estimated that this phenomenon is growing rapidly. Despite the importance that rental housing acquires, detailed knowledge of the socioeconomic principles at force in this sector remains largely unexplored in Brazil, within the remit of both social housing policies and academia. Since the early 1990s, sites-and-services and titling programs have been reinforced by urban and housing policies in this country, but none of the initiatives implemented so far have been based on proper awareness of real estate and rental dynamics inside informal settlements.

The imminence of rental housing in informal settlements implies substantial changes in the production of urban informality and in how slums grow. Better understanding of the dynamics involved in the allocation of rental housing—the constraints and alternatives that this tenure embodies—is crucial to the accomplishment of any action targeted to improve the lives of slum dwellers and ensure safe access to shelter.

5.2 Access to Housing for the Poor in Brazil: From Squatted Land to Rental Housing

In Brazil, housing for the poor has been a critical problem for many decades. Growth of migration processes—between 1960 and 2000, the urban population increased from 45% to over 80%—and the continuing economic crisis throughout the 1980s led to the worsening conditions of urban poverty and informality in Brazilian cities. Over the past few decades, the impact of government in housing supply for the urban poor presents an essentially pessimistic picture in Brazil: the critical problem facing public social housing in this country was that supply never matched demand; the public sector was not able or willing to invest in social housing programs, and the deficit in this sector has greatly widened (Taschner 2003; Marques 2007).

As a result of the lack of effective responses to widespread inadequate conditions of shelter, a massive housing problem developed along with a range of other social and environmental issues of major significance. The state visibly failed to promote mechanisms of housing provision for the poor, and the substantial neglect of this class resulted in consolidating informality as the only solution enabling them to live in urban areas (Valladares 1988; Maricato 1995; Zaluar and Alvito 2006).

The expansion of informal settlements presented a startling picture in Brazil. In 1980, the national census held by the Brazilian Institute of Geography and Statistics (IBGE) found that slums existed in 126 municipalities in Brazil, and 20 years later, in 2001, the number had leapt up to 1,542, accounting for 28% of the total number of municipalities in the country. In São Paulo, for example, the slums grew at an expressive rate of 16.4% per year during the 1990s. The population living in favelas in Rio de Janeiro, according to the national census held in the year 2000, was around 1.1 million (Taschner 2003). Reassessment of the 2000 national census revealed that Brazil ended the twentieth century with 12.4 million people living in 3.2 million households in slums throughout the country[2] (Marques 2007).

[2] There is one main criticism concerning the measurement of informal housing adopted by the IBGE, which considers only settlements comprising more than 50 households. In the case of São Paulo, for example, surveys compiled in 1987 and 1993 respectively showed that 21.9% and 21.2% of the population lived in squatter settlements with fewer than 51 households and were not considered by the census. (Taschner 2003). Reassessment of the 2000 national census was made by the Centre of the Metropolis on request from the Ministry of the City and revealed that the estimated population living in precarious conditions reaches the double found by the national census, which was 6.3 million (Marques 2007).

The growth of slums in Brazil has been recognizably associated with the informal double practice of land occupation and self-help construction. For many years, this constituted the dynamics underlying social and spatial production of informal settlements all over the country, all too often, followed by massive degradation of areas of high environmental importance. Nevertheless, there have been changes in such dynamics, and the discussions were reopened from evidence showing that access to housing is increasingly difficult for the poor (Davis 2006; Lonardoni 2007; Abramo 2003, 2009a).

Studies conducted in eight metropolitan areas in Brazil—Rio de Janeiro, São Paulo, Porto Alegre, Florianopolis, Brasilia, Recife, Salvador, and Belem—demonstrated that real estate consolidation is the main gateway to accessing land and housing in slums throughout the country (Abramo 2007). In addition, such studies showed that tenancy percentages in slums in Recife, Florianopolis, and Brasilia were respectively 58%, 42%, and 39%. In Belem, Rio de Janeiro, and Salvador, this kind of tenure accounted for more than 20% of the real estate transactions analyzed in the study[3] (Abramo 2009b). Therefore, the data gathered in Brazil supports the fact that renting constitutes the alternative chosen by more and more people living in slums with rapidly increasing demand: in Rio de Janeiro, comparative data from 2002 and 2006 showed that tenancy increased by about 30% inside informal settlements in this city.

5.3 Rental Housing in Slums: What Drives This Phenomenon?

The underlying causes of increases in rental accommodation seem to be highly correlated to the local tenure structure and the level of state intervention in the housing sector. Most of the countries in Latin America went through a critical economic downturn during the 1980s and 1990s and had to systematically intervene to reduce deficits to the detriment of social welfare policies, such as housing. The period of recession that most of the countries experienced, and which substantially curtailed their role in housing provision, had two major consequences as shows Abramo (2009b). The first was the rapid increases in informal occupation of urban land in countries where it had never previously existed. The second one was the development of informal real estate in those countries where free land was scarce and control over squatting processes had been tightened. In other words,

[3] In Brazil, the INFOSOLO-Network, developed the research project called *Mercado informal e o acesso dos pobres ao solo*—(Informal real estate and access to housing for the poor), which gathered together research teams from eight metropolitan regions. The sample comprised slum residents who had moved into the settlement within the 6 months preceding the field work, either by purchasing or renting a dwelling, and those who intended to sell their properties at the time of the survey. The results draw on data gathered from more than 50 different informal settlements, where around 3,500 dwellers were interviewed. The INFOSOLO reports on the eight metropolitan areas are available on www.habitare.com.br.

"the solution for those families devoid of financial resources was choosing one of the following strategies: either occupy or rent a shelter in an informal settlement" (Abramo 2009a: 38).

Although variations between different countries and cities are common, some aspects are recurrent when attempting to understand the emergence of rental accommodation in slums. Firstly, disputes and control over urban land are increasing and the option to invade or squat has become less feasible for the poor, even inside informal settlements (Gilbert 1993; Abramo 2007; Smolka 2003). Since it is difficult for low-income families to find sites that they can occupy free of charge, the demand for housing inside existing settlements rises, and owner-occupiers start extending their own houses, building additional rooms and floors, so that they can profit from selling or renting shelters for those who cannot afford to own land or purchase a shelter. For owner-occupiers, renting out represents an opportunity to supplement their income, and many are willing to take advantage of the situation.

Secondly, the larger cities become, the more difficult life is likely to become for the poor in the urban outskirts. Cheap land sites might be available in the less commercially attractive areas, but public transportation and infrastructure are scarce. In addition to shelter not responding to all the daily essentials, living far away from the central urban areas means higher household expenditure on transport and less accessibility to infrastructure, services, and employment opportunities. Even though crowding tends to be higher in the central areas, many of the poor prefer to forgo their plots in the suburbs and live as tenants in the city center because they can benefit from the central location and superior services.[4]

One of the major problems concerning access to housing for the poor is the price of urbanized land along with the difficulties encountered to entry in formal housing markets. In 2001, it took an average of between 12 and 15 years for a family with household income of three minimum wages[5] to purchase a 200-square meter urbanized plot in Brazil, that is, provided with sewage, water, and electricity systems (Smolka 2003: 121). Smolka (2003) argues that the increase in urban informality is not only an issue of impoverishment but rather of exclusion of the poor from the private market. "In the last decades, the rates of housing informality growth were far higher than those of the households joining the group living under the poverty line" (Smolka 2003: 122). Hence, speculation and high prices of urban land preclude the majority of low-income households from housing options in the formal market and contribute to the problem of slums.

Lastly, an aspect which might be of critical importance to comprehend social dynamics involving informal rental housing in Brazil is what Abramo (2009a) calls

[4] Such dynamics cast doubt on the dominant urban growth model prevalent until the 1980s, which was based on extensive land occupation towards peripheral areas and uncontrolled development of the cities. Statistic data from many Latin American countries reveals that in the last two decades, population growth rates in peripheral areas were on the decline while population numbers were increasing in the central districts of several cities (Harms 1997: 193).

[5] Brazilian minimum wage was US$ 90 during the period in question.

a change in the demographic profile of the population living in informal settlements. By leaving their parents' houses, the second and third generation of slums dwellers may affect or intervene in the rental market in two ways. Firstly, it is likely that as soon as they abandon the family household, they have not yet gathered enough resources to purchase a house and will probably have to live in rental accommodation. Secondly, their absence generates a number of vacant rooms which will possibly join the rental housing stock and provide owner-occupiers with supplementary income (Abramo 2009a: 36).

5.4 Rental Housing for the Poor: An Alternative After All?

The issues arising from rental housing in slums are many and paradoxical, and they pose major challenges for both theory and practice. While rent offers an opportunity for landlords to supplement their income and mitigate poverty, for tenants, it is easily regarded as overspending that deprives them of other essentials and indefinitely postpones the achievement of homeownership. The fact that access to land in slums results from legally unfounded practices places great pressure on landlords, who are often charged for the commercial use that they make of plots of land that they have not paid for.

Two main aspects should be considered to understand and explain the growth of rental housing. Firstly, for the owner-occupiers, it is a means of producing wealth from their own assets, and it increases the ability of owners to build larger and better-quality housing. Secondly, for those lacking resources to purchase real estate (on a formal or informal basis), rental accommodation may offer a first-step means of entering complicated urban housing markets and an alternative of affordable housing in better-off slums.

The way of recognizing the potential of informal rental housing should first exploit the new forms of vulnerabilities that it might engender and even go beyond that. This requires a shift of the analytical framework to think about its informality, constraints, and alternatives. It calls for a debate on rental housing with an approach that addresses urban informality taking into account the different roles of housing, strategies of livelihood, and assets that these groups produce, whether material, social, or symbolic.[6]

[6] This aspect has been particularly discussed in several areas of the literature on poverty and informality (Gutiérrez 2005; Friedmann 1996) and in the studies of social capital (Bourdieu 1980, 1986). An important contribution to the discussion is brought by Bayat's "quiet encroachment" describing "the silent, protracted, but pervasive advancement of ordinary people in relation to the propertied and powerful in order to survive and improve their lives" (Bayat 2004: 90). In Bolay et al. (2007, 1996), several case studies in Latin America evidence the inventive capacity of the urban poor and the role they play themselves in fighting and mitigating poverty, very often benefiting from their social networks.

In order to do so, some important changes should tackle historical neglect of rental housing and demystify social rejection of this kind of tenure. In Brazil, this is a difficult task owing to the traditional ideological construction around the ideal of homeownership that is adhered to by all classes of the population.

5.5 Neglect of Rental Housing

Despite the significance of informal rental housing and its essential role for the poor in developing countries, the number of governments aware of or actually considering its existence is rather small. While most governments in Europe have implemented a systematic rental housing policy addressing the low-income population, in developing countries, the policy cupboard is largely bare of initiatives and rental accommodation has been neglected both in the formal and informal sectors. Since the late 1980s, a number of reports have made policy recommendations for the rental sector, advising that rent should be considered as a partial answer to the housing problems in the third-world countries: governments should review their housing policies, and incentives coming from the public sector should also contribute to mitigating the prejudices against tenants or nonowners (UN-Habitat 2003; UNCHS 1996). Yet, very few initiatives have been implemented along these lines.

In Latin America, most governments actually appear glad at the disappearance of rental housing (UN-Habitat 2003: 02). Since the 1950s, public housing provision for low-income and middle-class families has been mostly for sale, and dramatic shifts towards owner-occupation have been observed.

Neglect of rental housing is widely supported by ideological, political and economic reasons. Many governments continue to extol homeownership as a symbol of national prosperity and spread the myth that it can be universally achieved (Gurney 1999; Krueckeberg 2004). For the poor in particular, homeownership is expected to bring about a wide range of social and behavioral changes, due to the economic investment that it implies. In economic terms, it is valued because of the belief that it contributes to maintenance and growth of a huge housing infrastructure that includes developers, financial services industry, real estate, planners, builders, and so forth (Shlay 2006: 512).

In Brazil, rental housing has been wholly neglected, and many of the policy goals of low-income housing are framed by ideological statements about homeownership. Since the 1940s, housing policies in Brazil have been devoid of rent-based initiatives and have massively supported the ideal of homeownership. The figures illustrate this trend: the number of homeowners went up from 25% in 1940 to 75% in 2000 (Bonduki 2002; IBGE 2000).

It is evident that the preference for homeownership cannot be simply summed up as an ideological phenomenon. In Brazil, the house itself is perceived by the popular classes as true support of family survival. It provides them with security and fills the gap left by incomplete public policies. On the other hand, it is evident that government intervention has played an important role in changing people's attitudes to its desirability. It seems a common sense that any public policy proposing rental housing would face a high degree of social rejection in Brazil, but the question of whether homeownership is a good asset-building strategy for low-income families has yet to be conclusively answered.

Since the 1980s, the urban and housing policy framework in Brazil has been strongly affected by neoliberal approaches and further emphasis on market performance. In more concrete terms, the introduction of a policy framework in line with decentralization, loss of state regulation, and a market-driven process of land and housing delivery have been applied, resulting in more critical effects for the low-income population. To tackle the uncontrolled growth of urban informality, government intervention first redirected the practice of massive slum evictions to a progressive replacement by regularization and upgrading programs. Such initiatives have been supported by progressive law rectification and placed the security of tenure at the forefront of social housing policies for the last two decades in Brazil.

Yet, many of the policy determinations rely on the exclusive premise that homeownership and title deeds are going to incur economic benefits for low-income families. In truth, these policies prove their limited understanding of the diversity of socioeconomic dynamics involving access to housing inside slums by assuming that every slum dweller is an "owner-occupier," who has possession of a plot of land and a shelter, and will be granted the title deeds of these assets. In Brazil, these instruments continue to disregard rental housing and perpetuate homeownership as the only housing alternative inside informal settlements. Tenants and landlords remain invisible, although they represent a significant part of slum dwellers.

5.6 Neglect of Rental Housing and Challenges for Policy and Regulation

A potentially significant reform in the context of social housing in Brazil was the 2001 federal law known as the Statute of the City—*Estatuto da Cidade*.[7] Ever since the enactment of the Statute of the City, urban and housing policies have reinforced their affirmative overture in Brazil. Local governments were provided with legal instruments to serve the dual purpose of promoting security of land tenure with title deeds and upgrading the living conditions of the existing informal settlements.

[7] Federal Law 10.257 which aims to regulate the chapter on urban policy founded by the 1988 Constitution. The Statute of the City assigned to municipal governments advocates the implementation of participatory master plans, defining a set of tools to stamp out real estate and land speculation and promote the regularization of slums. The Statute transformed the character of urban policy in Brazil by subordinating property rights to collective interests (The Statute of the City, available on line: www.polis.org.br/obras/arquivo_163.pdf).

However, the approach recently adopted for the regularization programs in Brazil illustrates substantial misinterpretation of the mechanisms of access to housing in slums. None of the regularization and upgrading programs implemented so far within the framework of the Statute of the City has been based on proper awareness and significance of rental housing inside informal settlements. They virtually assume that slum dwellers have possession of a certain shelter and hold a plot of land, for which title deeds will be granted.

Within the framework of provision of title deeds, there are two main legal instruments to establish incontestable tenure for slum residents in the Statute: the *special usucapion rights for urban property* (adverse tenure rights) and *concession of special use for housing purposes*. The former shall apply in cases of private urban land possession and the latter in cases when public land is at stake. Their contents are quite similar concerning who has the right to be granted. Article 9 of the *usucapion* and Article 1 of the *concession of special use* respectively determine the following:

> Art. 9. Someone who has been in possession of an urban area or building of up to two hundred and fifty square meters, for five years, uninterruptedly and without contestation, who uses it for their residence or that of their family, can establish their dominion (by means of the usucapion), as long as they are not the owner of any other urban or rural real estate.
>
> Art. 1. Whoever, until June 30, 2001, had possessed as his or her own, for five years, without interruption and without opposition, up to two hundred and fifty square meters of public real estate located in an urban area, using it for their own residence or that of their family, has the right to concession of special use for housing purposes in relation to the property that is the object of said possession, as long as they are not the owner or concessionaire, in any form, of any other urban or rural real estate.

According to these instruments, landlords do not have the right to request title deeds unless they use the same premises for their own residential purposes. In this case, they will be granted only the fraction which is occupied by them, and the right will be equally provided to the tenants for the portion of the property in which they live. In the cases where it is not possible to identify the land occupied by each possessor, "the judge will attribute an equal ideal portion of the land to each possessor, independently of the size of the land that each occupies." Such measures are based on the determination that tenancy inside informal settlements is legally unfounded, even if a rental contract has been signed between the parties, "this contract is illegal and does not grant any legitimacy to the relationship between landlords and tenants".[8]

Allocation of rental housing in slums seems to be banned on the basis of illegal ownership of land and of latent tension that emerges from residential use of squatted land being transformed into commercial use—especially when public land is at stake. These policies demonstrate a clear and valuable intent to prevent "market forces" and the development of a wholly commercial practice around

[8] The Statute of the City, available on line: www.polis.org.br/obras/arquivo_163.pdf.

access to housing in informal settlements. However, more appropriate definitions should specify the exact extent of the right to be granted to the poor and what are the underlying criteria of legitimacy for these initiatives. Several studies revealed that there is no concrete evidence neither proving that landlords are reproducing a wholly commercial misguided attitude nor that tenants are being exploited *per se* (Gilbert 1993; UN-Habitat 2003).

In fact, evidence indicates that rent is far more a way for many landlords to improve their conditions of poverty due to the extra income procured from the rent. In several circumstances, many families showed their preference for living in these places and valued many aspects of the social networks that they had developed within the community (Abramo and Pulicci 2009: 202). For some groups, rental housing proved a preferred and appropriate shelter in circumstances such as (a) high residential mobility, that is, resident needs to move with a certain frequency (most slum dwellers do not handle formal employment bonds and move frequently according to job opportunities); (b) inability to fulfill bureaucratic rental requirements in the formal sector; (c) early-stage household and lack of accumulated resources to purchase a property at once; or (d) a transitory residential condition (rent is a temporary shelter while building their property or saving up to purchase one).

It is also important to consider that, if the rental activity has been condemned for its supposed "illicit nature," the regularization programs, with their triumphs and failures, have proved to play a paradoxical role in activating housing land markets (in many cases, increasing real estate prices and stimulating gentrification processes). Distribution of individual title deeds have, in effect, "become one of the main pillars of instituting formal market mechanisms in squatter settlements (. . .) the state intervention has played a very important role in changing people's attitudes towards the desirability of legalizing land titles as the main response to tenure security" (Zetter and Souza 2004: 175). These instruments keep reproducing the idea of homeownership as the only tenure alternative.

Although these programs undoubtedly embody a great deal of progress in acknowledging the right and democratization of access to urban land and housing for the poor, their intended goal to promote development of the land market and economic growth by providing the poor with title deeds has been the subject of a number of well-documented criticisms (Payne 1997; Zetter and Souza 2004; Fernandes 2003). "When regularization involves the delivery of individual property titles, it produces a series of 'perverse' results that undermine the stated intention of providing security of tenure for the beneficiaries. Speculative rises in the price of land and the costs imposed on residents both directly and indirectly (in the form of charges and property taxes) lead to the displacement of original population. Rather than increasing security of tenure, regularization actually diminishes it; but security of tenure is precisely what residents need, not property titles per se" (Azuela and Duhau 1998: 163).

In Brazil, the cases of the municipalities of Recife and Florianopolis are emblematic. Recife was the pioneer for implementation of regularization and titling programs, starting in the 1980s. Yet, recent data from several slum settlements in the city show that, despite the advanced stage of these programs, the informal real estate and the rental market proved rather dynamic (57.9% of transactions concerning informal real estate in the slums surveyed in Recife concerned tenancy, Lacerda and Melo 2009: 118). In Florianopolis, the regularization initiatives started in 2005 following approval of Municipal Law *673/2005,* which established the first steps towards regularization of 16 informal settlements located in the central area of the city. Since approval of the law, the prospective security of tenure and urbanization improvements have seemed to rapidly stimulate commercialization processes among the slum residents. Surveys conducted in the area in 2006, thus shortly after the first legal referrals, showed that allocation of rental housing was rather expressive in several of these settlements (INFOSOLO-UFSC 2006; Lonardoni 2007). In the two cases of Recife and Florianopolis, the ability of these instruments to prevent real estate development in slums proved doubtful.

5.7 Final Considerations

Approval of the Statute of the City represented a milestone in the acknowledgment of the right to housing and security of tenure for slum dwellers in Brazil, "the first steps of a necessarily long and continuous process aimed at transforming, through institutional changes, an ancient tradition marked by authoritarianism and inequality, which have deeply affected Brazilian cities" (Maricato 2006: 07). However, progress still needs to be made to understand the socioeconomic dynamics involved in the production of housing alternatives in slums and the importance that rental housing acquires for the livelihood of their residents. In future approaches, public intervention should be focused more on recognizing its existence, assessing its potential, and effectively intervening in the aspects in which it may constrain the access to housing or worsen the poverty level of slum dwellers.

The increasing importance of rental housing for slum dwellers should also be taken as a major issue to open the debate on social rental housing policies in Brazil. Many of the ideological constructs of homeownership are rooted in the (under) development project that historically reduced the burden on state spending on social housing. Self-constructed housing, unlike the social rental accommodation provided by European welfare states, delegated to the poor the fate of finding shelter in cities. It is not surprising that the tradition of self-construction and housing production currently integrates important aspects of their livelihood and poses more complex challenges to decode the political economy of urban informality.

Findings on and a better understanding of the socioeconomic principles involved in access to housing and housing tenure inside slums will be of great value for policymakers: both for the content of current regularization programs—to more properly address rental housing inside informal settlements—and to support future guidelines on new rent-based housing policies in Brazil. Qualitative and quantitative recognition of the various relationships established between landlords and tenants will provide evidence so as to not only investigate and comprehend the reproduction of these individuals as workforces but also contribute to the studies on social reproduction of poverty and the mechanisms that these individuals develop to overcome it.

As urban informality is a worldwide phenomenon and poses particular challenges to long-term sustainable urban development and planning, it is critical that professionals, stakeholders, and policymakers acquire an in-depth understanding of the current lives of slum residents, how they access housing, their living conditions, and the nature of the vulnerabilities that they face.

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Chapter 6
Multiple Innovations and Urban Development in Burkina Faso

Françoise Lieberherr-Gardiol

6.1 Introduction

The pairing in technology institutes worldwide of technological innovation and development seems a straightforward and logical combination. Nonetheless, years of experience in development – with all its obstacles and barriers, as well as its opportunities and success stories – have shown that creation and implementation of innovation require a far more complicated mix of ingredients, in which innovation interacts with a societal framework and with a given rationale for development. That is to say that the development dynamic depends on multiple innovations, in technology, society and culture, the environment, politics and institutions. The technicist approach to development needs to be set aside in favour of a process that takes account of the active role played by different stakeholders in defining their own society. This implies the possibility of constituting an endogenous social plan rather than relying solely on an exogenous model. It also implies the possibility of a discussion in terms of sustainable development.

6.2 Development Called into Question and Sustainability

Before relating the discussion to a particular case in Africa – specifically Burkina Faso – some clarification is called for of the various much-debated conceptual approaches to development, sustainability and innovation. The optimistic post-war notion of 'development' that emerged in 1949 was rooted in the western paradigm of progress and gave more importance to economic and technical change than to politics, society or culture. It was rooted in the European philosophy of progress as

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a universal movement in human history (Morin and Kern 1993). The idea of development implies its opposite, ‘underdevelopment’, as a characteristic of societies that need economic and technical assistance in order to become nations. This central concept was adopted by the United Nations (UN) and was a preoccupation of every ideology in the second half of the twentieth century. At the same time, given the failure of numerous attempts to introduce modern agricultural, medical and industrial methods and, on the other hand, policies based on models of development deriving from specific cultural contexts, like those of Gandhi, Nyerere or Castro, for over 20 years, there has been a lively debate on the putative merits of a universal well-being (Rist 1996). Failures in development can weaken the fabric of society, marginalize traditional skills and add to poverty and distress. For some time now, development has been branded a western myth that promises Third World countries a better future while instituting an international order with a North-South divide and privileging western influence above that of other civilizations.

The concept of sustainable development grew out of a discussion of the failed post-war development model, which prioritized consumerist economic development above other considerations and regarded the environment as a side issue to be dealt with only a posteriori, as the need arose. Sustainability arises from a double awareness: firstly, the realization that while ex-colonies have a right to development, an economic growth model merely accentuates the inequality; and secondly, a growing perception of the environmental risks inherent in the present ecological crisis (Guay et al. 2004). Sustainable development replaces mere economic development with a three-pronged approach combining economic, social and ecological dimensions on the basis of three principles: economic effectiveness, social equity and ecological balance (Lieberherr-Gardiol 2005b). The 1987 Brundtland Report setting out a new standard of sustainable development marked a fresh international awareness of a development paradigm integrating economic, social and ecological factors in the light of two guiding principles: historical justice as between both the old and the young generations, and spatial justice as between North and South, East and West (Brunel 2005).

Although sustainable development is almost a new orthodoxy – even, for some, a catch-all concept – its implementation varies according to ecological diagnostics and development concerns: for the North, wastage of resources, inappropriate consumerism and the pursuit of technological progress; for the South, worsening living conditions, growing poverty and inadequate basic services (Allen and You 2002).

The transfer of technology, together with the transfer of knowledge and skills and their impact on development, is also the subject of heated debate between its proponents and its critics. The overall theme of the present international forum – technology for development – requires us to examine the process of transfer. In the first place, any new technology is an innovation that the target society can either reject, if it is incompatible with traditional beliefs and practices, or alternatively adopt, if there are clear benefits. Secondly, ‘innovation and change are never accepted automatically. The process underlying their implementation is what may or may not achieve the necessary acceptance' (Callon and Latour 1991). Thus, the adoption of an innovation depends less on its intrinsic merit than on the collective enterprise of the local players, who actively identify, adjust and finally take ownership of the change. Thirdly, an innovation in a host structure never occurs in isolation, but is always accompanied by other changes at different levels, as we will see in the following case study.

6.3 The Burkina Faso Context

For a better understanding of the process of innovation in a developing country, it is first necessary to outline the context in which it evolved. This study concerns sub-Saharan Africa, and specifically Burkina Faso. Like other African countries, in the first decades of independence Burkina Faso sought to establish a modern nation state with stable institutions. But the coming of globalization disorientated the system: a worldwide market replaced the former framework, and the state began to abdicate its social responsibilities. In parallel with this, new players in civic matters made their appearance on the scene. In the historical evolution of Burkina Faso (Sawadogo 2001), traditional clan-based systems, the French colonial power, modern 'multiparty democracy' and international aid overlapped in time and intersected, giving rise to different centres of power, more or less traditional or modern, formal or informal.

By the late 1980s, the political and economic system in Burkina Faso had become that of liberal democracy and the market economy. But globalization was spreading worldwide and carrying with it a one-size-fits-all development model whose rules, values and economic norms were claimed to be universally valid. All country-specific social, political and cultural features are pasted into this unitary model. The 1991 adoption of a new constitution was a tipping point for Burkina Faso in political, institutional and international terms.

Two important factors for development made their appearance in the 1990s. Firstly, in 1993 the National Committee for Decentralization (CND) enacted five laws setting out the functions of the new decentralized bodies, for which the first democratic elections were held in 1995 in 33 communes formerly administered by prefects appointed by central government. Secondly, the Development Programme for Medium-sized Towns (PDVM) for urban development and country planning aimed to balance the development of the different regions and improve the technical, financial and institutional resources of ten medium-sized towns, with a view to counterbalancing the attraction of the two urban centres, Ouagadougou and Bobo-Dioulasso. There were thus two major innovations during the last decade of the twentieth century: the setting up of decentralized, democratic communes as an endogenous, purely Burkinabe, process, and the PDVM, an exogenous urban development project; both triggered further innovations in Ouahigouya (population 56,000), the provincial capital of Yatenga in the north of Burkina Faso.

6.4 Emerging Urban Communes

According to the Decentralization Guidelines (TOD) (Burkina Faso 1999), ‘the urban commune (minimum resident population 10,000), which is the basic unit of organization in the urban centers, is administered by a mayor and two deputy mayors, who constitute the executive… The Municipal Council is an elected body with a five-year mandate which sets up two permanent committees, for general business and for economic and financial affairs, and can also create ad hoc committees for specific purposes (…). The Municipal Council, which holds three-monthly ordinary sessions, lays down broad guidelines for municipal development, discusses and adopts development plans for the commune, discusses and reviews the commune’s budget and accounts. The mayor, as the representative of government in the commune, is responsible for carrying out the decisions of the Municipal Council and is also budget controller and registrar, and in charge of the municipal police and criminal investigation, to ensure security and public health’. Thus, the commune in Burkina Faso, a modern creation of the decentralizing process, is the best level at which to envision and to set up new democratic social and political systems that can transcend old village rivalries based on clan or religion.

This theoretical description of the new institution of the urban commune gives no conception of the upheaval taking place in the routine practices of the emerging Burkinabe municipalities, specifically of Ouahigouya. The nascent municipalities often suffer from shortage of technical skills, lack of management experience among newly elected officials, scarcity of human resources, weakness of the new institutions of the commune, a limited sense of citizenship among those accustomed to centralization and the absence of a local conception of long-term development and the stakes involved.

6.5 Development Programme for Medium-Sized Towns (PDVM): A Driving Force in Ouahigouya

The second major innovation, the implementation of PDVM, was an external initiative on the part of the Swiss Agency for Development and Cooperation (SDC), which has been active in Burkina Faso for some 30 years. In 1992, the SDC proposed a pilot programme in Ouahigouya, in preparation for the introduction of PDVM in two other medium-sized towns, Koudougou and Fada N’Gourma (Delsol 2004). The SDC’s policy of supporting local development and giving priority to local competencies favours a more democratic and sustainable development in which the individual is central and the aim is social change (PNUD 2002). Its urban policy consists in encouraging the development of medium-sized towns as intermediate centres to foster urban-rural interdependence and complementarity. The programme’s strategy is based on key projects which favour economic results by building up viable infrastructure and creating a web of small- and medium-sized enterprises and contribute to the consolidation of the democratic institutions of the commune by strengthening municipal management and by community participation.

Based on feasibility studies in Ouahigouya, the SDC worked out an interesting and original approach with four strategies: rebuilding markets, seen as economic drivers; organizing sanitation operations, seen as a social driver; setting up legal entities of a new type, the Commune Public Associations for Development (EPCD), seen as 'municipal services'; and action research, seen as a means of empowerment facilitating the emergence of civil society and the effectiveness of local government (Lieberherr-Gardiol 2005a). In comparison with other international programmes implemented in West Africa, the SDC approach constitutes an original and innovative mix. It goes with a development philosophy aimed at simultaneously strengthening, through step-by-step facilitation, the skills of the different stakeholders, the growth of democracy and citizenship and the local economy. PDVM was thus introduced when Burkina Faso was changing radically in its behaviour, social structures and values, in a local institutional and cultural context that was ill-prepared for the municipal management of public affairs.

6.6 The Commune Public Association for Development (EPCD): A Tool for Technical Support

In the PDVM context, the setting up of EPCD was a groundbreaking institutional innovation. Under a 1992 executive order, EPCD's first objective was to implement and manage the commune's Development Programme. With a board chaired by the mayor and consisting of representatives of the decentralized ministries, elected officials and members of civil society, EPCD provided technical backing through its various areas of activity – infrastructure, sanitation, planning and institutional support – and funded operations in these areas. Its operating budget derived from the receipts from market taxes, a contribution from the commune and a direct subsidy from the SDC. With considerably more specialized technical and management skills than the municipality possessed, EPCD oversaw the implementation of operations, from start-up and on-site monitoring to technical operations, from surveys to urban planning or from participatory activities to advice on taxation (DDC 2002). In Ouahigouya, EPCD was established before the actual start-up of the new commune in 1995 and thus played a founding role in local development.

This new body set up by the SDC in collaboration with the Burkinabe administration was, once again, a case of an external project being introduced into a framework with few technical resources. While it was a key player in implementing PDVM, constructing the market and improving sanitation and the environment, as described below, its novelty gave rise to misunderstandings and demarcation conflicts, to which the technical and managerial weakness of the new municipality contributed as well as an unclear division of roles and responsibilities. On the one hand, the municipality lacked the experience needed in order to define EPCD's tasks; and on the other, EPCD's attempts to comply with the municipality's requests were handicapped by some political and institutional uncertainty on the part of local authorities. As an external player, the SDC with an important normative role was involved in the strategic monitoring of the programme and with some difficulty juggled its twin roles of participant in the process and of source of funding responsible for the programme's success.

In connection with the joint activities of the municipality and EPCD, another innovation should be mentioned: the Support Fund for the Development of the Commune (FADEC), drawing its resources from managing the market and other services to be offered in the future by the commune, for use by the commune for social infrastructure development. In Ouahigouya, FADEC's resources made it possible to build a municipal high school in 1998. The use of the fund is regulated by an agreement between the municipality and EPCD, in which the SDC stipulated that in awarding contracts, preference should be given to local firms and the use of local materials (DDC 2002). Managing FADEC is thus a way of learning self-financing and building contract management, as it involves the municipality in the planning of strategic orientations, the formulation of options and mobilization of financial resources – in other words, the democratic management of local development.

6.7 Building the Market: A Ouahigouya Pilot Experience

An essential component of PDVM, the construction of the market began in Ouahigouya in 1994 after preliminary studies, discussions with traders and the prefect and proposals for the training of craftsmen. It was a big project – nearly one billion CFA francs (US$ 1.6 million), 1,500 shops and 600 stalls covering 3 ha – and was completed in 20 months under the supervision of a Swiss architect and inaugurated in 1996. The planning of the project was based on three – again, innovative – key principles: labour-intensive use of local materials (on-site manufacturing bricks and paving of compressed earth), training of local firms in technical and managerial skills and building site management by EPCD. The building of the market, in three phases, encouraged dialogue between traders and site managers and the increasing empowerment of the craftsmen, who were selected during the second phase on the basis of their performance. Since 1996, the management of the market has been in the hands of a small, dedicated EPCD team. The charges are levied with a view to recovering costs and paying off the initial investment within 25 years, plus running costs and minor maintenance. In 2000, annual market receipts totalled about 60 million CFA francs.

Widely perceived in Burkina Faso as a model, Ouahigouya market and its management system were the envy of other towns. But in 2000, a crisis erupted, with the traders questioning the levies and refusing to pay. Their arguments related to a decline in trade, uncertainty about the use of the money collected and the question of repaying money that had been donated. After violent demonstrations, the temporary closure of the market, a 50% reduction in rents decided by the mayor without consulting SDC and the freezing of Swiss support for infrastructure, the rents were finally renegotiated, making possible the renewal of Swiss funding in January 2002.

6.8 Innovative Market Management Challenged, Adapted and Accepted as Their Own

The crisis throws light on the adoption or rejection of innovations by the many stakeholders – municipal council, EPCD, market management and traders. On the basis of preliminary studies of the Burkinabe background and the development context, the SDC had proposed a market management system that included recovery of the costs outlined above and a threesome management structure: a technical management team, a board of directors and an advisory committee of traders.

While the innovative method of financial management worked well up to the crisis, with an excellent rate of recovery of charges (80–90%), three types of problem appeared in the application of the model: unclear division of decision-making powers between municipality and EPCD, payments not understood by traders and problems of communication between the municipality and the SDC (Lieberherr-Gardiol 2005a). The new democratic municipality, lacking management experience and trained personnel, mostly tried to solve urgent problems without clear formulation, planning and forethought. This meant that they left all the technical side to EPCD without really taking political responsibility for the running of the market.

The dissatisfaction shown by the traders was due to a strictly commercial- and profit-oriented view of their participation in the market. The case for local development with the market as linchpin was neither adopted nor even clearly stated. Individual interest prevailed over the common interest and immediate satisfaction of an economic need over the overall long-term improvement of living conditions in the community. The municipality, overwhelmed by the magnitude of its new responsibilities, was unable to fulfil its task of advancing political and democratic awareness. A final cause of the crisis was the lack of any agreed framework negotiated and formally agreed between the municipality, EPCD and the SDC, which hampered effective joint management of their dealings and decision-making.

The market crisis which revealed these operational failures gave rise to unpleasant overreactions like the traders' demonstrations and the suspension of Swiss aid, but it also led to a series of adjustments. The participation of a mediator chosen by the SDC facilitated negotiations between the parties, from which a new model emerged in 2002, put forward by a second, more experienced municipal team and a new mayor, a former World Bank expert. Under this new management plan, an Independent Ouahigouya Market Management Service (SAGMO), coming under the Municipal Council but independent of EPCD, was instituted, comprising three management teams: a managing committee, representing all stakeholders, which determines the rents; a users' advisory committee and an administrative and financial service for market infrastructure, with a lady cashier, female rent collectors and watchmen. At the same time, as these new bodies were set up, the municipality, with EPCD support, organized an awareness-raising campaign, with local radio programmes, dramatic performances and training in fiscal responsibility.

Among the different innovations involved in the market, it was the management itself – from the collection of the money to its use – that caused the resistance and incomprehension of the parties involved. Finance as the essential challenge in development can reorient alliances and the distribution of power. In order to resolve this conflict, the municipality in the end succeeded in establishing a new social and political balance that made possible true ownership of the market's organization by the commune authorities as a tool and driver of local development.

6.9 From Technical Sanitation to People's Perception of Quality of Life

Sanitation as another essential component of PDVM is an external innovation in the Burkinabe context. It was a conceptual part of PDVM but ran into considerable problems when it was first piloted in the commune in 1993. Its components included cleaning drainage channels and the repair and digging of drainage ditches, together with the construction of latrines and septic tanks, the collection of household waste and setting up a recycling and composting centre for it. A section of the EPCD municipal services was responsible for these operations and for awareness raising in the community (DDC 2002). But an assessment of sanitation operations in Ouahigouya revealed interruptions in the services provided, blocked and overflowing drainage ditches and lack of maintenance of public areas and shared facilities. This can be explained in terms of the gap between PDVM's exogenous, imported approach and methods and an endogenous response that included lack of municipal commitment, inadequate public involvement, EPCD's technical failings, a low level of environmental awareness and uncertainty in the privatization of public services in the absence of alternative proposals (Lieberherr-Gardiol 2005a). Neither the revolutionary period in Burkina Faso nor the more recent environmental projects have led to any progress because local opinion is not motivated by a merely technocratic approach that focuses on basic facilities. A highly complex process is involved which has three aspects: behavioural change by the population in relation to their environment, a change of attitude towards providing a service as a duty of citizenship and the funding of facilities in a commune with very limited means.

The first of these three aspects is rooted in the local culture. Unlike the Western view based on hygiene, Mossi culture sees a rubbish dump – the *tampuure*, literally 'guts of the mountain' – as a crucible symbolizing not filth but fertility (DDC 2002).

European history before Pasteur's revolutionary concept of hygiene showed similar beliefs about the beneficial effects of refuse in the insanitary towns of the period, as the author's own studies have shown. This fact is crucial to any understanding of the local incomprehension or even resistance to an imported concept of cleanliness.

The second element is related to one key ingredient: a population that is involved. For Burkina Faso, the problem is a result of exogenous theories of community participation that were imported in the 1980s, combined with revolutionary practices (DDC 2002). At the time, citizens had been drafted in to build facilities for their neighbourhoods and 'revolutionary' infrastructures (schools, cinemas, bakeries...) – a decision that was considered legitimate and necessary to make up for lost time. But this meant that PDVM's participatory projects were received with ambivalence, as demonstrated by the refusal to volunteer and take part in building facilities ('sweeping or carrying materials, that's no longer democracy!') and the reluctance to contribute financially to the cost of services. Confusion about the meaning of democracy had created a situation where only the rights of citizens had been highlighted, and not their obligations – a misinterpretation also to be found in neo-liberalism, which sees citizens as clients and users of services, with no collective responsibility and solidarity.

The third aspect reflects the paradox of decentralization – as the state withdraws, there is no clarification of the new roles of the different local authorities and no redistribution of the financial resources needed to support the responsibilities of the new municipal administrations. Within the PDVM framework, the Swiss financial contribution to infrastructure is matched by an undertaking from the commune to take into account environmental and sanitation issues in its municipal works, which sees the municipality collaborating in a concerted effort with the different stakeholders, thus stating its responsibility for public spaces and for meeting social needs. Associations and citizens are slow to take on this new role of participants in a civil society which both calls for and produces collective goods. The slowness of response at a local level also raises the question of sustainability with no real financial autonomy. These cleaning and sanitation measures clearly illustrate the mechanisms for transferring innovation, which went from resistance and rejection to adjustment and then ownership of new foreign techniques.

6.10 Citizenship in the New Era of Democracy in Africa

The last innovation, democratic citizenship, turns out to be a lot more difficult to determine. Though it was PDVM's main objective through various initiatives that were implemented, it is not measureable because no expected result or indicator was ever defined. Though underpinning the decentralization and democratic transition of Burkinabe society, it never fully crystallized and was not a visible element in the process. In 1995, when the first 33 fully functioning communes had just been created in Burkina Faso, the concept of decentralization was limited to media coverage and was not yet a social reality. In Ouahigouya, the commune took shape as a new framework for social and political organization and as a fabric of governance at local level. How are citizens going to make this local governance their own? How well is the population going to assume ownership of the commune? How will the communes devise appropriate policies for the common good? (Lieberherr-Gardiol 2005a).

PDVM is a testing ground for trialling the local democratic practices applied by the municipality and the citizens and their various associations. It introduces its own version of local development, a normative concept of public good and of effective and transparent management of this common good. PDVM also brings to the table its own model of a democratic commune. In order to be of use to its citizens, a municipality must define and implement appropriate collective policies of economic promotion for a better life and security for better solidarity. This means building an economic and social order that benefits all (Sawadogo and Barbedette 2001). These policies need to be forged through collective action involving multiple partnerships linking local authorities, the private sector and a pluralist civil society. Here, the commune plays the role of an administrator and a mediator of conflict between diverging interests. Within this normative vision, local democracy focuses on creating a public forum and on managing those assets of common interest. The commune acts as a political device which facilitates the interaction between the legitimate communal authorities and those citizens who not only are users of the services but also socially engaged and responsible, defending their rights and meeting their obligations. This coming together of communal politics and social reality should strengthen the feeling of belonging to the community and give rise to a new type of citizenship.

While PDVM may put forward a coherent and normative strategic vision, the Burkinabe model is undergoing deep changes in its behaviours, its modes of sociability and its values. The prime stakeholders are the municipalities. In the history of nascent democratic and decentralized communalization, poorly prepared local authorities have found themselves short of human and financial resources and overwhelmed by the municipal workload. A biased understanding of democracy originates from systems shaped by a colonial heritage of a highly centralized power structure, a single-party political tradition, local and traditional power bases that have favoured private ownership and the redistribution of privileges and benefits according to clan or ethnicity, as well as a notably paternalistic and clientelistic viewpoint of the role of mayor. Furthermore, '*the paradigm of democracy developed in the West and based on an individualistic conception of political power cannot be grafted onto a community-based social organization in which government structures are woven into the wider social structures where belonging to an ethnic group, a clan or a family and their particular values takes overall precedence*' (Bruyne and Nkulu Kabamba 2001). The building blocks of democracy are still missing, that is to say, a commune that is responsible for the overall management of an entire community's interests and a mayor acting as a modern-day manager responsible for the administrative, social, political and financial issues of a local community. And though the first municipal line-up mostly adopted a firefighter approach comprised of reactive leadership behaviours with no anticipation or planning, the second team has shown more political maturity. The image of mayor has changed, and the mayor is now seen as someone accessible, in touch with people, attentive to their needs and exerting influence on matters.

Another group of legitimate participants in local governance are the traditional chiefs. Being involved in political initiatives (nationally and locally elected representatives) and consulted, they have significant influence through the traditional practices and values that remain deeply rooted in society and survived colonialism. Nonetheless, their status and their way of operating are the reverse of those that define democratically elected representatives, that is to say, a hierarchical system with vertical relations based on authority and obedience versus a system founded on equal relations and equal rights, reliant on a sense of responsibility and autonomy. The continued existence of traditional power structures acts as a factor for integration between the old system, which endures in a diluted form, and the modern-day example of a decentralized commune fostering social exchange based on human rights and equity.

As regards a many-faceted and diverse civil society, it is appearing in many places (Laurent 2004) but without really yet becoming a democratic counterbalance or a private sector. As emerging local players, we can identify the competent and motivated small entrepreneurs, providers of goods and services (hairdressing, garages, second-hand clothes, refreshment stalls, etc.) and the socially innovating founders of different associations (for the handicapped, for waste disposal, community pharmacies, market traders, etc.) motivated both by genuine commitment to local regeneration and by the hope of attracting subsidies. Among these players, it is noteworthy that young people and women are often dynamic. Although still marginalized in the patriarchal social system, they are gradually making their appearance as drivers of change, the women hoping for a different future for their children and the young eager for modernization. Being still largely excluded from local politics, they act on their own to invent new forms of social interaction and support systems (consumption, children's education, clothing, leisure activities) as part of a social change characterized by the weakening of the traditional authority of patriarch or husband, new forms of employment, the adoption of urban values and the role of money.

The community is also the scene of social competition, playing for new stakes, such as real estate, which gives rise to speculation and conflict (Jacob 1998), or water, the recent commercialization of which arouses resistance and tension. Perceptions of space and time are also changing profoundly, under influences ranging from the bicycle to the car, from land plans to irrigation schemes and from long-term saving to short-term planning for maximum profit. Values and points of reference are also undergoing fundamental changes, with a movement from 'old people's ideas' to 'young people's ideas', raising questions in terms of coexisting traditional/modern, rural/urban and colonial/post-colonial conceptions about religious beliefs, the role of money, social behaviour and individual identity. The essentially rural traditional Burkinabe fundamentals, that is, the patriarch as seat of authority and the land of the ancestors as source of economic resources and social, cultural and spiritual values, are being replaced (Sawadogo and Barbedette 2001). In this evolution, the town is a context that fosters and speeds up change.

In a world teeming with new lifeblood and dynamism, the combined force of newly elected local officials and an emerging civil society should gradually create new spaces for citizens, but the line between public and private remains unclear. There is increasing social demand for improved living conditions, local services and jobs to meet the interests and needs of individuals. What is still missing is a clear expression of a common interest – a town cannot operate by responding to its citizens' combined individual interests. Elected local representatives are gradually coming to understand how to ensure management for the public good, with the idea of acting as facilitators and mediators. The associations play their part by offering spaces for social interaction between private stakeholders and by promoting attitudes of openness, creativity and solidarity. Furthermore, this contributes to creating public goods, such as health care, sanitation and education. The 'public matter' is beginning to take shape – slowly. The new roles must move away from the traditional and patriarchal feudalism still rooted in social and family structures and apply new democratic principles regulated by equal relationships and rights. This change is underway, supported by mediation to harmonize diverging interests and negotiation between opposing social forces, and should lead to a genuinely long-term political vision (Lieberherr-Gardiol 2012).

6.11 Conclusion: Towards Ownership of Innovation

Edgar Morin's promotion of the paradigms of complexity and context (1993) suggests that we reflect on this valuable Burkinabe experience, which allows us to identify the conditions for transferring technology and any ensuing reactions to their innovational nature. This highlights four features. In view of the assumptions laid out in the introduction, the transfer of technology and innovation – far from being a straightforward technical exercise – is in fact a global process involving an entire social group (Bolay 2004), as shown in the types of interrelationships played out in the Ouahigouya experience. The second characteristic is that the Burkinabe town was not passive in the transfer but participated actively in building collectively new skills and competencies. This means that innovation cannot be imposed; it is in fact a two-way process of transfer and acquisition. As a wise old peasant farmer put it, '*My son, all the difficulties we are experiencing in "the land of the Blacks" are linked to the fact that we have abandoned our fetishes and borrowed those of others, but the problem is that we don't speak the same language as those borrowed fetishes*' (Sy 2009). Thirdly, this process is discontinuous, moving forward at a variable pace, alternating periods of integration and successive adjustments with periods of dissension or even rejection, where foreign innovation may be seen as a threat to identity, an action against political independence or domination by the world market. The end result is true acceptance and ownership of innovation, a core ingredient of social, economic or institutional sustainability in the processes for local change. This experience has also brought to light one last feature – innovation is many sided, with multiple initiatives cascading down to different levels. Be it a Western, a national or a local innovation, the changes are slotted together according to alliances and the distribution power. This particular Burkinabe town has therefore used innovations to exhibit its modernity but has done so in its own time and space rather than have globalization imposed on it.

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Part IV
Construction and Housing: Cracks in Sustainable Development

Jean-Claude Bolay

Housing, in rural and urban areas alike, plays a key role in the development of any society. At individual level, it is the "hearth and home" that draws the members of a family together and, in many age-old community traditions, a place for sharing and for privacy; at social level, it represents the fabric of all human settlement, providing protection and security for the inhabitants of a village, neighborhood, or city, and also bears witness to history and cultures – a people's architectural heritage is a key element in the formation of their collective identity; at economic level, it has always been and still remains the driving force of one of the most dynamic and innovative sectors of small-scale and industrial activity, a provider of jobs and generator of income. Coupled with the process of urbanization that is sweeping its way through today's developing and emerging nations, housing, accommodation, and construction are phenomena that call into question the technologies deployed and their impact on the social and natural environment.

As Du Plessis states in Agenda 21 for Sustainable Construction in Developing Countries, a document she edited in 2002, "The construction industry and its activities are responsible for a substantial amount of global resource use and waste emissions. It also has an important role to play in socioeconomic development and quality of life." At global level, a "3 $\times$ 40%" rule seems to apply: the construction sector accounts for 40% of industrial production, uses 40% of resources consumed, and generates 40% of waste matter and contaminants produced on the planet. One particularity recognized by all specialists in urban planning is that, in the case of most citizens living in Southern towns, construction, of housing in particular, is an informal procedure, implemented by individuals or families, building for themselves or relying on neighborhood jobbers or micro-companies

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lacking the sector's customary technologies and machinery, technical knowledge, and capital, so creating "fragments of towns" governed by distinct regulations bearing both on their physical and material location and their social and economic foundations. In addition, a major and much decried issue in all developing countries is the overall blatant lack of up-to-standard housing accommodation, which has brought about an explosion in the construction of makeshift buildings that are often totally inappropriate to observed needs.

Behind the questions raised by housing construction lie further questions of a specifically technological nature – What materials? What processes for implementation? What maintenance? – along with other questions relating to transfer of know-how and social appropriation of alternative construction models.

The three chapters – two of them analyzing the Indian context and the third starting in Cuba and going on to cover all developing countries – complement each other perfectly, focusing their research questions on three turning points in the construction process.

In her chapter, Duyne Barenstein assesses two post-disaster reconstruction programs in India and the socioeconomic and environmental implications leading to introduction of exogenous building technologies following a disaster. Pressed by the urgency of the matter and of immediate needs, many agencies opt for industrially produced prefabricated elements and ignore local housing culture and building technologies, to the detriment of local construction habits and at a cost beyond the pockets of most low-income families, negatively impacting the cohesion of local communities over the long term.

In their chapter, Martirena and Scrivener give their reply to such fully justified and often-repeated criticisms. They present the research project they are currently working on, which proposes substituting Portland cement with supplementary cementitious materials obtained through processing agricultural wastes, such as sugarcane straw and bagasse combined with clayey soils, in order to assess new interesting possibilities for the use of activated clayey soils to produce high-quality materials. As they argue, such up-to-the-minute work on new materials should have consequences not only in Cuba but also in all countries, providing an innovative alternative based on local materials and saving on imports and costly energy expenditure. This constitutes up-to-the-minute scientific research providing simple solutions to basic needs.

Pittet, Jagadish, Kotak, Vaghela, Zaveri, Sareshwala, and Gohel conclude by focusing their attention on the environmental impact of building technologies developed in India and other developing countries, over a life cycle of more than 50 years and taking quantities of cement and water used in construction as criteria for measurement, making the connection between new technologies that make economical use of such resources and materials and environmental degradation.

These few examples demonstrate the importance of the construction sector and the impact it has in economic and environmental terms alike, and the wide margins that exist for improving the situation at local, regional, and global level through more rigorous assessment of direct and indirect costs and, above all, through appropriate technological innovations, with a view to taking better account of the societies in which such technologies are put to work and to reducing their environmental impact.

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Chapter 7
Towards Sustainable Post-disaster Housing and Building Technologies: Issues and Challenges with Special Reference to India

Jennifer E. Duyne Barenstein

7.1 Introduction

One of the most visible consequences of many disasters is the widespread devastation of houses. Recent data indicate that housing losses often account for over 50% of the total losses following disasters. Based on these considerations, governments and international humanitarian agencies increasingly focus their recovery assistance on housing reconstruction.

Disasters may be an opportunity to address pre-disaster vulnerabilities of the built environment and to promote technologies that are safe, economically affordable, socio-culturally and climatically appropriate, and environmentally sustainable. The importance of understanding housing as a complex socio-technical process and not merely as a physical asset is increasingly recognized by scholars and development agencies (Barakat 2003; Lizarralde et al. 2009; UN OCHA 2008). In addition, the World Bank's recently published handbook for reconstruction after natural disasters (Jha et al. 2010) clearly indicates positive institutional trends in this direction.

This chapter examines two post-disaster reconstruction programmes in India. Based on research in Gujarat and Tamil Nadu, it offers a critical analysis of the socio-economic and environmental implications of introducing exogenous building technologies following a disaster. It will be argued that all too often the only criteria considered in the choice of building technologies for housing reconstruction are safety considerations, construction speed, and efficiency. These considerations lead many agencies to ignore local housing culture and building technologies and to opt for industrially produced pre-fabricated elements or reinforced concrete cement. Such materials tend to be alien to the local context, have a high environmental

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impact, do not provide comfort, are detrimental to the cultural identity of a community, are unaffordable to low-income groups, and often cannot be maintained and upgraded by the local building artisans. As a consequence, the vulnerability of affected communities on a long term may even increase.

7.2 Appropriate Post-disaster Housing Designs and Building Technologies: Issues and Principles

Housing reconstruction following major disasters is generally much concerned about "building back better" (Clinton 2006). This endeavour often entails the replacement of local housing designs and building technologies with modern technologies, whose multi-hazard resistance can be scientifically proved. There is increasing evidence, however, that the introduction of new building technologies following a disaster does not necessarily contribute to reduce people's vulnerability. These may be theoretically safe, but if people are unable or cannot afford to maintain them, if they are uncomfortable, and if they are incompatible with their lifestyles and livelihoods, they may end up making their inhabitants even more vulnerable (Duyne Barenstein and Pittet 2007; Jigyasu 2009).

The critical importance of promoting housing designs and building technologies that are not only safe but also culturally appropriate, affordable, comfortable, and sustainable is recognized by the handbook for housing reconstruction recently published by the World Bank (Jha et al. 2010). The handbook recognizes the multiple challenges and complexity of housing and community reconstruction following a disaster and underlines that enhancing the resilience of disaster-affected communities requires a profound understanding of their cultural, socio-economic, and institutional context and of the links between livelihoods, settlement and housing patterns, and social organization. Considering the high environmental impact of the building sector, the handbook also emphasizes the importance of promoting building technologies with a low ecological footprint. The handbook underlines that building codes and standards for reconstruction should reflect local housing culture, climatic conditions, building and maintenance capacities, and affordability. To this aim, it is argued, building approaches adopted after disasters should be as similar as possible to those used in normal times. On social, economic, environmental, and cultural heritage grounds, the handbook also underlines the importance of repairing and retrofitting partially damaged houses and not just to focus on building new houses (Jha et al. 2010: 161). The World Bank handbook is the first of its kind. It covers cultural, social, technical, environmental, and institutional aspects of reconstruction in a practical way with the aim of helping decision-makers to develop and implement reconstruction programmes that are equitable and sustainable. Whereas it is too early to assess the handbook's impact on post-disaster reconstruction practices, this chapter aims at analyzing to which extent past reconstruction experiences in India followed its basic principles.

7.3 Housing Reconstruction in Gujarat Following the Earthquake of January 2001

Gujarat suffered a devastating earthquake of a magnitude of 6.9 on the Richter scale in January 2001. With over 20,000 deaths, it was the worst earthquake experienced by India in the last 50 years. Out of Gujarat's 18,356 villages, 7,633 suffered damages, and 450 were fully destroyed. Some 344,000 houses were completely destroyed, and 888,000 reported damages (UNDP 2002; WB/ADB 2001). The vast area affected by the earthquake is culturally, socio-economically, and ecologically very heterogeneous. This is reflected in Gujarat's rich housing culture, varying from sumptuous stone masonry houses belonging to the wealthy urban communities of traders, to beautifully decorated circular mud houses with thatched conical roofs belonging to semi-nomadic tribal populations in the north and north-east.

Less than 2 weeks after the earthquake, the state government constituted the Gujarat State Disaster Management Authority (GSDMA), which announced its rehabilitation policy only a few days later. It proposed relocation of the most affected villages, assistance for in situ reconstruction of the severely affected villages, assistance in less damaged areas for repair, and in situ reconstruction.[1] A systematic public consultation carried out by a local non-governmental organization (NGO) network in 480 villages revealed, however, that over 90% of the villagers refused the idea of relocation. The Government of Gujarat thus changed its policy and adopted an "owner-driven" reconstruction approach (GSDMA 2005). Instead of readymade houses, the government thus offered financial and technical assistance to all those who preferred to undertake reconstruction on their own and did not want relocation and full scale "adoption" by an external agency. Given the option, 72% of the villages decided to go for financial compensation and to reconstruct their houses on their own. The remaining villages chose to have their houses rebuilt by international NGOs or private corporations (Abhiyan 2005; Duyne Barenstein 2006a).

The governmental reconstruction programme allowed people to use local building materials and traditional house designs as long as they respected the government guidelines specifically designed to ensure their seismic safety. An engineer was placed in each village to provide technical guidance and supervise the construction. The financial assistance was delivered in three instalments. Each successive instalment was only released if the construction achieved the required standard. Large-scale training programmes of local masons aimed at reinforcing their building capacity and at raising awareness of multi-hazard resilient construction.

In 2004, we conducted an interdisciplinary research with the aim of assessing citizens' perspectives on the reconstruction approaches pursued after the 2001 earthquake by the Government of Gujarat and by NGOs. Our multi-sited research proved the multiple advantages of owner-driven reconstruction: 93.3% of

[1] Cf: URL: http:// www.gsdma.org

households reported to be satisfied with their post-earthquake housing situation, which was considered better than before the earthquake and the quality of construction of owner-built houses was found to be good[2]; people who managed reconstruction by themselves were able to move back to their houses earlier than those who depended on NGOs. Owner-driven reconstruction also showed several advantages from a social and environmental point of view. In fact, self-built houses often made extensive use of salvaged and locally available construction materials, which was not the case with contractor-managed reconstruction (see Figs. 7.1 and 7.2).

Both citizens' satisfaction and quality of construction were significantly lower in villages that were reconstructed through external contractors by NGOs. In some villages, less than 20% of the villagers were satisfied with houses they had received, which were considered of poor quality, uncomfortable, and unsafe from future earthquakes in spite that their cost was up to three times higher than the financial assistance provided by the government to those who opted for owner-driven reconstruction (see Figs. 7.3 and 7.4). Most international NGOs promoted the use of reinforced concrete, a construction material with a high ecological footprint. Another environmental problem related to the use of concrete is the high demand for water, for the process of curing, which is particularly problematic in semi-arid zones such as Kutch, where over 85% of the reconstruction took place. In many places, the water demand for construction competed with domestic and agricultural requirements leading to social conflicts. The quality of construction suffered due to the lack of water, as curing was hardly ever done with sufficient care. By compelling communities to move to newly built relocated sites, damaged villages were simply abandoned, which is undesirable, not only from a psychological point of view, but also from an environmental and landscaping one. NGOs and private agencies also showed little or no interest in supporting the repair of partially damaged houses. It is estimated that over 38% of the houses built by NGOs replaced houses that would have been reparable (Abhiyan 2005). Another problem with the NGO contractor-managed reconstruction was that it was to a large extent supply-driven. NGOs concentrated their assistance in few villages in which they agreed, however, to build as many houses as their funds allowed them. As a result, a study carried out in 2004 found that in villages reconstructed by NGOs, there was a massive (up to 83%) increase in the number of houses but an occupancy rate in some villages as low as 20%. The new houses were not equally distributed among all community members. Influential households inevitably succeeded in getting more houses. From a socio-cultural point of view, it was shown that contractor-driven reconstruction led to several other negative impacts. Houses and settlements sponsored by some large agencies, and built by contractors, strongly deviated from the local housing culture and were perceived as incompatible with local livelihoods. Many people rejected these houses and ended up building their own. However, as

[2] High construction quality was also found by a Third Party Quality Audit appointed by the GSDMA which inspected nearly 100,000 houses and found a rate of conformity with the governmental building codes of over 95% (GSDMA 2005).

Figs. 7.1 and 7.2 Owner-built houses in Gujarat (Source: Duyne Barenstein)

they had officially received housing assistance from an NGO, they were not entitled to financial assistance from the government and did not receive any technical guidance (Duyne Barenstein 2006a).

Gujarat's reconstruction experience shows that people have the capacity to manage the construction of houses that are more likely to respond to their needs than houses provided by external agencies if adequate financial and technical support and other enabling conditions (e.g. good supervision, training of local

Figs. 7.3 and 7.4 Contractor-built houses in relocated sites in Jamnagar District, Gujarat (Source: Duyne Barenstein)

masons, and access to good quality and subsidized construction materials) are provided. Owner-driven reconstruction proved to be the most cost-effective, sustainable, socio-culturally sensitive, and empowering approach to rebuild houses after a disaster. Gujarat's positive experience with owner-driven reconstruction inspired the approach pursued by the Government of Sri Lanka after the tsunami of 2004 and the Government of Pakistan after the earthquake of 2005. Also in these two countries, several authors found that owner-driven reconstruction was highly successful in terms of reconstruction speed, quality of construction, and cost-effectiveness (Aysan et al. 2006; Karunasena and Rameezdeen 2010) Unfortunately however, as the case of reconstruction after the 2004 tsunami in Tamil Nadu will show, whereas governments and international finance institutions recognize the advantages of owner-driven reconstruction, international NGOs tend to be reluctant to adopt this approach which gives them less visibility and control over reconstruction projects.

7.4 Housing Reconstruction in Tamil Nadu Following the Tsunami of December 2004

On 26 December 2004, a severe earthquake measuring 8.9 on the Richter scale hit northern Sumatra causing one of the most powerful tsunamis of recorded history. In India, the disaster killed over 15,000 people (GOTN/GOP 2005). Nearly 80% of the human and material losses were concentrated in the state of Tamil Nadu and were registered among its coastal fishing communities. Before the tsunami, most lived in vernacular houses characterized by plastered brick walls, thatched or tiled roofs, and spacious verandas. They were comfortable, beautiful, affordable, well adapted to the local climatic conditions, and had a comparatively low ecological footprint (Duyne Barenstein 2006b, 2010; Duyne Barenstein and Pittet 2007).

Soon after the disaster, it was estimated that over 130,000 new houses were needed for people made homeless by the tsunami (ADB et al. 2005). These figures were not the result of an accurate damage assessment. In fact, the first reconstruction policy issued by the government in January 2005 envisaged permanent relocation of all coastal communities, which implied the need for new houses for all affected people. Another factor that contributed to giving less importance to a housing damage assessment was the assumption that 87% of the coastal people were living in "kachcha" houses. The Hindi word *kachcha* is officially translated to "temporary" and reflects a negative attitude towards vernacular housing prevailing in most states in India. Reconstruction was thus considered an opportunity to upgrade the housing condition of all those who used to live in *kachcha* houses before the tsunami, thus erroneously assuming that already before the tsunami, the majority of the people in coastal Tamil Nadu used to live in "temporary houses." Pejorative attitudes towards vernacular housing led to a reconstruction programme that aimed at replacing all "vulnerable" *kachcha* houses with "multi-hazard resistant" *pucca* houses, costing about 30 times more than a *kachcha* house (ADB et al. 2005).

According to the government's initial reconstruction policy – as described in the project document of the World Bank funded "Tsunami Emergency Reconstruction Programme" (TERP) – housing reconstruction was to be either supported through financial assistance from the government or to be ensured through public-private partnerships (ADB et al. 2005). The Government of Tamil Nadu thus issued detailed guidelines and building standards and invited national and international

NGOs, voluntary organizations, and public and private sector enterprises to adopt particular villages for their reconstruction programme. In December 2005, the government reported that 43 agencies were in charge of the construction of over 17,000 houses in 80 villages (GOTN/GOP 2005). All of them delivered flat-roofed concrete matchbox type of houses sometimes even smaller than the 320 ft^2 in size prescribed by the government. These were built by external contractors, and in most cases, community participation was minimal.

Reconstruction in Tamil Nadu entailed a massive demolition of undamaged houses such as those shown in Figs. 7.5 and 7.6. The promise of getting new houses led several communities to ask for relocation, with the hope of local people

Figs. 7.5 and 7.6 Owner-built pre-tsunami houses in Tamil Nadu that were demolished in the reconstruction process (Source: Duyne Barenstein)

ultimately being able to own two houses. However, while agencies were eager to spend their funds on building houses, finding land for relocation turned out to be difficult. Agencies thus started pushing for reconstruction in situ, which was possible only by demolishing the existing housing stock and by clearing the ground from all trees. A survey carried out in two villages in Nagapattinam District in 2006 revealed that out of 1,500 houses that a Swiss NGO was planning to build, over 780 would replace good quality undamaged or reparable houses (Duyne Barenstein and Pittet 2007). Some agencies went as far as demolishing houses built by other agencies, promising villagers even better ones. In one village, it was found that an NGO demolished 110 undamaged concrete houses which had been built by the fishery department a few years earlier within the framework of a social housing scheme and which had already been upgraded after the tsunami by another NGO (Duyne Barenstein 2010). Not all house owners voluntarily demolished their houses, but they were often forced to do so by their local leaders. Villagers who tried to resist this process were put under tremendous pressure by being excommunicated from their communities. They were thus not allowed to go fishing and were cut off from services such as water supply and electricity, and the rest of the community was not allowed to interact with them. Such repressive measures are possible in fishing communities where the informal *panchayat* (community leaders) continue to be very powerful (Anath Pur 2007; Vincentnathan 1996).

Reconstruction in Tamil Nadu has led to a severe depletion of the natural habitat. Coastal villages in Tamil Nadu are traditionally immersed within the thick vegetation of a large variety of bushes and trees. Shade-providing trees are of vital importance in a very hot climate and are the source of important resources such as fuel, fruits, vegetables, and fodder. However, in several villages, the contractors employed by NGOs for housing reconstruction refused to start any reconstruction work before the ground was completely cleared from pre-tsunami houses, trees, and other vegetation. In some villages, people estimated that 800–1,200 trees were cut down in the process of building the new village, which consisted of endless rows of concrete houses without any vegetation (see Figs. 7.7 and 7.8). Naimi-Gasser (2011) found that the absence of trees in post-tsunami villages had dramatic consequences on coastal communities' well-being, livelihoods, social life, and health situation.

The houses built by contractors are also inadequate from a socio-cultural point of view. Fishing communities in Tamil Nadu have a strong housing culture that reflects their specific way of life and religious beliefs (Duyne Barenstein 2009). These fishing communities' housing culture was not taken into account by any of the agencies. The agency-built houses were too small for an average-sized family, but the homestead plots were not large enough to allow for extensions.

The case of Tamil Nadu shows that when agencies are exclusively concerned with risk reduction and trust that resilience can be enhanced by introducing multi-hazard resistant building technologies, the result may be the opposite; the outcomes may negatively affect the well-being of the people and be unsustainable, even though the output may well fit the "building codes" for hazard safe structures.

Figs. 7.7 and 7.8 Contractor-built houses in situ in Nagapattinam District, Tamil Nadu (Source: Duyne Barenstein)

7.5 Summary and Conclusions

This review of two recent reconstruction experiences in India shows that there is a close link between building technologies promoted after a disaster and reconstruction approaches. Sustainable building technologies are more likely to be adopted when reconstruction is owner-driven, when agencies recognize the value of local housing culture, and when they make a conscious effort to strengthen local building capacities. This was the case in Gujarat, where the reconstruction policy built upon a thorough understanding of the strengths and weaknesses of local building technologies and accordingly facilitated a sustainable and contextually appropriate reconstruction process. This was possible thanks to a constructive collaboration between government, national NGOs, and civil society. The two cases show that international NGOs, in spite of their familiarity with developmental discourses emphasizing sustainability, equity, and participation, are more likely than local governments and local NGOs to introduce building technologies that are contextually not appropriate and disempowering and detrimental to the well-being of local communities. The reconstruction approach pursued by most international NGOs in Gujarat and Tamil Nadu further indicates that they tend to overemphasize safety considerations and that they have excessive faith in modern building technologies. This has generally led to neglecting the potential of locally available materials and skills and to the employment of external contractors for housing reconstruction. Safety considerations, the very same reasons that are used to justify the introduction of exogenous building materials, appear to be misleading; in fact, once people start building extension to their "safe" houses, if they have been excluded from the reconstruction process, they tend to fold back on unsafe building practices. The incoherent use of both traditional and modern building technologies resulting from a post-disaster exposure to different materials and designs, combined with what remains available in terms of local skills and affordable building materials once external agencies have withdrawn, may lead to a built environment that is even more vulnerable than the pre-disaster one.

The recently published World Bank handbook for reconstruction after disasters highlights these risks and encourages decision-makers to make technological choices that are locally affordable, sustainable, and contextually appropriate. However, unless the reconstruction practices of the multiple actors involved in reconstruction are regulated by mandatory national and international policies, there is a risk that humanitarian agencies will continue acting based on their specific interests and on a poor understanding of local contexts. More than an end, the World Bank handbook should thus be considered as an instrument for advocacy and as a means towards developing policies that empower disaster-affected communities to have more control over the reconstruction of their houses and that protect them from becoming the victims of a second disaster. The case of Gujarat shows that alternatives to top-down agency-driven approaches exist and that these are more sustainable, cost-effective, faster, and culturally sensitive than conventional approaches.

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Chapter 8
Ecomaterials in Low-Cost Housing. Connecting Cutting-Edge Science with the Grassroots

Fernando Martirena and Karen Scrivener

8.1 Introduction

The collapse of socialism in Eastern Europe at the end of the 1980s and the ensuing crisis in Cuba also brought about a shift in the country's housing policies. Large-scale, energy intensive prefabrication plants were phased out in favor of smaller plants where production could be undertaken with far less energy while keeping transport to a minimum.

Likewise, scientific institutions in the country were called upon to provide solutions to manufacture building materials under these new conditions. In 1993, the Centro de Investigación y Desarrollo de Estructuras y Materiales (Center for Research and Development of Materials and Structures, CIDEM[1]) was integrated in a network of institutions working on development of appropriate technologies for decentralized manufacturing of building materials and innovative methods for construction of low-cost housing. CIDEM also joined international networks such as the Latin American Network for an Ecologically and Economically Sustainable Habitat the Sustainable Habitat (EcoSur, www.ecosur.org), thus gaining additional access and knowledge to other approaches for manufacturing.

CIDEM's approach was to cover the whole innovation cycle: fundamental research, applied research, machinery development and manufacturing, implementation, and after-sale services. The scientific component of the innovation cycle was

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carried out in collaboration with academic institutions in industrialized countries such as Switzerland, Germany, and Canada. Funding for these activities was raised through donors sponsoring academic collaboration between North and South partners, such as the Swiss National Science Foundation (SNSF). Implementation of the ideas and methods developed was accomplished with practice-oriented institutions like EcoSur, with funding coming from international donors, such as the Swiss Agency for Development and Cooperation (SDC).

This chapter attempts to illustrate the fruitful partnership established between scientific staff from CIDEM and the Laboratory of Construction Materials at the École Polytechnique Fédérale de Lausanne, Switzerland (LMC-EPFL). The work was carried out in the spirit of cooperation of EcoSur as a North-to-South endeavor.

8.2 Partnership with LMC-EPFL

Professor Scrivener, a leading scientist in the field of research on cementitious materials and head of the Laboratory for Construction Materials at EPFL, and Professor Martirena, in charge of CIDEM at the Universidad Central de Las Villas (UCLV), in Cuba, had the opportunity to share their common interests during a series of scientific meetings in Germany and Switzerland. In 2005, a project proposal was developed, and the first stage approved by SDC-SNSF was entitled "Ecomaterials for Low Cost Housing Projects." The purpose of the joint research project between EPFL and UCLV was to study pozzolans derived from mineral or agricultural sources and understand their effect as cement replacement in concrete[2] (Fig. 8.1). This phase was implemented during the period 2005–2009.

The encouraging results of the first phase showed that relatively common (low-grade) clay can be activated to provide a pozzolan similar in performance to fly ash (from coal-fired electricity generation) widely used in the developed world. The decision was made to apply for a second phase of the project, on the SDC-SNSF budgetary line. The project was approved and started in September 2009.

8.3 Recycling Agro-Waste into Highly Reactive Supplementary Cementitious Materials (SCMs)

Pozzolans have drawn the attention of cement manufacturers for their good performance as cement replacement materials. Many types of waste from industrial processes, such as fly ash, produced by burning coal to produce electricity, are

[2] The research was carried out by one Ph.D. student from EPFL and three Ph.D. students from UCLV. Each Cuban student spent 4 months at EPFL training in the characterization techniques available in the LMC and producing their own research results.

Fig. 8.1 Cuban and Swiss scientists exchange at EPFL, Lausanne

suitable to be used as pozzolans. There is also great potential for producing pozzolanic materials from waste in the agriculture and food industries. Recycling this waste could open up new prospects for cement manufacturers in the developing world and further contribute to improved sustainability of cement manufacture (Day et al. 2000; Martirena 1994).

Extensive research has been conducted in processing and using rice husk ash (RHA) to produce a highly reactive pozzolan (Jauberthie et al. 2000). Recent studies have shown that waste from the sugar industry, mainly sugarcane bagasse ash (SCBA) and sugarcane straw ash (SCSA), is high in silica content, and the ash produced from firing these materials can have pozzolanic properties when fired and cooled under conditions that produce amorphous silica (Martirena 1994; Mehrotra and Masood 1992). Both rice husks and sugarcane bagasse and straw constitute waste matter that shows good potential for recycling in the building materials industry.

Sugarcane has the ability to fix silica in its organic structure. When burnt, the organic volatiles disappear, and the remaining ash is rich in amorphous or micro-crystalline silica. Depending on the burning and cooling conditions, ash is produced in an amorphous, reactive state or in less-reactive crystalline forms. To produce a reactive pozzolan from sugarcane, it must be fired in the temperature range of 400–800°C in order to prevent formation of crystalline phases during heating (Boateng and Skeete 1990; Mehta 1979; Syed Faiz 1994).

Throughout the course of the last decade, CIDEM and its international partners have studied different approaches to produce pozzolans from recycling processes that involve burning biowaste of the sugar industry:

1. Collecting the ash produced during the firing of agricultural waste in boilers.
2. Producing ash from the firing of sugarcane straw under controlled conditions in a specially designed incinerator.
3. Producing reactive ash, which consists of thermally activated clay resulting from the firing of a solid fuel block (SFB), a briquette made of clay and finely shredded sugarcane straw.

SCBA produced in sugar industry boilers shows poor pozzolanic activity. The high firing temperatures, incomplete, nonuniform combustion and slow cooling that take place in the boilers are likely reasons for low reactivity. The main factors that affect reactivity are the degree of crystallinity of the silica present in the ash and the presence of impurities like carbon and unburned material. SCSA that is produced from burning sugarcane straw in the open air, however, has proved to be a reactive pozzolan that fulfills the principal requirements for pozzolanic materials (Martirena et al. 2006). This is probably due to the lower temperatures occurring in combustion, mainly providing an amorphous structure of the silica present in the ash.

In order to obtain higher reactivity from the pozzolan, a rudimentary incinerator was designed and built with the aim of firing the biowaste at temperatures under 700°C, with residence time under 2 h, in order to create optimal conditions for producing reactive ash (Fig. 8.2). The incinerator was designed to process raw sugarcane straw. Target incinerator output is 25 kg of ash per hour (Martirena et al. 2006).

Based upon the strength results, there appears to be no significant benefit to be reaped from firing sugarcane waste in semicontrolled conditions, as compared to firing in open-air heaps. Although mineralogical study shows that the ash from incinerator firing has fewer crystalline phases and more glass phases, this difference

Fig. 8.2 Firing SFBs in an experimental kiln

is not reflected in strength gain. This outcome, combined with low output of the incinerators during their use, confirms that, from a practical and economic viewpoint, transition from open-field firing to rudimentary incinerator firing is not warranted.

When firing above 750°C, the ash from burning biowaste becomes highly crystalline and thus nonreactive (Shi et al. 2000). At this range of temperature, the only opportunity to produce reactive pozzolans with thermal treatment is by calcining clay. This is a well-known procedure, which involves relatively high energy consumption, but yields a highly reactive pozzolan. If the energy needed to calcine clay could come from firing biowaste, the whole process would be more economically viable and less dependent on external energy.

To explore this possibility, the authors developed the SFB (Martirena 1999). In this block, biowaste is mixed with clay before being burnt and pressed into briquettes. Its high calorific value can be used at its maximum potential and the resulting ash – a mixture of the nonreactive ashes from the biomass (approximately 20–30%) and the potentially reactive activated clay (approximately 70–80%) – may be used as a pozzolan. The SFB burns at temperatures of around 800–950°C. The higher firing temperature increases the options for use of the resulting energy – for instance, to fire clay bricks. Various techniques for energy utilization from this process are currently under investigation.

8.4 Phase 1 of the SDC-SNSF Project: CIDEM-LMC-EPFL

The first part of the project included the construction of experimental kilns both in Switzerland and Cuba, where the SFBs produced with the selected clay could be fired and the ashes tested for reactivity. Although firing the SFB was carried out under controlled conditions in both places, large amounts of carbon were found in the resulting ashes, which compromised material reactivity. The decision was made to fire the clay separately at three different temperatures (600°C, 800°C, and 900°C).

Simultaneous studies with pure clay systems were undertaken to understand the changes that pure clay minerals undergo during thermal treatment. These studies included assessment of mineralogical changes with thermogravimetric analysis (TGA), differential thermal analysis (DTA), and X-ray diffraction (XRD), and the use of nuclear magnetic resonance (NMR) to assess changes at atomic level. New and relevant information about the nature of the pozzolanic reaction in calcined clays was obtained, contributing to expanding knowledge of this problem.

Further testing was carried out using Cuban clay with kaolin content under 40% to determine the optimal firing window for reactivity purposes. The ashes were fired and processed into pastes, mortars, and concrete to assess their physical and mechanical properties, based on the explanation of the changes observed on the macroscale (mechanical properties) due to changes in material microstructure, related to hydration of the calcined clays (Fig. 8.3). The experimental program

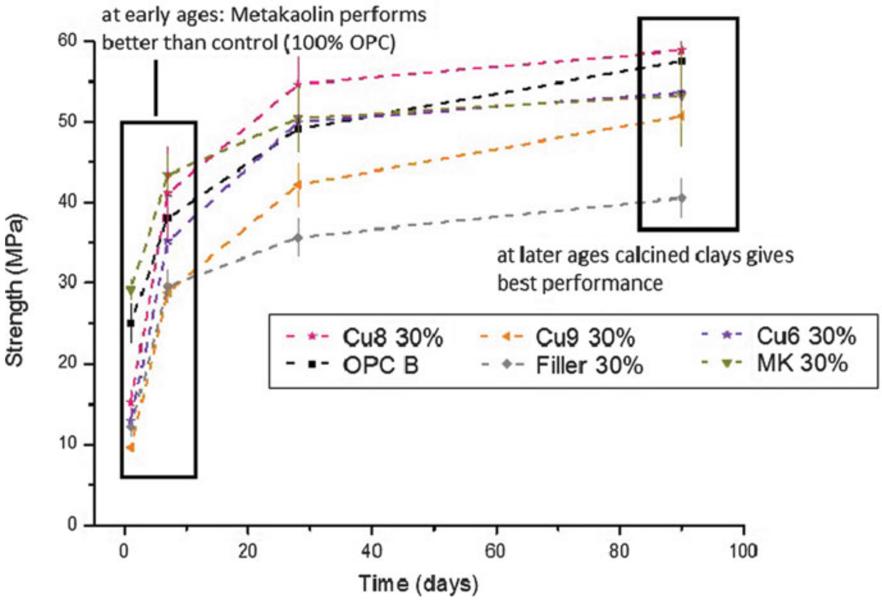

Fig. 8.3 Comparison of activated Cuban clays with metakaolin

applied appropriate balance between the use of sophisticated testing methods, such as scanning electronic microscopy, X-ray diffraction, and thermal analysis, and simplified testing methods, such as the measurement of chemical shrinkage and conductivity testing, which are far more suitable for the conditions of developing countries.

For calcined clays fired at temperatures higher than the activation window (600–800°C), which may well represent the ash of an SFB fired under good combustion conditions, physical and chemical activation methods were successfully tried out, thus widening the scope of the application of this material to higher activation temperatures, which opened up new opportunities for engineers to access a cheap and sound material in terms of strength and durability.

The results from the first phase of the program are:

- A highly reactive pozzolan can result from thermal activation of a clayey soil with a mixed mineral composition, where kaolinite is identified among the main clay minerals. The optimal firing window is between 600°C and 800°C. Pastes made with material treated within the optimal firing window show reactivity similar to highly reactive pozzolans, such as metakaolin (MK), characterized by a high rate of calcium hydroxide consumption in pastes and high compressive strength in mortar prisms made with 30% cement replacement.
- For activation temperatures higher than 800°C, reactivity of the treated clay is low. However, if ground to a fine grain size, the material shows moderate reactivity and displays similar features to the original material treated at

temperatures within the optimal firing window. This could create an opportunity to use the ash produced from the burning of solid fuel blocks, provided grinding facilities are included in the process, the amount of carbon in the ashes is limited, and firing temperature is kept under 900°C.

- Use of clayey soils instead of pure clays opens up new economic opportunities for the activation of clays as an alternative for the production of a good pozzolan at a cheaper price. Furthermore, the possibility of using the briquettes as fuel at energy generation facilities and the ash resulting from combustion as a likely pozzolanic material constitute the economic and environmental profile of the proposal.

This outcome demonstrates that a suitable material to replace Portland cement can be produced by activating clayey soils. The results also indicate that it would be possible to greatly improve this reactivity, by optimizing the process conditions, so as to provide high levels of substitution and substantial improvements in cost-performance ratio.

8.5 Phase 2 of the SDC-SNSF Project: CIDEM-LMC-EPFL

The second phase of the project implements an interesting and innovative process for clay activation based on flash calcination. The principle is to produce an improved aluminum silicate–based material of high pozzolanic reactivity (50% of the pozzolanic reaction is completed after 3 days) by thermally treating clayey soils rich in kaolinite. Clay particles are subjected to a combined process of heating and grinding, and the fine dry particles are transported in a gas stream at temperatures of around 600–850°C, during the time needed to achieve the target level of dehydroxylation. This MK has proven to be more reactive than other benchmark products. This interesting development raises the question of impact of the activation process on reactivity of activated material.

The research project includes setting up of a pilot activation unit (clay activation unit – CAU) in Havana, where firing conditions can be optimized on the basis of achieving the highest possible reactivity. A clayey soil with approximately 60% of kaolin was found in Pontezuela, in the east of Cuba. This material has been activated in a pilot activation unit constructed by the company ARGECO in Toulouse, France. Initial results of tests performed with the Pontezuela clay show reactivity that is comparable to other commercial MKs.

Availability of a relatively cheap MK-type material, locally produced with low-grade clay, enables high levels of clinker substitution to be achieved. The amount of extra alumina incorporated in the system by replacing cement clinker with MK can foster the reaction of calcareous materials sometimes added to cement, which otherwise act as fillers, to generate stable reaction products, and thus further contribute to strength while reducing the clinker factor in cement. Initial results show that clinker in Cuban cement can be reduced by 45%, and mechanical strength of the resulting cement would outperform traditional cement by about 20%, as early as 7 days (Fig. 8.4).

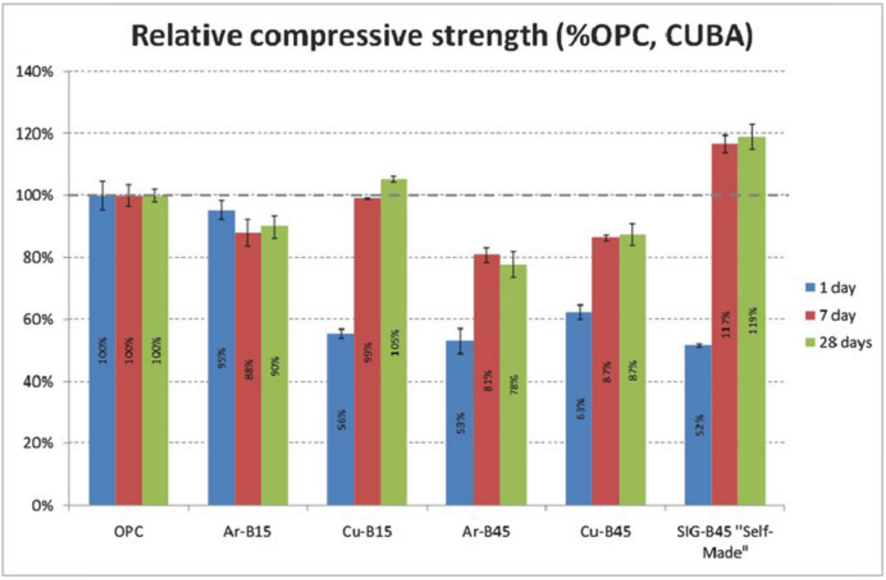

Fig. 8.4 Compressive strength of concrete cubes made with different types of MK compared to the Cuban clay, called SIG-B45

8.6 Application of the Results in Cuba and Other Developing Countries

The process of transforming scientific results into a practical technological package is complex, especially if it is done at the grassroots level in developing countries. This process is generally described as the innovation cycle. Figure 8.5 illustrates the model adopted by CIDEM for the innovation work. This model covers all stages of the process, including fundamental and applied research, machinery development, and implementation. For the purposes of the current chapter, the authors mainly focus on the implementation phase.

Applied research builds on the results of fundamental research. This is normally conducted in Cuba, with the participation of masters and diploma students. Here, the experimental program focuses more on the formulation and proportioning of concrete or cement made from the newly developed material, while the physical and mechanical properties of the new material are assessed, along with its durability.

The level of application depends on complexity of the technology. There are some international technology developers, such as the Swiss enterprise PEG S.A. (www.pegeng.ch), who have developed and applied technologies for flash calcinations of some materials, which are designed and tailored to the conditions of most developing countries, and operate at a scale that in the context of cement manufacture can be considered "small," both in terms of production (120 tpd) and investment (US$ 2.7 million). CIDEM and the Cuban cement industry are currently negotiating setting up of the first plant in Pontezuela, Cuba, with funding provided by the Cuban cement industry.

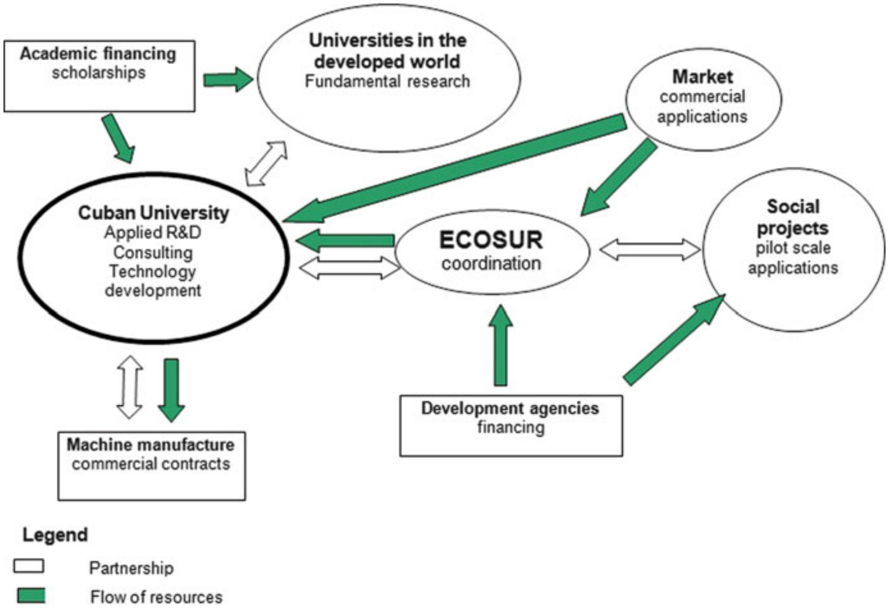

Fig. 8.5 Innovation scheme adopted by CIDEM-EcoSur

CIDEM also foresees the possibility of operating on an even smaller scale, in rural conditions, but with high energy efficiency. Gasification of waste biomass, included in the project, could provide an interesting opportunity to significantly scale down the size of the plant, and thus make it accessible for low-tech users. CIDEM has done this in the past with other technologies with great success (Martirena et al. 1998).

Should this idea prove viable, it will be rolled out through the channels established by EcoSur. It should include a concrete technological package, incorporating the "hardware" or machinery needed to undertake production. Moreover, it covers the "software" or technical information needed to start up production, along with quality control. The technology is improved at pilot workshops, which operate in close cooperation with the research institute and which are frequently visited by the research personnel. They provide the feedback required to tailor the technology devised to the customer's ultimate needs.

8.7 Advantages and Disadvantages of Working with International Cooperation

There are several advantages to be gained from collaboration with academic partners in industrialized countries:

- Direct access to new knowledge and information: most universities in Europe and North America have access to international databases where the most up-to-date information on any scientific topic is available. The information centers in most academic universities are equipped with user-friendly tools to access the desired data. Ph.D. students from Cuba are often able to attend doctoral courses relevant to their program during their research stay in Switzerland or elsewhere in Europe. Participation in these courses makes it possible for them to access the latest scientific information directly from the source.
- Access to publications in renowned international journals, listed in the Web of Science: collaboration often results in work suitable for publication in prestigious journals. The papers are coauthored by scientists from both the developing and the industrialized countries. This solid scientific basis ensures the quality of the article, making the approval process much faster.
- Access to and expertise in state-of-the-art testing equipment in experimental programs: The Cuban Ph.D. students have the chance to stay 4–5 months in Switzerland through the sponsorship of the SDC-SNSF project and are thus given the opportunity to be trained in the use of sophisticated equipment for their experimental programs.
- Cultural exchange with partners in the North: this is a two-way exchange which is very positive for both sides. The relationship is normally characterized by mutual respect and understanding.

However, this kind of cooperation does have some negative aspects:

- The Cuban Ph.D. students are exposed to interesting job opportunities during their research stays in Switzerland and/or in Europe. There is always the chance that some may decide to stay in Switzerland or Europe afterward to take advantage of a job offer. This is yet to happen in the case of this program.
- The visa application process for citizens of developing countries traveling to European countries is often cumbersome. This frequently results in cancellation of activities or last-minute modifications of plans, leaving all the participants with a feeling of frustration.

8.8 Concluding Remarks

- CIDEM is a good example of the impact of building capacity on a developing country's institution. The partnership with a high-ranking research institution in Switzerland has been a major contribution to CIDEM's success.
- The research project undertaken by both CIDEM and LMC-EPFL has yielded interesting, innovative, and practical results that can be of benefit not only to developing countries – the main target – but also to industrial applications.
- Research in developing countries must be clearly oriented to grassroots application of its results. Closing the innovation loop would greatly contribute to providing sound results that can be rolled out with good economic performance.

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Chapter 9
Environmental Impacts of Building Technologies: A Comparative Study in Kutch District, Gujarat State, India

Daniel Pittet, K.S. Jagadish, Tejas Kotak, Kiran Vaghela, Pratik Zaveri, Humaira Sareshwala, and Jayesh Gohel

9.1 Background and Objectives

This chapter is based on the findings of a research project co-financed by the Rector's Conference of the Swiss Universities of Applied Sciences (KFH) and carried out in 2008–2009 in collaboration between the World Habitat Research Centre, University of Applied Sciences of Southern Switzerland (SUPSI), Lugano, the Center for Environmental Planning and Technology University (CEPT), Faculty of Architecture in Ahmadabad, India, and Hunnarshala Foundation for Building Technology and Innovations in Bhuj, Gujarat, India. The project aims at filling a gap in the assessment of environmental impacts of building technologies in India. Previous research on global sustainability of post-disaster reconstruction have indeed clearly identified the lack of scientific data on such impacts in this country (Ding 2008; Duyne Barenstein and Pittet 2007; Gumaste 2006; Jönsson 2000). The lack of data hinders agencies and professionals from making informed choices of materials and technologies aiming at reducing environmental impacts of construction. Based on these considerations, the project's specific objectives were (a) to design and test a methodology for assessing the environmental impact of building materials in a specific context, (b) to provide data on environmental impacts of building technologies in Kutch District, (c) to provide and disseminate knowledge

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for increasing the sustainability of housing projects, and (d) to exchange and transfer knowledge and research capacity on environmental impacts of building materials assessment.

9.2 Environmental Impact of Buildings in the World and in India

9.2.1 Relevance of the Issue

The housing sector is generating worldwide substantial environmental impacts. In fact, it contributes to about half of the total energy consumption of high-income countries and is responsible for a major share of greenhouse gas emissions also in low-income nations (Asif et al. 2007; Cole 1999; Emmanuel 2004; Stern et al. 2006). In the industrialized world, the issue has been extensively addressed in terms of reduction of operating energy needs and, to a lesser extent, concerning the embodied energy of building materials and processes (Huberman and Pearlmutter 2008). The latter is however gaining greater importance in relation to operating energy consumption of new buildings that has drastically been reduced in the last decades (Dimoudi and Tompa 2008). Hubermann and Pearlmutter (2008) have demonstrated that the embodied energy of buildings in the Negev Desert in Israel is responsible for 60% of the total energy needs over the houses' life cycle (over 50 years) and that it can be reduced significantly by using alternative materials such as stabilized soil blocks. Similarly, Morel et al. (2001) have demonstrated the importance of using locally available materials in reducing environmental impacts: compared to standard concrete houses, the use of stone masonry and rammed earth walls in Southern France allows to save about 60%, respectively 63% of energy. Similarly, Boerjesson and Gustavsson (2000) have demonstrated that the use of wood frame instead of concrete frame structures can reduce their respective primary energy needs for the production of materials by 60–80%.

In low-income countries and in particular in the case of India, climatic conditions and living standards of the vast majority of people require relatively limited amount of operating energy; the environmental impacts of housing are thus mainly related to the construction and maintenance works (Debnath et al. 1995; Emmanuel 2004; Gumaste 2006; Shukla et al. 2008, Jagadish 1979). In India, with a value of 22%, the construction sector is responsible for the highest share of carbon dioxide emissions (Shukla et al. 2008), and previous research has demonstrated that the use of alternative building technologies can reduce drastically (up to 50%) the embodied energy of the production processes (Chani et al. 2003; Venkatarama and Jagadish 2003).

9.2.2 Indicators of Environmental Impacts

Environmental impacts of building materials' production and construction processes fluctuate largely according to the region where they take place. In fact, compared to highly industrialized nations, low-income countries have generally less efficient processes that will consume more energy and generate more environmental impacts for producing the same materials (Asif et al. 2007; Buchanan and Honey 1994; Emmanuel 2004; Harris 1999). Besides, energy production processes might differ drastically between countries and even regions, that is, electricity production could derive mainly from hydropower, nuclear, or thermal plants that generate drastically diverging environmental impacts (Cole 1999). Moreover, local conditions may affect seriously the environmental impacts of processes due to large variations in transportation distances (Huberman and Pearlmutter 2008). For these reasons, it is not possible to use the same values of energy consumption and/or environmental impacts for a given material in different contexts. Most of industrialized nations have generally elaborated data banks documenting the environmental impacts of building materials and processes in a rather exhaustive way (Citherlet and Defaux 2007; Ding 2008; Ecoinvent 2008; Huijbregts et al. 2008; Jönsson 2000). The situation is very different in most of Southern countries where only limited amount of such data has been generated (Dimoudi and Tompa 2008; Gumaste 2006; Huberman and Pearlmutter 2008; Shukla et al. 2008; Venkatarama and Jagadish 2003; Yasantha Abeysundra et al. 2007).

Harris (1999) insists on the fact that various indicators of impacts must be expressed separately because it can happen that, for a same material, good results in one indicator might be accompanied by very bad ones observing another indicator. However, the aggregation of a group of indicators into a single one has been developed in various methods (Emmanuel 2004). Though being advantageous in terms of simplification of results interpretation, this approach implies a loss of information and transparency on particular performances according to specific indicators. Huberman and Pearlmutter (2008) observe that the use of single point indicators (such as energy) to assess environmental impacts might not represent all environmental aspects but are more tangible than complex models and easier to understand. The same authors have used CO_2 emissions based on primary energy consumption as a prime indicator of environmental impact because of the importance of the latter in global warming and because energy efficiency is an indicator of a building's overall resource efficiency, see also Pearlmutter et al. (2007) and González and Navarro (2006) and Gustavsson & Sathre (2006). Similarly, Buchanan and Honey (1994) consider that, among the various greenhouse gases emitted by human activities, CO_2 is the most important by-product of the manufacture of building materials. Huijbregts et al. (2006) have demonstrated that, in the case of material production, there is a good correlation between the cumulative fossil energy demand of a product or a process and the main environmental impact indicators. Morel et al. (2001) have used indicators such as energy consumption and amount of building materials to be transported for expressing environmental impacts of construction. Svensson et al.

(2006) have studied the relevance of using primary energy indicator for expressing environmental impacts in the European context. They observe that such indicator is commonly utilized (especially in terms of embodied energy in building sector) and that its relation with environmental impact seems for many to be obvious. However, though the use of energy is more or less directly connected to environmental pressure in many aspects and has also proven to affect many of the environmental impact categories, some of the latter are not directly influenced by energy consumption. In fact, Svensson et al. (2006) have demonstrated that, in the European Union context, energy indicator provides strong to moderate reflection of environmental impacts for the following categories: depletion of fossil fuels (as a resource), climate change, toxicity aspects, acidification, and waste heat, unlike the following categories that are weakly reflected by the energy indicator: depletion of minerals, metals, and other abiotic as well as biotic resources, impact of land use, desiccation, stratospheric ozone depletion, photo-oxydant formation, eutrophication, odor, and noise. The authors insist thus on the importance of using the energy indicator in conjunction with others which allow to differentiate and complete the impacts assessment. Besides, Hubermann and Pearlmutter (2008) emphasize the importance of expressing the results of impacts in a functional unit that represents building elements (i.e., [m^2 of wall]) or the entire house (i.e., [m^2 of floor area]) rather than comparing impact values per volume or weight of building materials. This is motivated by large variations of densities and content concentrations of various composed materials and by the fact that, for comparison purpose, it is much easier to compare the environmental performances of building elements instead of separate materials that, alone, do not represent the performance of a building's function.

9.2.3 Life Cycle Assessment

Pearlmutter et al. (2007) as well as Hubermann and Pearlmutter (2008), Cole (1999), and Boerjesson and Gustavsson (2000) insist on the importance of considering the entire life cycle of buildings in assessing environmental impacts for establishing comprehensive results. They propose to divide the life cycle into the following three phases: *pre-use* (embodied energy), *use* (operating energy, maintenance), and *post-use* (demolition, possible recycling, and reuse). Here again, contextual characteristics in terms of climate, construction technologies, and living culture and standards can signify drastic variations in terms of phases shares of environmental impacts. The Life Cycle Assessment (LCA) concept and methodology is thoroughly addressed in ISO (2006, 2008) where it is structured into four phases: *goal and scope definition, life cycle inventory, impact assessment, and interpretation*. The same structure can be applied for life cycle energy analysis where primary energy is inventoried and used for measuring the environmental impact (Pearlmutter et al. 2007). The disposal of building materials after demolition can represent a major environmental burden, accounting for about 29% of overall landfill volumes in the United States of America, more than 50% in the

United Kingdom, and up to 30% in Australia (Emmanuel 2004); it is consequently important to consider the afterlife of buildings in assessing environmental impacts. In fact, the environmental performances of building materials can vary substantially according to the way the materials are managed at the time of building demolition (Boerjesson and Gustavsson 2000).

9.3 Methodology

9.3.1 Approach

The research has been carried out in three main phases: (a) selection of building materials and technologies to be assessed with corresponding case studies and elaboration of the assessment method and tools, (b) LCA implementation, and (c) comparative analysis of the environmental impacts of the various technologies.

9.3.2 Life Cycle Assessment

The LCA applied here is a simplified version based on the European standards "Environmental management – Life cycle assessment", "Principles and framework" (ISO 2008), as well as "Requirements and guidelines" (ISO 2006).

Goal and Scope Definition
This LCA aims at providing quantitative and comparative values of the environmental impacts of various building technologies in the given context. It is applied to the realization of selected case studies of walling materials and building technologies through their life cycle.

The product to be assessed is the wall of single-family, one-story residential houses. *One square meter of wall [m^2] is the functional unit (FU)*; the reason for this choice is that what is to be compared is the environmental impact of a function (the function "wall") and not only of single building materials considered separately.

Inventory Analysis
The product boundaries include the walls of the house from plinth level up to the top of the wall, till inferior level of roof-level beam, gable wall included. Structural elements are also included such Reinforced Cement Concrete (RCC) columns (if part of the wall only), RCC reinforcement bands at sill, lintel, and roof level.

If there is a common wall shared with a neighbor house, this wall has to be included. Since the goal of the project is to assess the environmental impact of building technologies for walling systems only, the following elements that do not depend on the walling technologies are *not included* within the product boundaries:

windows, doors, sun protections, electric appliances and all secondary equipments, elements that are part of the roofing system, and groundwork (foundations) elements.

The quantities of materials, energy, and work necessary for 1 [m^2] of a given wall technology is obtained dividing the total amount (of materials, energy, and work) by the surface of the wall. For the materials (including water), this quantity includes the losses and breakages during production, transportation, and construction, for the energy, it does correspond to the final energy needs. The energy and materials used for production of equipments, tools, and infrastructures are not included within the boundaries.

In terms of wall construction processes, the system boundaries are covering the raw material acquisition, the production phase of the materials, the transportation to the site, the construction phase of the walls, their maintenance for over 50 years and the demolition, and the possible reuse of the materials or energy (the latter being assessed qualitatively).

9.3.3 Selected Indicators of Environmental Impact

As discussed above, because most of the available data banks on environmental impacts of building materials are consistent only in the context of industrialized countries, there is a scarcity of data for assessing such impacts in low-income countries. To do so, it is thus necessary to choose a batch of indicators that are sufficiently representative and that can be calculated with primary data and available secondary data within the timeframe and the resources available for conducting the study. Based on previous research and considering the context and particularities of the study, the environmental impacts will be expressed here mainly through indicators related to energy consumption. In addition to the total amount of energy (whatever the source), the quantity of nonrenewable energy (NRE) will be used as an indicator. Besides, in order to further evaluate the different impacts of various energy sources, CO_2 emissions will also be established. All energy values considered here are not including the indirect energy of the various processes (part of the energy to produce the machineries, the vehicles, the infrastructures that are used). Indirect energy represents a "truncation error" estimated to be around 10% of direct energy (Pearlmutter et al. 2007). In addition, Kutch District having a limited and problematical access to water, the consumption of water is also considered as an important indicator of environmental impact here. Dust generation can be a relevant issue in terms of local environmental impact, but it is not considered here due to lack of data and difficulties in quantification. For the same reason, the land surface use corresponding to the various materials' production is not taken into account. The following indicators and their corresponding units have thus been selected:

Indicator 1: Total amount of energy in megajoule per square meter [MJ/m^2]
Represents all energy sources that are used (animate, fossil, renewable). Since the modes of production and construction might evolve in the future (maybe toward more mechanized processes), this indicator represents also the potential level of

environmental impact in case of major mechanization of processes for technologies that make currently extensive use of renewable energies.

Indicator 2: Amount of non renewable energy [MJ/m^2]
The distinction between renewable energy (RE) and NRE consumption will allow a clear differentiation of environmental impacts of the various materials and walling technologies.

NRE sources utilized in the framework of this study are coal, lignite, diesel, and 83% of the electricity (the part produced with thermal and nuclear plants).

RE sources are 17% of electricity (the part produced with hydropower), human, wood, and animal energy sources. The indicator NRE will also be utilized for representing the importance of transportation in energy needs of the various processes.

Indicator 3: CO_2 emissions in kilograms of CO_2 per square meter [kg (CO_2)/m^2]
CO_2 emissions represent here the Global Warming Potential (GWP). Due to lack of data, other indicators of GWP such as CH_4 are not represented here. However, as discussed earlier, CO_2 emissions can be considered alone as representative in terms of GWP for comparative purpose.

Indicator 4: Water consumption in liters per square meter [lt/m^2]
The total amount of water used for materials production and whole construction and maintenance processes.

9.3.4 Data Requirements and Assumptions

It is essential for representative results that the data are corresponding to the real context conditions. Since such very limited data are available, most of them had to be collected as primary source in the field. For each material and technology under study, data on the materials' origins, quantities, transportation distances and means, production procedures, and energy consumption have been collected (see Table 9.1). Concerning the equipments and transportation means, consumption values have been collected in the field and compared with primary data available. The values of various energy sources that have been utilized have been collected in various sources and compared in order to determine average values to be considered in the calculation of impacts.

Assumptions made for the calculation of transport and energy impacts are presented below.

9.4 Results

9.4.1 Building Technologies Under Study

The physical characteristics of every technology (wall thickness, structural strength, thermal resistance, heat storage capacity, durability among others) are variable and derive directly from the building materials and corresponding

Table 9.1 Assumptions made for the calculation of transport and energy impacts

Objects	Assumptions
Transportation distance for cement	Average distance of 450 km is considered for all applications
Transportation distance for steel	Average distance of 1,500 km is considered for all applications
Transportation distances for other materials	According to actual distances of case studies
Energy for water supply (pumping)	Average energy consumption based on: $\Delta h = 120$ [m], discharge = ca. 80 [lt/min], E = ca. 6.3 [kJ/lt], considered for all applications
Electricity mix	Electricity mix corresponding to the national mix average is considered. Electricity is generated in India by 80% of thermal, 17% of hydro, and 3% of nuclear power plants. This mix is generating a very high amount of CO_2 emissions equal to 1.37 [kg (CO_2)/kWh] or 0.3806 [kg (CO_2)/MJ] (TERI n.d.)
CO_2 emissions for coal	0.1127 [kg (CO_2)/MJ]. Average between the values given by IPCC (n.d.) and VSBK (2008)
CO_2 emissions for lignite	0.1668 [kg (CO_2)/MJ] (Sarkar 1988)
CO_2 emissions for diesel	0.0809 [kg (CO_2)/MJ]. Average between the values given by IPCC (n.d.) and VSBK (2008)
CO_2 emissions for wood	Considered zero, CO_2 emissions at the moment of combustion is approximately the same amount compared to the CO_2 that has been absorbed by the tree during its lifetime (IPCC n.d.)

technology. Those variations might have important consequences in terms of overall building performances that are only partially considered in the framework of this study. The results presented here derive from samples that integrate seismic resistance features in the cases where such elements are originally not present (if the technology requires it in order to resist seismic forces). The durability is considered through the assessment of maintenance works over 50 years. The various technologies that have been studied present substantial variations also in terms of combination of materials, for example, a same walling material (i.e., natural stone) has been assessed in combination with different types of mortars for the joints or different types of plasters. However, in order to provide comparative and synthetic results of the main technologies under study, out of 67 samples, we have elaborated a list of 17 cases that have been made uniform in terms of strength and seismic resistance. Their thicknesses as well as the presence and type of plastering mainly depend upon the respective technology characteristics; they have been made uniform only when this was realistic.

9.4.2 Results

9.4.2.1 Total Energy Consumption for Construction and Maintenance Phases

Wattle and daub, cob wall, and unstabilized adobe are clearly the technologies using less energy during the construction phase. Then come the uncoursed random

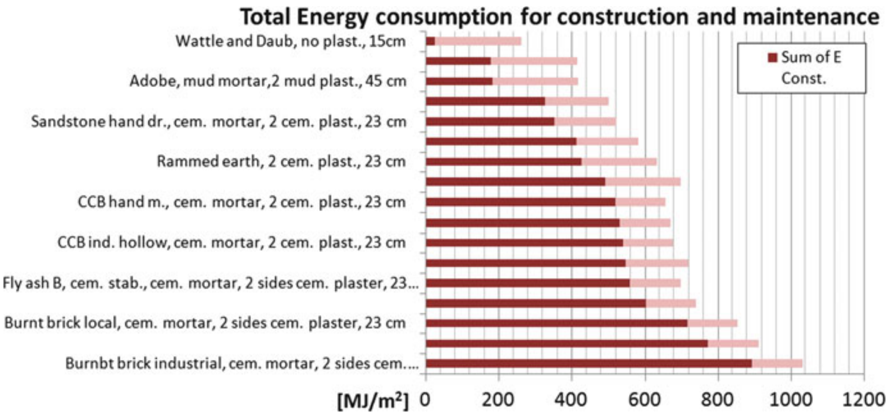

Fig. 9.1 Total energy consumption for construction and maintenance phases

masonry (UCR) with mud mortar, sandstone masonry, rammed earth, compressed-stabilized earth block (CSEB) wall, various cement concrete blocks (CCB), UCR with cement mortar, cement- and lime-stabilized fly ash blocks, locally burnt bricks, and RCC and industrial burnt bricks.

The results in terms of total energy consumption (for construction plus maintenance) correspond almost to the same rating but in terms of energy needs for maintenance there is a notable difference of proportion between the earth-based technologies that have no plaster or mud plaster and those technologies that have cement or lime plaster. In fact, when cement plaster is there, the energy needs for maintenance are proportionally much lower compared to the needs during the construction phase. Instead, when no cement plaster is there, maintenance works absorb a big share of the total energy needs. In the cases of adobe and cob walls, it represents about 56%, and in the case of wattle and daub, about 90% of the total energy needs are due to the maintenance over 50 years.

The influence of using cement mortar instead of mud mortar in the case of UCR walls is relevant. In fact, though the thickness of the UCR wall using mud mortar is major to that of the wall with cement mortar (45 instead of 38 cm), its total energy need is 30% lower. Figure 9.1 below and Table 9.2 at the end of the chapter provide more details on those findings.

9.4.2.2 Total NRE and RE Energy

Making abstraction of the energy needs for transportation, the share between NRE and RE consumption is characterized by high levels of NRE needs for the technologies based on industrial materials (about 80% and above). On the contrary, the technologies based on local natural materials and extensive workmanship

Table 9.2 Values of indicators for various technologies

Technologies	E const. [MJ/m^2]	E maint. [MJ/m^2]	NRE without transp. [MJ/m^2]	RE without transp. [MJ/m^2]	NRE transp. [MJ/m^2]	RE transp. [MJ/m^2]	CO_2 const. [kg/m^2]	CO_2 maint. [kg/m^2]	Water const. [lt/m^2]	Water maint. [lt/m^2]
Wattle and daub, no plast., 15 cm	26	236	35	176	43	8	1	19	202	4,477
Cob wall, mud mortar, 2 mud plast., 45 cm	179	236	166	179	63	7	34	19	502	4,477
Adobe, mud mortar,2 mud plast., 45 cm	183	236	187	188	40	4	34	19	420	4,477
UCR, mud mortar, 2 cem.plast., 45 cm	327	174	335	62	103	1	59	35	225	124
Sandstone hand dr., cem. mortar, 2 cem. plast., 23 cm	353	170	379	66	77	1	70	35	110	124
Sandstone mach. dr., cem. mortar, 2 cem. plast., 23 cm	413	170	388	69	125	1	78	35	110	124
Rammed earth, 2 cem. plast., 23 cm	426	208	456	120	57	1	80	41	144	186
CCB hand m., cem. mortar, 2 cem. plast., 23 cm	519	139	511	79	67	1	112	28	385	124
CCB ind. solid, cem. mortar, 2 cem. plast., 23 cm	532	139	485	75	109	2	107	28	335	124
CCB ind. hollow, cem. mortar, 2 cem. plast., 23 cm	540	139	498	76	104	1	108	28	329	124
Fly ash B, cem. stab., cem. mortar, 2 sides cem. plast., 23 cm	559	139	482	76	138	2	110	28	255	124
CSEB, cem. mortar, 2 cem. plast., 23 cm	492	208	524	97	77	1	103	41	377	186
UCR, cem. mortar, 2 cem. plast, 38 cm	548	170	524	78	116	1	112	35	191	124
Fly ash B, lime stab., cem. mortar, 2 sides cem. plast., 23 cm	603	139	525	64	151	2	95	28	255	124
Burnt brick local, cem. mortar, 2 sides cem. plast., 23 cm	717	139	524	278	52	1	95	28	227	124
RCC, 2 sides cem. plast., 15 cm	774	139	722	88	101	2	161	28	108	124
Burnbt brick industrial, cem. mortar, 2 sides cem. plast., 23 cm	895	139	857	61	114	2	127	28	227	124

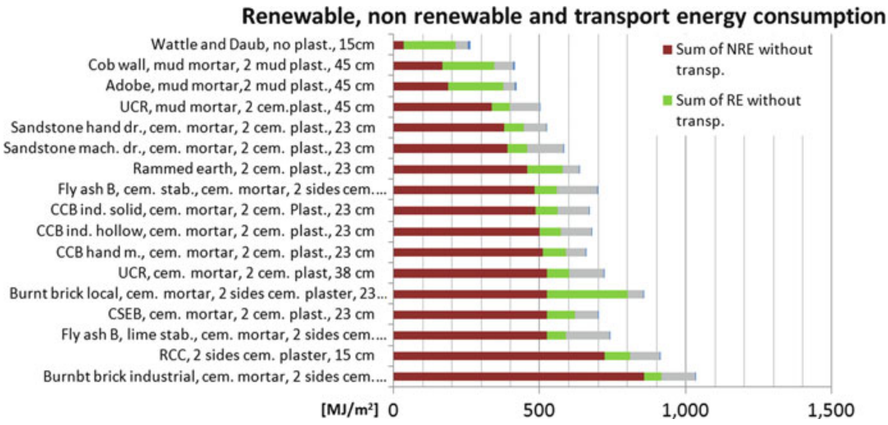

Fig. 9.2 RE, NRE, and transport energy consumption

(earth) are making predominant use of renewable energy. In the case of adobe and cob walls, the share is about 50%, for locally produced burnt bricks (that make partial use of wood), RE represents 35% of the total energy consumption, and for wattle and daub, RE is predominant with a share of 84% (see Fig. 9.2 and Table 9.2).

9.4.2.3 Transportation

The medium value of transportation energy (NRE and RE) for all technologies is 93 [MJ/m^2]. Most of it is from NRE sources (Diesel), in fact, only limited transportation is realized with renewable energy sources such as human and animal, and this is the case mainly for adobe, cob, and wattle and daub walls. The medium percentage of transport energy compared to total energy consumption for all technologies is ~15% and it varies from 6% to 22%. The technologies making predominant use of locally available materials are naturally those presenting the lowest energy consumption for transportation (51–70 [MJ/m^2]).

9.4.2.4 CO_2 Emissions for Construction and Maintenance Including Transport

CO_2 emissions are not linearly proportional to energy consumptions because of the fact that various energy sources generate variable CO_2 emissions for a given quantity of consumed energy (see Sect. 9.3.4). In the present case, earth-based technologies are very clearly those emitting proportionally less CO_2 because they make larger use of RE. On the contrary, the technologies that make extensive use of

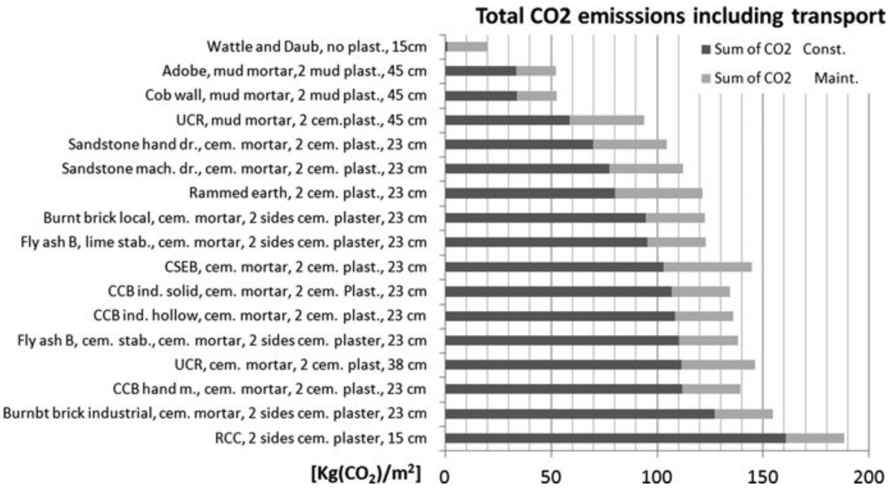

Fig. 9.3 CO_2 emissions including transport

NRE are those generating proportionally more CO_2. Besides, they are substantive differences of CO_2 emissions intensity among NRE sources as well. In India, cement production is consuming a lot of electricity (and coal), and electricity production there results in a very high amount of CO_2 emission (see Sect. 9.3.4). Consequently, technologies with a high content of cement are high CO_2 emitters (comparatively to their energy consumption). Here RCC wall is from far the highest CO_2 emitter even though it is not the one presenting the highest energy consumption level. Generally, extensive use of electricity (mainly produced through thermal plants fuelled with carbon), coal, lignite, and diesel is responsible for the highest CO_2 emissions levels (see Fig. 9.3 and Table 9.2).

9.4.2.5 Water Consumption

There are huge variations of water consumption among the various technologies, mainly concerning the water needed for maintenance (see Fig. 9.4). Unstabilized earth walls, in particular cob walls, as well as wattle and daub walls are by far the technologies using the highest amounts of water. Cob walls are also consuming the biggest amounts of water in construction phase. Apart from the latest categories, all technologies require equal or less water for maintenance than for construction. It is essential to keep in mind that the water consumption for maintenance purpose results from the cumulated amount over 50 years. The maintenance activities that need big amounts of water can be planned, taking into consideration seasonal variations in order to take advantage of rainwater when it comes. If the conditions

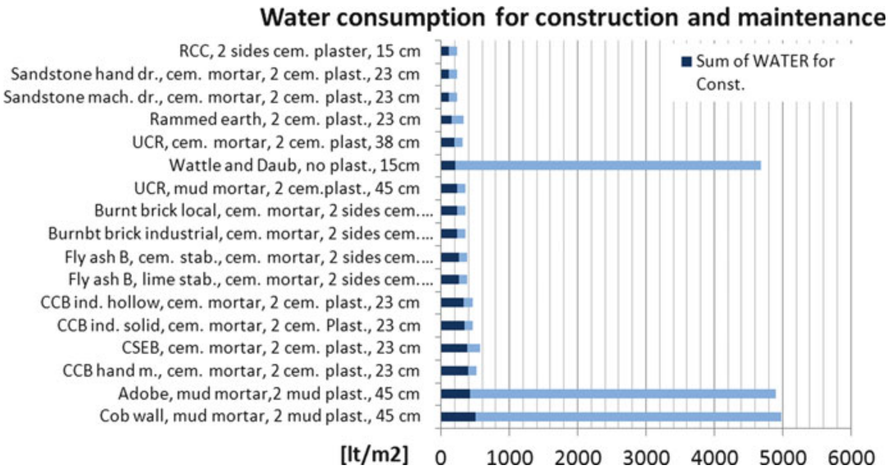

Fig. 9.4 Water consumption for construction and maintenance phases

and the maintenance needs allow such strategy, then the issue of water consumption for maintenance might become less problematic.

9.4.2.6 Environmental Impacts of Demolition

Such impacts have been estimated qualitatively because there are extremely difficult to measure effectively. Every technology has been evaluated considering two criteria (a) energy needed for the demolition of the wall (weight 2) because it is assumed that this aspect has higher direct impact compared to b and (b) recycling possibilities of the materials (weight 1). The highest impacts of demolition are reached with RCC walls and lime-stabilized fly ash block walls. In fact, both imply a high amount of energy for demolition and present difficulties in recycling the wastes from demolition. Block and brick walls as well as stone walls and CSEB using cement mortars and stabilized rammed earth present medium to high demolition impacts. Finally, cob walls, adobe, wattle and daub, and UCR masonry with mud mortar have the lowest impact in terms of demolition.

9.5 Conclusions

This research has demonstrated that there are considerable variations of energy and water consumption as well as CO_2 emissions between different walling technologies. In order to reduce substantially the energy consumption and related CO_2 emissions, technologies such as adobe, cob walls, wattle and daub, and stone walls, making limited use of cement or lime mortar and plaster should be encouraged. Rammed earth, cement, and fly ash blocks as well as stabilized earth technologies represent possible alternatives, in particular if they make limited use of cement or lime mortar and plaster. In this case, proper constructive and maintenance measures must be observed in order to preserve the durability of the structures. When such technologies are applied in combination with significant amounts of cement or lime mortar and plaster, their environmental impacts increase substantially. Burnt clay bricks, in particular those coming from industrial processes, as well as RCC walls present from far the biggest impacts in terms of energy consumption and CO_2 emissions. Because of the characteristics of the cement production processes in India (energy mix and efficiency), the CO_2 emissions of RCC are exacerbated compared to the energy consumption.

Water consumption is presenting totally different figures, in the sense that the technologies that are performing better in terms of energy consumption, CO_2 emissions, and demolition phase (adobe, cob walls, wattle and daub) are those consuming drastically higher amounts of water, especially during the maintenance phase. However, the relevance of this issue could be lowered when maintenance activities that need big amounts of water are planned according to seasonal variations taking advantage of the abundance of water during the rainy season. If the conditions and the maintenance requirements allow such strategy, then the issue of water consumption for maintenance might become less problematic and relevant.

The results of this study are valid only in the context of Kutch and, to a certain extent, in other Indian regions because they are directly influenced by various local factors such as the characteristics of energy sources and the specific uses made of such sources for the various production processes. In particular, the composition of the electricity mix (shares of thermal, nuclear, hydro, or other renewable sources for producing electricity) has a drastic influence on CO_2 emissions. Similarly, the fact that the production of a material can be done using different energy sources according to the region (i.e., using coal instead of wood for firing bricks) will influence seriously the impacts on the environment, like the energy efficiency of production processes. The impacts due to transportation of materials are also variables according to the distances and the means utilized. The contextualization of environmental impact assessment is consequently of primary importance in the search for representative results.

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Part V
Vulnerabilities: At the Heart of the Risk

Magali Schmid

Disaster risk reduction (DRR) is one of the four priority fields of concern of the UNESCO Chair in Technologies for Development at EPFL. Unlike the other three (habitat and cities, information and communication technologies for the environment, and sustainable energy production), which are more clearly delimited fields, disaster risk reduction – although it has its own terminology, concepts, and methods – should rather be thought of as an interdisciplinary issue, transversal to the others.

Bearing in mind that disasters can have a devastating impact on development prospects and dangerously compromise the millennium development goals (MDGs), it is essential that we do not approach DRR in compartmentalized fashion but rather weave close ties with other key sectors, such as development or reduction of poverty, along with humanitarian activity – postdisaster reconstruction must draw lessons from the disaster itself and incorporate concepts for risk reduction. Further links must be forged and consolidated with experts in climate change adaptation, for, as Intergovernmental Panel on Climate Change (IPCC) experts continue to emphasize, the challenge of global warming is likely to engender increasing numbers of extreme climatic events (floods, landslides, hurricanes, etc.) along with disasters occurring gradually such as drought and desertification – all of which also means that we should in no way neglect the essential links with another major sector: environmental management.

One basic concept lies at the heart of DRR: vulnerability. No vulnerability, no disaster. Major natural phenomena have always existed, but, for centuries, many of them could hardly be considered as disasters as they had little or no impact on mankind or their environment. With a world population that should have crossed the seven-billion mark by the end of 2011, and with a majority of people now living in urban areas, the question of vulnerability takes on a whole new dimension.

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Increasing population density leads to the emergence of new kinds of vulnerabilities, often interlinked and therefore frequently superimposed: those arising from the dangers inherent in a particular area (e.g., flood-prone areas); those arising from individuals themselves (those at risk due to age, sex, ethnic group, or state of health); those arising from social status (poverty, education, or social networks); and, on a wider scale, those linked to social protection and governance (political and economic conditions).

In this part, the question of vulnerability is approached from a number of different angles.

In the first chapter, Provitolo carries out a detailed analysis of the concept of (biophysical and social) vulnerability, in the light of which she presents notions of capacities and resilience, before going on to develop a proposal for a conceptual model of "resiliencery vulnerability," stressing the complexity of the two concepts – a complexity arising from the close synergies that bind them.

In the second chapter, Kern, Bolay, and Ngo Thanh propose a more targeted approach to vulnerability arising from climate change, in the periurban context of Vietnam's Mekong Delta. On the basis of an interdisciplinary project bearing on environmental diagnosis and study of the socioeconomic context, they examine the strategies for adaptation adopted, including the policy of relocation and rehousing of local populations implemented by the State, and finally recommend development of tools to assist decision-making.

In the final chapter, Tabi, Adiku, Ofori, Nhamo, Omoko, Atika, and Mayebi take us to Africa, examining the ways in which vulnerabilities are perceived in the face of climate change and the strategies adopted by small rice producers, this time from a far more technical point of view.

Through their differences and also through their complementarity, these three chapters demonstrate – if it were necessary to do so – how complex and variable a concept vulnerability is and also how central resilience and capacities for adaptation are to better understanding of risk and to the setting up of a concerted mitigation strategy seeking to limit as far as possible negative impacts of disasters throughout the world.

Chapter 10
The Contribution of Science and Technology to Meeting the Challenge of Risk and Disaster Reduction in Developing Countries: From Concrete Examples to the Proposal of a Conceptual Model of "Resiliencery Vulnerability"

Damienne Provitolo

10.1 Introduction

Human societies and territories have always been confronted with hazards and risks, which are occasionally the source of disasters (Quarantelli et al. 2006). Over recent years, natural disasters have taken a heavy toll throughout the world, and more severely so in the developing countries: from the tsunami in the Indian Ocean to the earthquakes in Iran and Southern Asia, including the hurricanes in Burma, the Caribbean, and the Pacific; torrential rains, mudslides, and landslides in various parts of Asia and Latin America; and volcanic eruptions. Even if the situation in poor countries varies, the distribution of disaster victims illustrates the contrast between developed countries and developing countries (Fig. 10.1). In developing countries, the loss of human life and means of subsistence as a result of disasters due to natural, technological (EM-DAT Database n.d.), or social causes are major. The population explosion in Southern countries, development of megalopolises, anarchic urban growth, environmental degradation and the impact of climate change combined with the social and economic context of these societies, and their lack of means and organization in terms of risk and disaster prevention and management, all contribute to making these events catastrophic. Apart from the fact that these factors increase the vulnerability of Southern countries, the consequences of these disasters can also constitute a brake upon development.

Over the last 30 years, research on risks and disasters has greatly increased. This is partly due to the influence of the action of the United Nations (UN), which instituted an International Decade for Natural Disaster Reduction (IDNDR), the Kyoto Protocol linked to the United Nations Framework Convention on Climate Change (UNFCC),

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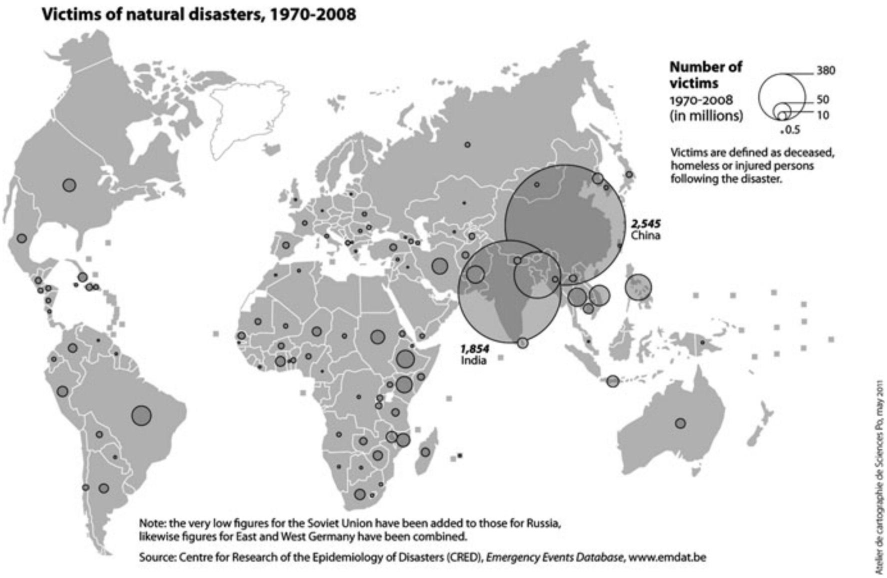

Fig. 10.1 Distribution of natural disaster victims 1970–2008 (Source: Atelier de cartographie de Sciences Po [http://cartographie.sciences-po.fr] 2011)

and the International Strategy for Disaster Reduction (ISDR). Furthermore, the European Union is developing a strategy for disaster risk reduction in developing countries as part of the Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters. This strategy must be linked with adaptation to climate change strategies and actions for the prevention of and reaction to crises of human origin. Lastly, the Millennium Development Goals (MDGs) aim to make risk and disaster reduction a local and national priority via initiatives to promote resilience to disasters or disaster risks, such as climate change. All these objectives can be attained, thanks to the contribution made by science and technology concerning disaster reduction and the protection of societies and their adaptations to risk situations (Subcommittee on Disaster Reduction 2005).

The aim of this chapter is to show how science and technology can help to meet the challenge of risk and disaster reduction in developing countries and thus participate in the implementation of actions to promote development. In the first part, based on reflections in this domain and concrete actions, we will show how research and technology transfer can be dedicated to modifying the vulnerabilities and resilience of societies and therefore development. Then, in the second part, we explain the evolution and multiplicity of meanings of the concepts of vulnerability and resilience. This analysis highlights the fact that one of the challenges for research today is to understand the relationships established between these two concepts and reexamine the idea that there is, on one side, the vulnerable societies (and thus the weak: developing countries are more often than not stigmatized in this category) and, on the other, the resilient societies (and thus strong, capable of fighting back, recovering from a hazard: the developed countries). This is why the third and last part is devoted to the presentation of a conceptual model for analyzing the vulnerability and resilience of systems (socioeconomic systems, territorial systems, etc.) exposed to disaster risks. This is the “resiliencery vulnerability”[1] model. The idea is to help societies to anticipate and understand disasters that are becoming more and more complex and systemic, as we now see with events in Japan, the Haiti earthquake, and so on.

10.2 How Science and Technology Can Help Meet the Challenge of Risk and Disaster Reduction in Developing Countries: Some Concrete Examples

Many developing countries combine exposure to numerous hazards and high social and economic vulnerability. Whether it concerns prediction and monitoring, prevention, or action when a disaster occurs, populations find themselves in a situation of vulnerability. Here we are not going to list the vast number of science and technology initiatives to act on the vulnerability and resilience of societies in developing countries. We are simply trying to show how science and technology can assist development and thus reduce risks and disasters, and do so more particularly in the domain of natural resource management and food security, information and communication, and health disaster management.

10.2.1 Science and Technology for Natural Resource Management and the Challenge of Food Security in Developing Countries

The management of natural resources, of ecosystems, especially by land use planning and improving development activities, contributes to the reduction of the poverty of populations, disaster risks, and vulnerability factors (IFAD n.d.). At Mount Kenya (in the country of the same name), for example, natural resource management on the eastern slopes has been based on varied adaptation measures: reforestation, improvement of water resource management (confronting rainfall shortages, thanks to the installation of appropriate structures, such as water collection and storage tanks), and appropriate agricultural practices. The most outstanding results are achieved via the improvement of water supply infrastructure, rehabilitation of degraded land, and riverbank protection, thanks to plantations and agroforestry (IFAD n.d.).

[1] The original French term is “vulnérabilité résiliençaire.”

In all developing countries, demographic growth, urbanization, and more recently climate change jeopardize water supplies for people and crops, local agricultural production, and therefore the means of subsistence of populations. The management of water (deficit and surplus) and agricultural production by the management of natural resources are key factors in poverty reduction and improved food security. This, therefore, involves providing these countries with tools and technologies allowing them to ensure food production and food security and predict local and regional shortages (as well as water excesses that can be equally devastating, as was the case with the floods in Pakistan in 2010). To meet these needs, science and technology are intensifying research to provide local actors in developing countries with climate models adapted to the local context (information regarding the regional impact of climate change), propose technology transfers from developed countries to developing countries to build disaster-resilient drinking water and sanitation infrastructures, enable the construction of water conveyance facilities protected against the effects of climate change and other natural hazards, and develop water storage systems. These structural measures are accompanied by nonstructural measures (increasing public awareness, development and diffusion of knowledge, implementation of more rigorous construction standards, etc.). And here too, technology helps with the implementation of these nonstructural measures.

10.2.2 Science and Information and Communication Technologies Dedicated to Disaster Reduction and Management

All disasters, whether of natural, technological, or social origin, reveal needs for information and communication. Indeed, when a disaster occurs, there is generally a malfunction or breakdown of telecommunications networks. And yet, in crisis, disaster, or catastrophe management, communication needs are of paramount importance, both for intervention and coordination operations and for warning the population. Information and communication technologies, therefore, have their role to play in the management of these events, at different levels of intervention: mitigation of the impact of hazards and the vulnerability of societies, individual or collective preparation for the event, intervention, coordination, and communication (between rescue teams for example) on the site of the disaster. These technologies must also allow the installation of rapid warning systems to inform populations of the procedure to be followed in the event of exposure to a threat.

These technologies include particularly remote sensing (observation, data collection and transmission, event monitoring); Internet, web sites, and portals (accessibility to data, information and knowledge sharing, informing the population concerning the risks involved, etc.); and communication systems (television, radio, satellite, mobile phones, broadband to predict the event and diffuse information). Satellite technology, for example, is used to monitor and evaluate damage, analyze environmental impacts, and guide rescue teams in disaster areas.

In developing countries, satellite technology has been used during many disasters, whether for monitoring the development of hazards and the affected areas (weather event resulting in floods in Pakistan in August 2010, anticipating the path of a cyclone), analyzing damage (as in the earthquake in Sichuan, China, for example), or identifying priority measures to be taken following natural disasters (the 2010 earthquake in Haiti). With regard to population warning, the Council for Scientific and Industrial Research (CSIR) has set up an Advanced Fire Information System (AFIS) in South Africa aimed at improving the management of these events. This system enables fires to be detected by satellite (the MODIS satellite can locate active fires with a precision of approximately 200 m), and rapid warnings to be sent to the population via mobile phone, a technology available in the remotest parts of Africa where the population has access to mobile phones (Frost 2009). This low-cost technology is also used to send warnings via Short Message Service (SMS) to the population of Bangladesh, exposed to numerous natural hazards including hurricanes and storms. Likewise, an early disaster warning system for Africa (designated SERVIR) was set up several years ago as a result of collaboration between the Regional Center for Mapping of Resources for Development (RCMRD was created in 1975 by the United Nations Economic Commission for Africa [UNECA]) and NASA. SERVIR provides free of charge on the Internet and in real-time data concerning several types of disasters, especially drought (Ottichilo 2009). Another example, the *Global Monitoring for Food Security* project, uses technologies to provide rapid warning services concerning famine in sub-Saharan Africa. The current challenges are notably to succeed in diffusing, or continue to diffuse, the use of these space technologies to all developing countries and allow transmission of information obtained via satellites to the population.

Finally, a last example concerns the role of science and technology in health disaster management.

10.2.3 Science and Technology Help to Combat Health Disasters in Developing Countries: The Example of AIDS

The AIDS pandemic is an example of a health disaster illustrating the contrast between the vulnerability of the populations of developed countries and those of developing countries, the former being less severely affected than the latter by this disease. Scientific research carried out for the most part in rich countries helps to meet the challenge of AIDS, even if for the moment no drug has enabled this scourge to be eradicated and no preventive vaccine has been found. But science is making constant progress. Although HIV treatments – both old and recent – target the constituents of the virus, those of the future will attack their interactions with the components of the infected cell (Mouscadet 2009). Since 1996, the tritherapies in particular have increased patient life expectancy. But these treatments are expensive despite the development of generic medicines, and especially so for developing countries. One of the challenges of the World Health Organization (WHO) is to act on this public health problem in the world, particularly in poor countries, and it, therefore, collaborates with its member states to curb the spreading of the disease and attenuate its effects. Initiatives for technology transfers from developed countries to developing countries are under way, for example, to provide local manufacturers with the know-how necessary for the manufacture of anti-HIV generic drugs. This technology transfer contributes to meeting the needs of populations affected by HIV infection and improving access to medicines and thus the health of the infected population. This technical know-how not only concerns the manufacture of anti-HIV generic drugs (technologies for health disaster management) but also extends more globally to the manufacture of medicines (technologies for development and public health). Research is also being carried out in developed countries to produce vaccines against AIDS. Since Africa is the continent most affected by the HIV infection, the diffusion of these vaccines will also require technology transfers to acquire the know-how and production capacity necessary for their manufacture.

The presentation of these few actions originating from varied domains shows that an approach based on prevention, adaptation, and resilience, an approach supported by science and technology, encourages the implementation of new practices in the fight against disaster risks. But these actions also show that the vast majority of measures for adaptation to risks and disasters are part of more or less costly and sometimes inadequate development interventions. Just reading about these few examples, it is easy to understand (1) that "development" interventions and those intended to improve the responses of developing societies confronted with risks and disasters are closely linked and (2) that science and technology are needed to innovate and diversify the responses of societies confronted with risks and disasters and thereby act on their vulnerability and resilience.

And here again, research plays a key role in understanding the vulnerabilities and resiliencies of societies and the expansion of these concepts.

10.3 Vulnerability and Resilience, a Rainbow of Meanings

On the conceptual level, the terms vulnerability and resilience have been the focus of passionate interest over the last 20 years on the national and international scientific scene. Although vulnerability and resilience can apparently only be understood in relation to each other (Van der Leeuw and Aschan Leygonie 2005; Gallopin 2006), these two concepts remain polysemic, and their multiple definitions tend to obscure their meaning.

We will enumerate the different meanings of these concepts, identifying the scientific context in which they appeared. The aim is not to impose a uniform meaning but to extract the rainbow of meanings, to use D. Collin's (n.d.) expression, attributed to these two concepts.

10.3.1 Vulnerability in the Spotlight

If risk has long been restricted to the study of hazard, a change became apparent in the 1950s with the appearance of the notion of vulnerability. Since then, this notion of vulnerability has continued to establish itself, expand, and become more complex. The probable occurrence of a risk and the consequences of a disaster can no longer be understood by studying hazard (Beucher and Reghezza 2004).

But the relatively recent appearance of vulnerability studies on the scientific scene and the multidisciplinary aspect of this subject make it a polysemic notion that still remains to be explored (Gilbert 2009) and, in the face of the issues of climate change and gradual risks (Brooks 2003; Luers 2005), reexamined. We will not relate all the historical development of this notion (we invite readers who are interested in this point to refer to the syntheses and research carried out by Becerra and Peltier 2009; D'Ercole et al. 1994; Gilbert 2006; Magnan 2009; November 2006; Beucher and Reghezza 2004).

Based on the Anglo-Saxon approach that distinguishes biophysical vulnerability from social vulnerability (Adger 1999; Adger and Kelly 1999), we show that beyond the limits of these notions, vulnerability paved the way for the concept of resilience.

10.3.1.1 From Biophysical Vulnerability to Social Vulnerability

Behind this concept of vulnerability lie two approaches. One analyzes vulnerability based on an assessment of damage (human, material, species, heritage); the other focuses on vulnerability from the point of view of the response capacities of a system subjected to a hazard. In the first instance, vulnerability is the result of the impact of the hazard on the system. In this case, we talk of biophysical vulnerability (according to Anglo-Saxon terminology). In the second instance, the system's vulnerability is evaluated independently of the hazard. This is social vulnerability (according to Anglo-Saxon terminology).

As specified by Beucher and Reghezza 2004, the term biophysical suggests a physical component, a biological (for a natural system) or social (for a human system) component. Three factors influence the biophysical vulnerability of a system: the exposure of the elements to the event, their resistance, and their sensitivity. The level of exposure is defined by the nature, magnitude, and frequency of the hazard and the proximity of societies and territories to the hazard area. Resistance is the system's potential for absorbing or counteracting the effects of a disruption without sustaining damage. This may involve the physical resistance of infrastructures or the physical or mental resistance of a person or group of individuals. Technological solutions for resistance to a risk are usually favored: build a dike to prevent flooding, earthquake-resistant construction to reduce the vulnerability of the built environment and populations, and so forth. Protective structures (dikes, dams), water storage structures (to develop resistance to climate vulnerabilities), earthquake-resistant constructions are therefore a form of societal resilience for a type of risk and given intensity. The transfer of these forms of resistance to developing countries must enable the resistance of collective facilities (hospitals, schools, etc.), major infrastructures (vital communication channels and transport routes), and buildings to be protected and improved. It should also be borne in mind, however, that these defensive, protective structures are themselves vulnerable. They do not provide absolute protection and sometimes give the population a false sense of security, both in developed countries (as in the examples of the windstorm Xynthia that crossed Western Europe on February 26–28, 2010 or the cyclone Katrina in 2005) and developing countries. The sensitivity of the system derives from its resistance – sensitivity being meant in the sense of the damage that the system is likely to sustain. Thus, the greater the losses, the higher the sensitivity and vice versa. Biophysical vulnerability is therefore based on estimation of damage in terms of losses and, more rarely, in terms of gains. But this approach underestimates the social dimension of vulnerability and, particularly, the capacity of living systems to anticipate, cope with, manage the event, and recover.

Social vulnerability is considered "as a property of the stakes that depend on the social system and not on the hazard" (Beucher and Reghezza 2004). It is a state that exists within a system before it is confronted with a hazard (Adger 1999; Adger and Kelly 1999). In this sense, social vulnerability is inherent to a system (Brooks 2003) and does not depend on either exposure to the disruption or its intensity. Research is therefore being carried out to identify the factors determining vulnerability (Cutter 1996; Pigeon 2005). According to the authors, social vulnerability depends on the level of resources – income, capital, and social networks – and the level of accessibility to credits and information (Blaikie et al. 1994; Cross 2001; Wisner 1998, 1999), cultural and institutional factors (Bolay 1994; Maskrey 1993; Ouallet 2009; Thouret and D'Ercole 1996), and technical and organizational factors. It, thus, involves a qualitative approach that focuses on the identification of vulnerability factors intrinsic to the social system studied. Generally, this approach concentrates on the human dimension (individuals, groups, institutions) of social systems. Social vulnerability, therefore, depends on a series of socioeconomic factors that determine the capacity of individuals, groups, or institutions to cope with the impacts of disruptions (Allen 2003).

10.3.1.2 The Conceptual Limits of Biophysical and Social Vulnerabilities

These approaches to vulnerability have several limits.

Firstly, the notions of biophysical vulnerability and social vulnerability are sources of ambiguity as they do not distinguish between vulnerable elements and their vulnerability factors or abilities to combat their vulnerability. In this context, social vulnerability would be analyzed on the basis of active factors (capacities), while biophysical vulnerability would be analyzed on the basis of passive factors, or rather factors considered as being passive (exposure, resistance, sensitivity). And yet a biophysical system, like a social system, develops coping capacities. This brings to mind particularly the adaptation (or nonadaptation) of living species (fauna and flora) to climate fluctuations (extinction of dinosaurs, woolly mammoths of Eurasia, or the present adaptation of certain forest species in the face of climate change). Likewise, it seems to us that these notions of active and passive vulnerability are obsolete. Indeed, to talk of passive vulnerability would mean that the behaviors and practices of a living system could not in any way modify its exposure, resistance, and sensitivity to hazards, while these criteria can in fact be modified as a result of new practices and behaviors adapted to the situation.

Furthermore, a system's social vulnerability is said not to depend on either exposure to the hazard or its intensity. At the moment, opinions differ regarding whether or not the exposure component should be integrated into the vulnerability system. For Gallopin (2003), for example, exposure is not a component of vulnerability. However, research (IPCC 2001, 2007) and disaster simulation models (Provitolo 2002, 2003) have shown that vulnerability is modified by the dynamics of the event and the system's exposure to these dynamics. In fact, if we wish to make a diagnosis regarding vulnerable territories apart from any consideration of potential threat, neither the identification of a specific event nor the exposure criterion is necessary; on the other hand, if the vulnerability of systems is being studied in the context of risks (climate change) or events (accidents, disaster, catastrophe), the exposure criterion must be integrated into the vulnerability system.

Finally, these two approaches barely consider the interactions that exist between man and the spaces he occupies and develops (Provitolo 2002, 2009; Hilhorst 2004; Reghezza 2006). And yet, on whatever scale a complex system is being analyzed, interrelations between its constituents, between physical and human processes, are identified. On a planetary scale, human activities tend to increase the concentration of greenhouse gases in the atmosphere, leading to a climate risk (situation of deficit or excess of water that varies in different regions of the globe). On this subject, researchers have shown that Africa is likely to be the continent most seriously affected by the effects of climate change although its contribution to the increase in greenhouse gas emissions is minimal. On a local scale, coastal erosion is aggravated by human activities (river management, aggregate extraction in riverbeds and the sea, drainage of coastal marshes).

The human and social sciences and multidisciplinary research groups then develop this concept of vulnerability further by showing that the two abovementioned approaches are not contradictory. Vulnerability has two sides: it is endogenous to the system, but it also depends on its capacity to sustain a disruption, absorb it, adapt to it, and then resume normal functioning. Human societies, for example, are capable of adapting to the hazard, learning, and thus modifying their exposure to the hazard. The 2001 report of the Intergovernmental Panel on Climate Change (IPCC) follows the same line of thought by defining vulnerability as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability extremes. Vulnerability is a function of the character, the magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity."

The notion of vulnerability, thus, paves the way for resilience.

10.3.2 Resilience, a Changing and Disparate Concept

Resilience is a concept of physical origin, transferred to the social sciences after a detour via ecology. When these transfers between sciences occur, the concept is diversified and becomes polysemic.

10.3.2.1 From Disciplinary Resilience

The term resilience was first used in physics and metallurgy (Gordon 1978). In these fields, resilience designates the material's resistance to impact and the structure's capacity to absorb impact or continuous pressure without breaking or being deformed (Mathieu 1991). The concept was then expanded following its appropriation by different disciplines, particularly the ecological sciences and human and social sciences.

(a) Resilience as Seen by the Ecological Sciences

Resilience, a key concept for ecosystem analysis, was for a long time the domain of the ecological sciences. As from 1973, Holling defines it as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling, 1973). In this meaning, resilience represents the capacity of a system to experience disturbance and still maintain its ongoing functions and controls (Gunderson and Holling 2002). Resilience, thus, expresses on the one hand a system's resistance capacity during the disruption and on the other its capacity to cope, recover, and regenerate itself (e.g., the regeneration of a forest after a fire or storm). This definition is reminiscent of that of social vulnerability previously presented. This dual capacity of resistance and recovery, without any change in structure, can indeed be applied to numerous subjects of study, whether a population, society, or city is involved.

Then, as from the mid-1980s, two contradictory currents of thought become apparent. For one, a resilient system is a stable system in an almost permanent state of equilibrium (Pimm 1984). Resilience is the capacity of a structure sustaining a brutal shock or continual pressure to endure without undergoing transformation. It is measured on the basis of resistance and rapidity of return to equilibrium. This is known as *engineering resilience*. For the other, a resilient system is a system that maintains its essential functions and structures not by maintaining a single state of equilibrium but by going through different states of equilibrium (stable and unstable). This is known as *ecosystem resilience* or *ecological resilience*.

The *ecosystem resilience* concept is more suitable for the study of complex adaptive systems since it allows the single equilibrium paradigm to be surpassed. Indeed, a complex system is a system open to its environment (in the systemic sense of the term) that can theoretically move toward equilibrium, but that can also shift toward stable or unstable stationary solutions far removed from equilibrium. Of course, all complex systems are not adaptive, but all those involving living societies are. This is why research carried out in the human and social sciences (Dauphiné and Provitolo 2007; Gallopin 2006; Maret and Cadoul 2008; Vis et al. 2001) or in transdisciplinary fields has also contributed to enriching the concept of resilience.

(b) The Contribution of Human and Social Sciences and Transdisciplinary Research

This concept has spread to a variety of different contexts. We can mention as examples research concerning the resilience of persons (Cyrulnik 2002), spatial systems (Aschan Leygonie 2000; ISDR 2005, 2009; IHDP 2003), and other research on the resilience of socioeconomic systems (Décamps 2007) and urban productive networks, or focusing on the links between ecological and social resilience (Adger 2000).

As far as ecology is concerned, economists give a similar but richer meaning to the concept of resilience. The resilient economy can in fact have two different meanings: that of the integral preservation of the economic system when confronted with disruption or that of the renewal of the economic system. This second approach is not based on the notion of monoequilibrium and conservation, via transformations, of the qualitative structure. As a continuation of these reflections, Dovers and Handmer (1992) have emphasized that resilience can adopt two forms: reactive resilience and proactive resilience. Reactive resilience is connected with the idea of the system's resistance to change during the event. Proactive resilience on the other hand depends on the capacity of populations to anticipate, learn, and adapt.

In the face of these disciplinary approaches to resilience, a new concept, that of systemic resilience, is making an informal appearance.

10.3.2.2 To Systemic Resilience

Transdisciplinary works concerned with nature/society interactions and environmental and social pressures (Berkes and Folke 1998; Berkes et al. 2003; Gunderson and Holling 2002; Holling 2001; Janssen and Ostrom 2006; Kasperson et al. 1995; Klein et al. 1998, 2003; Resilience Alliance n.d.; Smit and Wandel 2006; Walker et al. 2004) are developed in *Resilience Alliance*.

Resilience Alliance, a multidisciplinary research group that studies the dynamics of adaptive complex systems, has been particularly responsible for the evolvement of the concept of resilience by developing that of systemic resilience. The latter applies to all physical and social systems. Systemic resilience goes beyond just the idea of resistance to change and preservation of existing structures to prefer notions of system renewal, reorganization, and the emergence of new trajectories.

Systemic resilience is interpreted in stylized models of the adaptive cycle (Walker et al. 2004) and of panarchy (Gunderson and Holling 2002). These models describe the dynamics of the system. The adaptive cycle is a transition model between different states. For ecosystem and socioecological system dynamics that can be represented by an adaptive cycle, four distinct phases have been identified: growth or exploitation, conservation, collapse or release, and reorganization. This model, therefore, focuses on the different trajectories that the system follows but does not incorporate the interaction of spatial and temporal scales. This limit is surpassed in the panarchy model that offers a stylized representation to understand multilevel transformations in natural and human systems.

Systemic resilience is thus a concept well adapted to the management of risks with a physical and social dimension (Van der Leeuw and Aschan Leygonie 2001). But here again, this definition is not clearly distinguished from that of vulnerability. To study the vulnerability of a population or system is also to analyze its capacity to recover from a situation, to recuperate. And yet the renewal of a system, its reorganization, or even the emergence of new trajectories (all notions connected with the concept of resilience) are recuperation properties (property linked with the notion of vulnerability).

This is why, in the third part of this chapter, we consider the vulnerability-risk/disaster-resilience trio and propose a systemic risk model based on the notion of "resiliencery vulnerability."

10.4 Construction of a Systemic Risk Model Based on the Notion of "Resiliencery Vulnerability"

The conceptual model for analysis of "resiliencery vulnerability" in the face of risks and disasters is based on A. Sen's "capabilities" space. Adopting this approach enables us to avoid a list *à la Prévert* of the factors determining vulnerability. There are of course specific vulnerability factors corresponding to each type of system (human, societal, ecological, terrestrial, territorial, etc.). There is also however a set of generic criteria that allow us to comprehend the vulnerability of any system.

10.4.1 The "Capabilities" Space Paves the Way for the Notion of "Resiliencery Vulnerability"

Applied to the analysis of the "resiliencery vulnerability" of systems confronted with risks and disasters, the "capabilities" space enables the potentialities of any reactive system (human, animal, plant species) to be dissociated from its capacities for action, reaction, and implementation.

10.4.1.1 The "Capabilities" Approach

The "capabilities" approach (Sen 1993, 1999) involves evaluation of the well-being of persons based on individual freedom to choose between possible ways of life and to act. A. Sen (Nobel Prize in economics) proposes this concept of "capability" to encourage the development of poor countries and societies based on new measures of poverty, no longer merely monetary but multidimensional.

It is not our intention to take a stand on debates regarding individual freedom, the social construction of freedoms, and development of countries. As a continuation of the works of Alkire (2007), Lallau and Rousseau (2009), and Nussbaum (2000), our intention is rather to show how the notion of "capability" opens up the field of research on vulnerability and resilience and proves well adapted to the issue of risks and disasters.

Developed in his article *Equality of What*, "capabilities" depend on the potentialities and capacities of individuals to bring them into play. The notion of "capability," thus, corresponds to all the capacities of an individual to carry out his "functionings." The functionings of a person represent their characteristics, what they do, and what they are, whereas their "capabilities" correspond to an individual's capacity to actually achieve things and accomplish their potential (Bakhshi et al. 2008). Sen, thus, establishes a distinction between what is done and what can be done. "Capabilities," therefore, designate all the actions taken using the resources potentially accessible to an individual in a given context.

This approach has been essentially applied to the analysis of the vulnerability of populations in developing countries (Bebbington 1999; Gondard-Delcroix and Rousseau 2004; Lallau and Dumbi 2007; Rousseau 2007).

Our approach is different. The capabilities space paves the way for the notion of "resiliencery vulnerability." It allows three domains of "resiliencery vulnerability" to be identified: the potentialities of a system, the capacities for implementing its potentialities, and the actual implementation of its capacities, namely, the "capabilities."

10.4.1.2 "Resiliencery Vulnerability": Looking in Another Direction

Resilience is often presented as an antonym of vulnerability (Folke et al. 2002), which is usually portrayed in negative terms as the susceptibility to be harmed. We suggest a new conceptual framework that apprehends the vulnerability and resilience of systems (socioeconomic system, territorial system, economic system, etc.) as a continuum, as linked concepts. The notion of "resiliencery vulnerability" that we propose enables us to question the idea that vulnerability is necessarily a concept with a negative connotation and that resilience is a positive response to the disruption. It allows us to question the fact that there is, on one side, vulnerable (and therefore weak) systems and, on the other, resilient (and therefore, strong, capable of fighting, recovering) systems. It allows us to avoid designating and identifying a priori systems as being vulnerable or at risk. As a continuation of the reflections of Revet (2009), we call into question the idea that children, women, and old people are de facto the most vulnerable persons when events occur or that developing countries are stigmatized as high-risk countries.

The notion of "resiliencery vulnerability" is intended to convey the idea that vulnerability can be intertwined with and modified by resilience considered from a wider perspective; in other words, this resilience can, on the one hand, be directly linked to the vulnerability to which it applies and, on the other hand, have a positive or negative effect depending on the scale on which the system is studied, the nature of the risk, and its magnitude. The neologism "resiliencery vulnerability" opens up the field of research by introducing the idea that resilience can be contingent and, not necessary, can have a negative effect and that vulnerability can have a positive effect when change leads to a positive transformation. This is the power of vulnerability. We are therefore obliged to take these parameters and interactions into account so that the study of the vulnerability/resilience tandem is pertinent, these different parameters constituting the whole complexity of this issue.

This notion does not deny the fragility of a system. On the contrary, it allows all the potentialities, capacities, and capabilities to be brought to light, enabling a vulnerable system to protect itself against risks and disasters. Living systems, no matter what they are, do not remain passive in the face of events.

10.4.2 A Conceptual Model to Analyze "Resiliencery Vulnerability" in the Face of Risk and Disaster

The idea is to provide a usable conceptual framework for a global analysis of the "resiliencery vulnerability" of factors brought into play by events. The latter may be localized or diffuse, of natural, industrial/technological, or social origin.

The proposed conceptual model (Fig. 10.2) distinguishes the factual part that describes the context (the elements, events, and damage) from the "resiliencery vulnerability" part that describes the potentialities, capacities, and capabilities of a system to protect itself against risk or disaster for a complete temporal environment (before, during, after the event). This "resiliencery vulnerability" varies with time, from one country to another, depending on the geographical, spatial, institutional, political, and social contexts.

To reduce disaster risks, we have to know which events societies must cope with and which elements are exposed to these events. This is why the factual part identifies the elements pertinent to the analysis of a system subjected to potentially disastrous events (Provitolo et al. 2009a) and the exposure of these elements to "resiliencery vulnerability". The Element category comprises "living element," "physical element," and "miscellaneous infrastructure." To define the terms previously mentioned:

- The "living element" comprises all humans and natural populations, such as fauna and flora.
- The "physical element" corresponds to the description of the Earth's surface (oceanography, hydrography, pedology, relief, etc.) and is not directly concerned with human activities.
- The "miscellaneous infrastructure" includes the built environment, facilities, networks, and so forth.

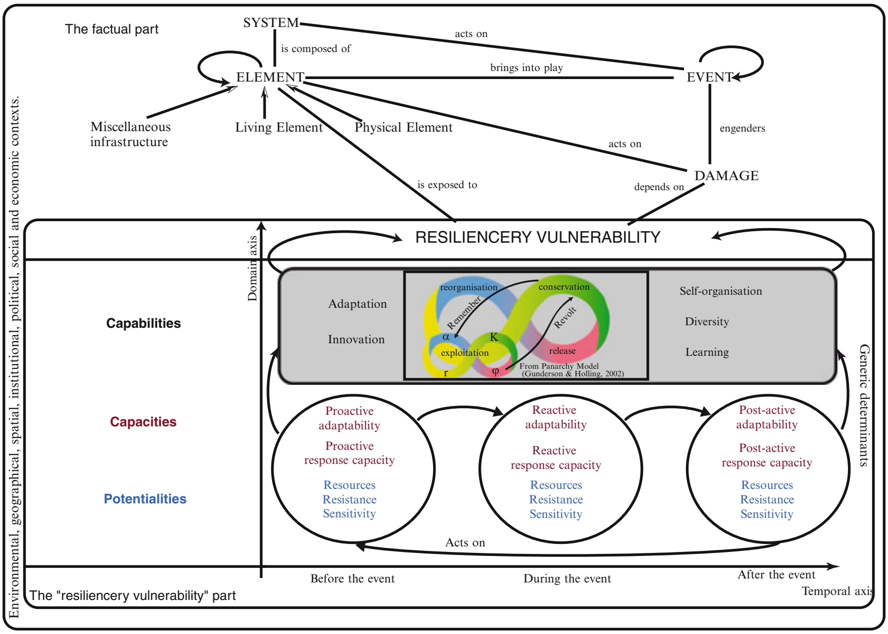

Fig. 10.2 A conceptual model for analyzing "resiliencery vulnerability" in the face of risks and disasters

The event brings different elements of the system into play. The same event may bring several elements into play, and one element may be subjected to several separate events. The "brings into play" relationship indicates that the element is exposed to the event, but this exposure does not presuppose its vulnerability. Therefore, the elements may act as catalyst for the event.

The event is usually an extraordinary fact, exceptional in relation to experience and daily life (e.g., the drought of 1976, the tsunami of December 2004 in the Indian Ocean, or the more recent one in October 2009 on the island of Sumatra). Certain events cannot be considered exceptional however. This is the case, for example, of the droughts that are nowadays perceived as one of the manifestations of climate change, thus announcing a greater frequency of these "abnormalities" which are no longer an exceptional event but a recurring event (Amigues et al. 2006), which is always considered as a disaster.

The event may correspond to an actual, probable, or potential phenomenon. When the event lies in the domain of the probable or potential, it relates to the notion of risk. On the other hand, when it is real, the event may be described as simple disruption, accident, disaster, or catastrophe. The event results in damage and can also cause other events. Events are thus linked together by relationships of causality that are expressed via the elements. This chain of causality corresponds to the domino effects often cited in the literature concerning risks and disasters, particularly by (Provitolo 2005;

Provitolo 2007; Provitolo et al. 2009b; Bak 1996; Blaikie et al. 1994; Chaline and Dubois-Maury 2004; Daudé et al. 2009; Kervern 1995; Dauphiné 2003). Likewise, the "acts on" relationship that links the system to the events illustrates the anthropogenic nature of the hazard and the interactions existing between Event and Element.

This model dissociates the elements from their vulnerability. An element is exposed to its own "resiliencery vulnerability" and the vulnerability of the other elements of the system. Elements, therefore, both sustain and exert "resiliencery vulnerability".

Two axes compose the "resiliencery vulnerability" part of the model: the temporal axis and the domain axis. The temporal axis distinguishes three temporal environments: before, during, and after the event. The domain axis describes three phases: the potentialities, capacities, and capabilities of a system to protect itself from an event in a complete temporal environment. This model makes a distinction between what is available, what can be done, and what is actually done. The "resiliencery vulnerability" part describes the potentialities, capacities, and capabilities of a system to protect itself from an event in a complete temporal environment.

"Resiliencery vulnerability" is therefore in evidence in the period prior to the event (the disaster has not yet occurred, it could happen, and it is therefore advisable to implement preventive strategies allowing, *in fine*, the disaster to be avoided), during the event, and in the future (period after the event). The behavior of these three temporal environments, by influencing each other mutually but not simultaneously, is made complex by the appearance of retroaction loops (Donnadieu and Karsky 2002). To quote Thiétart (2000), "yesterday's actions are the origin of today's reactions that lead, in their turn, to new action tomorrow." With regard to risk and disaster, yesterday's actions are those implemented within the risk system, especially via preventive measures and town and country planning policy. These past actions will affect the unfolding of the disaster and, therefore, lead to reactions during the event. Then, following the event, a postdisaster analysis, more commonly referred to as experience feedback, must enable the failures and errors in risk reduction and disaster management to be identified and analyzed. Experience feedback missions were carried out following the ice storm that paralyzed Montreal in January 1998, for example, or the cyclone Katrina that affected New Orleans in 2006. New strategies to combat the recurrence of a possible disaster are then put in place. These experience feedback missions are rarer in developing countries.

The *potentiality* of a system corresponds to the resources and capital available (economic, technological, social, human, knowledge, etc.). These resources allow the evaluation of a system's resistance and sensitivity. Resistance is the potentiality of a system (or of one of its components) to absorb or counteract the effect of a disruption without sustaining damage. This may be the physical resistance of infrastructures (a flood encountering a dike) or the physical or mental resistance of an individual or group. The sensitivity of the system derives from its resistance, with sensitivity meaning the degree of damage that persons and places can sustain (Adger 2006).

A system's capacity to implement its potentialities is realized by means of the system's response capacities and its adaptability. These properties are described as being proactive, reactive, or postactive according to their positioning in the unfolding of the event (before, during, after). Adaptability (or adaptive capacity) represents a potential rather than actual adaptation (Brooks 2003). The adaptive capacity will act on the adaptation process and on the result, that is, the system adapts itself. Generally speaking, adaptability is presented as a factor that increases the resilience of a system. However, a high degree of adaptability can unintentionally lead to a loss of resilience in three cases (Walker et al. 2006):

– The multiscale, multilevel: adaptability of certain groups of living elements to the detriment of others, adaptability on the microscale to the detriment of the macro.
– Adaptability of the system in relation to a very specific hazard can result in the decline of general resilience in the face of unknown hazards.
– Loss of response diversity.

We have seen in the first part of this chapter that space technologies (satellite remote sensing, GIS, etc.) are used in disaster management. However, although developed countries equip themselves with these technological resources, this is not always the case for developing countries. For example, all African countries have not adopted and do not have satellite data to monitor and manage disaster risks, particularly in the field of the prediction of and preparation for drought. According to Wilbur K. Ottichilo (2009), member of Parliament in Kenya's National Assembly, the failure to adopt these space technologies reflects notably a lack of institutional capacities, political will, and appropriate legislation for risk and disaster reduction. In addition to these explanatory factors, there is also the question of the cost of data. In order to provide equal data access, several initiatives have been taken, particularly that of the International Charter on Space and Major Disasters that supplies data free of charge to any country struck by disaster. The "satellite data" resource is then available following the event. But, as S. Lewis remarks (2009), this charter does not help developing countries acquire data for mitigation, planning, and preparation for disaster risks. There is therefore a hiatus between the resources available before and during the event (absence of satellite data for developing countries with no satellite of their own), and those actually available after the event. After the event, satellite data is available via the International Charter on Space and Major Disasters; the capacity to use and collect this data is activated at the request of a registered user; and the capabilities reveal that the data is actually available and can be processed by the local community for postdisaster management. The "resiliencery vulnerability" model, thus, reveals (1) a lack of coherence and of continuity in disaster event management due to the unavailability of satellite resources before and during the disaster and (2) a hiatus linked with the lack of institutional and political capacities to anticipate risks and the backlash effect of the lack of political commitment on the availability of technological resources before and during the event. This model could therefore help increase awareness among politicians in developing countries regarding the need to expend the necessary capacities to exploit technological resources throughout the temporal continuum of risk reduction and disaster management.

Capabilities correspond to both the properties actually implemented within the system exposed to risk and the different trajectories that the system follows. Knowledge and technology transfers and innovation allow the necessary capabilities to be strengthened with a view to disaster risk reduction. Regarding the different trajectories of the system, we have in fact incorporated in our conceptual model the panarchy model of Gunderson and Holling (2002). This model is coupled with the properties that will determine the dynamics of a system and thus its trajectories. The philosophy of the panarchy model is to propose a multiscalar analysis of the resilience of dynamic systems. The connections between levels are made via two trajectories: one, designated "revolt," represents the progression from the collapse phase to the preservation phase; the other, known as "remember," represents the direct progression from the preservation phase to reorganization. The multiscalar approach of this heuristic model implies that the disappearance of a subsystem can reveal the resilience capacity of a metasystem. Among the properties that determine the dynamics of a system affected by disruption, five are often cited: diversity, self-organization, learning, innovation, and adaptation. In ecology, loss of biodiversity is considered as a factor that reduces the resilience of the ecosystem; the same applies to economies based on a monoactivity. Likewise, self-organized systems have a large capacity to restore themselves, as the "functions" of the damaged parts are assumed by the other elements. Self-organized systems are therefore generally resilient. Likewise, resilience depends on the capacity of the living system to adapt, which is the case of living societies, thanks to learning. For example, in a society in which the population is well prepared to react in the face of a particular type of event, panic behavior is less likely to occur than in an inadequately or badly informed population. The adaptation of a system also reflects its capacity to anticipate an event (we talk of adaptation by learning) or adjust to it. Finally, science, technology, and innovation will foster the implementation of new practices and new actions to combat risks and modify "resiliencery vulnerability." Paradoxically, the stability and continuity of a society are achieved through change (Dauphiné and Provitolo 2007).

10.5 Conclusion

This chapter has shown how science and technology are a driving force behind economic and social development and contribute toward meeting the challenge of risk and disaster reduction in developing countries. As stated in the Millennium Declaration, disaster risk reduction is important for the fulfillment of development objectives. Events such as droughts, floods, and cyclones can, for example, compromise the means of subsistence based on agriculture and water supply for crops. Science and technology enable the resilience of developing countries to be strengthened by means of various actions, such as the storage and protection of water supplies, adoption of new farming methods, and development of drought-resistant crops, a series of actions allowing the challenge of food security to be met. The technology transfer of know-how also helps to confront the challenge of AIDS, and information and communication technologies offer developing countries the possibility of improving their living conditions, particularly via the use of space remote sensing for risk reduction and disaster management. Science and technology, thus, make it possible to innovate and diversify societies' responses to risks and disasters and, therefore, act on their vulnerability and resilience.

This chapter has also addressed one of the challenges for research today – that of understanding the relationships established between the concepts of vulnerability and resilience. A first reflection on the construction of a conceptual model of "resiliencery vulnerability" has been presented. The realization of this model is based on current knowledge of the risk and disaster domain. But although resilience is often presented as a sort of ultimate aim, we see things differently. The notion of "resiliencery vulnerability" is in fact intended to express the idea that vulnerability can be intertwined with and modified by resilience considered from a wider perspective, in other words, that this resilience can, on the one hand, be directly linked to the vulnerability to which it applies and, on the other hand, have a positive or negative effect depending on the scale on which the system is studied. Within the framework of this chapter, we have therefore endeavored to understand the relationships that exist between resilience and vulnerability and to reconsider the idea that vulnerability is necessarily a concept with a negative connotation and resilience is a concept with a positive connotation. There is no intention whatsoever to call resilience strategies into question but rather to propose a conceptual framework that takes into account the diversity of variables to be considered, the interactions between these variables, and the temporalities of an event. This notion does not deny the fragility of systems. On the contrary, it permits us to clarify the potentialities, capacities, and capabilities that enable systems to protect themselves against risks or disasters and confront them. Living systems do not remain passive in the face of events.

This model is certainly imperfect and needs "testing" on specific spaces of vulnerability in order to be validated. Its objective, however, is to make individual and organizational actors aware of the necessity of carrying out global analyses of vulnerability and linking these analyses to the domains of prevention and management in order to combat the fragility of mankind and territories.

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Chapter 11
Peri-Urbanisation and the Vulnerability of Populations to the Effects of Climate Change in Southern Vietnam: Innovating Solutions in Research

Abigaïl-Laure Kern, Jean-Claude Bolay, and Loan Ngo Thanh

11.1 Introduction

The economic capital of Vietnam, Ho Chi Minh City (HCMC), and its near periphery – as well as the Mekong Delta region – rank amongst the areas which, on a global scale, will be the most exposed to climate change in the next 30 years. This is due to three major phenomena: sea level rise, growing flood levels and flood intensity, and the resurgence of cyclonic phenomena (Nicholls et al. 2008). The impact of climate change in Vietnam is already tangible. For the last century, and in each decade, the sea level and temperature have increased respectively by 3 cm and 0.1°C. And yet, it is the poorest populations living in the periphery of HCMC and in areas subject to strong urban pressures in the Mekong Delta that are the most vulnerable to these changes (Fig. 11.1).

However, ongoing actions in Vietnam to mitigate climate change as much on a local as on a national scale seem to contribute only partially – given the lack of resources – to reducing the vulnerability of these populations, due to the many challenges that they still have to face in terms of access to information, governance, adaptation of public policies and resource management.

This chapter introduces the original approach developed by two North-South research teams, in Switzerland and Vietnam, in an attempt to meet the multi-faceted challenges confronted by this region's inhabitants.

Thus, the Ecole Polytechnique Fédérale de Lausanne (EPFL) and the University of Ho Chi Minh City agreed to spotlight an interdisciplinary approach combining technological advances and human sciences to measure as best as possible the

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Fig. 11.1 Water is rising (Source: Getty Images, Xavier Collé)

tangible consequences of climate change on the populations of the peri-urban areas of HCMC and the Mekong Delta. By focusing on at-risk territories from which many families have already been displaced as a result of the combined after-effects of growing urbanisation and the worsening trend in climate change, this innovative and original solution appears to have successfully defined new climate change adaptation strategies for these particularly vulnerable populations.

This chapter describes the benefits of an interdisciplinary approach in addressing risk factors such as climate urgency and growing urbanisation, and the vulnerability of the inhabitants of these territories.

First of all, an assessment of climate change in the Mekong Delta shows a genuine vulnerability of populations to these risks, especially since these risks are compounded by other factors such as urbanisation and declining ecosystems.

Initial analysis of the inhabitants' adaptation strategies also reveals the extent of both informal and official migrations. In order to put this innovative solution to the test, two field research sites displaying a large number of these characteristics and risk factors were identified.

And this technique seems to be able to address the challenges facing these territories and their inhabitants by offering two parallel approaches: an environmental diagnosis processing hydro-meteorological and land-use data through various system applications, and a socioeconomic study aimed at identifying and assessing the true consequences of climate change for displaced populations.

Finally, in line with the major risk reduction principles of international organisations, this approach put forward by research appears to contribute to the implementation of effective climate change adaptation strategies in this area.

11.2 Vulnerability of Populations to the Ongoing Impact of Climate Change in the Mekong Delta

11.2.1 The Mekong Delta, a Vital Region for the Vietnamese Economy, Heavily Threatened by Climate Change

More than 18 million people live in the Vietnamese part of the Mekong Delta, accounting for 22% of the national population. The delta, the country's 'rice bowl', constitutes more than 40% of the country's farmland and represents more than a quarter of the country's gross domestic product (GDP). It produces half of the country's rice, 60% of its fish and 80% of all fruits. The region also provides 90% of the total exports of Vietnamese rice (ADPC 2003).

Still, the Mekong Delta is one of the world's regions most threatened by the consequences of climate change, in particular due to its altitude, which is only slightly above sea level. Two major phenomena pose a threat to the territory.

First of all, experts forecast a sea level rise of between 0.3 and 0.8 m by 2080, this in light of the fact that an increase of 0.75 m would immerse roughly 20% of the delta and 10% of HCMC (IPCC 2007). Furthermore, whatever the scale and speed of this increase, difficult to foresee as it is highly dependent on the melting of glaciers elsewhere on the planet, it will have direct repercussions on arable land, threatened by increased salinification. Indeed, the equilibrium could be endangered, and this equilibrium is dependent upon the cyclical reversal of flow direction, coupled with intense alluviation which fertilises the land and which, in the past, has seen salt water travelling up to 60 km past the mouth of the Mekong at flood tide (Fig. 11.2).

Although most models have had some difficulty forecasting accurately future precipitation levels, most scenarios bank on a rise in sea levels and a growing frequency of regular floods, which will be increasingly accompanied by heavy rain.

Floods play a significant role in the delta's economy and are considered an integral part of the region's agricultural cycle, as inhabitants live to a rhythm

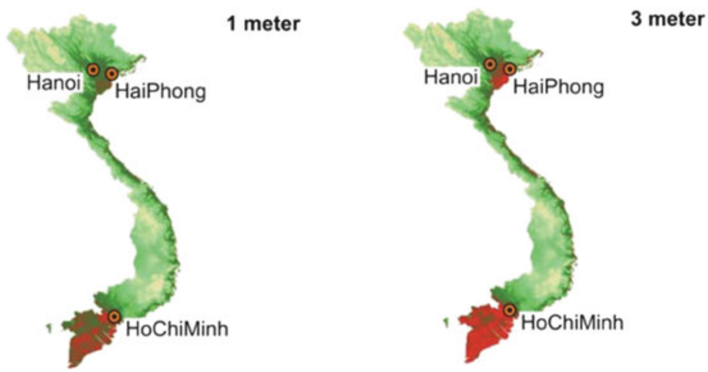

Fig. 11.2 Maps showing Vietnam's immersed surfaces during a sea level rise of 1 and 3 m (Source: IBRD/WB, Dasgupta et al. 2007)

dictated by the monsoons, which provide the primary means of subsistence for the vast majority of people. Thus, floods with a depth ranging from 50 cm to 3 m are viewed as normal and are known as ‘good floods’ (*ngâp nông*) because they enable the population to be self-sufficient. However, flood levels between 3 and 4 m (*ngâp vùa*) genuinely challenge the resilience of populations affected, as they have a significant impact on their food supplies. More worryingly, floods in excess of 4 m (*ngâp sâu*) have seen their magnitude and frequency escalate over the last few decades (Lettenmaier 2000). A case in point, the historical floods of 2000 affected more than 4 million people and lasted more than 3 months, resulting in significant economic damage (more than US$ 3 billion) (ADPC 2003).

Moreover, these phenomena are compounded by so-called ‘underlying risk factors’ (UNISDR 2009) such as flawed urban governance, the struggle of rural communities to make a living and declining ecosystems (deforestation, construction of hydraulic infrastructures, etc.). These underlying risks ‘support the rapid expansion of disaster risks related to meteorological phenomena’ (UNISDR 2009).

Finally, under the aggregate effect of these phenomena and rising temperatures – more than 3°C by 2080 (IPCC 2007) – there has been a resurgence of extreme events such as typhoons and cyclones in a region which, unlike the rest of the country, had previously been spared from these climatic events.

So natural disasters, combined with strong environmental pressures resulting from the socioeconomic boom in Vietnam – and more generally in Southeast Asian countries – intensify the existing threats related to climate change which Vietnam is faced with. These issues increase even further the fragility of Vietnamese natural resources and heighten the vulnerability of populations that rely on these resources for their livelihood (Table 11.1).

11.2.2 An Approach Based on the Vulnerability of Populations to Climate Change

In light of this alarming state of affairs, the approach developed jointly by EPFL and the University of Ho Chi Minh City aims to define strategies to help particularly vulnerable populations to adapt to climate change.

Table 11.1 Vietnam, typology of risks related to climate change per region

Regions	Zones	Main types of climatic events
North	Highlands of the North	Floods, landslides, earthquakes
	Red River Delta	River floods during monsoons, typhoons, storm surges
Centre	Central Coast provinces	Typhoons, sudden flooding, storm surges, drought, salt water ingress
	Central Highlands	Sudden flooding, landslides
South	Mekong Delta	River floods, typhoons, great tides and storm surges, salt water ingress

Source: Adapted from CCFSC (2001)

The term ‘vulnerability’ may be construed very differently in various academic fields, including within the disaster risk reduction community itself.

For the United Nations (UN), ‘vulnerability concerns a propensity or susceptibility to suffer loss or is associated with a range of physical, social, political, economic, cultural and institutional characteristics’ (UNISDR 2009). However, in our opinion, the concept of vulnerability should be used in a broader sense to encompass the notion of ‘resilience’. This term describes ‘the ability of people or economies to absorb and recover from the event’ (UNISDR 2009). Impoverished households often show little resilience in the face of loss because they lack the savings, supplies or insurance that would enable them to reimburse the cost of continuing to support themselves and protecting their harvest. On the other hand, social factors such as extended families and community networks help individuals recover from misfortune.

Indeed, it has been demonstrated that poor communities suffer a disproportionate percentage of the losses recorded after a disaster. ‘Poor households are usually less resilient to loss and are rarely covered by insurance or social protection. The disaster impacts lead to income and consumption shortfalls and negatively affect welfare and development, often over the long term’ (UNISDR 2009).

In order to meet the multi-faceted challenges posed by climate change and to curb the growing vulnerability of populations, this original and innovative solution is the outcome of a truly eco-systemic approach, combining geographic information systems, hydrology, meteorology, social sciences and urban planning.

11.3 Adaptation Strategies and the Issue of Population Displacement

11.3.1 Migrations and Population Resettlement: A Climate Change Adaptation Strategy

Environmental degradation, and particularly the impact of flooding, is one of the primary factors leading to rural exodus and the displacement of populations in the Mekong Delta.

Due to multiple extreme weather conditions, the inhabitants of the Mekong Delta adapt in different ways. And migration is one of these mechanisms, all the more so because Vietnam is undergoing very rapid socioeconomic change, giving rise to a strong desire of populations to move to an urban environment.

According to a recent study (Dun 2009), some factors compel the populations living in the Delta to migrate, for example, the lack of alternatives to more traditional means of subsistence and the growing difficulty of living year in, year out with flooding. Those who rely exclusively on farming to survive, such as rice growers, are particularly vulnerable when a series of floods destroy their crops.

During the flood season, many inhabitants become seasonal workers in urban centres to make both ends meet.

In the face of this ‘informal’ climate change adaptation strategy, the Vietnamese government has set up an ‘official’ strategy: the displacement and resettlement of populations living in risk-prone areas.

The government has implemented a programme entitled ‘Living with Floods’. This programme has gained in prominence over the years as consequences of climate change have shown a worsening trend. It is a flood management strategy, which entails displacing and rehousing people living in areas subject to risks (Le et al. 2007).

In the province of An Giang, for example, about 20,000 poor, landless households will have to be relocated by 2020. The families are selected according to various criteria related to their environment, such as living in zones where natural disasters abound (floods, landslides) or zones threatened by the erosion of various riverbanks.

This resettlement programme allows families to request a 5-year, interest-free loan in order to give them the means to purchase land and to build the basic structure of a house. As this sum is not sufficient, households often need an additional loan to finish building their home. A number of essential basic services are provided such as education, health or water and sanitation. However, those people who are displaced and relocated within the context of this programme generally belong to the poorest households and do not own any land. As a result, there is nowhere they can move to, should their house be destroyed, and they are too poor to settle in urban areas. Their livelihood often rests upon social networks, which enable them to find day-hire employment (Dun 2009). Although the new places of residence are often located less than 5 km away from their former dwellings, moving these families away from their social networks jeopardises their income and contributes to a strong feeling of isolation, severely undermining their resilience. Finally, the same studies point out that these new places of residence do not allow newly-arrived residents to partake in local activities (Dun 2009).

So the Vietnamese strategy devised through the ‘Living with Floods’ programme aims to combine displacing and then rehousing individuals, increasing ‘shifting livelihoods’[1] and migration. This programme is fundamental since according to forecasts, one out of ten Vietnamese living in the Mekong Delta will have to be displaced due to a sea level rise in the future (Dasgupta et al. 2007).

[1] ‘Shifting livelihoods’, being able to change jobs according to climatic events, for example, shifting from rice production to the fishing industry.

11.3.2 Limits of This Approach: The Choice of Field Research Sites

Due to resource shortages, this government incentive is limited to very specific parts of the delta that are largely rural and far from large urban centres. Both field research sites included in the interdisciplinary approach presented in this chapter are located in the periphery of the region of HCMC on the one hand and in the vicinity of Vinh Long on the other hand, one of the main cities of the delta. Both districts under study are coastal, peri-urban areas linking the rural world and urban clusters.

According to initial findings and a handful of data collected, although these territories are subject to urban planning, the latter is fragmented and lacks synchronisation, with, for example, a number of government programmes (one focusing on energy, the other on tourism) due to be launched in 2012. These programmes will result in the displacement of several hundred families just as the economic appeal of these two territories is being turned around.

Furthermore, as both territories are located in coastal areas, they have to cope with the growing consequences of climate change. Given the lack of resources and forecasting tools, the provincial authorities have no choice but to take sporadic action. Consequently, in order to respond to emergencies, certain areas were evacuated, and inhabitants resettled rapidly on land that was barely sustainable (some of it prone to flooding in the wake of the first rainy season), in poor-quality housing located far from any economic activity.

Lastly, these areas under study are peri-urban territories, meaning that they are situated in the 'space around cities, subject to their direct influence and likely to be significantly affected by the processes triggered by such proximity' (SEGESA 1994). The urban sprawl of HCMC (Bolay et al. 1997), and also of the city of Can Tho, the most important of the Mekong Delta, is placing acute urban pressure on both territories.

11.4 Benefits of an Interdisciplinary Approach: A Focus on Forecasting Models, Participatory Management and Multi-level Analysis

Given the information collected and the data presented above, this approach contains two main parts: an environmental diagnosis and a socioeconomic study. In a multidisciplinary perspective, three different methodologies are used to create a forecasting and decision-making tool.

These two elements, as well as the decision-making tool, can immediately be transposed to both field research sites, before being duplicated at a later stage in other places of habitation.

11.4.1 Environmental Diagnosis

The ‘environmental diagnosis’ part is divided into two main components: first, hydro-meteorological forecasts and second, geographic information systems (GIS).

The overall objective of the hydrological component is to obtain an accurate estimation of the physical impact of climate change and to create a model to enhance the protection of river catchment areas against flooding. For this purpose, two steps are necessary: the preparation and the selection of parameters according to various scenarios in order to implement a modelling system encompassing the entire Mekong Delta, which can then produce various models on a local scale, this in order to better factor in the idiosyncrasies of these territories.

Based on existing codes, this new model comprises innovative multiple-criteria enhancement concepts and real-time simulation. The simulations contain various scenarios of the region’s economic development, the building of flood control structures in the Mekong and the previously assessed consequences of climate change (Jordan et al. 2008).

A large amount of meteorological data are already available for this region and can easily be updated from the forecasting models of large Western research centres.

The second component of the ‘environmental diagnosis’ part relies on the use of GIS. Such tools are broadly used today and consist of a ‘system of computer hardware, software and procedures designed to support the capture, management, manipulation, analysis, modelling and display of spatially referenced data for solving complex planning and management problems’.[2]

An initial stage of data collection and standardisation precedes the application of one of the main principles of spatial analysis: a multiple-criteria analysis. The GIS tool provides accurate and detailed information on land use, which – correlated with hydrological and meteorological data – helps identify sustainable land that is not liable to flooding and could accommodate those populations that are displaced and relocated.

11.4.2 Socioeconomic Study

The second part of this interdisciplinary approach is a socioeconomic study conducted in two stages.

During the first stage, it is necessary to identify the socioeconomic aspects of vulnerability drawn from qualitative interviews and quantitative data.

[2] The American definition comes from the Federal Interagency Coordinating Committee on Digital Cartography [FICCDC] (Giordano et al. 1994). We owe the French definition to economist Michel Didier (1993): A GIS is ‘a set of spatial data that allows for the easy extraction of key information for decision-making’.

A participatory action research methodology is implemented to limit as much as possible the bias inherent to this type of study. This model was elaborated within the social sciences in an attempt to bridge the gap between the researcher and the group being studied (Whyte 1995). The researcher calls on a number of group members to take part in all the stages of the research process, which allows all participants to operate beyond the interpersonal relationships that are often at play during this type of research, thus making it easier for some members of the group being studied to voice their opinions.

Indeed, the mitigation of climate change requires a multi-dimensional approach, which itself needs ‘planning strategies that can empower communities and open the window for local participation. The most vulnerable in society are often those most excluded from community decision-making and in many cases this includes women’ (UNDP 2004).

The main groups that will give shape to this participatory management have already been identified. First of all, the people’s committees (Bassand et al. 2000) of the districts under study are good candidates as the role of local government is instrumental in the fight against climate change and the reduction of hazards related to natural disasters (Moser and Satterthwaite 2008): these committees support the people’s councils that control Vietnamese provinces, which are elected by the population.

Other representative groups should also be included, such as women’s associations. Admittedly, as in many other countries, Vietnamese women continue to be sidelined from decision-making and positions of power, in what remains a very Confucian society. Even if the principle of gender equality is enshrined in the 1946 Constitution, women of all social backgrounds, ethnic groups and ages are still disadvantaged, most notably in rural areas (Drummond and Rydstrom 2004).

The studies focus on two fundamental aspects: the tangible consequences of climate change for these populations and their adaptation strategies. Indeed, ‘local level community response remains the most important factor enabling people to reduce and cope with the risks associated with disaster’ (UNDP 2004).

The second stage of the ‘socioeconomic study’ focuses essentially on the creation of a risk assessment matrix, and this, through a multi-level analysis.

The use of multi-level analysis is quite recent in social sciences. Its goal is to explore different methods of statistical analysis to measure and compare the impact of the local context on a particular phenomenon (Courgeau and Baccaïni 1997). These models are adjusted according to geographical context, and the end result is a custom-made model highlighting regional outcomes.

In order to produce relevant indicators for this analysis, an accurate typology of hazards has to be established, first on a mainly theoretical basis and then on a more practical level, in accordance with existing socioeconomic data as well as data extracted from the previous stage.

This quantitative analysis helps to distinguish the various hazards (hydrological, meteorological, urban, socioeconomic, etc.) faced by the population, according to both their initial and second area of residence, in the event of displacement and resettlement.

This tool seems therefore able to put forward appropriate adaptation strategies for inhabitants that are in keeping with their current or future place of residence.

11.5 Selection of a Tool and Adoption of Major Risk Reduction Principles

11.5.1 Decentralised Decision-Making Tool

The interdisciplinary approach described here is finalised during the elaboration of the final decentralised decision-making tool.

This tool is based on the initial version of the GIS developed during the environmental diagnosis and on the multi-level analysis implemented during the socioeconomic study.

First, an internet-based information system for risk assessments is developed thanks to the first version of the GIS.

Second, hydro-meteorological and socioeconomic data (Kientga 2008) are incorporated and combined with the above-mentioned multi-level analysis.

This tool should help identify land suitable for the long-term settlement of displaced populations while taking into account projected hydro-meteorological data as well as all the economic, urban and hydraulic development projects of the areas concerned. The work conducted jointly with representatives from the local population should lead to the proposal of specific adaptation strategies with regards to the construction of homes, economic development and income management (from fishing, farming).

It should be easy to introduce this tool to the relevant local authorities, and training sessions should be provided to local technicians within the framework of regional planning schemes before eventually transferring it to other territories.

11.5.2 An Innovative Solution in Line with the Recommendations Derived from International Studies

The original approach described here seeks to fit within the scope of a worldwide movement of studies and risk management strategies relating to climate change, and to contribute to the definition of adaptation strategies for the populations most vulnerable to climate change.

These concerns clearly mirror those highlighted in the Millennium Development Goals (MDG) adopted by the Member States of the United Nations during the Millennium Declaration (2000), and particularly Goal 7: ‘ensure environmental sustainability’, meaning to ‘use natural resources wisely and protect the complex ecosystems on which our survival depends’. This goal was translated into various targets, among which Target 12 aims specifically to 'integrate the principles of sustainable development into country policies' and to 'reverse the loss of environmental resources'.

Thus, assuming that the mitigation of the effects of climate change requires an integrated and multidisciplinary approach, the technique suggested here follows the recommendations of several international reports, such as the United Nations Development Programme's 2008 report. The latter, entitled 'Fighting climate change: human solidarity in a divided world' urges to, among other things, 'strengthen the capacity of developing countries to assess climate change risks and integrate adaptation into all aspects of national planning' and also to 'empower and enable vulnerable people to adapt to climate changes by building resilience through investments in social protection, health, education and other measures' (UNDP 2008).

Furthermore, preliminary studies carried out in the Mekong Delta underline some of the principles that the project seeks to render mainstream, most notably the need for further research to better understand the link between flooding and migrations, or the necessity of setting out recommendations to integrate populations in resettlement projects and ensure that their vulnerability does not increase once they have been displaced (Dun 2009).

Finally, the suggested approach endeavours to make use of the initial works conducted in the Mekong Delta, and in doing so to advocate the implementation of their recommendations.

A study conducted by Oxfam (Shaw et al. 2007) promotes the implementation of databases, which then need to be continuously updated by individuals with sufficient technical skills. These tools help the authorities monitor closely local weather conditions and to develop emergency plans. The research project includes training on the use of the two tools that have been implemented, and this in order to secure their use beyond the completion of the project.

11.6 Conclusion

Through a policy of open dialogue with local inhabitants, the first part of this interdisciplinary approach helps to determine and assess the tangible consequences of climate change for displaced populations, not only in order to provide information and conduct awareness-raising campaigns, but also to give individuals the opportunity to improve their own capacity to adapt by building personal resilience.

The second step in this approach is to outline sustainable, non-floodable land for future population displacements and to make a number of decision-making tools based on geographic information systems available to local authorities.

Finally, in light of the completed diagnosis and the methodology used, this innovative solution and the final decentralised decision-making tool selected both advocate the implementation of real climate change adaptation strategies to mitigate its impact on the most vulnerable populations of developing countries.

The proposed tools and methodology – as well as the interdisciplinary and innovative characteristics inherent to this approach – should in the long term enable populations to fully settle in their new homes and ensure that these homes become more than simply shelters but also places where daily life – with all its practical, functional, trade and social activities – can flourish in all its forms (Pattaroni et al. 2008).

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Chapter 12
Perceptions of Rain-Fed Lowland Rice Farmers on Climate Change, Their Vulnerability, and Adaptation Strategies in the Volta Region of Ghana

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12.1 Introduction

Climate change is already impacting negatively on Africa through extreme temperatures, frequent flooding and droughts, and increased salinity of water supplies used for irrigation (IPCC 2007). Widespread poverty and high dependence on rain-fed agriculture in Africa renders the continent more vulnerable to climate change–induced disasters than other regions of the world. Sub-Saharan African countries form the bulk of countries in a protracted food crisis (FAO 2010). The recent waves of food crisis in West Africa attest to this (Oxfam 2010). Therefore, urgent measures need to be undertaken to improve the resilience of African communities, especially those in rural areas, to enable them to better adapt to climate change and other constraints to food production. In the next decades, world food demand is projected to increase as it is currently being rapidly redefined by new driving forces (von Braun 2007). Income growth, climate change, high energy prices, globalization, and urbanization are transforming food production,

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consumption, and markets. Economic growth (especially in some Asian countries) has helped to reduce hunger through increased propensity to consume (von Braun 2007); the prices and markets of the world are getting increasingly linked and have significant effects in food consumption patterns (Sardaryan 2002). There is a current dilemma on diverting farmland meant for food crops to growing crops for biofuel as a measure to mitigate climate change.

Because tropical farmers are highly dependent on climate for food production, they are highly vulnerable to climate change. Hunger currently affects about half of Africa's population and is expected to worsen if the current trends are not halted or reversed. Vulnerability in the context of climate change is defined as "the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC 2007). The vulnerability of a system to climate change is determined by its exposure, by its physical setting and sensitivity, and by its ability and opportunity to adapt to change (Adger et al. 2003). Adaptation is defined as "the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2007). It involves a process of sustainable and permanent adjustment in response to new and changing environmental circumstances.

Rice is a C3 grass that evolved in semiaquatic, low-radiation habitats and is currently grown in wider range of environments from humid tropics to arid and semiarid conditions and even to temperate zones. As such, it carries a peculiar range of adaptations to existing and changing environments compared with other crop species. This broader adaptation will make rice more amenable for manipulation to adjust to climate changes as a consequence of global warming (Wassmann et al. 2009). In addition, rice is an important crop in the continent, both for food security and commerce, and increased rice production will be crucial in meeting food demands and reducing poverty. However, rice production in Africa is affected by abiotic stress such as heat stress, flooding, drought, and salinity, all of which are expected to worsen with climate change. In Ghana, rice is one of the major food crops. Until 1996, it ranked only next to wheat in terms of the quantity imported (Sam-Amoah 2004). Since 1997, it has overtaken wheat with an average import of 212,625 ton per year (Sam-Amoah 2004). The above figures indicate that while rice is an important crop, its importation constitutes a huge drain on the country's scarce foreign exchange reserves.

Drastic changes in rainfall patterns coupled with rising temperatures will introduce unfavorable growing conditions into cropping calendars, thereby modifying growing seasons which could subsequently reduce productivity (Manneh et al. 2007). The risk of high temperature stress is present in all rice production systems from uplands to lowlands. Water stress has been identified as one of the most important production constraint in Africa. Compared to other crops, rice is particularly sensitive to drought, which can reduce stand establishment, tillering, plant height, and spikelet fertility and also delay flowering. The degree of impact of drought is dependent on the stage of growth of the crop (Manneh et al. 2007).

Major questions on climate change remain to be answered in Ghana as well as other African countries: are farmers aware of climate change? How vulnerable are they? What are their coping strategies? How can mainstream research on climate change improve their awareness as well as assist them in designing appropriate adaptation strategies? What according to them are the causes of climate change? Do farmers perceive climate change to have occurred already, and if so, have they begun to adapt? What kinds of adaptations have they made to climate change? What, if any, is the role of government in overcoming barriers to adaptation? In order to provide farmers, policy makers, and planners with information to formulate climate change adaptation strategies, a first step is to establish baseline information on farmers' perceptions of climate change, how vulnerable they are, and what they consider as adaptations to these changes (Maddison 2006).

Objectives:

1. To assess the perceptions of rice farmers of climate change
2. To determine their level of vulnerability
3. To establish causes of climate change according to farmers' views
4. To identify possible adaptations and determinants of choice of adaptation

12.2 Materials and Methods

12.2.1 Site Description

The study was carried out in Hohoe District (Long. 00° 24′E; Lat. 07° 12′N) of the Volta region in Ghana. Long-term average annual rainfall is 1,554 mm. The rains start in late April and end in October. The dry season lasts for about 6 months of the year from November to April. The long-term average mean temperature is 27°C. The district falls within the derived Savanna agroecological zone. The soils are acidic (pH 4.6–5.7) and of average-to-low fertility status. Rice cropping is a major activity carried out by the inhabitants. In the rain-fed lowland rice ecology, one rice crop is grown by direct seeding or transplanting between the months of June and November.

12.2.2 Data Collection and Analysis

A survey of rice-based cropping systems was carried out to assess farmers' perceptions of climate change, to determine their levels of vulnerability, as well as to identify possible adaptation options to climate change. The survey covered 6 villages (Akpafu-Odomi, Mempeasem, Hohoe, Koloenu, Santrokofi, and Ve-Wegbe) within the Hohoe District. The villages were chosen with the help of agricultural extension staff to adequately represent the different landscape units used for rice cultivation within the area. A total of 74 farmers were interviewed using structured questionnaires. Questions were designed to provide background information on socioeconomic status of the farmers and their perceptions of and possible adaptations to climate change and constraints in rain-fed lowland rice cultivation. Farmers were also asked if they had received any advice on climate change from extension officers (and other sources) and how this information (if adopted) has changed their production practices. Interviews were conducted with individual farmers, leaders of local farmers' associations, as well as with representatives of agricultural extension services. Twelve farmers and two agricultural extension officers were interviewed to evaluate their knowledge of climate change and what they are doing to cope and/or help farmers adapt to these changes. The respondents' rate was 100%. A 30-year monthly record of rainfall and temperature (1971–2000) was used to verify farmers' claims of changes in rainfall and temperature as well as occurrence of extreme climatic events. The annual mean temperature was calculated for the district.

Descriptive statistics based on summary counts of the questionnaire structure at the district level were used to provide insights into farmers' perceptions of climate change. In addition, a multinomial logit regression model was used to analyze the determinants of farmers' choice of adaptation strategies. It permits the analysis of decisions across more than two categories, allowing the determination of choice probabilities, and is also computationally simple (Deressa et al. 2009).

The multinomial model has probabilities:

$$p(y = j|x) = \frac{\exp\left(x\beta_j\right)}{\left[1 + \sum_{h=1}^{j} \exp(x\beta_h), j = 1, \ldots, J\right]}, \tag{12.1}$$

where

y denotes a random variable (adaptation choices) taking on the values $\{1,2,\ldots,J\}$
j is a positive integer
x is a set of conditioning variables (household, institutional, and environmental attributes)
β_j is $K \times 1$

Local-level analyses can help in highlighting and prioritizing adaptation interventions, thus facilitating the creation of a more sustainable and equitable production environment (Wehbe et al. 2006).

12.3 Results and Discussion

A typical rain-fed lowland rice farmer surveyed in the Volta region of Ghana is male, 50 years old, has attended middle school, has a household of six people, and has about 13 years of rice farming experience, with labor on field mostly provided by the family. He owns (inherited) one rice field of approximately four acres, with rice farming as his principal occupation, accounting for 64% of total income. He has easy access to both field and market. This farmer has heard of climate change and is aware of these changes for at least 7 years. The 64% of total income reported above confirms the findings of Appiah et al. (2009) that income from agriculture constituted 60% of the average total rural household income in Ghana. The indicators of climate change are summarized in Table 12.1.

Farmers' perceptions of changes in rainfall can be grouped under two broad headings – change in amount and timing of rains (Fig. 12.1). In the first group, 42% observed less rainfall and short duration of rains and 2% observed drought.

Table 12.1 Compendium of climate change indicators perceived by rice farmers

Climate variable	Indicators of climate change
Rainfall	Decreasing rainfall amount
	Changing rainfall pattern
	Early/late onset of rain
	Erratic rainfall
	Frequent storms
	Drought
	Short rainy season
Temperature	High temperatures
	Severe sunshine
Others	High frequency of bush fires
	Poor animal health
	Disappearance of swamps
	Bird and animal migration
	Change in kind of weeds, increase in pests/diseases
	Low crop yield

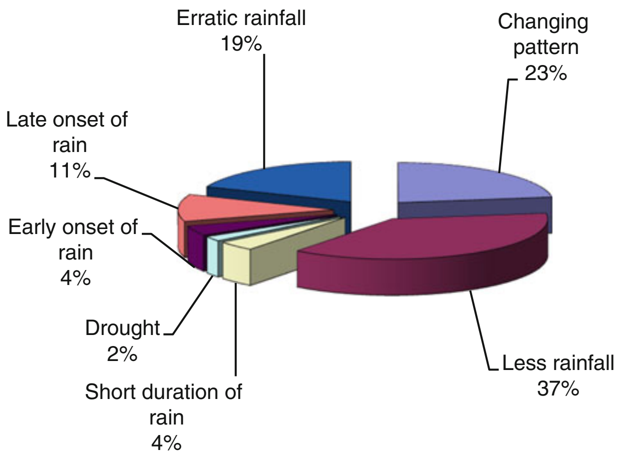

Fig. 12.1 Rice farmers' perceptions of changes in rainfall in the Volta region of Ghana

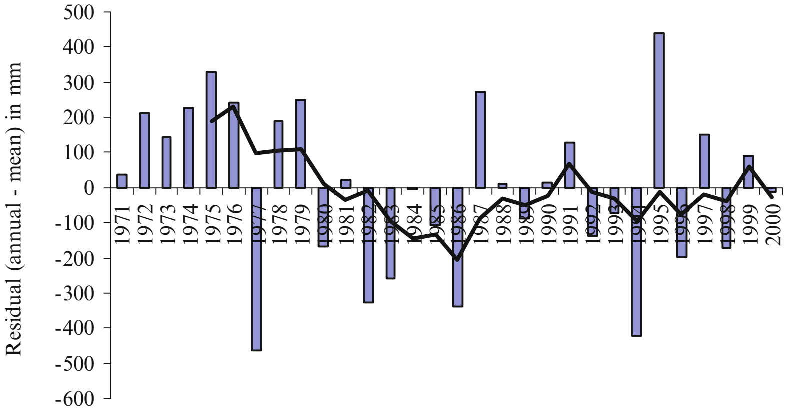

Fig. 12.2 Annual rainfall residuals and moving average for Hohoe District

With respect to timing of rains, 23% observed changing rainfall pattern, 19% erratic rainfall, 4% early onset, and 11% late onset of rains. Summarily, rainfall in the Volta region is characterized by high variability and decreasing amount.

Rainfall anomalies (annual rainfall amount minus 30 years average) between 1971 and 2000 are shown in Fig. 12.2. The solid line represents 5 years moving average. The data revealed an alarming decreasing trend in rainfall amount between 1976 and 1986. More frequent extreme rainfall events have been observed since 1977. We observed rainfall deficits between 1980 and 1986 in 5 out of 7 years, with severe deficits (drought) in 1977, 1982, 1986, and 1994. The moving average clearly reveals the possibility of experiencing low rainfall amounts in the coming years. Interannual variability in rainfall amount varied between 3% and 39%, with high variability characterizing rainfall between late 1980s and 1990s. Farmers' perception of high rainfall variability, decreasing rainfall amounts, and high frequency of extreme events is supported by rainfall data available for the site.

Seventy-two percent of rice farmers think rainfall (amount and distribution) will be a problem in the future because of the persistent decline in amount and erratic nature, high incidence of bush burning, deforestation, and increasing frequency of extreme events. All farmers perceived long-term changes in temperature as confirmed by meteorological records (Fig. 12.3). The results reported above support the findings of Madison (2006) that climate change has in fact occurred. Perception of climate change by rice farmers is high and hinges on farmer experience. According to IPCC (2007), extreme weather events have changed in frequency and/or intensity over the last 50 years and have occurred repeatedly in West Africa in recent years.

12.3.1 Vulnerability

Because of the poor soils characteristic of this area, farmers are highly vulnerable to climate change. In the northern states of Nigeria, Leary and Kulkarni (2007)

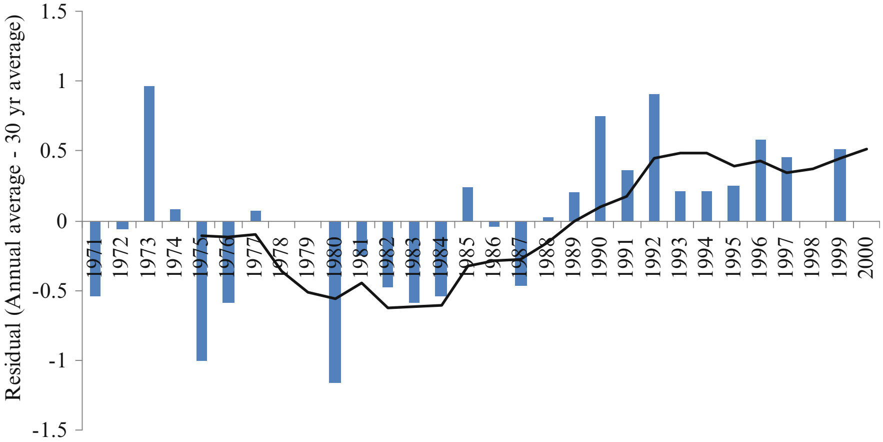

Fig. 12.3 Annual temperature residuals and moving average for Hohoe District

identified ownership of land and quality of land cultivated among others as key characteristics that control vulnerability. Less than one-third of the respondents are engaged in off-farm activities. An average of 64% of total income is derived from rice cultivation. The vulnerability of the rice farming community is exacerbated by the difficult land tenure system, whereby security on continuous cultivation of same piece of land is not guaranteed. This is particularly true for migrant farmers (29%) who have moved from other communities because their lands have become unproductive and are no longer suitable for rice cultivation. These farmers cannot find jobs in other sectors. The following are different agreements reached between landlords and tenants to safeguard landholding for the next season's cropping: payment of one to two 50-kg bags of rice for each acre cultivated, giving of 12.5% of current year's harvest, 40 GHC/acre/year (1 US$ = 1.4 GHC), or sometimes 2–3 years' payment of rents in advance. Some farmers interviewed reported that landlords do not differentiate between years of poor and good harvests. Similar results have been reported in Wenchi District in Ghana (Mapfumo et al. 2008). Short-term climate variations therefore pose a major threat to the security of tenure for the immigrant farmers.

Finally, 43% of respondents rate the price of local rice in the market low, which is a major disadvantage compared to the increasing cost of inputs and labor. Farmers are not provided insurance in situations of crop failure and have limited or no access to credit facilities. Rice cultivation and crop production in general has thus become a very risky enterprise in which those involved are scared to make meaningful investments. Although they are aware of the importance of farm inputs, they do not think any investment on them will pay off under their current farming conditions. Adejuwon (2006) cited by Leary and Kulkarni (2007) compared the vulnerability of peasant households to climate shocks in different states of Nigeria using household census data and observed that the percentage of households employed in agriculture is an important determinant of vulnerability.

12.3.2 Causes and Impact of Climate Change

Rain-fed lowland rice farmers attribute changing climatic conditions to increasing deforestation (91%), burning of fuel wood for charcoal production (67%), bad agricultural practices (e.g., continuous burning of fields) (48%), natural (57%), and burning of fossil fuels (12%). Farming practices that reduce the negative aspects listed above, which farmers are aware of, would provide suitable adaptation strategies. Pannell (1999) points out that if farmers are to adapt to conservation techniques, they must first be aware that the technology exists and perceive that it is possible.

The impact of climate change in rice growing communities (Fig. 12.4) is seen as increased poverty and food insecurity, loss of farming capital, shortage of water (portable drinking water and for cropping), slow development, and increase in social vices (stealing of produce in the field and in store; borrowing of food, seeds, and money; and inability to pay back). These are all indicators of vulnerability of the community to climate change.

12.3.3 Adaptations

Crop production is naturally sensitive to climate and among the most likely to be affected by changing climatic conditions in the future. Farmers have certain capacities under certain conditions to deal with and adapt to various challenges with the objective of minimizing the adverse effects of changing climatic conditions or taking advantage of them on their farm by adopting wise practices

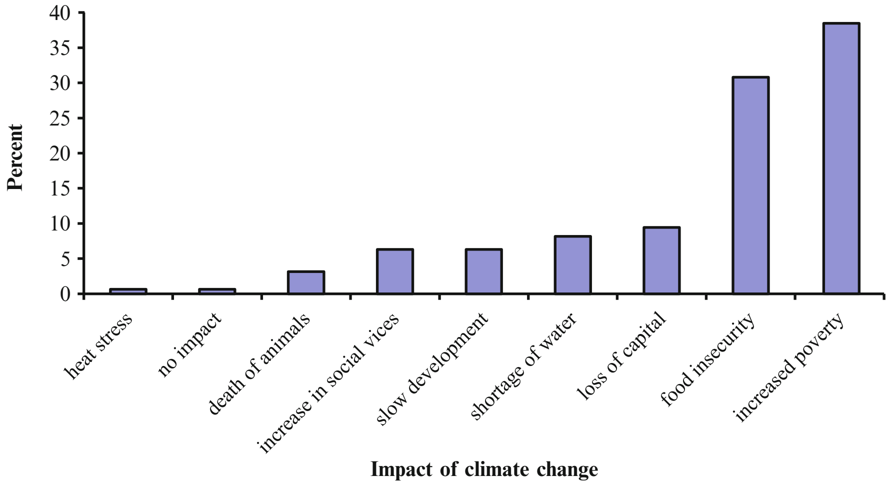

Fig. 12.4 Impact of climate change on rain-fed lowland rice farming community

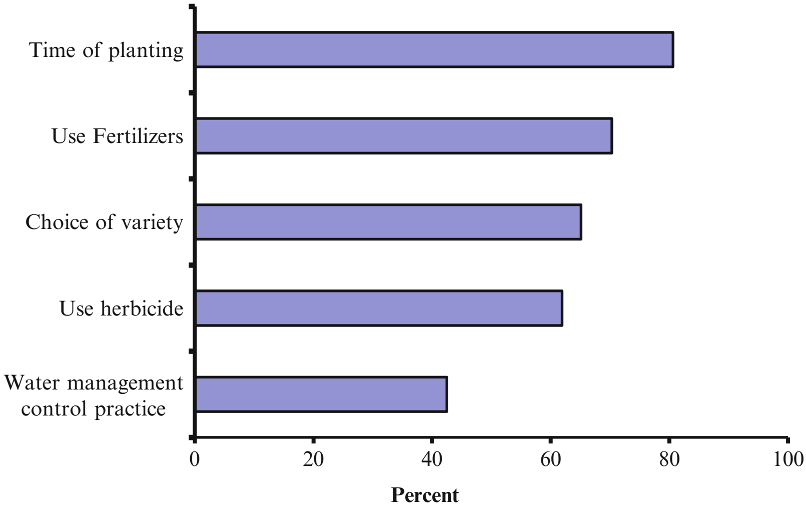

Fig. 12.5 Adaptations to climate change in rain-fed lowland rice systems

and strategies. Farmers use a combination of adaptation strategies from the five different choices recorded in the region (Fig. 12.5). The most frequently used strategy is varying time of planting (81%) and the least, water management control practice (43%). Use of fertilizers (70%), choice of variety (65%), and use of herbicide (62%) were the second, third, and fourth adaptation choices, respectively. Despite perceiving a decrease in the volume of rainfall, less than half of the farmers perform any water control practice. Seventy-eight percent of farmers attempt to reduce risk to climate variability and change by diversifying production (grow other crops). Among adaptations made in response to climate change, planting different varieties of the same crop and changing dates of planting are important in Africa (Maddison 2006). Agricultural diversification requires farmers to carefully orchestrate what, where, and when to plant their crops to respond to both current and expected conditions (Ingram et al. 2002). The following were identified as barriers to the adaptations listed above: limited access to credits, irrigation facilities, and equipment for quick and appropriate land preparation; lack of farm inputs; as well as climate forecast. These barriers constitute technologies which can increase development in the rice sector by reducing the impact of climate change and increasing benefits.

12.3.4 Determinants of Adaptation

Description of the variables used in establishing determinants of the different adaptation options is presented in Table 12.2. Age of the household head and access to and availability of labor significantly ($p < 0.10$ and $p < 0.05$, respectively)

Table 12.2 Description of variables

Variables	Description (with codes)
Sex	1 Male, 2 female
Age	Continuous
Education	1 No education, 2 primary, 3 middle school, 4 ordinary level, 5 high school, 6 tertiary
Household size	Continuous
Farm size	Continuous
Distance to farm (F) and market (M)	1 Near, 2 average, 3 distant
Number of farms	Continuous
Advice	1 Received advice, 2 no advice
Credits	1 Access to credits, 2 no access
Length of stay in rice farming	Continuous
Labor	1 Not available, 2 available

affected adoption of water control management practices (Table 12.3). Age is surrogate for experience, and as such, the farmer will not hesitate to employ measures he has witnessed over time that guarantee good harvest. Deressa et al. (2009) observed increasing probability of adoption of soil conservation measures with increase in age of the household head. The result obtained is in line with that of Gbetibouo (2009), who observed that experienced farmers are more likely to adapt to perceived climate change. Soil moisture control practices which include leveling, bunding, and digging of canals are all labor-intensive practices. Increasing access to and availability of labor will increase the adoption of water control measures. Leveling for example provides farmers the opportunity for good seedling setting, good water controlling, reducing water consumption, and effective fertilizer and pesticide application for increased yield (Beser 2001).

Limited extension agent–farmer contact and lack of advice on varying planting dates and choice of varieties as adaptations to climate change limit their adoption. Farmers' knowledge on climate change is low, and if left on their own, they cannot take technical decisions on the above-mentioned adaptations. The information they obtain from the media (radio and television) is usually not sufficient, and as such, they depend on agricultural extension agents (Fig. 12.6), who in most of the cases, lack the necessary competence to deliver information on suitable planting dates and other climate change–related issues (ECOWAS 2009). The latter has a deep implication for extension services, which could offer more realistic and continuous training programs to farmers to overcome the difficulties. In the Limpopo basin in South Africa, access to extension services (which implies having more knowledge of management practices to climate change) increased the likelihood of adoption (Gbetibouo 2009). Although farmer-to-farmer extension (information from neighbors) was not tested as a determinant for adaptation in this study, it is an important medium for exchange of climate change and related information (Fig. 12.6). In the Nile basin of Ethiopia, farmer-to-farmer extension increased the likelihood of using different crop varieties as adaptation to climate change (Deressa et al. 2009).

Table 12.3 Parameter estimates of multinomial logit climate change adaptation model

Explanatory variables	Water control practice		Varying planting date		Choice of variety		Use herbicide		Use fertilizer	
	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level
Intercept	−3.322	0.468	2.626	0.698	4.251	0.480	−3.268	0.582	−6.881	0.223
Gender	0.609	0.514	−0.020	0.990	0.691	0.638	1.941	0.144	0.139	0.901
Age	0.070*	0.097	0.082	0.172	−0.068	0.170	0.038	0.436	0.030	0.429
Education	0.292	0.370	−0.088	0.827	0.006	0.987	0.171	0.605	0.540	0.104
House_size	−0.109	0.419	0.241	0.288	−0.193	0.287	−0.051	0.783	0.122	0.543
Farm size	0.073	0.374	0.022	0.883	0.507	0.254	−0.470	0.302	−0.031	0.722
Distance_F	0.165	0.806	−0.031	0.967	−0.251	0.757	0.879	0.276	0.657	0.359
No._Farms	−0.734	0.462	2.145	0.117	0.751	0.428	−1.871	0.065**	−1.148	0.190
Distance_M	−1.228	0.122	1.756	0.172	2.167**	0.044	−2.117	0.025**	−2.019**	0.013
Advice	−0.491	0.587	−2.807**	0.021	−3.134**	0.018	2.043	0.128	−0.070	0.936
Credits	−1.372	0.327	−1.580	0.482	0.476	0.783	1.161	0.486	2.398	0.176
Labor	1.996**	0.025	−2.238	0.107	−1.469	0.218	0.135	0.141	1.140	0.250
Length_stay			−0.105	0.901	0.141	0.117	−0.435	0.677	0.124	0.117
Base category	No adaptation									
LR chi-square	27.485***				21.32**		21.70**			
Log likelihood	−23.3				−18.31		−21.37			
Pseudo-R^2	0.388				0.359		0.364			

Education implies level of education; House_size is size of household; No._Farms is number of farms owned; Distance_F and Distance_M is distance to farm and market, respectively; Advice is making use of advice from extension workers; Credits is having access to credits; Labor is having access to labor; Length_stay represents how long farmer has been growing rice (in years)

*, **, *** significant at 10%, 5%, and 1% probability level, respectively

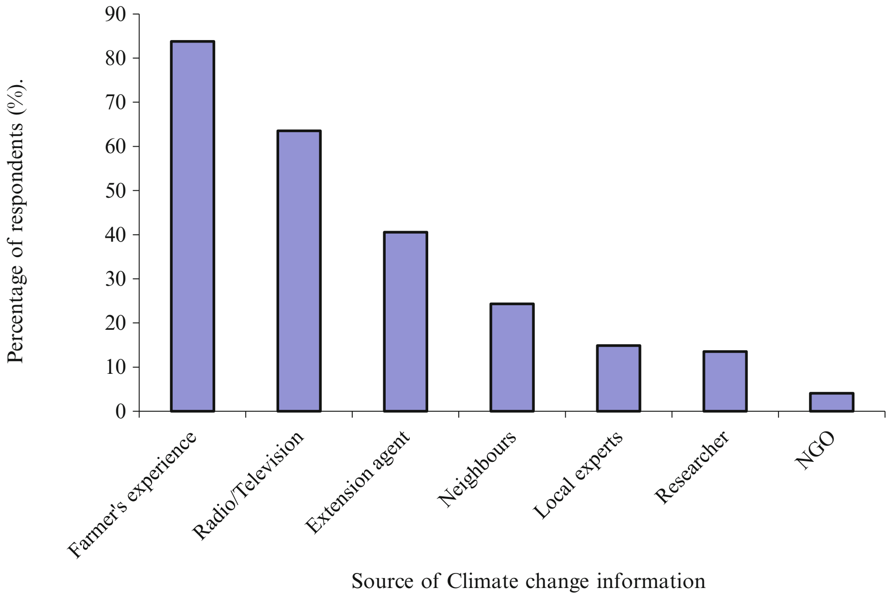

Fig. 12.6 Farmers' sources of climate change and related information

Increasing distance to market increases significantly ($p < 0.05$) the probability of choice of variety as adaptation to climate change and reduces significantly ($p < 0.05$) the use of herbicides and fertilizers. Most distant fields have marginal productivity, and farmers try as much as possible to spend less on such fields as they are not sure of any profits. The farmer incurs huge expenses transporting his produce to the market. Although he is more likely to perceive climate change relative to a colleague on a more fertile soil with sufficient moisture (Gbetibouo 2009), he is unable to respond because of his poor financial backing, low prices in the market, and difficult land tenure systems. Farmers with lower levels of land ownership are less likely to adopt alternative technologies than those with higher levels of ownership (Schuck et al. 2002). Only adaptations which attract little or no extra expenditure, for example, choice of variety, are likely to be adopted. Previous research has identified proximity to market as an important determinant of adaptation, presumably because the market serves as a means of exchanging information with other farmers.

12.4 Conclusions

The study established that rice farmers are aware of climate change and perceive it as fluctuating rainfall amounts, delayed onsets of rains, increased frequency of drought, storms and winds, reduced volume of streams, increased temperature, increased bird population that invade their fields, increased weed and pest populations, occurrence of new weeds, and increased frequency of crop failure. Because these farmers lack the necessary capacity to adapt (limited access to credits, low income, limited engagement in off-farm activities, and difficult land tenure systems), they are highly vulnerable to changing climatic conditions. Rain-fed lowland rice farmers attribute changing climatic conditions to increasing deforestation (91%), burning of fuel wood for charcoal production (67%), bad agricultural practices (e.g., continuous burning of fields) (48%), natural (57%), and burning of fossil fuels (12%). They use a combination of adaptation strategies among varying time of planting, water management control practice, use of fertilizers, choice of rice variety to plant, and use of herbicide. These adaptations are determined by the experience of the farmer, access to and availability of labor, distance to markets, land productivity, and advice received from agricultural extension agents. The impacts of climate change on rice cropping systems will depend on the baseline conditions of the soil, water supply system, and ability of the farmers to respond not only to climate change but also to changes in demand, technology, social, and legislative conditions. Rice farmers will adapt better to climate change and variability if they have access to credits, irrigation facilities, and equipment for quick and appropriate land preparation; subsidized farm inputs; as well as appropriate and timely delivery of climate and agronomic information.

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Part VI
Network Technologies

H. S. Jamadagni and Alexandre Repetti

Information and communication technologies (ICTs) have grown worldwide beyond imagination during the last decade. According to the International Telecommunication Union (ITU) and GSM Association (GSMA), cell phone subscriptions in 2007 reached 28 subscriptions for 100 habitants in Africa, 38 in Asia, and 67 in Latin America. The penetration rate is even higher with cell phone sharing: for example, 97% of all Tanzanians say they can access a mobile phone, with only 21 subscriptions for 100 habitants. On the other hand, Internet usage is lower. In 2010, the number of Internet users was 11% in Africa, 24% in Asia, and 36% in Latin America, whereas it reached 60–80% in Western Europe and the United States. In comparison, Senegal reported 1 computer, 0.3 Internet connections, and 6.6 Internet users for 100 habitants.

Internet, cell phone applications, wireless networks, high computation power at low cost, sensors, measuring devices, and other network technologies are all offering promising potential for agriculture and environment in developing and emerging countries: mobile information systems are used to produce sets of data on the environment, GSM applications contribute to better understanding of the governance of environment, and the combination of Internet and cell phone technologies can make powerful models available through adapted interfaces on cell phones. Although network technologies are powerful and promising, enabling these tools in developing and emerging countries remains a challenge in the form of obstacles to technology transfer, closing numeric gaps and contributing to ensure environmental and agricultural sustainability.

The promising potential of information and communication technology for the environment and the numerous remaining challenges have led the UNESCO Chair in Technologies for Development at EPFL to define one of its four priority areas as

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ICT for the Environment. The chapters hereafter present innovative applications of these technologies and overcome the challenge of enabling technologies for development.

The mobile system developed by Niang, Demanou, Ndiaye, and Ba is an innovative solution turning to SMS, GIS server, and cell phone maps for integrating cattle grazing and water points management. Nomadic breeders can learn from other breeders when a water point is dry or when diseases have been signaled. The application has direct benefits for the nomadic population in the vast Sahel bush.

The mobile information and communication system presented by Prabhakar, Jamadagni, Knoche, and Sheshagiri Rao is turning to automatic data gathering through a network of sensors. Their combination of technologies centralizes the data in a server and makes it available through a specific cell phone interface in the local language. The farmer can then know about temperature, soil moisture, precipitation, and humidity at a very accurate scale. The team has faced power supply and low-literacy questions with original solutions.

The mobile information and communication system presented by Ceperley, Repetti, and Parlange highlights the potential of network technologies for environmental modeling and agriculture. In a remote region of Burkina Faso, the scientific team has gathered an impressive dataset that is used to precisely monitor and model all the parameters important for agriculture and agroforestry. Such a thorough understanding of the environmental phenomena is sure to contribute to improving the agricultural production and the sustainability in developing regions.

Chapter 13
Optimizing Pastoral Mobility Based on Mobile Geographic Information Systems (MGIS)

Ibrahima Niang, Cyrille Demanou, Samba Ndiaye, and Papa Dame Ba

13.1 Introduction

In the agropastoral areas of Eastern Senegal, the goal of pastoral units (PU) is to improve the daily life of breeders and farmers. PUs are characterized by a low population density, and inhabitants are scattered throughout the region. In such cases, it is difficult for breeders and people living in these areas to share information. Many pastoral breeding systems in Africa are conditioned either by the dry season or by the rainy season. This approach incorporates local knowledge covering two complementary strategies: mobility and geographic localization of the resources that should be used.

In order to mitigate impact of scarcity of resources (e.g., water and grass), breeders move their cattle around. This geographic mobility, known as transhumance, constitutes a strategy for finding resources during both seasons. During the dry season, it is necessary to go toward good pasture areas. Nevertheless, this transhumance still incurs several problems.

First, breeders should avoid crossing farmers' areas, which quite often leads to conflicts between them. Therefore, finding good routes that do not cross farms is mandatory. Second, water point management is crucial. Lack of information, either about water shortage and/or potential overload of water points or the existence of routes that cross farmers' areas should be resolved.

Despite the existence of local knowledge, the endogenous information system is poorly structured and has no traceability (Ancey 2003). Ancey and Astou (2004) have shown that oral communication is the most common way to access or to share information in PUs. The traditional information system used by these populations

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has reached its limits. Indeed, in order to sustain high productivity, breeders should have distributed geographic information systems (DGIS).

Nowadays, solutions based on information and communication technologies (ICTs) can overcome these limitations. In the same way as geographical information systems (GIS), ICT can be used to transmit and keep up-to-date information flows between people that live in pastoral areas. Existing systems, known as PC-based, use global positioning system (GPS) and Internet mapping information. In so doing, they enable pastoral resources to be tracked and managed. The aim is to improve the coordination of breeders' movements and to protect soil and water resources during the dry season. Due to the lack of skills and for economic reasons, this PC-based approach is not appropriate for rural areas.

We have noticed the current use of GIS on mobile phones. This technology, known as Mobile Geographic Information Systems (MGIS) (Tsou 2004; Nyamugama and Qingyun 2005; Noriyuki et al. 2004), is useful for managing geographically distributed databases. In other words, MGIS is the use of geographic data in the field on mobile devices. It should be pointed out that, over the last 7 years, the number of mobile phones has largely exceeded the number of wired phones (ARTP 2008). We have also observed a high penetration rate in rural areas, even if these populations quite often have low incomes. Based on penetration rate of mobile phones in the area studied, we have designed an approach based on short message service (SMS) and which uses GIS. The SMS system is primarily a service that tends to overcome the voice service of mobile telephony, and the price of an SMS is cheaper than a telephone call.

This chapter presents a new approach for information systems management in pastoral areas. The goal is to set up a dynamic platform for water point management. Therefore, at any time, breeders are able to know the status of any given water point. It is worth mentioning that there are three types of status for water points: not available, overloaded, and free. This information is sent to the breeders' mobile phones by SMS from a server which has gathered data from the different collectors (e.g., radio station, selected persons, breeders, etc.) designated in each rural area.

We have therefore designed and implemented MGIS, covering transhumance routes and water points on each mobile phone. Simply put, this platform ensures dynamic management of information on pastoral resources (water points, tides, etc.), and management of transhumance trails by factoring in difficulties that may arise in certain areas (disease, failure of boreholes, etc.). To overcome the language barrier, the output messages for mobile phones are translated into two local languages.

The rest of this chapter is organized as follows: Sect. 13.2 reviews the related work approach-based GIS and information systems in pastoral areas. Section 13.3 presents our approach based on MGIS. Section 13.4 discusses the penetration rate of our approach with respect to the breeders living in the area studied. Finally, Sect. 13.5 presents our conclusions and some research prospects.

13.2 Related Work

At present, mobile GIS, Internet GIS, and wireless web applications are increasingly playing important roles based on the entire geoinformation application. In this chapter, we focus on mobile GIS. Mobile GIS can be defined as an integrated software or hardware framework for access to geospatial data and services using mobile devices via wired or wireless networks (Tsou 2004). Although a lot of research work had been done on the use of mobile GIS technology, not much has been done in the field of environmental monitoring using dynamic information management.

Integration of mobile GIS technologies and wireless telecommunications is the key focus of this chapter (Tsou 2004). Tsou proposes combining mobile GIS application software, GPS, and wireless networking technologies for an application based on mobile GIS and dedicated to natural habitat conservation.

Noriyuki et al. (2004) introduce GIS using a mobile phone that is equipped with a camera and a GPS and displays. The authors aim to provide social information spaces for local communities or towns. Users can add text notes and also photos to physical spaces by sending emails from their mobile phones attaching photos and location information identified by GPS.

Binzhuo and Bin (2005) present a new mobile GIS application, based on mobile scalable vector graphics (SVG) (W3C 2003), known as TinyLine SVG, which is intended for heavily resource constrained handheld devices. This application is a tourism-oriented map application of the Shenzhen territory for mobile phones. This application was designed to perform satisfactorily on devices (mobile phones) with low processor speed and small memory for the GIS application and GIS data. Memory requirements are kept low by using mobile SVG.

Nyamugama and Qingyun (2005) propose a method for constructing an extensive wireless GIS network by utilizing Java cellular phones as GIS terminals for environmental monitoring through dynamic location disaster-emergency notification management of spatial databases. The main purpose of this paper is to assess the use of Java cellular phones as a GIS terminal for environmental monitoring through dynamic location disaster-emergency notification management of spatial databases.

Kaboret (2003) proposes ICT tools for mapping pastoral movements. The overall objective is to enable Sahelian populations to access pasture resources and use them more effectively during the dry season with the help of new ICTs. The proposed solution is web mapping based on GIS with the use of GPS. Based on the results obtained, effective livestock farming methods incorporating ICTs were identified and validated, not only to help reduce conflicts between growers and breeders and animal pressure on pasture lands, but also to enhance productivity of traditional livestock farming, with the direct consequence of increasing family income.

13.3 An Approach Based on SMS and Mobile GIS for Pastoral Resources Management

13.3.1 Overview of Our GIS Architecture

Figure 13.1 illustrates our two-tier approach and shows the interactions that exist between different poles (sites). It describes the different communication phases that should be established so as to obtain operational GIS. The different sites depicted in Fig. 13.1 are the university area, rural area (pastoral unit), and rural radio station. The university site hosts our GIS server, which embeds an SMS server that is able to handle and process SMS messages sent by the collectors and/or users located in the pastoral unit zone. For instance, these SMS messages are used by breeders to find the geographic location of water points, retrieve the status of water points, or seek the shortest route to any given water point. For the record, the purpose of the radio station in Fig. 13.1 is to send information to the users who do not have mobile phones.

To use our GIS service, the mobile phone customer sends requests to the server, for instance, in order to acquire the URL of target map files. The mobile phone customer also has an SVG (W3C 2003) parser (included in the TinyLine SVG) to parse SGV files, and a TinyLine SVG to display geographic information (Fig. 13.2). In fact, the TinyLine SVG provides virtually all the methods to display and control SVG document objects. It should be pointed out that some SVG files may also be

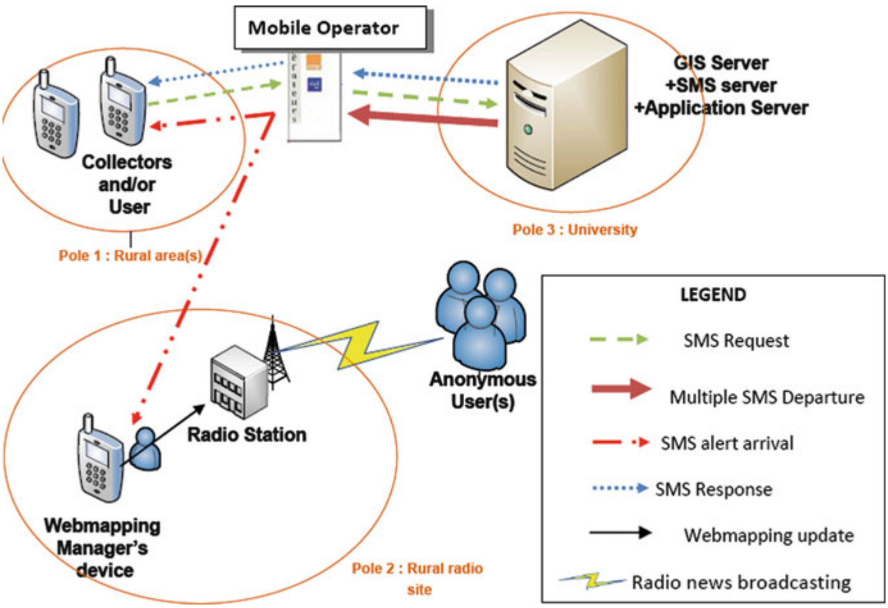


Fig. 13.1 Our mobile GIS middleware

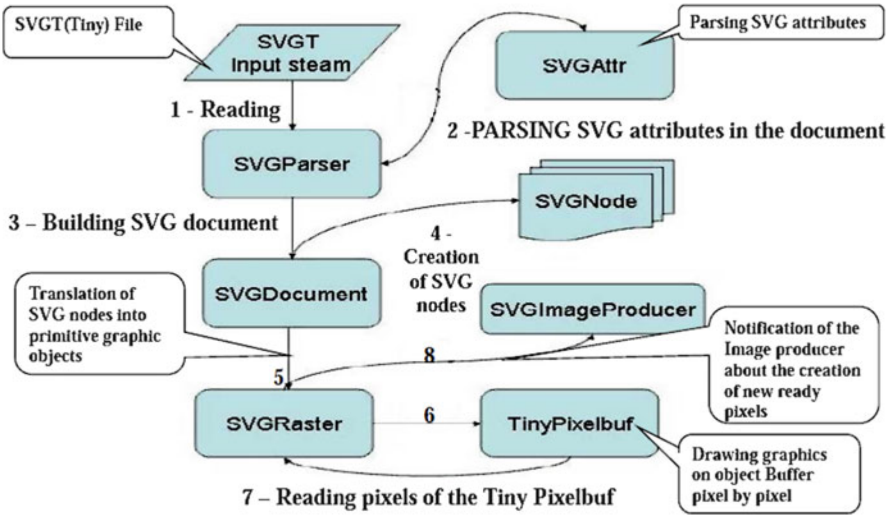


Fig. 13.2 General organization of SVG technology

placed in mobile phones. On the server side, some SVG files are precreated, and Java components are built to generate SVG files forming the database. When a request is received from the mobile phone, the URL specific to the SVG file is transmitted; otherwise, the Java components should generate the SVG file and then transfer the file to the mobile phone. In fact, SVG files or data sources are placed on the web server.

13.3.2 Breeder Use of GIS Applications

The information system implemented is based on SMS and GIS technologies and is freely available. This system consists of two servers and mobile phones as illustrated in Fig. 13.3. One server, located at the university, is used as the SMS server and the other one as a relay through the web mapping application installed at the rural radio station of Koumpentoum, which is a region located 30 km from the study area (Kouthiaba PU). Mobile phones with open-source software (J2ME) are distributed to the 16 breeders participating in the study.

Our experiments used the Nokia N70 for mobile devices as illustrated in Fig. 13.3. For the record, the map of the Kouthiaba PU has been compiled in vector format. Our results show that the breeders have understood the application functionalities during the training and know how to use the mobile device. For instance, two case studies are described here. During the first one, the breeder seeks the status of different water points (Fig. 13.4). For the second case study, the goal is to find the shortest route to a given water point (Fig. 13.5). Figure 13.4 shows the

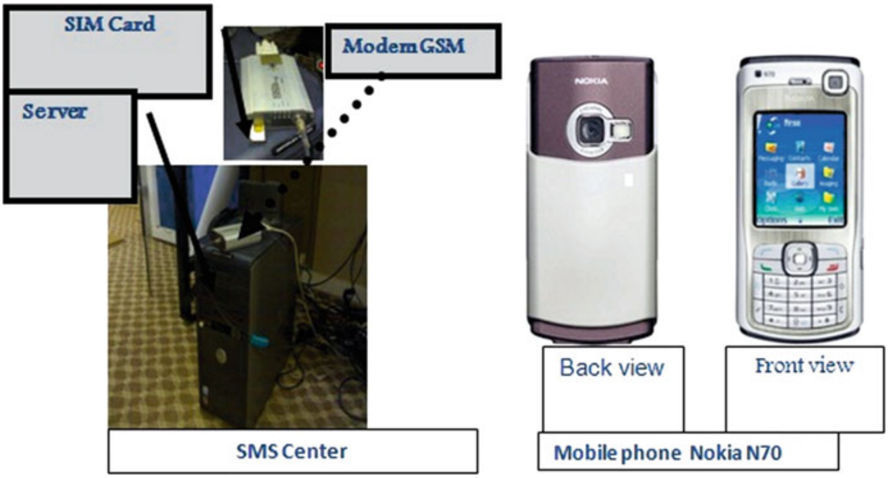
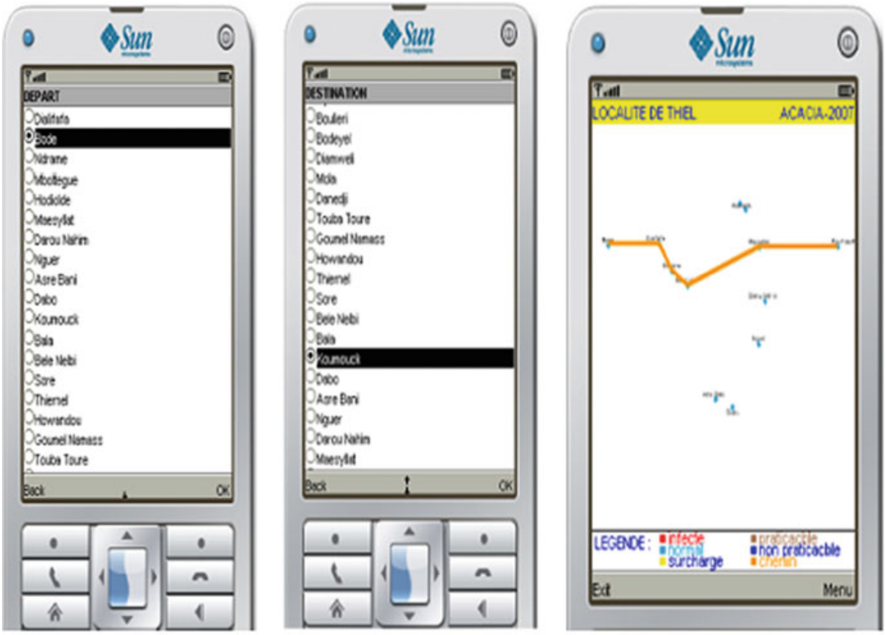


Fig. 13.3 Study material and equipment for the SMS center

(a) Choice of the task (b) SMS validation (c) Graphic response

Fig. 13.4 Access to status information



(a) Source (b) Destination (c) Shortest path

Fig. 13.5 Finding the shortest path toward a given water point

different steps that the breeder should follow in order to find the status of different water points. The breeder can select a given task from the menu on his mobile device (Fig. 13.4a). He sends a single SMS and then waits for the response according to availability of this task (Fig. 13.4b).

For instance, if the breeder wants to know the status of the available water points, he can receive a map on his mobile phone as illustrated in Fig. 13.4c. It is worth mentioning that the status of the water point is indicated with three colors on the geographic map of the PU displayed on the mobile device. The meaning of these colors is (1) red indicates the presence of a disease; (2) yellow means that the water point is dry; (3) blue illustrates that the water point is usable.

Figure 13.5 illustrates how to find the shortest route between two given water points. In such cases, the first (source) water point (Fig. 13.5a) and the second (destination) water point (Fig. 13.5b) should be selected. After selection, the breeder sends an SMS in order to retrieve the shortest route between the source and the destination. He then receives a response by SMS, which is shown as a map on his mobile device (Fig. 13.5c).

Scalable vector graphics (SVG) (W3C 2003) transcribe the SMS format into a graphical map on the mobile device. The mobile phone GIS based on the mobile SVG can then easily display the map on a phone screen so that simple operations can be carried out on the phone. In our study, this tends to give the breeders too much of an edge.

13.4 Discussion

In this section, we discuss and analyze the penetration rate of our GIS infrastructure with respect to the users located in the village of Kouthiaba. We factor in different parameters, such as the degree of usability, income of the population, and efficiency of the GIS architecture.

13.4.1 Sociogeographical Aspects

The village of Kouthiaba, which is a pastoral unit, hosts telecommunication infrastructures for the use of GSM technology. Since a wireless network covers the village, it is possible to deploy GIS based on ICT. As Kouthiaba is located in the Sahel region, during the dry season, many pools can be infected, spreading disease that may affect cattle. Therefore, the GIS application and web mapping can contribute to reducing the risk of disease in rural areas such as Kouthiaba.

Literacy rate in the Sahel region is very low. Therefore, utilization of mobile devices by these populations is limited despite the fact that mobile screen output is translated into their mother tongue. To overcome the language barrier, we use different menus, such as environmental and sanitary matters, so that users do not need to write an SMS to retrieve such information. Despite this facilitation, it remains difficult to expect full appropriation of mobile GIS based on SMS among illiterate persons.

13.4.2 Training and Testing of Usability

Each breeder has been trained for 28 h in using mobile phones and related applications. However, training duration cannot be considered as a probable cause of lack of appropriation of the applications. In fact, at the end of the training, feedback received from the breeders shows that they have profound understanding of how to use SMS technology, start applications, and consult the various interfaces.

13.4.3 Content Distributed in Applications

Our mobile GIS architecture takes into account two key elements in the pastoral area: the status of pools (drinkable or not) and the routes that lead to these pools.

- First, breeders in the Ferlo region consider the status of pools as strategic. Ancey and Astou (2004) have shown that breeders in the Ferlo region travel following the geographic location of weekly markets. The mobile GIS is therefore

designed as a structural element for accessibility and availability of information in pastoral areas. However, both in the endogenous system and in modern information systems, information has a limited lifetime. Knowledge of the status of pools in the Kouthiaba PU has temporal validity spread over 2 or 3 months of the rainy season, but draining of the pools in 7 months makes the tools obsolete.
- Second, finding the shortest route between two pools can benefit the breeders living in the pastoral unit. The shortest route means a given route that avoids sanitary obstacles (infected areas and drained pools) and crossing the farmers' areas. This information secures breeder mobility. It is worth mentioning that during our test with the breeders, this functionality was not used enough – perhaps due to the innovative feature of this application.

13.4.4 Usability of Our GIS-Based Applications

ICT is considered appropriated by a given population when the following conditions are fulfilled: (1) low cognitive control of ICT by users; (2) significant social integration of the use of this technology in daily human life; and (3) the possibility of building innovative solutions using ICT.

- The satisfaction survey conducted after training did not reveal any major complexity of the mobile GIS according to the users. No personal investment has in fact been made by the breeders to acquire mobile GIS. This factor excludes the hypothesis that the cost of innovation would work in favor of compliance. As the PU power grid is not totally operational, sometimes farmers painfully continue to walk 8 km to reach the solar panel of some individuals in the PU to recharge their phones. However, we realized that the farmers are deprived of ensuring permanent autonomy of their phones, as multimedia features tend to run down the battery.
- While the use of mobile phones and SMS can cope with local practices of communication as pointed out, the fact remains that this is hardly noticeable when innovation is not a service whose value does not provide direct economic profitability. The successful example of Grameenphone in Bangladesh (Adam 2005) for economic profitability of the phones stemmed from the fact that women could buy minutes of communication at wholesale prices which they could then resell at retail prices so that they were able to repay the loan and generate income.

13.4.5 Analysis of Quantitative Indicators

Two quantitative elements enabled us to characterize appropriation in this study: efficiency and intensity of use.

- Penetration rate: 12 months after system deployment and training of the breeders, the results show that more than 50% of the breeders have used the system.
- Mobile GIS efficiency: the mobile phone is nowadays one of the most accessible ICTs for the base population, and the project has enabled people to receive free phones that cost on average 200 euros per unit for the Nokia N70. Applications built from free and open-source software do not require upgrades, and thereby purchase of a license. These factors have undoubtedly contributed to reducing the digital divide for some of the breeders in the Kouthiaba PU.

13.5 Conclusion

We have proposed two-tier architecture based on MGIS in order to overcome the lack of information in the Sahel region. In fact, breeders are confronted with many problems, such as finding water points and routes that do not cross farms. We have designed an application based on mobile GIS and have conducted real experiments with the breeders located in the village of Kouthiaba.

The results obtained show that more than 50% of breeders have used our application despite the low literacy rate observed in this village. This percentage can be explained by the apprehension that some breeders may feel about this new technology. This study also shows that the process of appropriation of ICT is not linear. It can take a long time for a given population to adopt innovation based on the use of SMS to access information according to their needs.

We are investigating the possibility of providing the amount of water usable in a given water point. It may be useful for cattle breeders to know if it is necessary to reach a water point depending on the size of his herd. We plan to use sensor technologies to monitor the different water points in order to update our database dynamically.

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Chapter 14
Data Gathering and Information Dissemination for Semiarid Regions

T.V. Prabhakar, H.S. Jamadagni, Hendrik Knoche, and P.R. Sheshagiri Rao

14.1 Introduction: The Need for Localized Data

Small and marginal farmers own about 1–4 ha of land and solely depend on rainfall for irrigation. Their lands are generally located at a higher elevation (2 to 25 m) compared to the farmlands of the rich resulting in a high runoff. Farming in semiarid regions is further characterized by low rainfall (500 mm over 6 months). Crop production is subject to weather and large-scale attack of pests and diseases. Over 75% of the tillable land in Karnataka State in India is dependent on rainfall. According to Kalavakonda and Mahulb (2005), the state has witnessed a deficit in rainfall 1 out of every 4.3 years. The Indian Government has long introduced crop insurance to farmers to pass their weather-related risks to a third party. Farmers from Karnataka State participated in almost all risk management schemes offered by the Government. The first crop insurance scheme introduced in 1972 was based on the "individual farm" approach for cotton. It also included groundnut, wheat, and potato. The Pilot Crop Insurance Scheme (PCIS) was launched in 1979. This was based on an "area yield" approach. In 1985, PCIS was replaced with another scheme called the Comprehensive Crop Insurance Scheme (CCIS). The National Agricultural Insurance Scheme (NAIS) launched in 1999 replaced the CCIS and was adopted in Karnataka from 2000 onward. Most schemes were unsuccessful

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and had to be discontinued due to administrative and financial difficulties. All insurance programs have generated claims well in excess of premiums. For example, for CCIS, only 4 out of 22 states had insurance charges greater than the claims. Moreover, for a period of 12 years (1985–1997), one single crop, namely, groundnut, received 48.8% of the insurance claims from the state of Gujarat.

A weather-index based insurance contract is a possibility since high correlation exists between crop yield and rainfall parameters. However, small and marginal farms are non-contiguous. Usually, landscape features like large reserved areas, fallow patches, dried-up ponds, and uneven earth mounds separate them. They might also be sandwiched between fertile farmlands of the rich that have substantial land holdings. Two important and characteristic features of these lands are the high runoff and the high variability in soil texture. One may notice a change in the terrain and soil texture over 100 m. The farmer may have had an extremely low crop yield despite a good rainfall in his village. Therefore, a high rainfall indication might not necessarily reflect high soil moisture content.

The uncertainty of claims for insured farmlands based on the area-yield approach is not completely suitable for an individual farmer, leading to data monitoring of individual farmlands and aggregating the data using a suitable technology to a central system. There is a need for a mechanism to collect localized data over a wide area. Insurance companies can look up rainfall and soil moisture parameters specific to individual farmlands to cover the risk. A further reason and perhaps the most important for localized data is individual advice on crop status. Predicting crop yield from software-based crop model simulations is another well-researched area with soil moisture sensors employed for water stress evaluation on the standing crop. The crop model may also use other inputs such as weather forecasts to improve its prediction on crop yield. Timely advice from models can let farmers adapt their farming strategies. Thus, a wireless sensor network (WSN) deployed to monitor environment parameters of small and isolated farms but spread over a wide area is a requirement.

14.2 Data Gathering

Having established the need for a WSN network with regard to crop insurance and personalized information, we now explore the data gathering and information dissemination paradigms. The existing system and perhaps the most reliable one working over many decades is the traditional knowledge possessed by the farmer. Physical inspection, followed by application of this knowledge, and finally dissemination in an oral form to the farmer is well established. However, such strategies are not replicable and scalable together with the requirement of the "wise" man. Another approach, a scientific one, is to gather several environment parameters from farmlands and use them as input parameters toward an expert system software model. Such a model can predict the incidence of a pest attack or predict the crop yield. This approach calls for collecting individual in situ farmland data. A trained and literate person is required to visit each farmland with perhaps a computer or a similar embedded system. The computer runs the model and provides advice in real time. Another approach is to deploy a "representative" sensor network in the village and provide advice based on this system. This system is however not very accurate as it does not match any specific farmland. In particular, soil moisture data value can be completely off from a farmer's land, although data such as rain and wind can still be used.

In our approach, we deployed several sensors in individual farmlands and aggregated the data to one node. We call this the Field Aggregation Node (FAN). The FAN is also able to use the services of telephone links and GPRS technologies to relay sensor data for the purposes of data processing. This was necessary, as most human expertise is available outside the village. Our experiments were continued in the site mentioned in Panchard et al. (2006), where the authors explore the application of WSN technologies for the benefit of such farmers in semiarid regions. Figure 14.1 shows the network deployed at CKpura village in Tumkur District of Karnataka State in South India. The paradigm we utilized was to monitor several farmlands and aggregate the data to one cluster point in the field. We call this Cluster 1. It uses Wi-Fi with a telephone dial-in system to relay the data to the Data

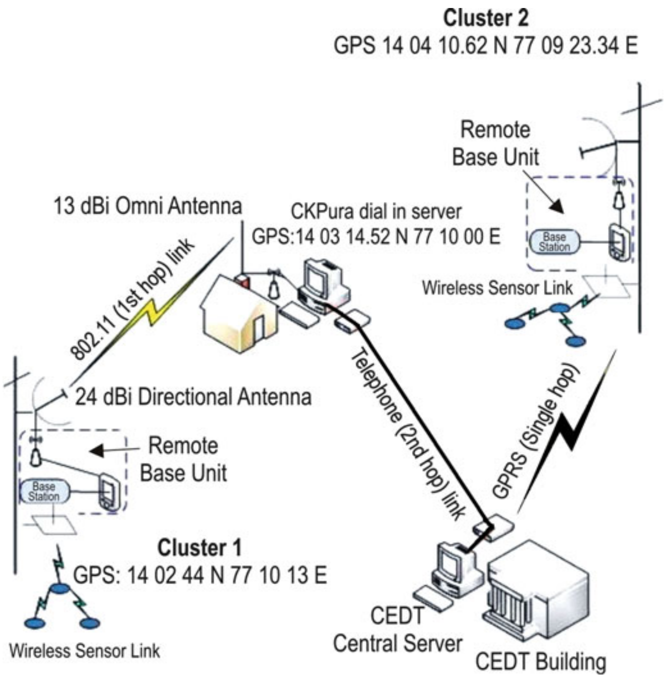

Fig. 14.1 Existing deployment

Centres. The data requires two hops from the remote base unit to reach the CEDT[1] building Data Centre. Subsequently, we later explored the possibility of using GPRS technologies in Cluster 2 to relay data and require one hop from the remote base unit to reach the CEDT building Data Centre. Data Centres process the available data and disseminate the information to the farmer.

14.3 Information Dissemination: The Rural Context

Information dissemination in the rural context requires special attention. The traditional form of diffusion worked well as it was mostly verbal. Moreover, this method uses a local language in a manner that the farmer understands and relates extremely well. How can one convey technology-assisted information back to the farmer? Considering the literacy levels, Tumkur district in Karnataka is identified by the Indian government as one of the districts where female literacy levels are below 50%. Although this is based on data available from the 2001 countrywide census, our own experience in the field indicates the literacy levels have not improved in CKpura and surrounding villages. The government's Saakshar (Ministry of Human Resource Development 2009) program is underway to improve the level. At the same time, over 650 million Indians out the 1.1 billion possess mobile phones. This high rate of penetration prompts us to use the mobile phone as a device for information dissemination. However, one now needs to overcome the problem of an illiterate population. Interestingly, in the last half of the decade, Wi-Fi and Bluetooth technologies have undergone several changes from their original specification to support improved quality of service, data security, higher data rate, and increased coverage. These technologies have started to become ubiquitous interfaces on mobile phones and other embedded devices, embedded chipsets, plug-in modules, and are currently available on Universal Serial Bus (USB) dongles. Large Wi-Fi-based coverage is now possible within the framework of the transmission power regulatory requirements by forming campus-wide, village, and citywide mesh networks. Such network infrastructure can be used for public safety and health care, infotainment, and so forth. In the rural context specific to agriculture, such mesh networks can be used for information dissemination on latest farming practices, advice for carrying pest and disease attack prediction and even market-related information such as availability of seeds, and so forth. Camera sensors with Wi-Fi or Bluetooth can be used to capture images or video to demonstrate latest practices or predict cattle disease such as the *"BlueTongue"*.

Summarizing the above discussion, we now derive a use case and state the same as follows: "*There is a need to collect sensor data from individual farmlands to provide personalized advice and assist crop insurance agencies in settling claims.*

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Mobile phone services and its multiple network interfaces such as Wi-Fi, Bluetooth are attractive to enable access to village mesh networks or smaller personal area networks. However, as literacy levels are low, information dissemination for a technology-based diffusion is a challenge. Mobile phone users may not be able to read or retrieve messages."

14.4 Issues in Reliable Data Gathering and Information Dissemination

One deterrent to the widespread use of any technology such as a WSN, Wi-Fi, or Bluetooth in the rural context comes from the fact that most villages in India have very little access to the power grid. Often, power cuts last for 12–16 h a day for a few months of the year. Therefore, charging these devices or powering the fixed infrastructure using the power grid is almost next to impossible. In addition, most technical specifications do not mention the power consumption of such devices. In summary, there is no simple formula or means to predict how long a Wi-Fi or Bluetooth connection would last before a power recharge and the amount of data that can effectively be transferred. How then would one meet the requirements of the end user such as a farmer and yet circumvent the problem of power unavailability?

14.4.1 Issues with Cluster 1 and Cluster 2

A WSN network deployed for the purposes of data collection suffered from several outages. Since the nodes are equipped with a rechargeable battery, the lifetime is unpredictable because battery replacement is handled using partially charged batteries. A fully charged battery requires at least a few hours of power grid availability. Therefore, unreliability of data communication occurs due to premature node deaths. Furthermore, there were communication outages due to node vandalism and thefts. About 30% of the deployed nodes were lost or damaged due to theft and vandalism. This was one of the reasons we could not equip the nodes with solar panels because they would attract attention. Long distance connection using telephone links is an issue. The telephone dial-up connection is running for over 2 years now. In these years, there were several instances when the telephone link and exchange were unavailable due to outages. These outages were due to (a) heavy rains, (b) equipment failures, and (c) complete discharge of large battery backups due to unavailability of power grid. The village side dial-up modems were damaged by lightning strikes five times to date, thus preventing connectivity to urban Data Centres. Also, very often, the rural aggregation server is unavailable either due to lack of power grid or due to fluctuation in input voltage. The voltage varies from about 90 to about 400 V, causing a trip in Uninterrupted Power Supply (UPS) systems. This voltage fluctuation also affected the field aggregation units where the battery chargers get charred due to a high-voltage spike. There were 10 units destroyed in these years.

Cluster 2 was deployed at a different location and explored the possibility of using GPRS technologies. In view of the GPRS setup, one can now do away with the field station dial-in server and its downtime-related issues. One may also avoid the telephone dial-in connection and the unreliability due to RF connectors. GPRS technologies require sufficiently high energy for their operation. Energy efficiency and battery backup lifetime can be extended if we minimize the transmission energy overhead and avoid frequent GPRS transmissions. Several buffering techniques were explored where data collected over a day was transmitted. We however continued to have data unreliability due to the problem of power grid. The battery backup did not last long as it could not be fully charged. There was also the issue of self-discharge. Often, low voltage that persisted in the village did not allow the chargers to work. The battery charger was shutting down due to extremely low voltage (around 90–120 VAC). We even specially ordered chargers to work under low voltages.

Table 14.1 summarizes a few important problems we faced in Cluster 1. The network outage statistics was collected for 1 year. The last column shows the number of man-hours spent in restoring the network. In summer, the soil compaction reduces drastically due to lack of moisture in the soil and thus creates an air gap between the sensor and the soil. This often led to the sensor reading illegal soil moisture values. Since our technology intervention was in the peanut-growing region of CKpura, we placed the soil moisture sensors in depths of 30 and 60 cm. Other network outages include RF cable and connector problems, loss in line of sight due to foliage and lightning. There were outage problems in the field station dial-in server unit and in the field at the Remote Base Unit side due to lack of grid power.

14.5 A Worked-Out Solution

One solution to the problem of power grid is to ensure that high-energy components could only be used when there is power. Consequently, power generation in the village for driving such ICT applications becomes mandatory. We are thus motivated to free the data relay system from the power grid. One obvious choice is to generate power from solar panels to power the GPRS relay system at each cluster. However, this would mean that we once again fall back on batteries as storage devices. Also, solar chargers, other electronics and last but not the least – good sunlight is required. Such systems, besides attracting attention, require replication at each cluster, bringing down the reliability of the complete network. In this chapter, our solution comes from the observation of Table 14.1 where there is a high level of manual intervention to restore a network outage.

Our proposition is a human-powered bicycle, acting as a data mule to assist power generation and support data relay. In this solution, we consider a hybrid

Table 14.1 Problems related to deployment: Cluster 1

Problems faced	Reason	Number of times	Troubleshooting	Effort (man-hours)
Mote sensing negative value	Probe loosing contact with the soil especially during summer	8	Ensure that the probe is in contact with the soil. Resetting the mote has also helped a couple of times	1.5 h each time
No packet transmission	Low battery voltage, mote connectivity problem, RF cable end-to-end connectivity problem, loss of LOS due to foliage	20	Replace battery, solder wires when snapped, and clean up the dust on the RF terminals. Sometimes replacing the RF cable was the only solution; align the antenna	1–2 h each time
Flash corruption due to lightning	Sometimes, because of heavy lightning, the mote's flash got corrupted	5	Reprogram the node. Lightning conductors have also been erected on the poles	0.5 h
Problems at the Base Station Unit	(1) Low voltage on the backup battery due to unavailability of grid power especially when there is no power for 3 days and over, thereby bringing down the network	(1) Recurring	(1) Replace the backup battery with charged battery	(1) 2–3 h
	(2) High-voltage spike damaging the battery charger	(2) 8	(2) Replace charger with another charger	(2) 2 h
Problems in the Field Station Unit	(1) Low voltage on the backup battery due to unavailability of grid power especially when there is no power for more than 2 days, thereby bringing down the system and related components	(1) Recurring problem	(1) Used a battery with larger capacity that gives a backup of about 8 h	(1) Turn off CRT monitor, modem, etc., when there is low power
	(2) High-voltage spike damaging the telephone modem	(2) 8	(2) Replace modem with a new modem	(2) 1 week

network technology comprising of a “Wi-Fi-GPRS” bridging system. The overall idea is to opportunistically download the data using a Wi-Fi-GPRS-enabled device, fitted to a bicycle. The data is then bridged across to GPRS interface and relayed to the Data Centre. The complete system is expected to run on power generated by a bicycle dynamo. The energy is generated when the cyclist moves from one cluster to the other. We propose a low-power device such as a Personal Digital Assistant (PDA) or a similar device, which integrates both the technologies to complete the bridging functionality. We have done away with batteries, instead storing the generated energy in a low-leakage supercapacitor. Since supercapacitors have higher power densities compared to available batteries, they will be able to source the peak power requirements of the GPRS system. Since the marginal farmlands are non-contiguous, our bicycle model of a data relay is ideally suited. It has to travel from one set of farmlands to another set.

Concerning information dissemination, we implemented solutions for the mobile phone. Since this is the most preferred device of choice, we had to cater to application availability on low-end and medium segment phones. For instance, a S40-based mobile phone is a simple phone with no additional interfaces. The popular S60 phone could have multiple interfaces such as Wi-Fi and Bluetooth. Most recent phones support the Android operating system and, thus, many new and exciting applications can directly run on such high-end phones. To take care of the literacy problem, we implemented the complete mobile phone application with voice activation. For instance, an SMS message is read out and saved as a text message. It can also be played back and heard at any time. Furthermore, farmers within the radio footprint of the data mule can automatically receive information about weather forecasts, seed availability, and market prices on their mobile phones using the Wi-Fi or Bluetooth interfaces. Such messages can be heard orally in the local language. Thus, we not only attempt to localize the information free from any service provider, we make the data mule a free service for the community. Another feature of our application is the provision for the farmers to upload queries to the bicycle system using Wi-Fi and Bluetooth interfaces. Such queries could include “Should I add nutrients,” and “What advice for my standing crop.” Such queries are sent to the data mule. The mule on its part would now upload the query using the GPRS and receive the advice, which can then be disseminated using local interfaces or directly over SMS. Thus, dissemination of information on the phone is seamless by using GSM/GPRS for receiving SMS messages and Wi-Fi or Bluetooth interfaces for receiving other information. Additionally, all the interfaces such GSM/GPRS, Wi-Fi, and Bluetooth interfaces can be used for uploading queries. The reason for such flexibility is to take care of user’s mobile phone capabilities.

14.6 Implementation: Data Communication

Bicycle dynamos have long been known to give a power of about 3 W, that is, they source about 500 mA at 6 V at about 10–20 km/h speed. We observed that a 2-min cycle ride is sufficient to complete a GPRS transmission of ten data packets. A few additional minutes of cycling would be required to source energy for the Wi-Fi-based data download from the Remote Base Unit. As a result, a simple bicycle ride with a dynamo from one cluster to another should take care of the energy requirements to relay data from the village to Data Centres. Data from several farmlands arrive at the aggregation Remote Base Unit. A cyclist visits each of these clusters, typically two times a day. Each time, data is initially downloaded on the data mule from the field aggregation unit's computer using Wi-Fi or Bluetooth. The data is then uploaded to Data Centres using GPRS technologies.

For our field computer requirements, we used the low-power Intel Atom processor–based single-board computer. We run the Linux operating system that boots from a USB-based flash memory. We also ported the Delay Tolerant Network (DTN) (Cerf et al. 2007) stack to provide DTN node capabilities. We found that DTN offers us data reliability and is best suited for systems running out of harvested or generated power. To ensure high reliability, data is packaged into bundles before transporting over the link.

The data mule is built using Gumstix System On Module (SOM) Overo Fire as the controller and Siemens TC65 as the GPRS module. As the data mule moves from one cluster to another cluster, we harvest energy generated from the dynamo into a bank of supercapacitors as shown in Fig. 14.2. The figure also shows the cycle dynamo, power-conditioning unit, and a suitably sized supercapacitor bank. The cycle also carries the Wi-Fi-GPRS bridge device and the Bluetooth interface. Since

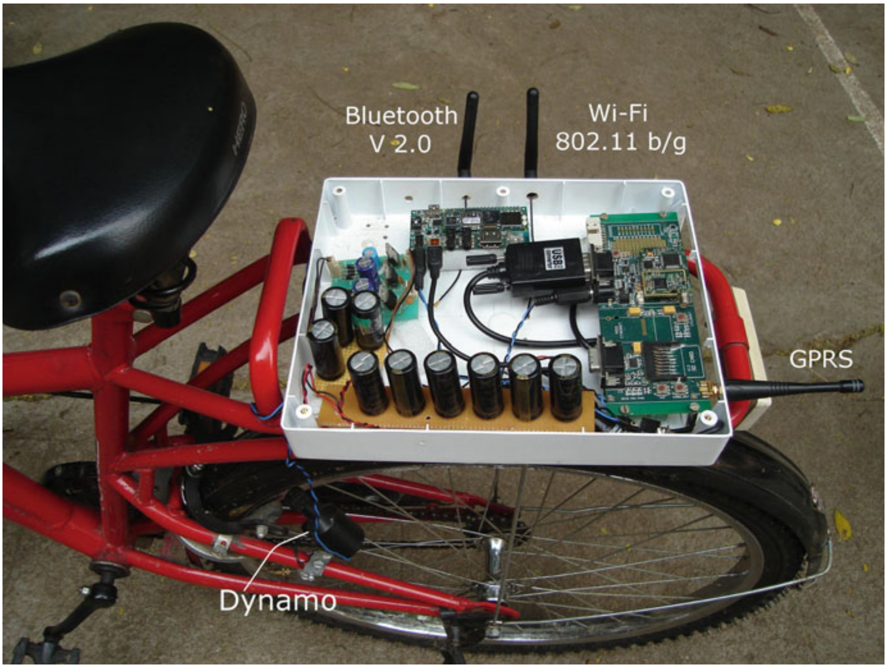

Fig.14.2 Dynamo-driven data mule

our energy requirement is to the extent of retrieving the data bundles from the FAN and transferring the same over a GPRS link, we do not require an infinite buffer. Based on the energy measurements we conducted, A 75 Farad capacitor is sufficient to transfer one data bundle of 50 packets over GPRS. The advantage of this optimal value ensures that the cyclist does not have to pedal for longer periods to kick off packet transmissions. We found that 22 min of cycling at about 13 km/h is required to generate energy sufficient to transfer a 50-packet buffer. We also measured 2.9 W as the power generated at this speed and by cycling at this speed and duration; the data mule can transfer data from 12 sensor nodes. This data is from 3 farmlands with 4 deployed sensor nodes. Each sensor node is monitoring soil moisture, rain, and temperature every 6 h. The data mule visits the cluster once a day to collect the aggregated data. If more frequent data is required, one may also place 3 sensor nodes in 3 farmlands and collect data samples every 3 h.

Table 14.2 shows the split time and energy breakup for a single-bundle transfer from FAN to data mule over Wi-Fi. The data mule consumes around 367 J and requires 193 s for a bundle transfer using DTN over Wi-Fi to download the data from FAN and use GPRS for uploading the bundle to the server (Fig. 14.3).

Table 14.2 Single-bundle transfer from FAN to data mule over Wi-Fi

Operations	Energy [J]	Time [s]
Powering up the SOM and GPRS module	77	30
Auto-login on SOM	86	30
DTN communication (send and receive)	42	13
Bundle transfer from SOM to GPRS	42	14
SOM shutdown	60	15
Siemens TC65 startup	25	60
GPRS transmission to the server	35	31

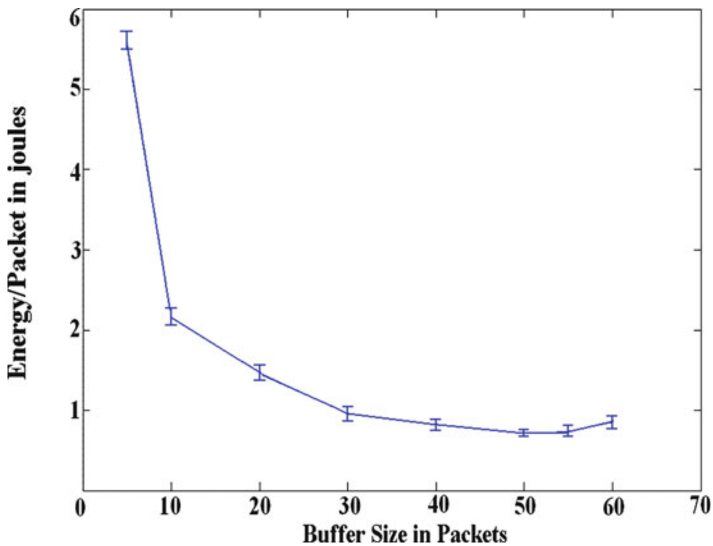

Fig. 14.3 Energy per packet versus buffer size for 95% confidence interval

14.7 Implementation: Data Dissemination

The data dissemination tool developed to support local language is shown in Fig. 14.5. The application is developed for the S60 platform-based mobile phones. Since this phone does not have other network interfaces, information dissemination is possible only using GSM technologies. The incoming SMS messages are played out and saved on the phone and can later be replayed. The complete application shown in the picture can be heard as a voice even during navigation.

We ported the Delay and Disruption-Tolerant Network (DTN) stack on the newer Android OS phones. Farmers subscribing to this service will have the application installed on the phone for the first time. The phone can then be used to obtain general information over Wi-Fi or Bluetooth interfaces. The farmer is also able to upload queries to the data mule each time it passes by. Replies to such queries return to the farmer's phone the next time the data mule passes and are automatically downloaded to his mobile. Figure 14.4 shows the screen shot of the application on an Android phone. Local language support is also available for these phones.

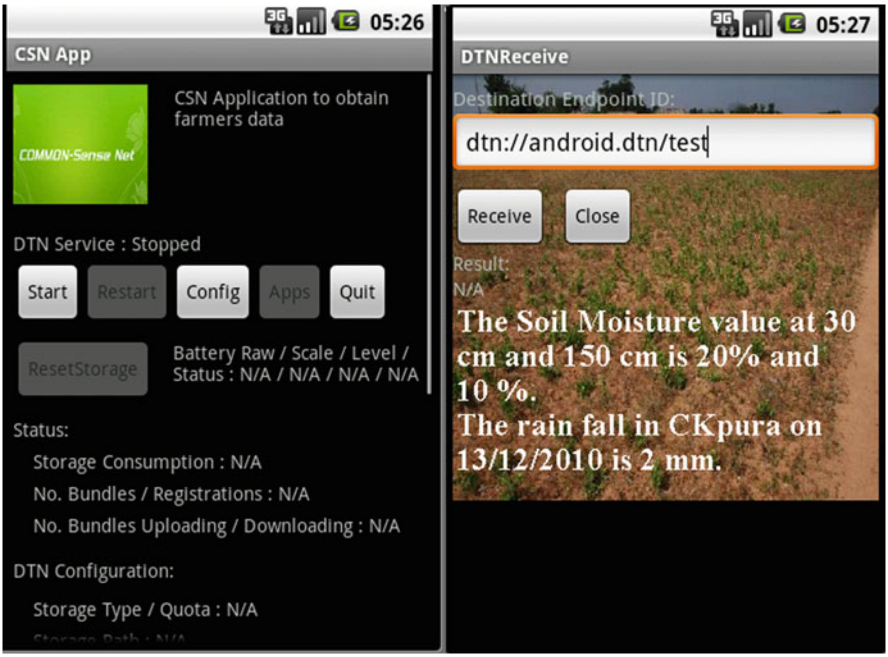

Fig. 14.4 Application on Android phone

14.8 Related Work

Sensors monitoring small and marginal farmlands have to be deployed in a manner not to obstruct routine agricultural operations and yet participate in the network formation. Most literature about *sparse* networks mention mobile entities such as "Mule's" visiting the field to periodically collect data and thus obviating the need for a fixed network infrastructure. None of them point out the reliability of data collection and the lack of grid power in the village. In Shah et al. (2003), three-tier architecture is presented and analyzed for collecting data from the field. Although no implementation is considered, the paper proposes performance metrics such as latency, sensor power, data success rate, and infrastructure cost. In Anastasi et al. (2007), the issue of energy-efficient data collection in *sparse* networks is addressed. The authors recommend a protocol called "ADT" (Adaptive Data Transfer) and conduct a detailed analysis. In Basagni et al. (2007), simulation results are presented indicating that controlled mobility is effective in prolonging network lifetime while containing the packet end-to-end delay, which is usually high in situation where mobility is uncontrolled. Myths in rural connectivity are discussed in Pentland et al. (2004) where the focus is on applying Wi-Fi-based broadband technologies for cost-effective rural communication. The paper discusses only e-mail and voice mail services offered to residents in rural villages. The model uses village kiosks and a mobile access point mounted on a tree, visiting one village after the other. While our bicycle is indeed a data mule, it generates electrical energy by running on small pathways deep inside farmlands to collect and relay the data as well as disseminate information (Fig. 14.5).

14.9 Summary and Conclusions

In this chapter, we discussed data gathering and information dissemination paradigms. We started by establishing the need for localized data gathering both for government agencies in settling crop insurance claims and for the farmer to make an informed decision about his standing crop. We highlighted that even though a large part of the population of CKpura village might be illiterate, most are in possession of a mobile phone. At the same time, the village has a serious shortage of grid power. Therefore, any technological intervention requires grid independence. We proposed and implemented a data mule that runs on a bicycle and generates power using the dynamo. The data mule has multiple network interfaces and has the capability to relay data inside and outside the village. Mature technologies such as Wi-Fi and GPRS technologies are suitable if exploited appropriately and can work to one's advantage, even in such harsh conditions, where availability of grid power is intermittent. Relay to Data Centres is no longer dependant on availability of grid power but dependant on human beings arriving on a bicycle at an aggregating point. A dynamo fitted to the bicycle stores the

Fig. 14.5 Application in local language

generated energy in a supercapacitor of a suitable size. Since batteries are not utilized, there is no need for battery chargers and power to charge the batteries. We get the additional benefit of infinite charge and discharge cycles. With the cycle dynamo system, we need to only generate energy to match functions related to acquiring data from the Remote Base Unit and relaying the same to Data Centres using GPRS. Thus, an energy-matched operation is sufficient. We do not require a large storage or any other energy-efficient mechanisms to manage residual energy at the supercapacitor. To help overcome the problem of illiteracy, we have developed voice-enabled mobile phone applications in local languages.

14.10 Future Work

Our immediate task is to complete field trials and retune the system based on user feedback. Scalability studies are necessary, and field results are required to observe the problems during data dissemination and interactive data transfers. We believe that the technology developed is self-sustaining and general enough to be used for other purposes such as health care and perhaps entertainment as well!

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Chapter 15
Application of Soil Moisture Model to Marula (*Sclerocarya birrea*): Millet (*Pennisetum glaucum*) Agroforestry System in Burkina Faso

Natalie Ceperley, Alexandre Repetti, and Marc Parlange

15.1 Introduction

15.1.1 Problem

Seasonally dry forests and savannas consisting of sparse tree canopies and dominated by open grassland make up about 16 million square kilometers of tropical land of which only 1 million worldwide remains as natural vegetation (Miles et al. 2006). The remaining seasonally dry regions are cultivated (Williams 2008). Natural vegetation is adapted to the extreme seasonality, characterized by deep taproot systems and seasonal deciduousness, whereas human propagated vegetation is not (Griffith 1961).

Watercourses and bodies in these areas are ephemeral because of the extreme seasonality of the hydroclimatic regime, which is further exacerbated by the presence of unusually high interannual rainfall variability (Murphy and Lugo 1986; Furley 2004). For example, the average total annual rainfall is 900 mm in

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Burkina Faso, but it is not unusual to have years with as little as 300 mm or as much as 1,500 mm of rain.

These regions are predicted to be sites of strong climate change (Donner and Large 2008). In Burkina Faso, precipitation isohyets have shifted to the south, reducing the average rainfall overall in the last 40 years, although some recovery has been seen in recent decades (Wittig et al. 2007). Up to 20% rainfall and 60% runoff reduction in Burkina Faso has been documented in the last decades (Mahe et al. 2005; Kallis 2008). Climate change is expected to further alter the precipitation patterns in terms of timing, even if original quantities are maintained (Hulme et al. 2000). These changes can be attributed both to regional land use, specifically vegetation change, and to global weather response to increased greenhouse gases. As a result, especially toward the middle and end of the dry season, lakes and streams become dry, while groundwater levels drop.

In a Sudanian savanna landscape, which occupies much of the country, these shifts in precipitation can be accompanied by a dramatic shift in species composition or a *sahelisation* that is irreversible due to the corresponding changes in soil physics and albedo. Zheng and Eltahir (1998) found that at a regional scale, deforestation along the coast in addition to the desert border of West Africa might be responsible for the decrease in precipitation in especially the Sahelian zone.

Resource poor farmers are among the groups most vulnerable to climate change in West Africa. Although in the Sudanian zone, less than 10% of water resources are currently exploited, these farmers have little access to the technology needed to increase access to water. Their livelihoods are almost entirely dependent on rainfed agriculture which is highly sensitive to even small fluctuations in the variability and quantity of rain. Since they are both the consumers and producers of their agricultural products, there is little external impetus for investment in climate change adaption; however, failure to adapt may result in large scale poverty, famine, migration, and possible conversion to livelihood strategies which further threaten global biodiversity and ecosystem services (Downing et al. 1997). Important adaptations include technological support to rural farmers that will allow them to predict, prepare for, and buffer the damages of climate hazards on their livelihoods.

Seasonality is the core principle of farming systems in these areas, as opposed to the temperature-driven agriculture present in temperate zones. Soils are generally fertile, and the rain is sufficient for rainfed cotton, maize, millet, and sorghum production, although the farmer must be especially attentive to anticipate and predict the rain. For example, the Yoruba know that the rain will arrive by observing changes in the leaves, the sky, and bird songs (Richards 1985). Late rainfall and poor timing of planting in relation to the rain can cause fatal problems. Although the most prosperous farmers can produce competitive crops in seasonally dry ecosystems, most farmers and their communities live in poor conditions, with food shortages, water stress, and related symptoms of poverty. Farming in valleys, floodplains, and wetlands is a tool practically unique to West Africa that is used to cope with the challenge of droughts in place of irrigation, although it can increase diversification of the generally limited crops. Paul Richards argued in 1985 that most rural farmers in West Africa (Nigeria and Sierra Leone) knew most of what agricultural science has to offer; however, they still had problems, and those were for the most part unsolved by scientific inquiry.

Two reasons explain the lack of exploitation of the water resource. The first is the difficulty for local population to manage a water resource characterized by very intense rainfalls followed by long dry seasons. During the wet season, runoff and erosion are extreme, but the recharge is limited due to actively transpiring vegetation and shallow soils. This suggests that lack of water is not necessarily the primary constraint and that even a doubling of crop yields would be hydrologically possible with relatively small manipulations of rainwater partitioning in the water balance. The second reason is the poor management of agricultural lands, grazing (Rockstrom and Falkenmark 2000), fires induced by humans (Delmas et al. 1991), and forest clearing (Fries and Heermans 1992; Savadogo et al. 2007). These activities have increased erosion, soil loss, loss of nutrients and organic matter, and altered natural stream ecology and regime. This poor management is due to the low understanding of natural phenomena, lack of management tools, and a low level of environmental education of the communities and the authorities (Wallace and Gregory 2002; Schuol et al. 2008).

15.1.2 Solution: Agroforestry

Seasonally dry ecosystems offer great possibilities for sustainable and profitable management of cultivated and natural areas (Fries and Heermans 1992). Improving rainfed agriculture by increasing the use of the portion of rainfall that infiltrates the soil and is accessible by plants to generate vapor flow in support of biomass growth (Falkenmark and Rockstrom 2006) is a commonly suggested solution.

Agroforestry, or the mixed planting of trees with crops, has long been practiced in West Africa (Neumann et al. 1998). Cannell proposed the central biophysical hypothesis of agroforestry to be that "the benefits of trees and crops only exist when trees can acquire resources of water, light, and nutrients that crops would otherwise not acquire" (Cannell et al. 1996). When they are water limiting, they increase the yield when increase the fraction of rainfall in plant growth. Improving water use efficiency by crops is an important tool to promote resilience in the face of occurring and predicted climate change (Thomas 2008). Optimizing the water use by trees benefitting from the unused crop water is an opportunity for adaption. The livelihood benefits are even more significant when one considers the added value that trees offer to agricultural land in terms of nontimber products, particularly in years of crop failure due to irregular weather patterns which are expected to become common in West Africa.

Reductions in soil moisture are one of the main reasons why farmers are resistant to adopting intensive agroforestry practices (Ong and Leaky 1999). Agroforestry solutions that emphasize the spatial arrangement of trees and crops accross differences in topography and soil variation may be the most beneficial to minimize root competition between crops and trees (Ong et al. 2002). Pruning or separating roots is shown as effective to separate the root space of the crops and trees as well. Some argue that agriculture must mimic a natural savanna ecosystem, where there is evidence of clear niche partitioning between the shallow water used by grasses and the deep water drawn by trees.

Shade offered by tree canopies may alter the subcanopy microclimate and thus the optimal species. Jonsson et al. (1999) found significant competition for light resources demonstrated by reduction in yields between millet crops and parkland shea nut (*Vitellaria paradoxa)* and African mustard trees (*Parkia biglobosa*). Optimizing agroforestry potential may be a matter of matching possible shade preferring crops with appropriate radiation shields offered by specific canopies rather than incorporating dominate crop into canopy space (Jonsson et al. 1999). Cotton yield, in contrast to that of millet and sorghum, is not reduced by shading of shea nut and African mustard trees, perhaps because water capture is improved by the shading with little effect on assimilation rates in species that rely on C_3 carbon fixation (Ong and Leaky 1999). However, Payne (2000) found that reduction of vapor pressure deficit over stands of pearl millet, through shading, in combination with soil nutrient supplements could help improve pearl millet yields.

Regardless, it is clear that benefits from tree products must outweigh losses in productivity due to shading and water competition; the yields can be compensated by species matching but unlikely that this will increase total production (Kessler 1992). *Sclerocarya birrea* was found to be one of the four most preferred species in 60 farmers' fields in Northern Burkina Faso and was most often valued for food (49%), fodder (21.4%), erosion control (3.9%), domestic use (7.8%), and shade in agricultural area (2%) (Leenders et al. 2005).

A diversification of rural economic activities and a social reorganization must accompany agricultural advances (Turner and Robbins 2008). Improvements must rely on results from modeling of water and energy fluxes in natural savannas (Brümmer et al. 2008a, b, 2009; Grote et al. 2009) in order to improve the separation between natural and cultivated patches to be compatible with local, cultural, and economic tendencies (DeFries 2008; Hobbs and Cramer 2008).

15.1.3 Solution: Wireless Sensor Networks

Wireless sensor networks (WSNs) are a new generation of measurement systems with a built-in capacity to produce high temporal and spatial density measures (Szewcszyk et al. 2004; Langendoen et al. 2006; Barrenetxea et al. 2008). They are composed of multiple autonomous sensing stations, which typically operate in a self-organized manner and communicate together using low-power radio modules. Sensing stations regularly transmit data (e.g., air temperature and humidity, wind speed and direction, soil moisture) to a sink, which in turn, uses a gateway to relay the data to a remote server. Due to their capability to produce high temporal and spatial density data, WSNs have a high potential for improving environmental data acquisition and for interfacing with scientists, managers, and farmers (Martinez et al. 2004; Werner-Allen et al. 2005; Sikka et al. 2006; Selavo et al. 2007).

One of the unique features of WSN is multihop routing (Buonadonna et al. 2005; Barrenetxea et al. 2008), which, under some restrictions, allows sensing stations to be placed farther away from the sink than the communication range of the low-power radio module. In this kind of routing mechanism, data packets are forwarded along a chain of stations, from the slave station to the sink. This feature has the advantage of enabling data to be gathered over a wide area with only one single sink. The sink usually relies on the GPRS network, largely available worldwide, to transmit the collected data from the deployed stations to any computer connected to the Internet.

Use of WSN in developing countries can stimulate innovative applications that would improve environmental sustainability by providing environmental data at low costs and improving understanding of environmental processes (Kumar et al. 2007, 2008, 2009). On a larger scale, the spread of information and communication technologies (ICTs) in developing countries remains a major preoccupation of the international community since developing ICT to its full potential still faces substantial difficulties (Zhou et al. 2008; Shah et al. 2003; Ouksel et al. 2006; Campailla et al. 2001). This is due to the lack of necessary infrastructures in less-developed countries and the difficulty in adapting existing and upcoming technology to the developing countries and the challenge of effectively managing and disseminating data for applications in a resource limited environment.

Although the cell phone is a successful example of ICT spread in developing countries, the internet has encountered more difficulties. For example, according to the International Telecommunication Union (ITU) and GSM Association (GSMA), in 2007, the number of internet users was 5.5% in Africa, 14.4% in Asia, and 26.1% in Latin America when it reached 70–80% in Western Europe and the United States; for instance, Senegal reported one computer, 0.3 internet connections and 6.6 internet users per 100 habitants in 2007. The cell phone network subscriptions in 2007 reached 28.4 mobile phone subscriptions per 100 habitants in Africa, 37.6 in Asia, and 66.7 in Latin America; for instance, 97% of all Tanzanians say they can access a mobile phone, with only 20.6 subscriptions per 100 habitants in Tanzania.

Self-organization and multihop routing make WSN highly versatile, which means their use will be favored in place of older, less user-friendly technologies. Thus, they offer potential for environmental monitoring. Given the severity of potential climate change, natural habitat fragmentation by agricultural conversion, human population increase and migration, soil salinization, and erosion in seasonally dry regions, WSN can provide appropriate monitoring systems for producing high temporal and spatial dense measurements. Moreover, as the cost for building WSN gets lower, they can cover larger monitoring areas with minimal costs, which meet the application requirements of high quality and wide coverage data, in various environmental sciences.

15.1.4 Objectives

Soil moisture emerges as the crucial variable necessary to understand in order to optimize the resource partitioning between agroforestry trees and surrounding crops and thus offers scientific support to rural farmers in countries such as Burkina Faso. Rodriguez-Iturbe et al. (1999) proposed an equation for calculating daily soil as a balance between the stochastic arrival of rainfall events and the deterministic rate of soil moisture losses at a point. They average over the rooting space or the product of soil porosity and the depth of the active rooting level. Although a stochastic model of plant water interactions has been demonstrated, the challenge of upscaling to account for competition between crops and trees is significant (Katul et al. 2007). This chapter takes the first step in exploring the applicability of such a model to a mixed *Pennisetum glaucum* and *Sclerocarya birrea* agroforestry parkland.

Data for this research was collected using wireless sensing devices (Fig. 15.1), making it the first experiment of this type using the Sensorscope network of wireless sensing devices both in an African rural development context and to study the environmental heterogeneity attributed to trees in an agricultural savanna landscape. Additionally, solar panels provided all energy for this project. Valuable lessons were learned regarding the feasibility of using this technology in this context and the potential of transferring this technology to rural farmers to improve agroforestry practices in the face of climate change.

In this chapter, we will run a simple model of soil moisture model using the actual measured rainfall from the beginning to the end of the rainy season (May to October)

Fig. 15.1 Wireless sensing device, Sensorscope' used for observation in agricultural field

as the sole input for both a herbaceous, millet-dominated vegetation cover and directly under a *Sclerocarya birrea* agroforestry tree. We will then compare the predicted soil moisture with measured values distributed over the rooting depth through the end of July. Finally, we will identify discrepancies between the modeled and the measured system to guide further study. This is a preliminary analysis of data that will guide subsequent research and point the direction for agricultural outreach inquiries specifically regarding arrangement of agroforestry trees.

15.2 Methods

15.2.1 Site Description

The Singou River Basin is located in southeast Burkina Faso in the province of Kompienga (Fig. 15.2). It is home to a rare diversity and abundance of wildlife as well as particularly dense vegetation cover, which is in part due to its protection by hunting concessions and national parks and in part due to its relative inaccessibility. However, residents of areas surrounding the protected areas have been forced to intensify agriculture that has resulted in soil degradation as well as increases in the frequency and severity of flooding and droughts. Local communities are heavily

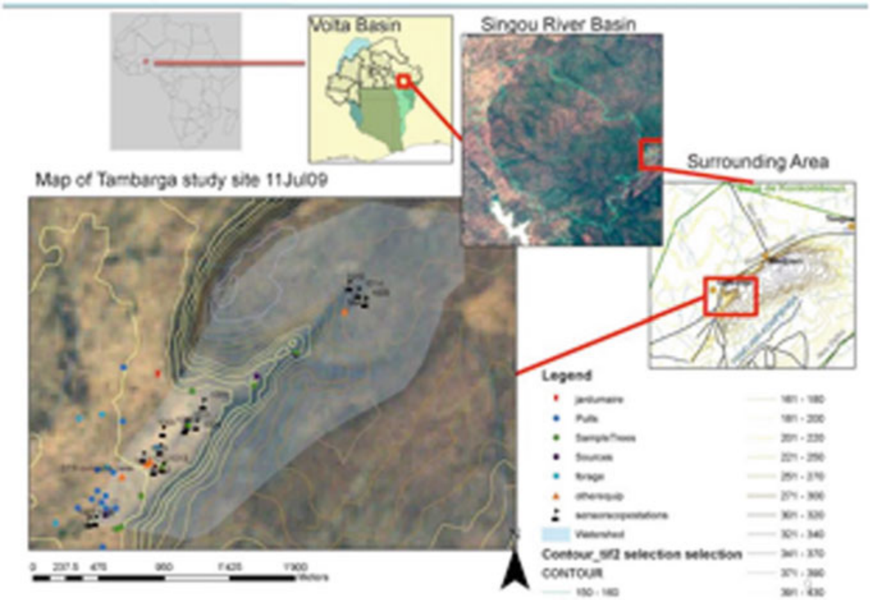

Fig. 15.2 Map of study site showing situation in basins, and equipment and sampling sites

dependent on rainfed agriculture, cultivating a mix of millet, corn, rice, sorghum, tubers in a parkland cropping system interspersed with karite or shea butter (*Vitellaria paradoxa*), Niere or African mustard (*Parkia biglobosa*), African grape (*Lannea sp*.), mango (*Magnifera indica*), Marula (*Sclerocarya birrea)*, and other fruit trees. Surrounding the farms and fallows, the landscape is a patchwork of tall grasses, meadows, interspersed large African ebony (*Khaya senegalensis*) and Baobab (*Adonsonia digitata*) trees, and shrub woodlands dominated by *Combretaceae*, wetlands, marshes, and riparian gallery forests.

This study is part of an innovative research-development project that applies recent Sensorscope technology to problems facing rural farmers in Southeastern Burkina Faso. Research themes and site choice were guided by a participatory mapping workshop held in 2008 during which residents identified current agroforestry techniques as being insufficient to buffer damages from hydrologic extremes such as droughts and floods and deforestation and reforestation with foreign species as threats to the traditional landscape.

15.2.2 Species Choice

A *Sclerocarya birrea* tree was selected to represent the large woody vegetation of the agricultural zone of the small basin based on its high prevalence and local importance (Fig. 15.3). We are currently investigating the importance of these trees to the local social economy, but in a rapid tree inventory of a representative hectare

Fig. 15.3 *Sclerocarya birrea* tree in unplanted millet field surrounded by components of wireless sensing network and solar power energy supply

of the agricultural land, six of the nine trees with a diameter at breast height (dbh) of over 10 cm were *Sclerocarya birrea*. Other species in the agricultural land include *Ficus thonningii, Magnifera indica, Piliostigma reticulatum,* and *Terminalia laxiflora*. The individual chosen is a medium tree with a dbh of 40 cm located in the agricultural upland. Comparison of large woody vegetation composition of representative 1-ha plots in agricultural and savanna land cover revealed that there are important differences between the land cover types in terms of their tree densities, species diversity, and age class distributions. Where the agricultural plot only contained nine individuals of four species, the savanna plateau site contained 254 individuals of 23 species, fewer *Sclerocarya birrea,* and all trees were considerably smaller and shrubbier. This indicates clear preference for *Sclerocarya birrea* by cultivators and is an evidence of their removal of small trees.

The relative soil moisture model that we use (Eq. 15.1) sets the change in relative soil moisture (*ds*) per time (*dt*) equal to the difference between the precipitation (*R*) and the sum of losses from canopy interception (*I*), runoff (*Q*), evapotranspiration (*E*), and leakage (*L*) or deep infiltration averaged over the rooting depth (*Zr*) and divided by the pore space (*n*). Values of soil moisture, rainfall, and interception as well as physical soil parameters were gathered during 5 months spanning the wet season.

$$nZ_r \frac{ds(t)}{dt} = R(t) - I(t) - Q[s(t), t] - E[s(t)] - L[s(t)] \tag{15.1}$$

Equation 15.1 Relative soil moisture

$$\begin{aligned}
R = h &= \begin{cases} \lambda < p \rightarrow h = 0 \\ \lambda > p \rightarrow p(h) = \dfrac{1}{\alpha} e^{\frac{-h}{\alpha}} \end{cases} \\
I &= \begin{cases} h < \Delta \rightarrow I = h \\ h > \Delta \rightarrow I = \Delta \end{cases} \\
Q &= \begin{cases} R - I < (1 - s) \cdot n \cdot Zr \rightarrow Q = (1 - s) \cdot Zr \\ R - I > (1 - s) \cdot n \cdot Zr \rightarrow Q = 0 \end{cases} \\
E &= \begin{cases} s < sw \rightarrow E = \dfrac{s \cdot E_{\max}}{sw} \\ s > sw \rightarrow E = E_{\max} \end{cases} \\
L &= K \cdot s^{2b+3}
\end{aligned} \tag{15.2}$$

Equation 15.2 Soil moisture model in detail

The relative soil moisture model that was used is based on the equation that the change in relative soil moisture (*ds*) per change in time (*dt*) is equal to the sum of canopy interception (*I*), runoff (*Q*), evapotranspiration (*E*), and leakage or deep infiltration (L) subtracted from the rainfall (R) averaged over the rooting depth (Zr) and divided by the pore space (n). This is a minimal model that can be coupled with other processes or expanded to include larger scales or higher complexity such as topography in the future. Each component of the model is calculated as shown in Eq. 15.2.

Rainfall was calculated as a marked Poisson process where time between events follows the exponential derivation, $\lambda e^{-\lambda}$, and the depth of rainfall events follows the exponential distribution of $1/\alpha e^{-h/\alpha}$. Values of λ and α were calculated for a single season, where λ is equal to the frequency of rainfall events and α is equal to the mean depth of event. Actual rainfall was recorded with a *Précis* transduction rain gauge with a resolution of 0.1 mm placed in an open area less than 100 m from the tree of interest.

Interception prevents a part of each rainfall event from reaching the soil because the canopy intercepts it. The quantity of rainfall intercepted is complex and depends on the species, the rainfall intensity, and other seasonal and climatic variables such as wind speed or stage of leaf growth. In the past, interception has been modeled as a percent of rainfall, but this model uses a simplified threshold where Δ represents an amount under which no rain reaches the soil surface. Following the approach of Laio et al. (2001), who calculated interception when the rainfall event was greater than a value Δ, the amount Δ was subtracted from the depth of the event to equal throughfall, or the depth of rain reaching through the soil surface, with $\Delta = 2$ mm for (trees) and $\Delta = 0.5$ mm for grasses (millet). Alternatively, we considered the method of Samba et al. (2001) who found interception to be 9–22% depending on distance from tree (0.5–1 of the radius) in the case of *Cordyla pinatta*. They fitted interception to an exponential function equal to 1.76 times event depth to a power of 0.2971.

Runoff was taken into account when throughfall was in excess of the storage capacity. The storage capacity was calculated as the soil moisture subtracted from one and multiplied by the porosity multiplied by the rooting depth. When throughfall was greater than this storage capacity, then the runoff was calculated to be the difference between them. Leakage, or the amount of water that drains from the soil to the depth of the active roots, was calculated as the rate of saturated leakage (K), which varies according to soil texture, multiplied by the soil moisture to a power of c, where $c = 2b + 3$, and b is coefficient that is strongly related to soil texture (Clapp and Hornberger 1978).

Evapotranspiration was considered equal to soil moisture (s) multiplied by maximum evaporation ($Emax$) over the point of onset of plant water stress (sw) until s equaled sw; thereafter it was considered to be equal to $Emax$, following the method of Federer (1979). $Emax$ was calculated from evaporation measurements calculated from eddy covariance technique using vertical wind speed measured with a Campbell sonic anemometer and fluctuations in water vapor concentration measured with a Kipp and Zonar Li-cor gas analyzer less than 100 m from the tree of interest in the agricultural field.

The relative soil moisture is the percent of the volumetric water content over the porosity, or in other words the volume of water in the soil over the sum of the

Table 15.1 Vegetation characteristics used in two scenarios

Scenario	Vegetation	Infiltration threshold	Rooting depth	Wilting point	Maximum evapotranspiration
		Δ (mm)	Zn (mm)	sw	Emax (mm/day)
1	Millet (*Pennisetum glaucum*)	0.55	1,400	0.12	3.4752
2	Marula (*Sclerocarya birrea*)	2	3,000	0.12	3.4752
Ref:		Laio et al. (2001)	Sivakumar and Salaam (1994), Smith et al. (1997)	Ong and Leaky (1999)	Measured

Table 15.2 Soil characteristics used in two scenarios

Dominant soil texture	Pore size distribution index	Porosity	Hygroscopic point	Saturated leakage
	b	n	s(1)	K (mm/day)
Silty loam	4.977	0.39	0.15	622.08
Bunasol (personal communication) 2008	Fernandez-Illescas et al. (2001)	Sampled	Initial measured	Clapp and Hornberger (1978)

volume of air and water. This model is only concerned with the soil in the active root space and averages over that depth. The values of soil moisture ranged between perfectly dry soil (0) and saturated soil (1). Initial soil moisture was estimated at the hygroscopic point, or as close to zero as possible since the model simulation began in January, in the dry season. Calculation was done at a time step of 1 day. All calculations were made in millimeters. Tables 15.1 and 15.2 show the values of all parameters used for the model.

Volumetric water content of soil was measured with the Decagon Devices EC-TM soil moisture and temperature sensor (Fig. 15.4), that measures the volumetric water content between 0 and 1 m^3/m^3 with a resolution of 0.0008 m^3/m^3. Sensors were placed along two axes running north and east from the base of the tree at radial distance of 0, 2, 5, and 7 m and depths of 15, 30, and 70 m following a general Doehlert design. Fifteen meters from the tree, sensors were installed in an agricultural field at 15 and 30 cm depth at a single point. For the purpose of this analysis, measurements at the depths are averaged for each point. Sensors were attached to a wireless sensing network of Sensorscope stations. In addition to automatic sensing, soil samples were taken for analysis of volumetric water content by drying in an oven at 105°C for 24 h. The volumetric water content was calculated by subtracting the dry weight from the wet weight and dividing by the dry weight. Soil porosity was calculated by weighing samples of 100 cm cubed after drying in a drying oven at 105°C for 24 h. The weight over the volume or apparent density was divided by 2.65 to obtain the soil porosity. These values were used to verify automatic sensor values.

Fig. 15.4 Decagon Devices EC-TM soil moisture sensor installed under tree

15.3 Results

Total rainfall for the 2009 season was 788 mm which is below the average for the nearest long-term data record at Pama, 60 km away, from 1978 to 2007 (867.2 mm, Meteo Burkina Faso). Modeled rainfall did not demonstrate the same level of variation and irregularity that the actual rainfall did, although the original values for frequency, 0.64495/day, and mean, 9.0575, were used (Figs. 15.5 and 15.6). For this reason, the subsequent model was calculated in response to actual rainfall.

As shown in Tables 15.1 and 15.2, the only changes between the scenarios were interception and rooting depth; however, we see that even these changes affect the sensitivity of the system. The leakage in particular is much higher in the case of millet, and the storage capacity is much higher for the Marula tree.

The final plots in Figs. 15.5 and 15.6 compare the actual response to precipitation and the modeled response. We see that in both cases, the predicted response is a good estimate until July when modelled soil moisture content continues to rise, whereas actual soil moisture decays. At the tree, we focus on the response at a midpoint of the rooting depth, 30 cm. We see that position in relation to the trunk changes the response considerably. The stemflow, flowing at the base of the tree, is a much larger input to the system than the canopy infiltration that we accounted for in this model. Counterintuitively, the values at the edge of the canopy, at 7 m, also are more important than the midcanopy (5 m), which is even, less than the near canopy (2 m). In the millet field, we observe that deeper soils are wetter until July when shallow soils respond much more quickly to the rain event.

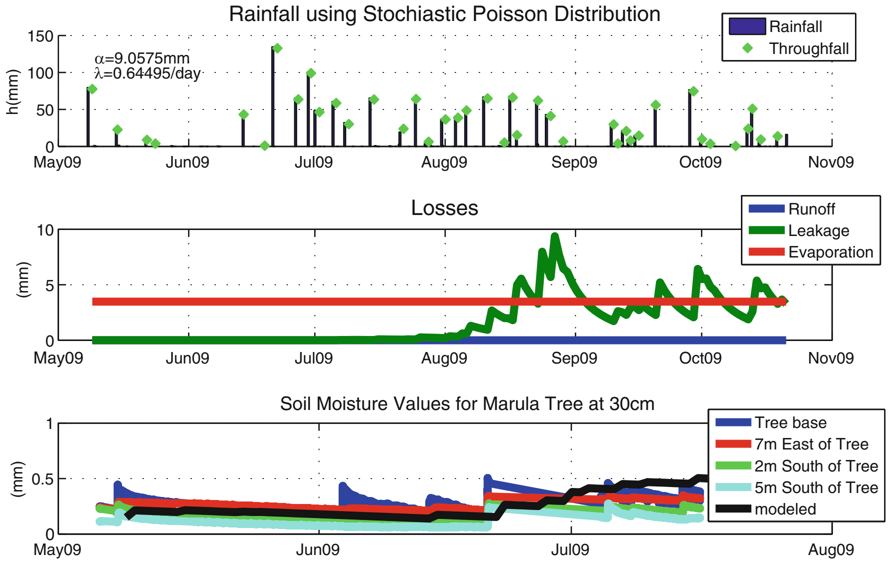

Fig. 15.5 Comparison of inputs, losses, and final soil moisture under *Sclerocarya birrea*

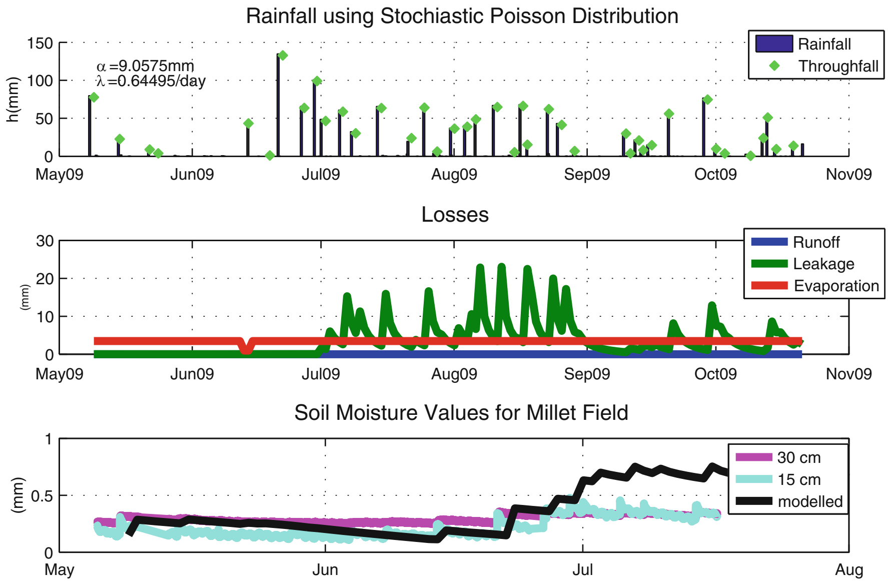

Fig. 15.6 Comparison of inputs, losses, and final soil moisture under *Pennisetum glaucum*

15.4 Discussion

The simplistic soil moisture model correctly approximated a part of the response of soil moisture to rainfall; however, it is inadequate as time continues. From examination of actual data, it is apparent that there is considerable spatial variation based on the direction and distance from the trunk because of the combined influence of water routing by the branches and trunk, exposure to direct sunlight, and possible slope effects. The model of soil moisture in the open field similarly gives an average response for soil moisture that it is approximately correct until late June. What happened around the transition from June to July that the model fails to include?

In both cases, the runoff component is zero for the entirety of the modeled time; however, there was clear evidence of runoff in both cases in the field following rain events, particularly as the season progressed. In our model, runoff is formed when the amount of throughfall received exceeds storage capacity. According to our current examination, this never occurred, but perhaps it did occur at different spatial parts of the soil, explaining the discrepancy between model and real values. The upper layer of soil may have been completely saturated, generating runoff, even if the vertically averaged storage capacity was not full. When rainfall intensity is high, it exceeds the infiltration capacity of the soil, pools and generates runoff (Brutsaert 2005). The infiltration capacity of the soil needs to be measured at different depths to improve estimations from the literature.

We see the importance of position under the canopy in the subtree moisture response (Fig. 15.5). Settin et al. (2007) found that the spatial averages over a large basin of the proposed analytical model do describe the soil moisture dynamics when seasonal dynamics are included. According to their work, improved parameterization of our soil moisture model could be made if we average all values spatially. For example, we have made estimations of wilting point and rooting depths based on literature for other species; however, this is an opportunity to solve the equation for these parameters.

Alternatively, we may need to further describe the spatial heterogeneity. Katul et al. (1997) proposed a linearized Taylor series to explain the vertical variation in soil moisture loss due to root water uptake in a growth chamber. Their model will allow for the inclusion of diurnal recharge due to the nighttime slow of transpiration. Developing our model so that it accounts for root density variation and benefits from sap flux measurements may help reduce the observed error.

Isham et al. (2005) proposed a method to account for the variability in space and time of the basic soil moisture model by breaking the model space into cylindrical cells. For our purpose, their strategy might allow us to account for the variation in factors such as radial direction and distance from tree base; however, addition of throughfall must be calculated in relation to the canopy architecture. Baldocchi et al. (2004) found in their examination of oak savannas that it is essential to account for variations in evaporative demand over the savanna space. Our current model used evaporation from a nearby eddy covariance tower, but we should explore methods to measure the latent heat flux at smaller scales and particularly to compare between and under canopies.

Caylor et al. (2006) proposed representing savanna heterogeneity as an overlapping network of leaf and root canopies. In this way, they describe the spatial variability of soil moisture at a larger scale. However, there is no clear account for interaction between woody and herbaceous vegetation in their case of a natural savanna using a Poisson distribution to estimate the spatial arrangement of canopies in a Kalahari transect. In 2005, Caylor et al. examined the interaction between trees and grasses using a coupled soil moisture and energy balance method for the Kalahari Desert (Caylor et al. 2005). They compare under canopy and between canopy levels of soil moisture in terms of the quantity of water stress on the vegetation. They found that areas between canopies experienced higher levels of stress than under canopies, and in this way the trees shielded the water stress of understory vegetation in periods of drying. This is the opposite of what we found over the rainy season; however, it might bare more similarity to what we will find as we continue our work into the dry season. We found that the soil moisture was less under canopies, where there is presumably more root uptake.

Our preliminary results are not conclusive enough to make a strong recommendation to rural farmers in regards to managing soil moisture dynamics through woody vegetation. However, our data does show that water is more available in the between canopy spaces, as Ong et al. (2002) warned. Even so, there were still generous levels of soil moisture under canopy, particularly at the base of the trunk. The high level of soil moisture that our model produced in contrast to the actual measured soil moisture shows the potential soil moisture if runoff was reduced to zero. Encouragement of pooling through artificial barriers is the most effective way to trap this moisture in both the open and subcanopy space. Our data suggests the importance of incorporating the spatial heterogeneity of subcanopy into planting techniques. We thus recommend exploration of crop varieties that correspond to the moisture and light regimes under canopies, coupled with half-moon techniques of stone lines to trap stemflow at the base of the tree trunk.

The soil moisture data used for this analysis was collected using soil moisture probes distributed throughout the rooting area of an agroforestry tree. These data were part of a wireless sensing network of Sensorscope stations. This research would not have been possible without multiplexing a large number of sensors on a single station, arranged around a tree. Over the 3-month period, these stations required very little maintenance; however, once the rainy season progressed into August, the combination of electricity and humidity rendered some of the components ineffective. Improvements have been made to prevent damage in future seasons. Solar energy provided all of the power for these stations without any problem, even over the course of the rainy season. Solar energy is well adapted to dry-land ecosystems as a minimal amount of daily solar radiation can be guaranteed.

15.5 Conclusions

This chapter made an important first step in applying a simplistic soil moisture model to the *Sclerocarya birrea* agricultural parkland in Burkina Faso. Further work needs to be examined to account for rainfall intensity and the subsequent runoff levels. Spatial heterogeneity under canopy space should be examined in more detail in particular in relation to root and canopy architecture and variations in evaporative demand. Our data suggests some preliminary agroforestry solutions that can optimize water use in this ecosystem such as under canopy planting of crops with lower light and water requirements and stone half-moon placement to encourage runoff infiltration particularly from stemflow.

This research represents an important first use of wireless sensing networks for environmental management in small-scale rural farms in West Africa. Data was successfully collected over the course of a rainy season. Subsequent work will make this technology more accessible to the farmers and community leaders themselves. The preliminary conclusions of this research already demonstrate the usefulness of this technology to find agroforestry solutions to the hydrologic problems presented by climate change for rural farmers.

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Part VII
Information Systems

Alexandre Repetti and H. S. Jamadagni

Information and communication technologies (ICTs) have been extensively developed over the past few decades, especially in developing and emerging countries. These technologies offer new development potential, based on powerful and accessible tools, and especially:

- Internet, with an increasing penetration rate (11% in Africa, 24% in Asia, and 36% in Latin America) and which enables data and ideas to be transferred on a global scale.
- Cell phone revolution, which enables information to reach virtually everybody.
- Calculation power of computers, whose prices have plummeted. This power, which just could not be imagined 10 years ago, enables large quantities of information to be stored and processed at reasonable prices.
- Development of sensors regardless of whether they are installed on satellites, airplanes, drones, or even on the ground, in the form of sensor networks.

Together these information technologies have enormous potential for application in various fields, and especially for sustainable management of natural resources and the environment. However, one challenge still needs to be overcome: harnessing these technologies for the service of development by surmounting the obstacles of technological transfer, digital divide, and application to foster sustainable development.

This promising potential of ICT applied to the environment and the numerous challenges that still need to be overcome have resulted in the UNESCO Chair in Technologies for Development at EPFL defining ICT applied to the environment in developing countries as one of its priority fields. The research presented below demonstrates relevance of the questions raised and the responses provided.

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The information system presented by Salami and Adepoju shows the use of satellite data to assess large-scale vegetal production and model the condition of land erosion on a country scale. The information system deployed identifies major disparities between the regions. This information is pivotal to the development of public policies and the ensuing scientific monitoring of their effectiveness.

The research presented by Wafo Tabopda gathers together satellite data and land observations in order to analyze changes in the forest in a natural reserve in Cameroon under pressure from firewood collection. The information system deployed not only shows which sectors are the most affected but also the relatively moderate impact of anthropic pressure on the ecosystem. Such information is required to define sustainable management modes for natural reserves, which reconcile conservation and provision of services for the local populations.

The decision support system proposed by Satizábal, Barreto-Sanz, Jiménez, Pérez-Uribe, and Cock deploys a machine-learning model to analyze and optimize localization and management of the different crops. Their database combines satellite data, results from NASA flights, meteorological data, and information directly collected by the farmers. In regions where the climate varies greatly from 1 year to the next, the information system deployed enables farmers to optimize the choice of crops tailored to the situations by factoring in interannual variability of conditions.

Chapter 16
Geo-Information System for Land Degradation Evaluation in Nigeria

Ayobami T. Salami and Kayode A. Adepoju

16.1 Introduction

Land degradation is one of the most serious global environmental issues of our time (Dregne and Chou 1994; UNCED 1992). It has been estimated that over 250 million people are directly affected by desertification, and some one billion people in over 100 countries are at risk (Adger et al. 2000). Land degradation has a broad range of definitions that essentially describe circumstances of reduced biological productivity of the land (UNCCD 1999).

According to the United Nations Convention to Combat Desertification (UNCCD) definition, land degradation can be caused by both human and climate factors (UNCCD 1999). Vegetation production in arid and semiarid regions is closely related to the long-term average precipitation (Rosenzweig 1968; Rutherford 1980) and interannual rainfall variability (Le Houe'Rou et al. 1988). Short-term variability in primary production makes it exceedingly difficult to distinguish long-term change as a result of human-induced land degradation from the effects of periodic droughts (Pickup et al. 1998; Dahlberg 2000; Dube and Pickup 2001; Prince et al. 1998). Human impacts are further obscured by spatial variability in topography, soil types, vegetation types, and land use.

The assessment of land degradation is greatly hindered by weaknesses in our knowledge of the current situation. According to some analysts, land degradation is a major threat to food security, it has negated many of the productivity improvements of the past, and it is getting worse (FAO 2000). Degraded land is costly to reclaim and, if severely degraded, may no longer provide a range of

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ecosystem functions and services with a loss of goods and many other potential environmental, social, economic, and nonmaterial benefits that are critical for society and development. In order to combat land degradation, countries need spatial monitoring systems that are able to distinguish human impacts on vegetation production from the effects of rainfall variability (Pickup 1996).

The choice of an appropriate indicator of land degradation is vital in addressing this problem. A key land quality indicator is the net primary productivity (NPP). NPP measures overall land productivity and ecosystem health and also provides some indication of land degradation and soil productivity in particular land use systems (FAO 2003). NPP is one of the primary processes describing the vegetation activity in terms of mass and energy exchanges between the earth's surface and atmosphere. It is defined as the rate of net production of organic matter (the total green biomass produced by all the plants) by the terrestrial vegetation and represents the efficiency with which the carbon (IV) oxide is absorbed by it (Bai et al. 2006).

Changes in NPP may be measured by remote sensing of vegetation indices to identify "hot" spots as well bright spots. The local and regional norms of Normalized Differential Vegetation Index (NDVI), which can be used as a proxy for NPP, can be calculated by stratifying the land area according to climate, soils, terrain, and land cover. NDVI deviation from the local norm may be taken as a measure of land degradation (Ustin et al 2006) or improvement (Bai and Dent 2006).

NDVI data have been widely used in studies of land degradation from the field scale to the global scale (e.g., Tucker et al. 1991; Bastin et al. 1995; Singh et al. 2006; Brown et al 2006). However, a negative trend in greenness does not necessarily mean land degradation, nor does a positive trend necessarily mean land improvement. Greenness depends on several factors including climate (fluctuations in rainfall, temperature, sunshine, and the length of the growing season), land use, and management; changes may be interpreted as land degradation or improvement only when these other factors are accounted for. Where productivity is limited by rainfall, rain-use efficiency (RUE), the ratio of NPP to rainfall, accounts for variability of rainfall and, to some extent, local soil and terrain characteristics. RUE is strongly correlated with rainfall; in the short term, it says more about rainfall fluctuation than land degradation, but its long-term trends distinguish between rainfall variability and land degradation (Tucker et al. 2005). In this work, land degradation was identified by a declining trend in both NDVI and RUE. The pattern of land degradation was further explored by comparisons with land cover and socioeconomic data.

16.2 Methodology

16.2.1 Study Area

Nigeria covers an area of 923,768 km located within longitudes 3° and 14° east of the Greenwich Meridian and latitudes 4° and 14° north of the Equator. About 98.6%

of the total area is land while the rest is water. It is the most populous African country with a population of 140 million in 2006. About 70 million ha in the country are considered to be suitable for arable cultivation, but only about 50% of this is currently under cultivation. The country is characterized by a strong climatological gradient north to south, with definitive dry and wet seasons. It is this gradient that defines Nigeria's ecological zones and main land cover types (Fig. 16.1). In terms of administrative arrangement, Nigeria is comprised of 36 states and a federal capital territory (FCT) that are grouped into six geopolitical zones.

Human activities have exacerbated the ecological problems in Nigeria, while the institutional capacity for combating the problems remains weak. For instance, land use change due to rapid urbanization, deforestation, desertification, agricultural practices, and lots more affect the physical and biological properties of the land surface in the country. The population of the country is expected to exceed 200 million in the year 2100 based on the current growth rate (Ogbonnaya, 2003). To feed the burgeoning population, agriculture and livestock grazing have expanded correspondingly, often into marginal areas that are not ecologically suitable for such activities. Since the 1900s, Nigeria has seen disruption of farming systems,

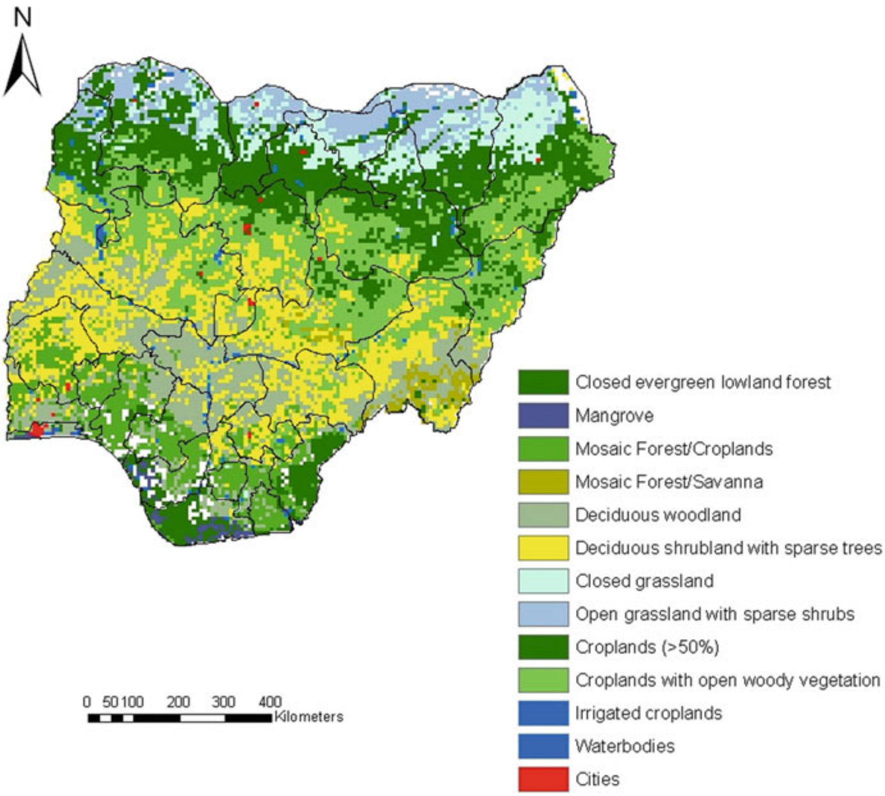

Fig. 16.1 Mainland cover types in Nigeria (Source: Adapted from GLC 2000)

degradation of natural resources, and a decline in production of many staples against a background of mounting pressure on natural resources from its growing population, now increasing at about 2.5% annually (World Bank 2005).

16.2.2 Data Collection

This study utilized NDVI data from January 1982 to December 2006 produced by the Global Inventory Modeling and Mapping Studies (GIMMS) group from measurements made by the advanced very high resolution radiometer (AVHRR) on board US National Oceanic and Atmospheric Administration (NOAA) satellites. Rainfall data for 36 stations were collected from the Nigeria Meteorological Agency for the period between 1982 and 2006 and was used for the analysis.
With respect to land cover data, global land cover data (GLC 2000, Fig. 16.1) were generalized for Nigeria for preliminary comparison with NDVI trends. The 2006 population census data for Nigeria were converted to grid format at a scale compatible with other datasets used for this study.

16.2.3 Data Analysis

The long-term trends of the indicators of biological productivity may be taken as indicators of land degradation (where the trend is declining) or land improvement (where the trend is increasing). Fortnightly NDVI data were geo-referenced using batch processing in Erdas Imagine software, and averaged and annual NDVI indicators were derived for each pixel while their temporal trends were determined by linear regression at an annual interval and mapped to depict spatial changes. A negative slope of linear regression indicates a decline of green biomass and a positive slope, an increase – except for standard deviation (STD) and coefficient of variation (CoV) – which indicates trends in variability. Simple NDVI indicators (NDVI minimum, maximum, maximum-minimum, mean, sum, standard deviation, and coefficient of variation) were computed for the calendar years using the spatial analyst extension and map calculator in ArcGIS software. The annual sum NDVI, the annual aggregate of greenness, was chosen as the standard proxy for annual biomass productivity. Monthly grids of rainfall for the period 1982–2006 were geo-referenced and re-sampled to the same spatial resolution as the NDVI (8 km) using neighborhood statistics in spatial analyst software. Spatial pattern and temporal trend of rainfall and rain-use efficiency (RUE, the ratio of annual NDVI and annual rainfall) for each pixel were determined by regression. The indices of land degradation and potential for improvement were then compared with land cover for a more localized analysis.

False alarms were eliminated to distinguish between declining productivity caused by land degradation and declining productivity caused by other factors.

Rainfall variability and irrigation were accounted for by identifying where there is a positive relationship between NDVI and rainfall, that is, where rainfall determines productivity. For those areas where rainfall determines productivity, rain-use efficiency (RUE) was considered; where NDVI declined but RUE increased, declining productivity was attributed to declining rainfall, and those areas were masked (urban areas were also masked). For the remaining areas with a positive relationship between NDVI and rainfall but declining RUE, and also for all areas where there is a negative relationship between NDVI and rainfall, that is, where rainfall does not determine productivity, NDVI trend was calculated as RUE-adjusted NDVI. Hence, land degradation was indicated by a negative trend in RUE-adjusted NDVI. CoV images were also generated to compare the amount of variation in different pixels by computing for each pixel the STD of the set of individual NDVI values and dividing this by the mean (M) of these values. This represents the dispersion of NDVI values relative to the mean value. A positive change in the value of a pixel-level CoV over time relates to increased dispersion of values, not increasing NDVI; similarly, a negative CoV dispersion means decreasing dispersion of NDVI around mean values, not decreasing NDVI.

16.3 Results

Biomass productivity fluctuates according to rainfall cycles. Countrywide, greenness increased over the period 1982–2006 (Fig. 16.2). The mean annual biomass productivity (represented by sum NDVI in Fig. 16.3) essentially follows rainfall which has fluctuated significantly, both cyclically (Fig. 16.4) and spatially (Fig. 16.4). Over the period 1982–2006, rainfall increased over nearly all of the country and so did overall biomass production, but correlation between spatially aggregated annual sum NDVI and annual rainfall is only moderate ($r = 0.26$) (Fig. 16.5); there are other factors at play. For this analysis, RUE was calculated as the ratio of annual sum NDVI and station-observed annual rainfall. Figure 16.6 shows trend in annual rainfall over the period 1982–2006: RUE is generally higher in the dry lands than in the humid areas which generate significant runoff. Rainfall variability has been accounted for using both rain-use efficiency (RUE) and residual trend of RUE (RESTREND). RUE is considered by, first, identifying pixels where there is a positive relationship between productivity and rainfall. For those areas where productivity depends on rainfall and where productivity declined but RUE increased, we attribute the decline of productivity to drought. Those areas are masked (urban areas are also masked). NDVI trends are presented for the remaining parts of the country as RUE-adjusted NDVI. Over the period, RUE decreased over 22% of the country and increased over the remaining 78%. Figure 16.7 depicts the negative trend of RUE-adjusted NDVI from 1982 to 2006. Close to 6.6% of the country suffered declining RUE-adjusted NDVI, mostly in the northeast and the southern part of the country, especially in the southeast and south-south. Degrading areas are not so conspicuous in the dry lands.

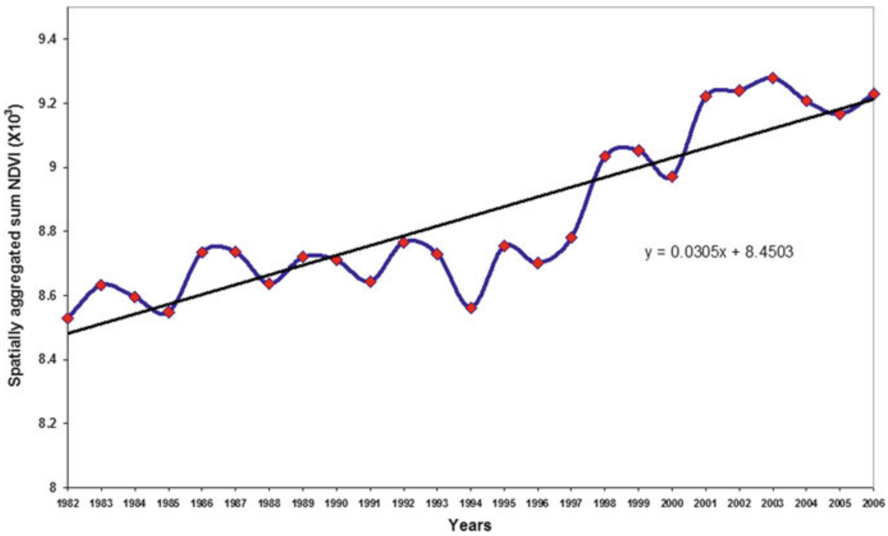

Fig. 16.2 Spatially aggregated annual sum NDVI (1982–2006), $p < 0.05$ (Source: Adapted from GIMMS, University of Maryland, and access given by Tucker et al. (2004))

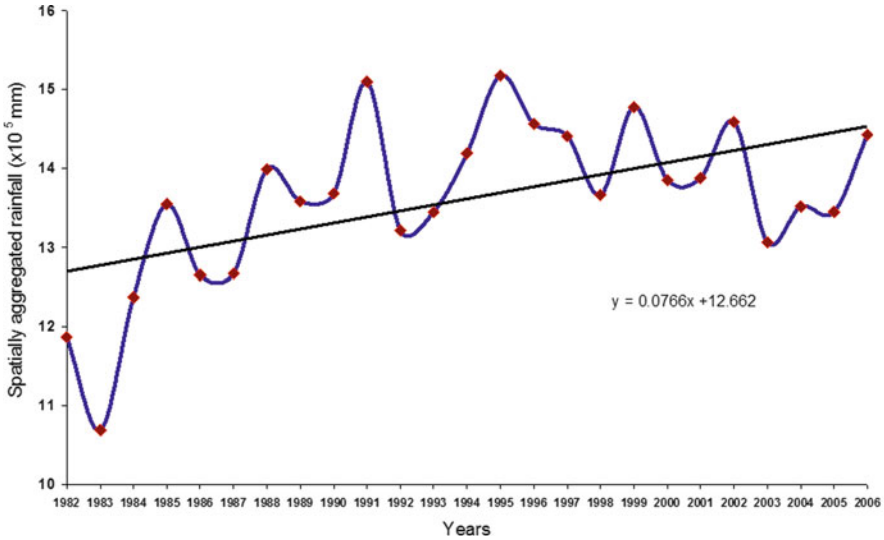

Fig. 16.3 Spatially aggregated annual rainfall (1982–2006), $p < 0.05$ (Source: is adapted from Nigeria Meteorological Agency (NIMET, 2009)

Land improvement was identified by combination of (1) a positive trend in sum NDVI for those areas where there is no correlation between rainfall and NDVI and (2) for areas where NDVI is correlated with rainfall, and a positive trend in rain-use efficiency. These areas account for about 45% of the country. Most of the

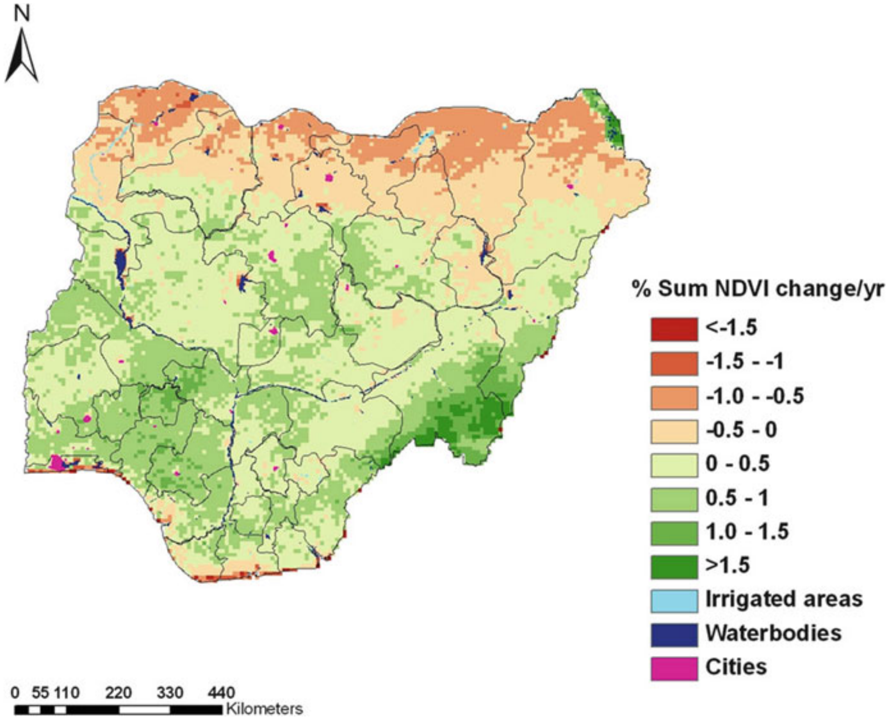

Fig. 16.4 Nigeria trend in annual sum NDVI (1982–2006) (Source: Adapted from GIMMS, University of Maryland, and access given by Tucker et al. (2004))

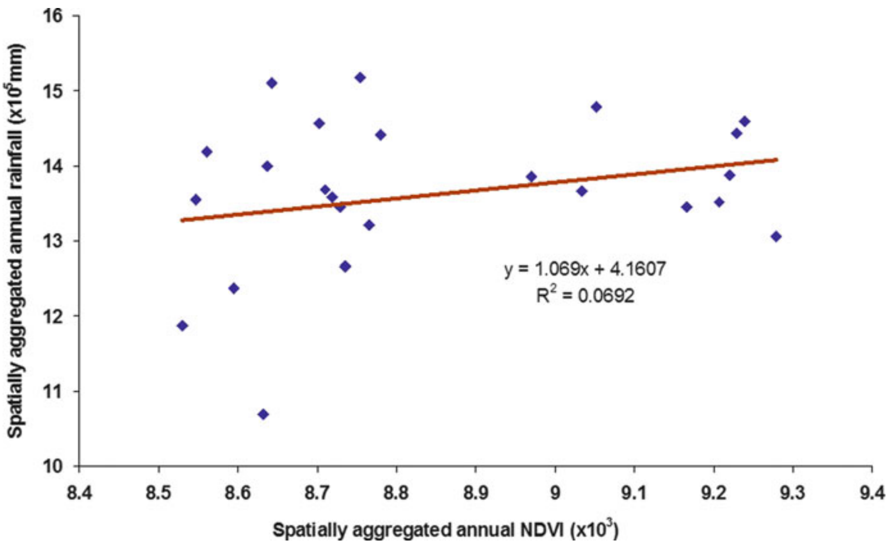

Fig. 16.5 Relationship between annual sum NDVI (all pixels) and annual rainfall (all pixels). Each dot represents 1 year $p < 0.05$ (Source: Adapted from GIMMS, University of Maryland, and access given by Tucker et al. (2004))

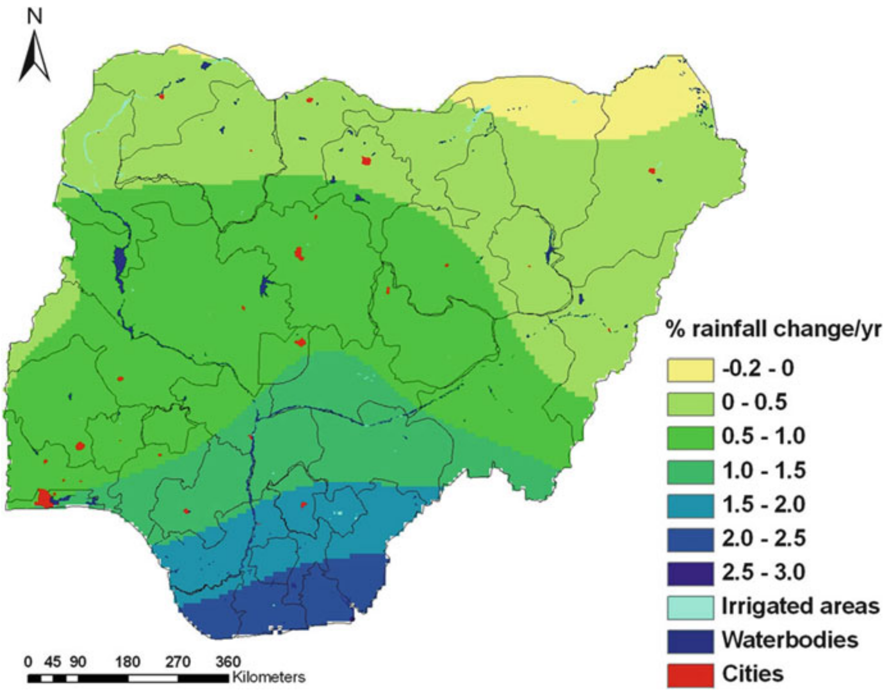

Fig. 16.6 Nigeria trend in annual rainfall (1982–2006) (Source: Adapted from Nigeria Meteorological Agency (NIMET, 2009))

improving areas are found in the southwestern, northcentral, and northeastern zones. Figure 16.7 shows the gain in NPP in those areas. A positive change in the value of a pixel-level CoV over time was found more in areas with potential improvement while decreasing dispersion of NDVI around mean values were mainly associated with decreasing NDVI (Fig. 16.8).

Comparing the combined index of land degradation and improvement with land cover (Tables 16.1 and 16.2), 18% of the degrading area is cropland, 8% represents mangrove, 5.6% represents closed evergreen lowlands, 6.4% represents degraded evergreen lowlands, and a further 8.4% represents swamp bushland and grasslands in all, 34.4% represents both open and close grasslands, and 6% of the degrading pixels constitute both deciduous woodlands and scrublands. Irrigated croplands represent 1.6% of the total degrading areas as well, and 9.2% of the degrading area is forest (Table 16.1). Given the fact that a great majority of the people in Nigeria are concentrated in rural areas, they depend on agriculture, exploitation of forest products, and water resources for their livelihoods. From the study, it is clear that a significant amount of degradation was going on in the croplands, forest, and mangrove regions, which is about 18%, 9.2%, and 8% of the total degrading pixels, respectively (Table 16.1).

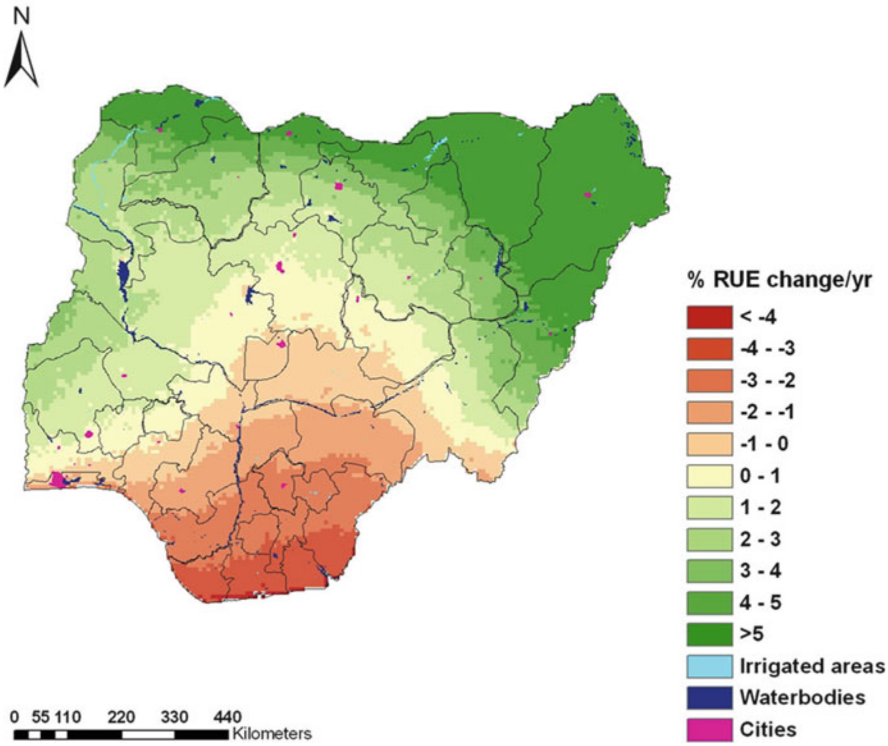

Fig. 16.7 Nigeria trend in annual rain-use efficiency (1982–2006) (Source: Adapted from GIMMS, University of Maryland, and access given by Tucker et al. (2004))

Most of the potentially improving areas are found in the southwestern, northcentral, and northeastern zones. Of the improving areas, 17.4% is cropland (>50%) and 34.36% is cropland with open vegetation, irrigated cropland is 0.485%, while an improvement of 3.02% and 2.55% were recorded for both closed and open grasslands, respectively. A further 2% improvement occurs for mosaic forest/cropland and 28.29% for both deciduous woodland and shrublands. About 0.1% improvement was recorded for mangrove, 0.034% improvements for degraded evergreen lowland, and no improvement for closed evergreen vegetation. As most of the improvements took place in croplands with open vegetation, 34%, 36%, and croplands (>50%), this suggests relatively good management practices in such areas. An improvement of about 3% suggests that the grasslands are likely to have experienced overgrazing throughout the study period. The result however portrays no significant improvement for closed evergreen vegetation and evergreen lowland forest which are most likely to have suffered from severe deforestation.

The result of this study however shows that over the years, only about 6.6% of the total country was suffering from land degradation while about 43.7% has witnessed an improvement in vegetation activity. However, this result is highly generalized due to the scale at which the study was carried out. Hence, at this scale,

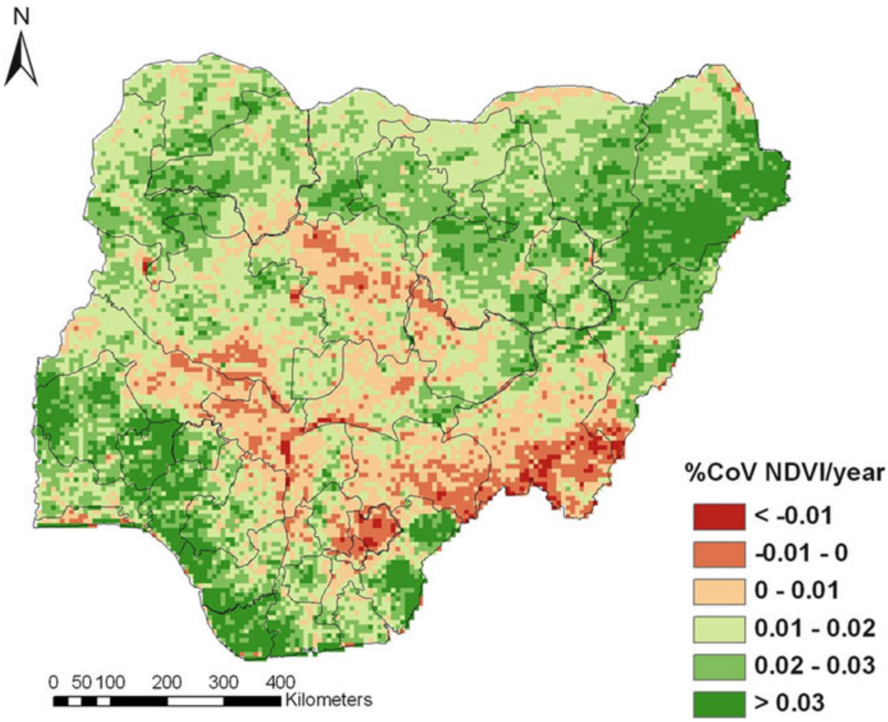

Fig. 16.8 Nigeria trend in annual CoV NDVI (1982–2006) (Source: Adapted from GIMMS, University of Maryland, and access given by Tucker et al. (2004))

Table 16.1 GLC 2000 database for land use/land cover in Nigeria

Land use/land cover	Value	Total pixel
Closed evergreen lowland forest	1	29,380
Degraded evergreen lowland forest	2	10,273
Mangrove	6	6,760
Mosaic forest/croplands	7	72,182
Mosaic forest/savanna	8	11,850
Deciduous woodland	10	137,265
Deciduous shrubland with sparse trees	11	160,340
Closed grassland	13	60,771
Open grassland with sparse shrubs	14	59,772
Open grassland	15	3,139
Swamp bushland and grassland	17	3,596
Croplands (>50%)	18	182,232
Croplands with open woody vegetation	19	188,780
Irrigated croplands	20	1,742
Water bodies	26	7,994
Cities	27	2,425

Source: Adapted from GLC database (2000)

Table 16.2 Degrading and improving land by land cover

Code	Land cover	Total pixels (TP)[a]	Degrading pixels (DP)[b]	DP/TP (%)	DP/TDP[c] (%)	Improving pixels	IP/TP (%)	IP/TIP[d] (%)
1	Closed evergreen, lowland forest	29,380	14	0.04	5.6	0	0	0
2	Degraded evergreen, lowland	10,273	16	0.16	6.4	2	1.95	0.03471
6	Mangrove	6,760	20	0.3	8	6	0.09	0.104131
7	Mosaic forest/croplands	72,182	8	0.01	3.2	120	0.17	2.08261
8	Mosaic forest/savanna	11,850	9	0.08	3.6	216	1.82	3.748698
10	Deciduous woodland	137,265	8	0.006	3.2	817	0.6	14.1791
11	Deciduous shrub with sparse trees	160,340	7	0.004	2.8	814	0.51	14.12704
13	Closed grassland	60,771	14	0.02	5.6	174	0.29	3.019785
14	Open grassland with sparse shrub	59,772	14	0.02	5.6	147	0.25	2.551198
15	Open grassland	3,139	58	1.85	23.2	173	5.51	3.00243
17	Swamp bushland and grassland	3,596	21	0.58	8.4	279	7.76	4.125998
18	Croplands (>50%)	182,232	35	0.02	14	1,003	0.56	17.40715
19	Croplands with open woody vegetation	188,780	10	0.005	4	1,980	1.04	34.36307
20	Irrigated croplands	1,742	4	0.22	1.6	28	1.61	0.485942
26	Water bodies	7,994	5	0.06	2	2	0.03	0.03471
27	Cities	2,425	7	0.29	2.8	1	0.04	0.017355

Source: Adapted from GLC database (2000)
[a]Pixel size, 8 × 8 km
[b]Urban extents are excluded
[c]*TDP* total degrading pixels
[d]*TIP* total improving pixels

there is every likelihood that the indicator is only able to detect cases of severe land degradation hot spots in the country, and this may not reflect all cases of land degradation. This result, however, agrees with a number of studies that showed that the perceived desertification in the Sahel (e.g., Lamprey 1975) can largely be attributed to variations in rainfall rather than human-induced land degradation (Tucker et al. 2005; Nicholson et al. 1998; Prince et al. 1998; Anyamba and Tucker 2005; Nicholson 2005). These studies also demonstrated that there was neither a progressive southward march of the Sahara desert nor large-scale expansion of less productive land (Tucker et al. 2005; Nicholson et al. 1998; Anyamba and Tucker 2005).

According to UNCCD (1999), it was estimated that between 50% and 75% of Adamawa, Bauch, Borno, Gombe, Jigawa, Kano, Katsina, Kebbi, Sokoto, Yobe, and Zamfara States in Nigeria were affected by desertification. Hence, this study was able to identify parts of Yobe and Borno states in Northern Nigeria and the Niger Delta in the southern part of the country as being affected by land degradation which is in agreement with UNCCD assessment. In these states, land degradation has been attributed to intensive farming combined with the effect of accelerated wind and water erosion, woodland destruction, water logging, and salinization of irrigated land. The menace also occurred following prolonged period of the Sahel drought between 1963 and 1978 which took a severe toll on the land and also led to competitions fueled with incessant communal conflicts that forced people to move into environmentally fragile areas and put undue pressure on the land (YSME 2001). The result also partly agrees with the findings published by FAO AGL (2005), where Borno and Yobe states were classified as being affected by severe soil degradation while the Niger Delta was classified as experiencing very severe degradation in the south. This finding corroborates the earlier ones by ERACTION (1998) and Aluko (2000) that oil exploitation has denied most people in the Niger Delta of their means of livelihood. In the case of Taraba State, this study revealed a positive improvement (Figs. 16.8 and 16.9), while the FAO findings presented it as experiencing degradation. In this study, it was found that about 8% of the total degrading areas were identified as mangrove. Another 8.4% loss in swamp bushland and grassland were due to oil exploration, transport, and production activities of multinationals in the Niger Delta. These had led to increased hunger and poverty among the poor people living in such areas whose main source of livelihood is agriculture. Such consequences has further triggered further exploitations of fragile and marginal ecosystems and increased pressure on migration of both human and livestock populations in search of greener pastures (UNCCD 1999). In the Niger Delta, for instance, agricultural land was reduced drastically since oil exploration started. Aluyor (1998) argued that farmlands in the Niger Delta have been made infertile and unproductive due to frequent oil spills that are never cleaned up properly. Most lands have been lost with no possibility of it being ever redeemed to forest and agricultural usage. Farmlands and fish streams pollution, deforestation, coastal erosion, and other woes have all been traced to the oil exploration and production activities of multinationals. The consequence is that the Niger Delta's mangrove and rainforests face real threat of being wiped out. Also facing possible extinctions are the fauna and the indigenous people that depend on them for survival. The coarse resolution of the GIMMS data is a limitation: an 8-km pixel integrates the signal from a wider surrounding area. Many symptoms of even severe degradation, such as gullies, rarely extend over such a large area; degradation must be severe indeed to be seen against the signal of surrounding unaffected areas.

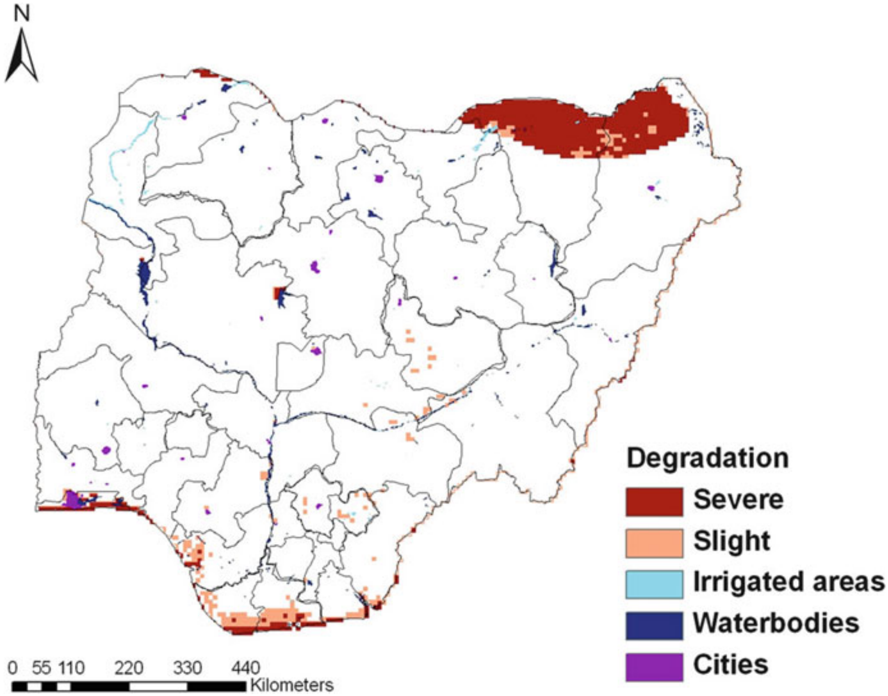

Fig. 16.9 Negative trend of RUE-adjusted NDVI (1982–2006) (Source: Adapted from GIMMS, University of Maryland, and access given by Tucker et al. (2004))

16.4 Conclusions

This study is based largely on the analysis of NDVI, which is calculated from the optimal red/near-infrared band combination for estimating leaf chlorophyll content or vegetation health status. NDVI data have generally been widely used in studies of land degradation from the field scale to the global scale, since it indicates the relative health or vigor of the vegetation. As healthy vegetation absorbs more visible light and reflects more of infrared than unhealthy vegetation, it has therefore proved useful for mapping areas where land is degraded based on its ability to support the biomass.

From the study, it is clear that a significant amount of degradation was going on in the croplands, forest, and mangrove regions, which is about 18%, 9.2%, and 8% of the total degrading pixels, respectively. Most of the improving areas are found in the southwestern, northcentral, and northeastern zones. Of the improving areas, cropland with open vegetation and irrigated cropland dominated while grasslands only improved slightly. Anthropogenic factors such as over-exploitation, over-grazing, deforestation, and poor irrigation practices as well as the inherent extreme climatic variability have resulted into the disruption of ecological systems in these areas. Poor land use and ever-increasing pressure put upon the available resources by the expanding population, climate, and socioeconomic conditions have been identified as the major drivers. Degraded sites (hotspots) were found more especially in the northern grasslands, most of which are marginal lands associated with intense overcropping and overgrazing activities. The southern degraded lands (mainly degraded mangroves) are associated with deforestation activities especially in the Niger Delta region. The south-south part of the country was found to fall within the areas of severe land degradation. This area incidentally is one of the most densely populated areas of the country with the population density more than twice the national average. This might be one of the social stressors fuelling militancy in the Niger Delta. Hence, the current effort by the Federal Government of Nigeria aimed at combating restiveness in the Niger Delta should incorporate measures to address the problem of land degradation in this region.

Over the years, the government agencies and policy makers in the country have been working with the assumption that desertification, largely attributable to human activities, has been occurring in the northern part of the country at a rate of about 0.6 km per annum. This study however suggests that desertification in the northern region of Nigeria is more as a result of rainfall variability than from anthropogenic forces. The human effects may however exacerbate the process once initiated by rainfall variability. It must be stressed that the low (8 km) resolution of the data used in this study can only provide a general view of land degradation in each of the regions of the country. Nevertheless, this study has provided the basis for a more detailed analysis. Data with finer resolution need to be employed in order to capture other indicators of land degradation such as erosion, which must have been excluded from the analysis in this study.

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Chapter 17
Characterisation and Monitoring of Deforestation in the Protected Areas of North Cameroon: Analysis Using Satellite Remote Sensing in the Kalfou Forest Reserve

Gervais Wafo Tabopda

17.1 Introduction

Since the mid-1990s, the Kalfou forest reserve has been the scene of several environmental, social and economic impacts. Fuelwood demand, demographic growth and the economic crisis have fostered the felling of trees in this environment even if it is protected. Availability of satellite images, especially from Landsat TM and ETM+ sensors, offers the possibility of characterizing and tracking vegetation cover changes in this reserve. Faced with the absence of spatial management tools for this area, remote sensing constitutes a means of identification and monitoring of vegetation cover changes.

For the past few years, this technology has been used for analysis of vegetation cover in the protected areas in tropical environment (Achard et al. 2002; Jusoff and Setiawan 2003; Mayaux et al. 2003). In this study, we will make diagnostics of the vegetation state in the Kalfou forest reserve based on processing and analysis of satellite images. In more precise terms, this involves highlighting the land cover state and quantifying vegetation changes over the past 20 years using the remote sensing tool.

Based on two Landsat satellite images with 30 m of resolution, we have produced spatial documents for the Kalfou forest reserve. These documents highlight successive vegetation cover states in 1986 and 2001. The longitudinal study of land cover using these multi-temporal documents has enabled us to quantitatively analyse and assess land cover between 1986 and 2001. This analysis was updated and supplemented with surveys conducted on the land between 2003 and 2006.

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17.2 Study Site and Local Populations

The Kalfou forest reserve (Fig. 17.1), located between 10°15′ and 10°22′ on the northern latitude and between 15°05′ and 15°11′ on the eastern longitude, was set up on 24 February 1933 with the aim of fostering reforestation by prohibiting any form of agro-pastoral use. At present, this protected area in category VI[1] according to IUCN classification is considered in Cameroon as an operational technical unit in the third category (Decree 98/345 of 21 December 1998). Its climate, typical of semi-arid regions, is of Sahelian type with rainfall of less than 900 mm per year.[2] It is characterized by a dry season, which may last for up to 8 months, from October to May, despite low rainfall observed during March, April and May, which are also the hottest months with average temperatures greater than 30°C. June, July, August and September are the rainiest months with total rainfall of around 700 mm for normal years.

This rainfall, sometimes violent at the start of the rainy season, is accompanied by milder temperatures. In addition, the climate is characterized by substantial inter-annual variations in the rain gauge, with alternating dry years (high level of aridity) and wet years in terms of rainfall (Yengue and Callot 2002). These variations result in periods of drought with the most memorable ones occurring in 1970 and 1980, recording annual average rainfall of 396 and 476 mm, respectively (Yengue and Callot 2002).

In climatic conditions marked by recurrence of aridity and close frequency of droughts, a forest reserve is welcome, as it is likely to regulate the climate and bring coolness, thus fostering intrusion of local populations, with the extension of their activities.

Local populations of the Kalfou forest reserve belong to the *Moundang*, *Masa* and *Toupouri* cultures. Relations with these different ethnic groups are of several types, namely cultural, agricultural and pastoral. On the cultural level, the reserve represents for certain among them a place of ancestral worship, where certain animal and vegetation species are considered sacred. This is the case for *Sterculia setigera*, known locally as 'Bobori', which is considered as a sacred tree by the *Masa* populations. In general terms, relations between societies and their environment are based on representations and management systems, thus perpetuating the practices and animal and vegetation species deemed useful and indispensable. This is the case for several modes of widespread use in North Cameroon, such as selective vegetation conservation. The same applies for vegetation species which are conserved by local populations. We can mention some of the emblematic

[1] Protected areas in category VI of the IUCN are mainly managed for sustainable use of natural resources and protection of environmental services.

[2] Rainfall and temperature data considered within the framework of this work is that of the Yagoua station located around 30 km from Kalfou.

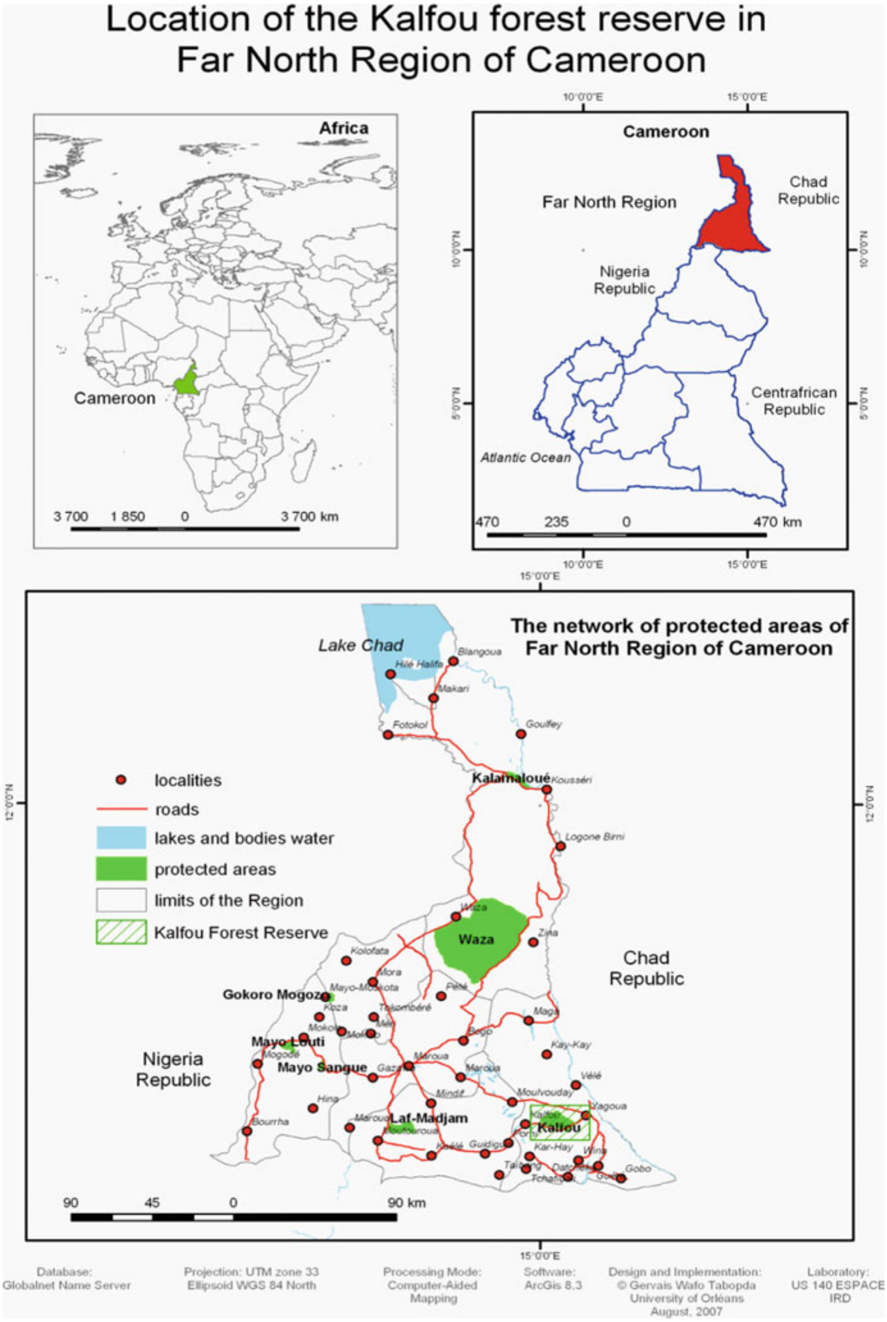

Fig. 17.1 Location of the Kalfou forest reserve in North Cameroon

species growing in the Kalfou reserve: *Tamarindus indica*, which is commonly used in traditional medicines, and *Acacia albida*, which is used for construction support of traditional huts.

17.3 Satellite Data Available and Processing

This research into trends in vegetation cover in the Kalfou forest reserve is more specifically focused on analysis of land cover dynamics on the local scale. In order to do so, the method used is based on processing and analysis of three sources of data: satellite images, socioeconomic data derived from official censuses and land surveys. Optical satellite images constituting the basis of work deploy geospatial technology, commonly used for assessment and mapping of land cover changes (Vaclavik and Rogan 2009; Reis 2008). Optical systems are widely used to map land cover due to the diversity of spectral measurements. Processing of data derived from these sensors can promptly identify the different surface states using analyses of spectral signatures (Faure et al. 2004).

The importance of optical satellite imagery lies in its ability to provide depth in time and synoptic vision of large areas (Carlson and Sanchez-Azofeifa 1999; Guerschman et al. 2003; Rogan and Chen 2004). In order to supplement digital information, other data is used, especially data from socioeconomic surveys and global positioning system (GPS) land surveys, indispensable for relevant interpretation of satellite images and explanation of land cover changes.

In order to do so, we have used two optical images derived from Landsat, TM and ETM+ sensors, dating from 1986 to 2001, respectively (Table 17.1). The two datasets have been obtained from the website Global Land Cover Facility (GLCF) [http://glcf.umiacs.umd.edu]. We have not used the thermal bands (10.40–12.50 μm) in our analysis, due to their low spatial resolution and low noise signal (Jensen 2004). However, the spectral bands considered (visible, near infrared and infrared), in the same way as the spatial resolution considered and dates of acquisition, offer the possibility of global and detailed observation in keeping with the type of information sought.

The data used was all acquired in the dry season, so as to eliminate, in this zone characterized by a hot and dry climate, factors likely to interfere with and alter detection of geographical objects (Tsayem Demaze 2002). The period situated between October and November is also that of the maximum differentiation of land cover components (crops, herbaceous plants and trees), due to the significant impact of phonology of land cover components (Verger and George 2004; Vaclavic and Rogan 2009). It is characterized by the lack of impact of atmospheric factors (absence of nebulosity) and the great capacity of reflection of an object compared to its neighbours.

Satellite data derived from the Landsat sensors is recommended for detection of land cover components and changes on intermediate and local scales. The contribution to management, monitoring and mapping of protected areas has been

Table 17.1 Characteristics of satellite data used

Data	Date of acquisition	Coordinates P/R	Spectral bands	Spectral range	Spatial resolution	Operating scale
			1. [0.45–0.51 μm]	Blue	30 × 30 m	
			2. [0.52–0.60 μm]	Green	30 × 30 m	
			3. [0.63–0.69 μm]	Red	30 × 30 m	
ETM+	21.10.2001	184/53	4. [0.75–0.90 μm]	Near infrared	30 × 30 m	1/50,000
			5. [1.55–1.75 μm]	Middle infrared	30 × 30 m	
			6. [10.40–12.50 μm]	Thermal infrared	60 × 60 m	
			7. [2.09–2.35 μm]	Far infrared	30 × 30 m	
			P. [0.52–0.90 μm]	Panchromatic	15 × 15 m	
			1. [0.45–0.53 μm]	Blue	30 × 30 m	
			2. [0.52–0.60 μm]	Green	30 × 30 m	
			3. [0.63–0.69 μm]	Red	30 × 30 m	
TM	20.10.1986	184/53	4. [0.76–0.90 μm]	Near infrared	30 × 30 m	1/50,000 to 1/100,000
			5. [1.55–1.75 μm]	Middle infrared	30 × 30 m	
			6. [10.40–12.50 μm]	Thermal infrared	120 × 120 m	
			7. [2.08–2.35 μm]	Far infrared	30 × 30 m	

highlighted by several authors (Wafo Tabopda et al. 2007; Carroll et al. 2004; Mayaux et al. 2003; Jusoff and Setiawan 2003). The purpose of the process of detecting changes, which justifies the method used, is to recognise land cover components on digital images. These components are likely to undergo changes between two or several dates (Muttitanon and Tripathi 2005).

17.3.1 Image Data Processing

The purpose of satellite data processing is to produce information compiled according to set objectives. The images retained are reset in the reference projection system, Universal Transverse Mercator (UTM) in zone 33, Ellipsoid and Datum, WGS 84 North. This involves extraction of useful information from the satellite images selected. This operation, which requires very strict application, is carried out in progressive and logical stages and sequences. This work is organised around three additional main stages: preprocessing, digital classification and highlighting of land cover changes, based on the technique of post-classification comparison (Keita and Zhang 2010; Rajeev et al. 1999). Numerous techniques have been developed in literature dedicated to post-classification comparison, namely conventional image differentiation, image regression, handheld scanning on the screen of analysis of the main change components and multi-temporal classification (Lu et al. 2005).

17.3.1.1 Preprocessing

Preliminary image processing or preprocessing is a set of operations whose purpose is to improve data legibility and facilitate interpretation and better extraction of useful information. These operations are applied using radiometric improvements and geographical resetting carried out after linear bleeding of the histograms in each spectral band (Wafo Tabopda and Fotsing 2010). Conventional coloured compositions (4R/3B/2V) are then displayed by overlay of the near infrared red and green channels. Lastly, new channels are created by calculating new planes of information.

Principal component analysis (PCA), which transforms the original data into a set of non-correlated variables, where the first components represent most of the variance from the original datasets, unlike the following cross-polarised components which are characterised by a higher proportion of noise (Eastman and Fulk 1993). Three new planes of information accounting for 98% of initial raw information are thus retained (PCA1, PCA2 and PCA3) from the set of six raw channels previously transformed. The Normalized Differential Vegetation Index (NDVI) and Index of Brilliance (IB) are also created. They enable special coloured compositions to be displayed. Visual interpretation of the different coloured compositions and determination of the potential classes of land cover constitute the last stage of analog interpretation.

17.3.1.2 Digital Classification of the Images Selected

Digital classification of the images is one of the most important tasks in the field of remote sensing. It is the process of production of thematic maps to show spatial distribution of characteristics identifiable in a given region (Karimi and Peng 2004). This is a process that is commonly used in remote sensing and consists of grouping together sets of similar pixels into classes (Wafo Tabopda and Fotsing 2010). The pixels may have the same radiometric value or substantial relations of proximity. This involves geographical breakdown into homogenous classes from radiometric data derived from satellite sensors. It is carried out using automated software programmes Envi 4.2.

Within the framework of this work, a mixed or hybrid method of classification was selected, consisting of borrowing from both directed classification techniques and those of non-directed classification. The first one is based on the maximum likelihood algorithm of Gaussian hypothesis, whereas the second one is automatically carried out by algorithms of dynamic blobs or moving centres (Wafo Tabopda 2008; Karimi and Peng 2004). This involves pseudo-directed hierarchical classification, during which successive partitions are carried out from a pixel set, and the pixels considered as properly classified are isolated as and when. The same process enables classification of poorly classified pixels to be recommenced until a result that is deemed satisfactory for all the target classes is obtained.

Determination of the classes is based on matching of radiometric information contained in the satellite image with information derived from observations and GPS land surveys. In the Kalfou forest reserve, and related to spatial resolution of the satellite images used, the following four main topics are adopted: vegetation cover, crops, earth and water bodies. Based on these topics, the following eight classes are highlighted: (1) burned areas, (2) water bodies and pools, (3) crops, (4) woodlands, (5) tree savannahs, (6) grass savannahs, (7) bare earth with little vegetation and (8) vegetation on floodable land.

However, effectiveness of segmentation with hybrid classification is debatable. It depends on several factors, such as good knowledge of the land and low rate of confusion between the land cover components. Therefore, new planes of information need to be created, and radiometric masks need to be used to constitute Iso reasoning zones – zones whose pixels contain similar spectral and spatial information. Although this method is long and fastidious, it nonetheless provided us with access to relevant findings.

The final result of classification into raster data, which represents the different classes of land cover, can then be converted into vector data and exported in a format which facilitates its integration in a spatial reference database. It then becomes possible to quantify the extent of the various land cover components for better understanding of the vegetation cover state of the reserve.

17.3.2 Post-processing

At the end of radiometric segmentation, similar classes are combined, and filters are applied to the final result for mapping logic requirements. The purpose of these post-classification filters is to improve quality of the final result. The filter which has been applied is majority analysis based on use of a filter of variable size (e.g. 3 × 3 or 5 × 5 pixels).[3] In addition, other operations may also be applied, such as the streamlining procedure to eliminate isolated pixels and homogenise the final result. This operation was developed using morphological operators already integrated in the software Envi 4.2.

Digital classification is one of the processes appropriate to processing of satellite images and recommended for production of geospatial information systems (Karimi and Peng 2004). In order to do so, this involves a stage of integration, management and manipulation of geographical information produced upstream during processing. The phase of integrating data in a geographical information system constitutes the post-processing phase.[4] This stage is implemented using the software ArcGis 8.3. It enables all the information useful for analysis of land cover dynamics inside and around the Kalfou reserve to be integrated in a common database. Information derived from satellite image processing, spatiotemporal analysis of land cover and GPS land surveys in 2006 and 2007 is exported in a geographic information system (GIS) database. It is supplemented with information extracted from exogenous data, such as the road network and localities. Related requests and statistical analyses are then carried out to respond to precise questions related to the central research issue. Finally, land cover mapping and synoptic maps are produced.

17.4 Results

17.4.1 Land Cover States on the Two Dates

Results derived from classifications enable land cover to be quantified and the extent of vegetation cover to be highlighted on the two dates. Surface area of the Kalfou forest reserve is 4,000 ha (Table 17.2 and Fig. 17.2). Rate of annual average change in each land cover component is thus calculated based on the formula $Tx = [((S_{2001} - S_{1986})/(S_{1986})) \times 100] \times 16$.[5]

[3] The central pixel of the majority option filter is applied to the class that is the most represented in the final result.

[4] Ducrot (2005) qualifies post-processing as high level processing.

[5] S represents the surface area in hectares for each component on each date, and 16 is the number of years between the two observations.

Table 17.2 Trends in land cover in the Kalfou forest reserve between 1986 and 2001

Land cover components	Surface area (ha)				Trends between 1986 and 2001	
	1986		2001		Size (ha)	Rate of change
Burned areas	59.04	1.48	73.00	1.82	13.96	0.01
Water bodies	13.28	0.33			−13.28	−0.01
Crops	20.89	0.52	193.09	4.83	172.21	0.11
Woodlands	2,313.73	57.84	1,118.00	27.95	−1,195.73	−0.75
Tree savannahs	1,479.81	37	969.45	24.24	−510.36	−0.32
Grass savannahs	44.92	1.12	1,558.06	38.95	1,513.14	0.95
Bare earth with little vegetation	18.1	0.45	26.47	0.66	8.37	0.01
Vegetation on floodable land	50.23	1.26	61.93	1.55	11.69	0.01
Total	4,000.00	100	4,000.00	100		

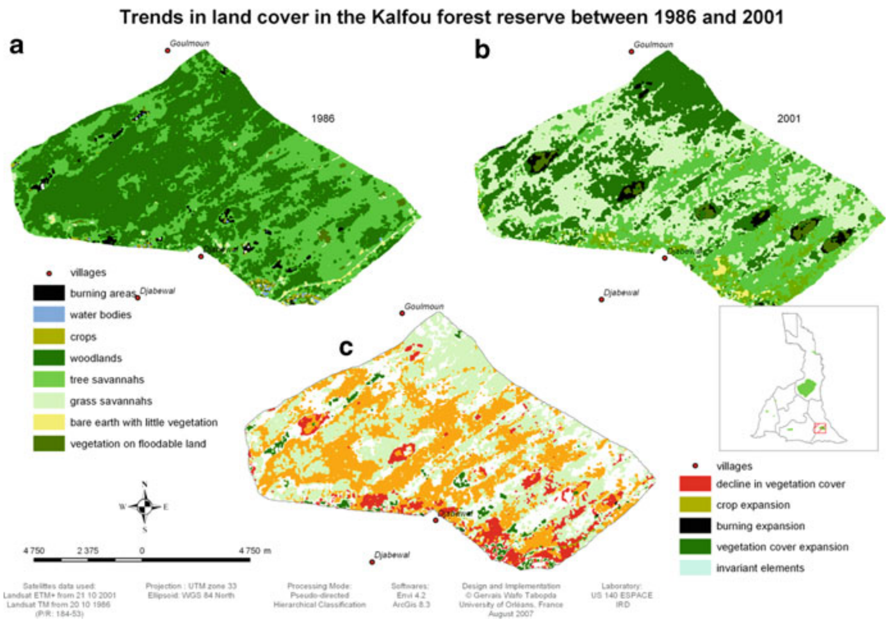

Fig. 17.2 Trends in land cover in the Kalfou forest reserve between 1986 and 2001

17.4.1.1 Vegetation Cover State in 1986

Land cover mapping in 1986 showed that vegetation (woodlands, tree savannahs, grass savannahs and vegetation on floodable land) covered surface area of 3,888 ha, that is, 97% of the entire reserve. This rate of vegetation cover illustrated a protected area with perfect stability. Woodlands (2,313 ha) and tree savannahs (1,479 ha) alone accounted for nearly 85% of the entire reserve. In addition, they illustrated the importance of tree cover, mainly composed of *Balanites aegyptiaca*, *Sclerocarya birrea, Kigelia africana* and *Sterculia setigera*. Grass savannahs scattered with *Andropogon* spp., and vegetation on floodable land accounted for 44 and 50 ha, respectively. The least covered areas accounted for more than 2.5% of the protected area. Spatial extension of burned areas (59 ha) was far more representative than bare earth with little vegetation which barely accounted for 0.45% of the reserve. With 20 ha, crops accounted for 0.52% of the total surface area mapped. They were located in the centre and in the east of the reserve (Fig. 17.2a). Hydrographic components, especially water bodies and pools, accounted for less than 1% with 13.28 ha.

17.4.1.2 Land Cover State in 2001

With 3,707 ha in 2001 (Fig. 17.2b), vegetation cover experienced a drop of 0.03% per year, nonetheless accounting for 92% of the surface area mapped. It was mainly composed of woodlands (1,118 ha), tree savannahs (969 ha), grass savannahs (1,558 ha) and vegetation on floodable land (61 ha). Crops with surface area of 193 ha accounted for 4.8% of the entire area mapped. Burned areas and bare earth barely accounted for 2.5% of land cover with 73 and 26 ha, respectively. The water bodies and pools in the southeast had virtually disappeared from the protected area (Fig. 17.2b and Table 17.2).

These findings show that the components which characterise land cover in the Kalfou forest reserve vary over space and over time (Fig. 17.2). Several factors may explain these variations especially that of vegetation cover: increasing scope of rural activities, tree poaching and insufficient protection.

17.4.2 Changes Identified Between 1986 and 2001

The longitudinal analysis of results of the two images processed enables behaviour of the different land cover components to be monitored over 15 years (Fig. 17.2c and Table 17.2). The analysis method adopted to detect changes is that known as post-classification comparison. A series of studies estimated that post-classification comparison was the most accurate change detection procedure, as it offers the advantage of indicating the type of changes (Mas 1999; Yuan et al. 2005). The technique of post-classification comparison (pixel by pixel) was thus used for mapping and quantification of vegetation cover components derived from the satellite images processed.

Surface area of classified objects can progress or regress. This group only considers that spatial location remained intact between the two dates. Land cover dynamics observed between 1986 and 2001 is quite a good illustration of the deforestation trend observed in the land in 2006 and 2007, as confirmed by the coloured composition of the Landsat ETM+ image of 20 November 2006 (Fig. 17.3).

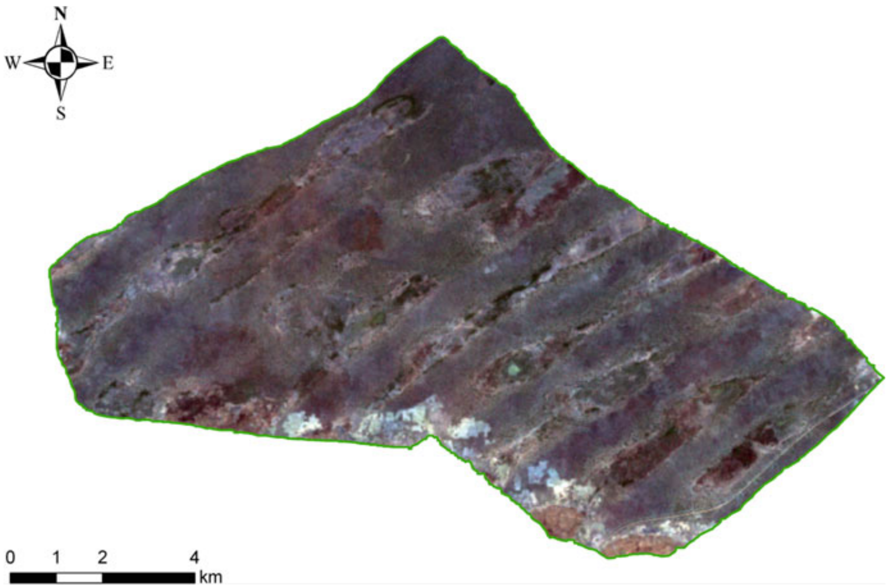

Fig. 17.3 The Kalfou forest reserve seen from the Landsat ETM+ satellite on 20 November 2006 (coloured composition R1/G2/B3-false colour). The *light* and *light grey* shades illustrate the extent of deforestation

17.4.2.1 Upturn in Components

Pseudo-directed hierarchical classification adopted during this analysis and merging of the results obtained highlight upward trends in some land cover components. The grass savannah is the component experiencing the greatest positive transformation in terms of percentage with +0.95%. The crops component experienced considerable growth on the scale of the protected area, that is, +0.11%. Burned areas, bare earth with little vegetation and vegetation on floodable land rose by 0.01%.

17.4.2.2 Downturn in Components

Except for water bodies and pools which recorded a drop of −0.01% per year, the other components in decline were mainly made up of trees. They decreased by just over 1%. The woodlands lost 1,195 ha, whereas tree savannahs lost 510 ha. This drop in tree species partly explains the rise in grass savannah and extension of crops.

17.5 Discussion

Land cover changes detected and quantified in the Kalfou forest reserve highlight the extent of deforestation. The recovery observed in grass savannahs (+1,513 ha) is proportional to the decline in woodlands (−1,195 ha) and that of tree savannahs (−510 ha). The results obtained correspond to the reality of the land, thanks to the tools and processing method applied. The pseudo-directed classification of Landsat satellite images deployed here requires trips to and from the land. Land missions are indispensable in order to validate findings derived from geospatial processing (Carlson and Sanchez-Azofeifa 1999; Guerschman et al. 2003; Keita and Zhang 2010; Yuan et al. 2005).

Consequently, this study, which is proposed to characterise and quantify deforestation of the Kalfou forest reserve, illustrates the importance of use of remote sensing in the analysis of vegetation cover dynamics in vulnerable ecological environment. In addition, remote sensing by facilitating mapping in successive land cover states enables deforestation to be characterized on the one hand and trends in vegetation cover to be quantified on the other hand. This technology has been successfully used for analysis of vegetation cover in protected areas of the tropical environment (Achard et al. 2002; Jusoff and Setiawan 2003; Mayaux et al. 2003), with Landsat optical images.

However, spatial resolution of the satellite data constitutes one of the weaknesses of the processing method. It is impossible for us to access specific categorisation of vegetation cover components, with spatial resolution of 30 m. In the same way, although the methodological sequencing applied is effective in terms of results obtained, it is long and fastidious. Its application requires several tests and field missions. Nevertheless, use of satellite images with very high spatial resolution, such as Quickbird (2.44 m) and Ikonos (3.2 m), would enable more detailed results to be more quickly obtained with object-oriented classification and automatic detection of changes, with the main disadvantage being financial cost of the operation.

In addition, for the sake of explanation of ecosystem transformations in the reserve studied, only local observations and surveys are capable of providing relevant information. In other terms, the methodological contribution of this research also participates in the proposal of a lasting solution to issues related to the theme of decline in fuelwood. It shows from the land observations that deforestation highlighted in the Kalfou forest reserve, using spatial-temporal classification of satellite data, is mainly due to rising fuelwood demand in the region.

In order to better understand the importance of this practice, it is important to know that the quest for fuelwood is one of the main causes of deforestation in dry regions (Ozer 2004). Wood collection is one of the most harmful practices for tree development in protected areas (Wafo Tabopda 2008; Wafo Tabopda et al. 2005; Sumati 2006). This collection, which takes the form of illicit felling is routine inside and around protected areas, remains uncontrolled and badly organised. It constitutes the offence the most often observed by the water and forest managers and non-governmental organisations (NGOs) in the Kalfou reserve. Vegetation cover is a component conditioning land cover in a protected area. Its presence or absence characterizes the type and state of the area excluded from grazing, as it controls the presence of fauna and specific diversity of flora.

In general terms, forest reserves have been prey to intense activity of illicit fuelwood collection over the past few years (Ntoupka et al. 2006; Wafo Tabopda et al. 2005; Abbot and Mace 1999). This situation which is observed in the Kalfou forest reserve could be attributed among other things to energy needs related to demographic growth and urban extension in the region, absence of surveillance of protected areas, lack of concerted strategy of fuelwood management and speculation related to charcoal trade[6] in the big cities of neighbouring Chad. In addition, 27% of the 2,956 m^3 of wood sold in the region comes from protected sites and their surroundings (Waza, Moutourwa and Yagoua), including 4% from the Kalfou reserve and its surroundings (Madi and Hubbs 2001).

Analysis of trends in vegetation cover at Kalfou, based on processing of satellite images, reveals the importance of fuelwood collection. Although the methodological stance adopted is widely used in land cover analysis, it is deemed innovative for its contribution to the assessment of conservation policies in southern countries. Highlighting of spatial-temporal trends in vegetation cover in this forest reserve constitutes a component for assessing management and effectiveness of protection. Therefore, the results obtained provide decision-making assistance tools and up-to-date mapping for sustainable development of the protected area.

17.6 Conclusion

This research into the contribution of geospatial technologies to sustainable development served a double thematic and methodological purpose. Its main objective was to take an inventory and assess trends in vegetation cover in the Kalfou forest based on analysis of deforestation using remote sensing. In methodological terms, the longitudinal study of land cover using pseudo-directed hierarchical classification of two Landsat satellite images enabled successive vegetation cover states to be highlighted and trends since 1986 to be analysed. The results obtained fulfil the study purposes and partly confirm the hypothesis, according to which land cover analysis makes it possible to fathom interactions between societies and protected areas.

In thematic terms, the results show that, despite the double demographic and climatic constraint to which the Kalfou forest reserve is subject, vegetation cover state and trends between 1986 and 2001 do not seem to be alarming. However, this generally positive finding must be qualified because the management rules are not complied with. Deforestation experienced a considerable rate of change, recording loss of around 1,700 ha. This change in aspect of the protected area ecosystem results from illicit fuelwood use. As regards population growth and the pressure it could exert, there could be accelerated deterioration in vegetation cover in this forest reserve, especially due to the lack of real management strategy.

[6] Selling of charcoal, which requires incineration of freshly felled tree trunks, is authorised in Republic of Chad but not in Republic of Cameroon.

Only management policy based on sustainable development principles, such as regular monitoring of spatial dynamics and involvement of local populations in site management, could constitute the beginning of a solution. Pressure on tree formation in dry zones of tropical Africa often reaches values which compromise the renewable nature of the resource (Balle n.d.). This could happen to the Kalfou forest reserve, where reinforcement of repression advocated by the managers starts to show its limits, insofar as impacts of overexploitation of wood go beyond purely ecological concerns. Furthermore, Abbot and Mace (1999) demonstrated in a study conducted at *Lake Malawi National Park* that pressure exerted by the authorities on offenders tended to aggravate wood collection inside the park.

In addition to its practical aspect, this study opens avenues to be explored if interactions between societies and protected areas require analysis. Remote sensing data used for this work is deemed highly appropriate to the issue covered. It offers an advantage for the strategies implemented to assess area conservation policies based on production of spatial-temporal data. The cartographic base created using data derived from remote sensing and GIS constitutes a management tool for conservation units and monitoring of trends in vegetation cover and land cover. Nevertheless, for reserve manager interests, a remote sensing utilisation platform should be set up at regional level, to facilitate cartographic updates and development of a structured database. Thus, remote sensing combined with GIS, appears to be an effective tool for regular monitoring of vegetation resources and protected area management, all the more so as the satellite images are henceforth easily accessible.

This method can be rolled out as is to other protected sites in the tropical Sudano-Sahelian environment of Cameroon and Africa. On the other hand, so that the method can be used in forest zones, dates of image acquisition need to be considered and optical data should be coupled to radar data in order to eliminate the regular presence of clouds in tropical forest environments (Tsayem Demaze 2002). Rolling out of this method does however pose the problem of training of protected area managers in the use of geospatial data and tools throughout the world and more specifically in Africa. Moreover, for the sake of improvement of these tools in Africa, would the development of an innovative process using light software and easier to use not enable land cover dynamics and their long-term effects to be modelled as well?

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Chapter 18
Enhancing Decision-Making Processes of Small Farmers in Tropical Crops by Means of Machine Learning Models

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18.1 Introduction

Decision making in agriculture is based on knowledge of the behavior of crops under site-specific growing conditions at any given moment in time. For many tropical crops, research is limited, and there is a dearth of readily available information on where to grow many crops and how to manage them effectively. Small growers create informal models of their crops based on their personal experience and traditional knowledge, and they use these models to guide their decisions on how to better manage their crops. Formal research to model site-specific crop responses to variation in growing conditions and management is frequently based on small plot experimentation. The particularity of this approach is that a small number of individual factors that affect the variable under study are

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varied in a controlled way. In tropical agriculture, the heterogeneous growing conditions and the possibility of producing throughout the year lead to an enormous number of possible combinations of management practices and varying growth conditions at different stages of crop development. Thus, the traditional approach of observing the response to a limited number of carefully controlled variables is not always appropriate for evaluating the multiplicity of conditions and factors that influence crop response in heterogeneous tropical conditions.

One possibility for resolving this conundrum is to use the intrinsic variability that is a feature of crop production. Under heterogeneous conditions, with much variation in management practices and the growing conditions, each time a farmer harvests his crop can be considered as a unique event or experiment in its own right. This observation leads to the idea that if it were possible to collect information of a large number of harvesting events under varied conditions, it would be possible to use this information to develop models for the production system. These data-driven models could then provide information to small farmers on how to better manage their crops according to the specific conditions on their farms.

The development of data-driven models with a large number of variables, as is necessarily the case in modeling tropical agriculture under heterogeneous conditions, requires information from a large number of events. The information required includes characterization of the growing conditions (weather, inherent soil, and terrain characteristics) as well as management practices and the crops response to these variables. Each farm can be characterized according to more general information on climate, weather, and soil extracted from public databases. Information on site-specific soil characteristics, management, and crop response can only feasibly be obtained from individual farmers who often keep poor records if they keep them at all. The proposed data-driven methodology induces the farmers themselves to become key actors in the capture of local information that is used to develop the models (see, e.g., Jiménez et al. 2009, 2011). Nevertheless, there is no doubt that the subsequent datasets will tend to be noisy and often incomplete under these circumstances.

Traditional statistical and mechanistic models were considered inappropriate for analysis of these noisy and often imprecise data. On the other hand, nonparametric models have been shown to be useful with this type of data and also when there is neither prior knowledge about data distributions nor information on possible mechanisms of response to variation. On the other hand, artificial neural networks (ANNs) are one of the machine learning methodologies that have been successfully applied to the problem of modeling agricultural systems with datasets with characteristics similar to those we wish to analyze (Schultz et al. 2000; Jiménez et al. 2008).

The research reported in this chapter is linked to two related but separate problems: (1) the association of crop productivity with growing conditions and management and (2) the identification of similar or analogue sites between which technologies can readily be transferred.

18.2 Materials and Methods

18.2.1 Two Cases Under Study

The proposed methodology was implemented on two crops in Colombia (for more detail, see Jiménez et al. 2009, 2011). Both crops are fruits that are cultivated by small growers in tropical regions, most of the time in mountainous areas with limited access and a lack of installed infrastructure (e.g., communications, roads).

- The first model was built on the Andean Blackberry (*Rubus glaucus Benth*.), also known as the Andes Berry or Mora de Castilla (Bioversity International 2005a), a fruit native to an area ranging from the northern Andes to the southern highlands of Mexico (National Research Council 1989). It is grown as a commercial crop in Colombia, Ecuador, Guatemala, Honduras, Mexico, and Panama (Franco and Giraldo 2002). It is an important source of income in the hillside regions of Colombia (Sora et al. 2006). Productivity varies widely from region to region and between farms. Furthermore, the crop is harvested continuously during the year, and the productivity varies throughout the year. At the same time, growers have little reliable information on the factors that affect the development and yield of the crop, and consequently, there is a dearth of readily available information on where to grow the crop and how to effectively manage it.
- The second model was created on Lulo (*Solanum quitoense Lam*.), also known as Quito orange or Naranjilla (Bioversity International 2005b), a fruit native to humid forests in the northwest Andes. It is raised as a commercial crop in Colombia, Costa Rica, Ecuador, Honduras, Panama, and Peru and is widely consumed in Colombia because of the quality of its juice, aroma, nutritional value, and its use in agro industry (National Research Council 1989; Franco et al. 2002; Osorio et al. 2003; Flórez et al. 2008; Pulido et al. 2008; Acosta et al. 2009). The production of Lulo has been reported as a challenging task due to limited genetic diversity and the high incidence of pests and diseases affecting its healthy growth. It produces all year round, and productivity varies throughout the year (National Research Council 1989; Estrada 1992; Flórez et al. 2008).

18.2.2 Data Collection and Compilation

Corporación Biotec developed an illustrated calendar which farmers used to record information on the status of their crops and production on their farms. The soil characteristics were determined by the soil and terrain evaluation methodology known as RASTA (Rapid Soil and Terrain Assessment) (Alvarez et al. 2004). The information collected by the farmers on the calendars, and with RASTA, was then transferred to the database of the site-specific agriculture for tropical fruits (AEPS) project. This database includes information on location, varieties, yield, harvest time, and data on soil characteristics. These records provided farmers' estimates of the quantity (in kilograms) of fruit harvested per plant for weekly periods.

Environmental information of landscape and climate, which covered the whole of Colombia, was obtained from a range of secondary data sources. This information with overall coverage was also linked to each of the individual sites. Topography and landscape data was extracted from the Shuttle Radar Topography Mission (SRTM) (Farr and Kobrick 2000), using geographical information systems (GIS) methodology and the version 3 dataset available from the Consortium for Spatial Information of the Consultative Group for International Agriculture Research (CSI-CGIAR). Long-term averages for monthly temperature and precipitation were obtained from WORLDCLIM (Hijmans et al. 2005), and daily rainfall was extracted from the 3B42 product of the Tropical Rainfall Measuring Mission (TRMM) database (Bell 1987).

18.2.3 The Resulting Datasets

Two types of datasets were generated from the information collected in the databases. The first contains the whole set of available variables for the crop, together with the yield of the crop for each observation. This dataset, called the "yield dataset," can contain several observations for the same site because each observation represents one harvesting event for the crop, and each site could be harvested several times during the time we collected the data. The second type of dataset, which contains only climatic and weather information, was named "the presence dataset." The presence dataset contains only one observation for each site where the fruit is cultivated and covers the whole country.

Both types of datasets were developed for each of the two crops, Andean Blackberry and Lulo. The dataset containing yield information was used to build computational models for the production of each fruit according to the specific conditions of each site-time event. These models provide insights into the underlying relationships between the input variables and the final yield. The second dataset with climate data was used to create maps of analogue zones in the country. Each pixel in the map represents the maximum degree of similarity between the climate of the point where the pixel is located and the climate of each one of the observations in the dataset.

18.2.4 Machine Learning Models

The techniques we used to build the computational models belong to a group of nonparametric techniques called artificial neural networks (ANNs). ANNs differ according to the computation done by their elementary components, commonly called neurons, and on how these elements are connected, the network topology. Moreover, there are also various algorithms that can be used to compute the parameters in the models. In spite of all the possible definitions of elementary units, topologies, and algorithms, some basic concepts remain invariable when working with ANN: (1) Networks are always composed of basic units which perform simple calculations; (2) the process of determining the model parameters always requires a set of observations from the phenomenon under study. The ANN model adjusts the parameters "learning" from the observations collected in an iterative manner. The algorithms performing this task are often called training algorithms; (3) the structure of a "trained" ANN contains information about the underlying process which generated the training data. This computational model can be used both to better understand the phenomenon under study as well as to predict the behavior of the process under new conditions.

The specific details of how we implemented each type of network lie beyond the scope of this chapter. Rather, we present examples of how we have used the different tools for various purposes all geared to enhancing the decision-making capabilities of small farmers.

18.2.5 Prediction Tools

We employed an architecture of ANN called multilayer perceptron (MLP) (Bishop 1995) in order to implement the prediction models for both fruit species. An MLP is a network of individual units called perceptrons, which are linked by weighted connections. The parameters of the model are thus the connections between units, and in our application they were calculated by means of the backpropagation algorithm (Bishop 1995), applied over the datasets containing yield information. The goal of this model was to reproduce the relationships between the input variables we fed into the MLP and the output variable we obtained from it, that is, the information on yield. The trained perceptrons were also employed to get insights about the relevance of the input variables we used to feed the model. In order to identify the variables which contribute most to yield, we conducted an analysis by means of the relevance metric based on sensitivity described in Satizábal and Pérez-Uribe (2007). By knowing which are the most relevant variables, we can focus the analysis on these variables, saving effort in processing irrelevant variables.

Such models can be useful to forecast yield in regions where growers wish to grow the crop under a variety of management practices. This assists the farmer first of all in deciding whether he wishes to grow the crop and second how to manage it according to the local conditions.

18.2.6 Visualization Tools

The most relevant variables were identified by means of a type of ANN model known as self-organizing map (SOM) or Kohonen map (Kohonen 1995). The SOM is a nonsupervised algorithm widely used in the visual exploratory analysis of high-dimensional datasets. The idea behind the SOM is to obtain a representation of a high-dimensional dataset in a lower-dimensional output space (generally a lattice of two dimensions). In this reduction of dimensionality, the relationships among the observations from the dataset are preserved: observations with similar characteristics in the high-dimensional space appear grouped together in the SOM.

The SOM topology consists of a lattice of fully interconnected artificial neurons. The SOM is trained through an iterative process where the dataset is presented to the artificial neurons. At the end of the process, the artificial neurons become prototypes (also called prototype vectors) that summarize the dataset used during training.

SOM allows both clustering and visualization. It reveals groups in the dataset and also facilitates the analysis of relationships between variables (Vesanto and Ahola 1999; Barreto and Pérez-Uribe 2007). The SOMs were used to visualize the relationship between the productivity and the environmental and geographical variables and to establish the combinations of values of these variables associated with high, medium, and low yield.

18.2.7 Analogue Zones

The datasets of presence, containing only climate data, were used to create maps displaying the degree of similarity between specific sites where the fruits are cultivated and the rest of the country. Sites with climatic conditions analogous to those with high levels of productivity are likely to be highly suitable for the cultivation of those crops from where the high yield was recorded. Two different strategies were used to build the maps, and each was based on the use of a different type of ANN. In both cases, the models were nonsupervised, and their goals were to summarize the dataset by calculating a set of vector prototypes. These prototypes are called the codebook of the model and represent a compressed version of the original dataset. The process of obtaining the codebook is called vector quantization (Fritzke, 1997). This compressed version keeps the most important features of the dataset but is easier to manipulate because of its reduced volume. Hence, we calculated the maps of similarity by computing the distance between the prototypes in the codebook and by displaying this value as a color over a geographic map. This mapping is possible because each point in the geographic map is represented by a prototype vector called the best-matching unit.

The two ANN models that we used to quantize the data were the growing neural gas (GNG) (Fritzke 1995), specifically the modified version of the algorithm proposed by Satizábal et al. (2008) and the growing hierarchical self-organizing map (GHSOM) (Rauber et al. 2002).

18.3 Results and Discussion

18.3.1 Prediction Tools

MLPs were evaluated over validation datasets to determine whether their performance was acceptable for our purpose of determining relationship between yield and the characteristics of sites where the fruits were grown. In the case of Andean Blackberry, we obtained a coefficient of determination of 0.89, which indicates that the model explained close to 90% of the total variation (Fig. 18.1).

The model was further analyzed (Fig. 18.2) in order to find the relevance of the variables that we used as inputs to predict yield using a sensitivity test (Satizábal and Pérez-Uribe 2007).

18.3.2 Visualization of the Most Relevant Variables

The effects of the most relevant variables were then analyzed. SOMs were trained with the same observations we employed to train the MLPs. The SOMs are

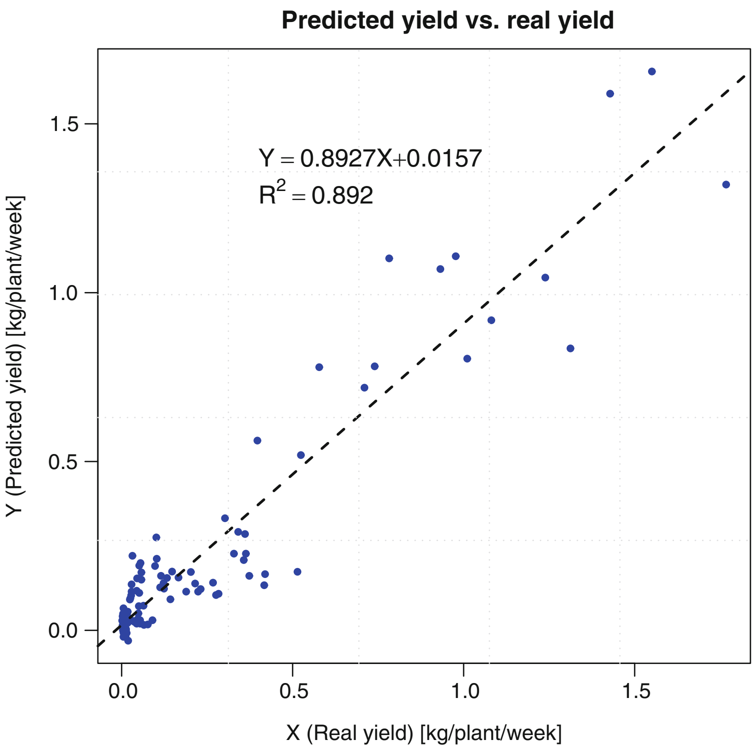

Fig. 18.1 Scatterplot displaying MLP predicted yield versus real Andean Blackberry yield, using the validation subset

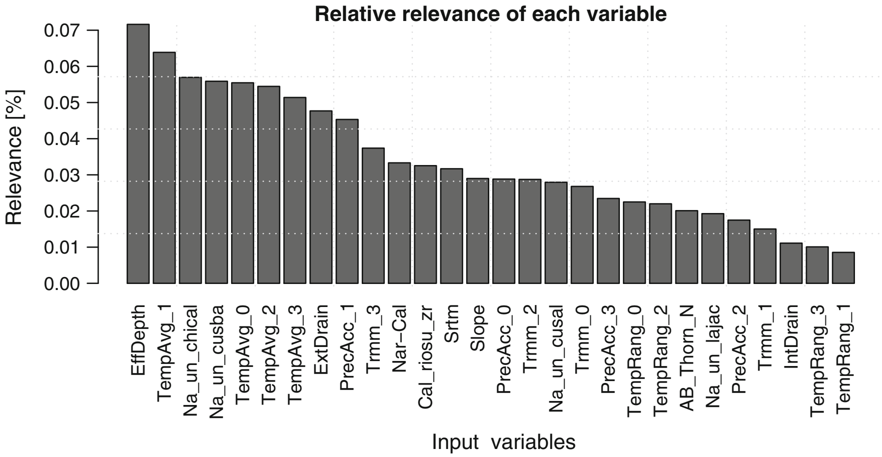

Fig. 18.2 Distribution of the sensitivity of the output with respect to the inputs for the dataset of Andean Blackberry

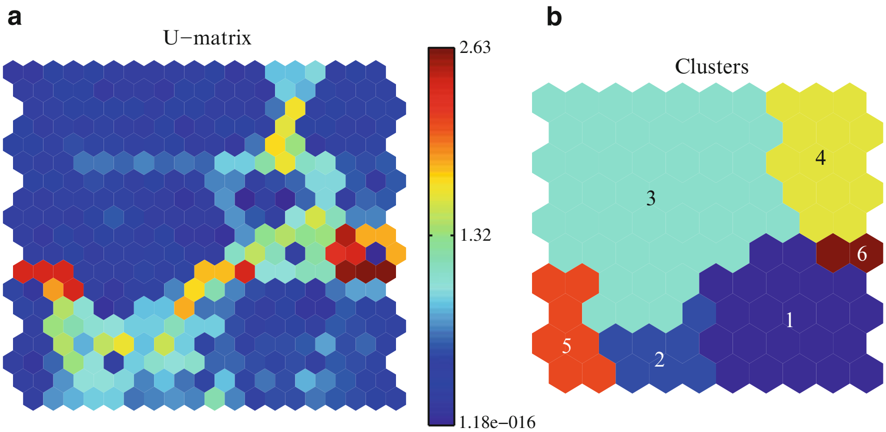

Fig. 18.3 SOM showing the resulting clusters for the dataset of Andean Blackberry. (**a**) Distance among prototypes. The *scale bar* (*right*) indicates the values of distance. The *upper side* exhibits high distances, while the *lower* displays low distances. (**b**) Prototypes of the SOM clustering displaying the six groups obtained

composed of vector prototypes which associate topological information of the original input variables with fruit yield. These prototypes were clustered to form groups of observations with similar features influencing yield, as shown in Fig. 18.3.

After creating the SOM, it is possible to visualize each one of the variables on an independent plane. This procedure is done by showing only the value of the component of interest for every prototype in the grid. By projecting the variable

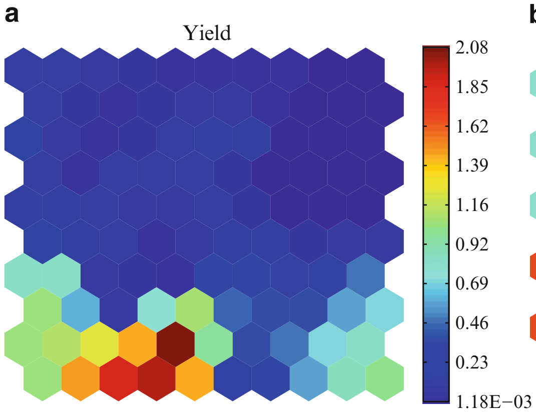

Fig. 18.4 (**a**) Component plane of Andean Blackberry yield, the *scale bar* (*right*) indicates the range value of productivity in kg/plant/week. The *upper side* exhibits high values of yield, whereas the *lower* displays low values. (**b**) SOM displaying the resultant six clusters and their labels according to yield values

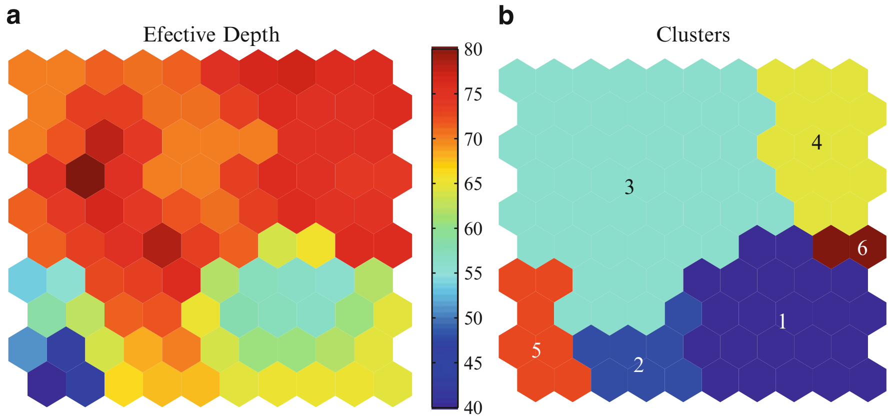

Fig. 18.5 (a) Component plane of effective soil depth for the model of Andean Blackberry, the scale bar (right) indicates the range value in centimeters of soil depth. The upper side exhibits high values of soil depth, whereas the lower displays low values. (b) SOM displaying the resultant six clusters and their labels according to yield values

we have as output (i.e., yield), labels can applied to each one of the clusters according to its productivity (Fig. 18.4).

The same procedure can be carried out for any input variable in the set and thus provide insights about its relationship with yield. For example, we show the variable effective depth for the model of Andean Blackberry, which is the most relevant variable according to the measure of relevance applied in the prediction models (Fig. 18.5).

From observation of Fig. 18.5, relevant information can be extracted about the relationship between the variable effective soil depth and yield. In the case of Andean Blackberry (Fig. 18.5), soil depths greater than 70 cm are associated with clusters 3, 4, and 6 which are all associated with low yields. In contrast, a soil depth between 40 and 70 cm appears to be related to medium to high yield clusters (1, 2, and 5). The cluster with the highest yields had soil depths in the range of 60–70 cm suggesting that this soil depth is optimal and that an effective soil depth greater than 70 cm is not necessary to obtain high yields. These results agree with some of the expert guidelines for growing Andean Blackberry (Franco and Giraldo 2002).

18.3.3 Analogue Zones

We tested two strategies for generating maps of similar zones. In each case, ANN-based approaches were used to create models for the datasets with only climate data for both fruits.

We used the GNG algorithm proposed in Satizábal and Pérez-Uribe (2007) and GHSOM to quantize the dataset of climate of the whole country. After developing a codebook for the dataset, we computed the similarity between vector prototypes of the points where the fruits were found and known to be grown successfully and the prototypes for the remaining areas. The resulting values were plotted on the geographic map, giving a spatial distribution of similarities, or in other words, showing zones analogous to the ones where the fruits are known to grow successfully.

This map (Fig. 18.6) reveals zones with similar characteristics to those where Lulo is known to grow well. The analogue zones are not necessarily located close to the regions where the observations were taken. The similarities between zones are measured in terms of the input variables (climate in this case) and not according to the geographic location of the points. Moreover, different variables can be used to create the maps. Maps of similar soils can be built by using soil information, and furthermore, maps combining several criteria (e.g., climate and soils) can be generated by merging different sources of information.

18.4 Conclusions

Small farmers who grow tropical fruits, which are mostly under-researched crops, have little reliable information on the factors that affect the development and yield of their crops. There is a dearth of information about suitable conditions for their cultivation and appropriate management practices for specific conditions. Farmers use their own traditional knowledge and personal experiences to guide their decisions on whether to grow a particular crop and how to manage it. We surmised that by exploiting the intrinsic variability of a crop cultivated and managed by many

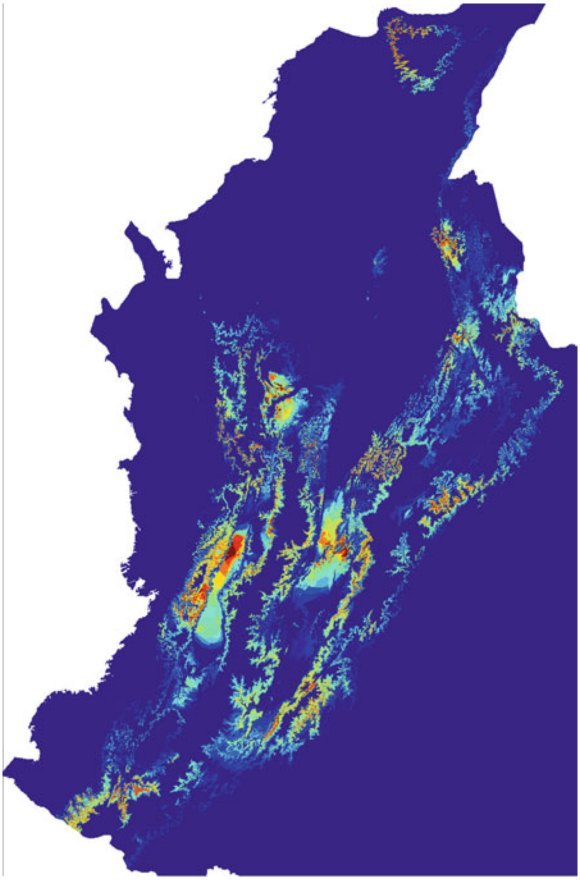

Fig. 18.6 Map of suitable zones for growing Lulo, generated by using the GNG algorithm as vector quantization method

farmers over a wide range of conditions, it should be possible to provide farmers with information to guide them in their management decisions.

A major challenge to this approach is to make sense of the noisy and incomplete information that is obtained from small farmers. ANNs appeared to be appropriate tools for analyzing the information. Our experience reported here with Lulo and Andean Blackberry supports the view that ANNs are indeed useful tools for interpretation of the information. MLPs were successfully used to develop models that explained close to 90% of yield variation associated with climate, soil, and management variables. In addition, the MLPs determined those variables that were most relevant in determining yield. Furthermore, SOMs were found to be effective tools to visually group events with similar characteristics and with similar output potential. Comparison of maps of events with similar characteristics with maps with similar outputs provides an insight into the best options for a given crop or a given site. These conclusions are supported by the work of Jiménez et al. (2009, 2011) which indicated that ANNs might be superior to traditional statistical techniques for interpretation of noisy datasets obtained from small farmers and multiple other sources.

In a region with extremely variable conditions, such as the Andean region, farmers often do not know which crop to grow, and if they do decide to grow a certain crop, they do not know where to find appropriate management technology. These conundrums can partially be solved by identifying sites where a crop is successfully grown and the management practices associated with the successful cultivation in those sites. If similar sites, often geographically distant from the original sites, can be identified, then the technology can be directly transferred from the original site to the similar or analogous site with a high probability of success. This process can potentially save years of experimentation and trial and error, particularly in perennial species, which take several years to enter production. GNG and the GHSOM models were used to successfully develop maps which showed similarity between one site and another.

We conclude that cultivation of native fruits in tropical countries by small farmers may benefit from the application of site-specific farming based on models that use information from a range of data sources, including data collected by the growers themselves. A series of analyses based on machine learning with ANNs facilitates the interpretation of the noisy input data and makes it possible to derive associations that can usefully be used by small-scale producers.

Acknowledgments This work is part of a cooperation project between Corporación Biotec, the International Center for Tropical Agriculture (CIAT), and the Haute École d'Ingénierie et de Gestion du canton de Vaud (HEIG-VD) named "precision agriculture and the construction of field-crop models for tropical fruits." The economical support is given by several institutions in Colombia: the Ministerio de Agricultura y Desarrollo Rural (MADR), the Departamento Administrativo de Ciencia, Tecnología e Innovación (COLCIENCIAS), the Agencia Presidencial para la Acción Social y la Cooperación Internacional (ACCI), and the State Secretariat for Education and Research (SER) in Switzerland.

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Part VIII
Sustainable Energy Production

Osman Benchikh and Denis Mencaraglia

We all know that the development paradigm that we have been employing thus far has exacted a heavy environmental cost. As the effects of climate change are felt across national boundaries, the use of renewable energy as a share of the total energy consumed will remain limited, despite its great potential, if no specific, directed policy measures are taken to promote its development, production, and use. In this context, we need new approaches in order to scale up investment in the more developed renewable energy sources such as wind, hydro, and solar energy.

The process of moving from the concept of energy development focusing on economic growth to a new one centered on global sustainable development, including environment protection, will be made possible only if the current energy development paradigm is changed. Spurred by concerns about climate change and the need to reduce greenhouse gas emissions, we are now witnessing the beginnings of such a paradigm shift.

Sustainable development and climate change mitigation underlines the need to manage energy resources judiciously; on the other hand, no development can occur without access to basic energy services. Access to energy is required in all economic and social sectors, and inequality in capacity to access energy resources and to utilize such resources for development purposes results in further inequality in wealth distribution, be it in terms of social welfare or economic competitiveness.

Energy strategies must therefore be governed by concerns about a whole range of intertwined issues taking into consideration evolving global priorities such as climate change, protection of the environment, and sustainable development. Therefore, efforts ideally should be concentrated on clean and sustainable forms of energy generation, which inevitably imply the development, diffusion,

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promotion, and application of renewable sources of energy. In parallel, efforts are also needed to promote efficient use of existing energy resources.

The revived interest in alternative and renewable energy resources, combined with the substantial advances in the related science and technology in recent decades, justifies the priority that should be given to this category of energy resources. We must address the role and impact of energy on human environment and its development as well as our overreliance on energy forms used over the last century. These issues face us all, whether we are from developed or developing nations, and they will face our descendants as well.

To that effect, it is crucial to address the need for joint international efforts, effective dialogue, and cooperation in order to find solutions to the ever-evolving complex energy-related issues, ranging from access to affordable sources of energy to development of substantial and environmentally sound means of energy generation that meet the needs of the rapidly developing global market, while ensuring sustainable development.

The three following chapters present complementary approaches in the sense that (a) they address three different renewable technologies (biofuel production, photovoltaics, and hydroelectricity), (b) they integrate societal issues since the very beginning of the project but with specific weights related to their different implementation stages, and (c) three different implementation levels are concerned (local, regional, and national).

The first chapter (Jupesta) is a modeling study intended to help to reduce risks before any initiative for a large-scale biofuel production. Under four scenarios, a multidisciplinary approach is developed, taking into account energetic, socioeconomical, and environmental aspects. Based on land allocation growth and technology development, it is shown that biofuel introduction could have a positive impact, provided all related parties are taken into account.

The second chapter (Gaillard and Schroeter) is a technical and operational description of a rechargeable battery lantern and solar charging station rental scheme, at a pilot implementation stage in Lao People's Democratic Republic. Service-oriented solutions, including rather sophisticated add-ons such as an integrated microprocessor monitoring the battery, are developed in a public-private partnership and found more efficient than only hardware interventions for rural electrification in developing countries.

The approach of the third chapter (Michelon and Nejmi) is more focused on local environment issues from the socioeconomical point of view. Learning from the project shows that, before its early development, upstream societal awareness is the mandatory key to guarantee the technical solution acceptation, as pertinent as it could be from technical considerations only. This conclusion, here explicitly expressed, is also included more or less implicitly in the other chapters and does appear as a general prerequisite for a sustainable energy development.

We hope the materials and views presented in this publication will interest readers and help develop measures to address the energy shortfalls that jeopardize achieving the goal of sustainable development in a changing world.

Chapter 19
Impact of the Introduction of Biofuel in the Transportation Sector in Indonesia

Joni Jupesta

19.1 Introduction

With an area of 2 million square kilometers and a population of 237 million (2007), Indonesia is the fourth most populous nation in the world. This country is facing serious energy problems, with a change in status from net oil exporter to net importer in 2007, highly subsidized fossil fuel prices (the fuel subsidy in Indonesia uses up a significant portion of the national budget), depleting oil resources, and strong dependency on fossil oil for gross domestic production. Action needs to be taken to tackle these issues.

In 2008, the fuel and electricity subsidy amounted to 14.3 and US$ 6 billion, respectively, which equals the total central government capital and social expenditure. Oil and gas contributed 32% of government revenues in 2006, but this decreased to 20% in 2008, in accordance with depleting oil resources (from 9×109 barrels in 1987 to half of that in 2007 (World Bank 2008)). For these reasons, in 2006, the government enacted the so-called energy mix policy to reduce dependency on fossil oil, by using a mixture of energy sources, utilizing local resources, renewable energy, and biofuels. The target is to reduce the share of fossil fuels in providing energy from 60% of total energy consumption, the percentage in 2006, to 20% by the year 2025. The remainder should come from coal (35%) and gas (30%), and renewable energy sources should account for 15% of total energy consumption.

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Among several alternative energy options, first-generation biofuel technology (fermentation and esterification) has the biggest potential, due to favorable climate conditions, and land and technology available in Indonesia. In addition, biofuels also mitigate climate change, as they are considered carbon neutral, generate income by export, and create jobs (agriculture and industry) (FAO 2008). Due to the market potential of biofuel products for replacing fossil oil and for export, several domestic and foreign companies have invested in the biofuel industry.

Biofuel development was expected to create at least 3.5 million jobs in agriculture in 2010 alone. In 2007, the transportation sector consumed 29 million liters of oil. Replacement of 5–20% of this amount by biofuel could have reduced fossil oil consumption by 1.4–5.7 million liters per annum. As the transportation sector used 5% of the total energy consumed in Indonesia in 2006 (biomass-derived energy for cooking in rural areas is excluded from this calculation), the admixture of biofuel to gasoline and diesel could have significantly diminished fossil oil consumption on a national scale.

The challenge of doing business with the introduction of biofuel in developing countries lies in the fact that the market suffers from a lack of information, infrastructure, and institutions (UNDP 2008). With inadequate information and poorly equipped infrastructure (policy, market, science and technology, and public acceptance), any initiative for large-scale introduction of biofuels is as yet premature, but modeling of this introduction may help to reduce risks.

This study analyzes impact of the introduction of biofuel in the transportation sector in Indonesia with four scenarios. Since biofuel is relatively new to Indonesia, impact of the introduction of biofuel is modeled with several aspects in mind: energy, economics, and environment. Socioeconomic factors are also considered in terms of job creation in industry and agriculture. Impacts are assessed by comparison with a base scenario (the do nothing scenario); the optimization scenarios are based on land allocation only, technology development only, or simultaneous land allocation and technology development.

The outcome of this study can be used by several stakeholders: academics for research, businesses for investment, and governments for policymaking. The aim of this chapter is to provide stakeholders with the answers to the following questions:

- What is the potential for volume of biofuel production in Indonesia and under which conditions?
- What impact does the introduction of biofuel have on energy balance? What are the economic value and labor requirements?
- How much could greenhouse gas emissions be reduced by and what is the technology assessment for biofuel development in Indonesia?

The purpose of this study is to maximize energy output from energy crops in Indonesia, with restricted growth on available land and technology constraints. The following sections describe the model and data used in the analysis, present the results analyzed from several perspectives, and draw the relevant conclusions.

19.2 Tools and Methods

19.2.1 Description of the Model

The most relevant tools for energy planning are models, which mathematically represent (a simplification of) reality (Reuter and Voss 1990). The tool used for this study was the BIOFUEL model. This model is based on the supply side, with the purpose of identifying an appropriate fuel and technology mix. The methodology uses optimization and simulation. This dynamic nonlinear programming is written in General Algebraic Modeling System (GAMS) modeling language with CONOPT as the solver (Brooke et al. 2008). The time is set at 2-year intervals, from 2007 to 2025. Figure 19.1 shows the structure of the BIOFUEL model.

The model structure is designed so that it has multiple crop supply chains: sugarcane and cassava to produce bioethanol and palm oil and *Jatropha curcas* to produce biodiesel. To avoid a conflict between food and fuel production, land allocation for food is secured, and the rest of the available land is used for biofuel production. First-generation technologies for biofuels are fermentation to produce bioethanol and esterification to produce biodiesel. Bioethanol is used to replace gasoline, while biodiesel is used to replace diesel fuel. The purpose of this model is to satisfy the demand in domestic transportation and to seek export possibilities for excess production.

19.2.2 Basic Equations of the BIOFUEL Model

Biofuel supply balance is determined based on land allocation for biofuel and food purposes. Biofuel is produced from the entire process, from agriculture to industrial output:

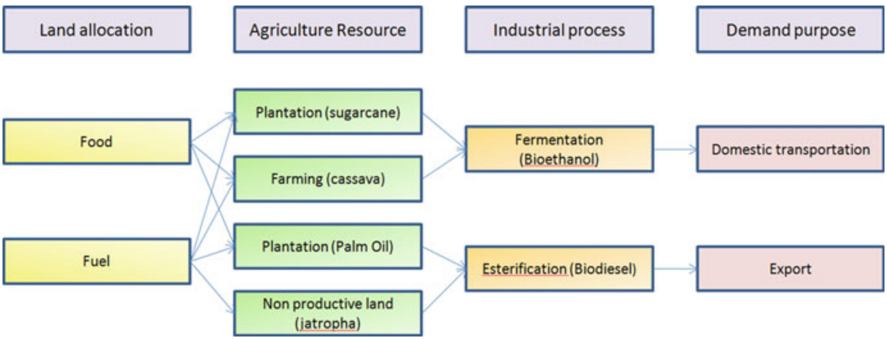

Fig. 19.1 Structure of the BIOFUEL model

$$\sum_i L = L_b + L_f$$

$$\sum_i F = \sum i(L_b \times Y_{agr} \times Y_{ind})$$

i : type of crops
L : land allocation
L_b : land allocation for biofuel
L_f : land allocation for food
F : total biofuel produced
Y_{agr} : crop yield in agriculture process
Y_{ind} : biofuel yield from industrial process

Biofuel cost balance is calculated as the aggregate cost from agricultural and industrial processes. Profit is fixed at 9% of the cost:

$$\sum_i C = \sum_i F \times \sum_i \left(C_{agr} + C_{ind}\right)$$

$$\sum_i P = 0.09 \times \sum_i C$$

C : total production cost
C_{agr} : cost during the agriculture process
C_{ind} : cost during the industrial process
P : profit

Biofuel emission balance is obtained from the emission avoided due to replacement of biofuel with fossil fuel and deduction of the emission generated during biofuel production. Biofuel emission is based on the emission from agriculture and industry. The emission avoided must be larger than or equal to the emission during biofuel production to ensure sustainability of biofuel production:

$$\sum_i G = \sum_i F \times \sum_i \left(G_{avoid} - G_{emit}\right)$$

$$G_{avoid} \geq G_{emit},$$

$$G_{emit} = G_{agr} + G_{ind},$$

G : total net emission balance
G_{avoid} : greenhouse gas avoided due to replacement of fossil fuel with biofuel
G_{emit} : greenhouse gas emitted during biofuel production
G_{agr} : greenhouse gas emitted during agricultural process
G_{ind} : greenhouse gas emitted during industrial process

Biofuel demand balance is the total of domestic and export demand:

$$\sum_i D = \sum_i \left(D_{\text{domestic}} + D_{\text{export}}\right)$$

$$\sum_i D = \sum_i F,$$

D : total demand
D_{domestic} : demand for domestic transportation
D_{export} : demand for export

The target purpose is to maximize biofuel energy balance based on the energy obtained from biofuel combustion, with the energy used for biofuel production deducted. The energy from biofuel production is used in agricultural and industrial processes:

$$\sum_i E = \sum_i F \times \sum_i (E_{\text{out}} - E_{\text{in}})$$

$$\sum_i E_{\text{in}} = \sum_i \left(E_{\text{agr}} + E_{\text{ind}}\right)$$

E : total net energy balance
E_{out} : energy output from biofuel during combustion
E_{in} : energy input during biofuel production
E_{agr} : energy input during the agricultural process
E_{ind} : energy input during the industrial process

19.2.3 Input Parameters

The model uses comprehensive data based on government policy and previous research. Table 19.1 presents the characteristics of the energy, cost, and emissions of biofuel production. Table 19.2 presents the parameters used in the study, based on data from 2007, and transportation fuel demand based on data from 1990 to 2007.

This model is a simplification with respect to (1) increased land allocation secured for food and biofuel; (2) biofuel production hypotheses, as the agricultural and industrial processes have a single output regardless of the different locations and plant capacities; (3) "perfect foresight" with no uncertainty surrounding fluctuation in production costs, climate change impact on agricultural production, and changes in energy demand; and (4) domestic transportation demand based on a policy that respectively requires 15% and 20% replacement of gasoline and diesel fuel by the year 2025. Excess production is exported. Technology development is

Table 19.1 Characteristics of crops for biofuel production in Indonesia

	Sugarcane	Cassava	Palm oil	*Jatropha*
Energy (MJ/l)[a]				
Agriculture	3	3.9	6.0	10.1
Industrial	3.34	12.1	12.1	21.2
Output	31.2	34.4	45.8	42.3
Cost (US$/l)[b]				
Agriculture	0.3	0.2	0.3	0.05
Industrial	0.1	0.3	0.1	0.43
Emission (kgCO_2eq/l)[c]				
Agriculture	0.2	0.3	1.5	0.9
Industrial	0.4	01.0	3.1	1.8
Avoid	1.8	2.6	4.9	10.5
Yield[d]				
Agriculture (ton/ha)	70	40	18	2
Industrial (l/ton)	70	150	230	189

[a]Source: Macedo et al. (2008), Nguyen et al. (2007), Pleanjai and Gheewala (2009), Reindhardt et al. (2007)
[b]Source: Milbrandt and Overend (2008)
[c]Source: Macedo et al. (2008), Nguyen et al. (2007), Reindhardt et al. (2007), Fargione et al. (2008)
[d]Source: FAO (2008)

Table 19.2 Input data and assumptions

	Sugarcane	Cassava	Palm oil	*Jatropha*
Land[a]				
Size (million ha)	0.4	1.1	5.5	0.06
Fuel share (%)	8.6	8.3	5.5	100
Fuel increase/year (%)	27.0	17.3	16.5	25.9
			Bioethanol	Biodiesel
Yield growth rate/year (%)[b]				
Agriculture			2.0	2.4
Industrial			2.0	2.4
Demand[c]				
Domestic (kl)			82,500	590,000
Growth/year (%)	Gasoline	Diesel	33.8	10.4
Energy content (MJ/l)[d]	32	36.4	21.1	34.5
Employee[e]				
Agriculture (person/ha)			0.7	0.7
Industrial (person/million liters)			4.2	4.2

[a]Source: National Team for Biofuel Development (2006)
[b]Source: Moreira and Goldemberg (1999)
[c]Source: Ministry of Energy and Mineral Resources Indonesia (2008)
[d]Source: ORNL (2009)
[e]Source: National Team for Biofuel Development (2006)

considered as technology learning indicated by the increasing yield in agricultural and industrial production (Coelho et al. 2006). Yield growth rate for biodiesel crops is set at 1.2 times that of bioethanol crops.

19.2.4 Scenarios

The following scenarios were analyzed:

A. Base scenario
   The base scenario reflects development based on the current energy situation and energy policy; this is referred to as the "do nothing" scenario.
B. Land scenario
   The "land" scenario assumes that biofuel production increases on a yearly basis depending on increased land allocation, where land allocation is based on the energy policy.
C. Technology scenario
   Dynamic yield growth rate is the result of technology learning and leads to an increased yield in agricultural and industrial production.
D. Land and technology scenario.
   This scenario combines both the "land" and "technology" scenarios.

19.3 Results and Analysis

19.3.1 Assessment of Energy Resource Development Impact

The total energy balance in all the scenarios is provided in Fig. 19.2. The highest energy balance is in the "land and technology" scenario, since the expansion of allocated land and technology development both boost output. The "technology" scenario shows the lowest output, as the growth of yield cannot keep up with the rising energy demand. The "land" scenario shows a higher energy balance than the "base" scenario, as land is selectively allocated to the highest energy output crops.

All scenarios, except for the "land and technology" scenario, show that bioethanol production merely fulfills domestic demand, while the "technology" scenario can only cover domestic demand until 2015. Figure 19.3 shows net energy balance for all the scenarios in 2025. Of all the crops, palm oil gives the highest contribution in all the scenarios. In all the scenarios, cassava gives the second highest contribution followed by sugarcane and *Jatropha curcas*. The latter has relatively low energy balance and is only suitable for biofuel production if cultivated in low rainfall areas, such as the Sumbawa and Lombok islands.

As palm oil is the preferred energy resource, biodiesel turns out to be the best option for production. Figure 19.4 illustrates biofuel production in all the scenarios

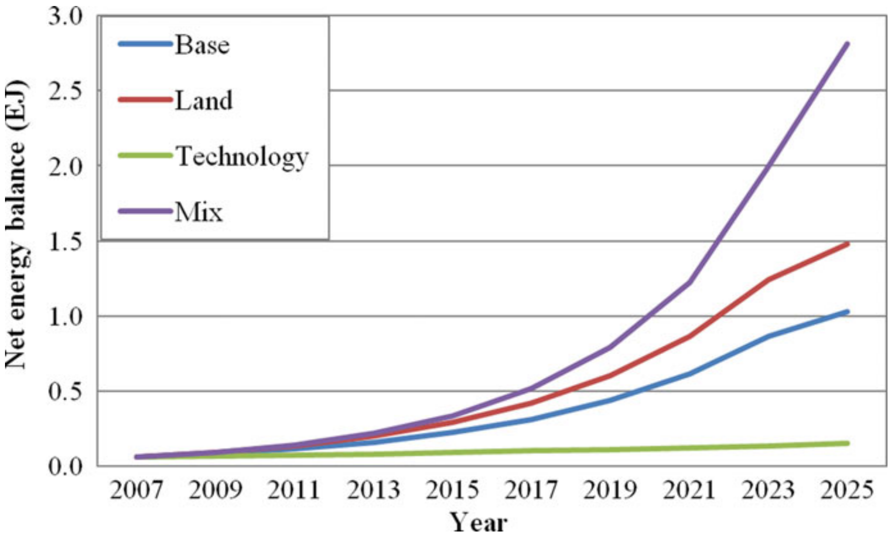

Fig. 19.2 Total energy balance

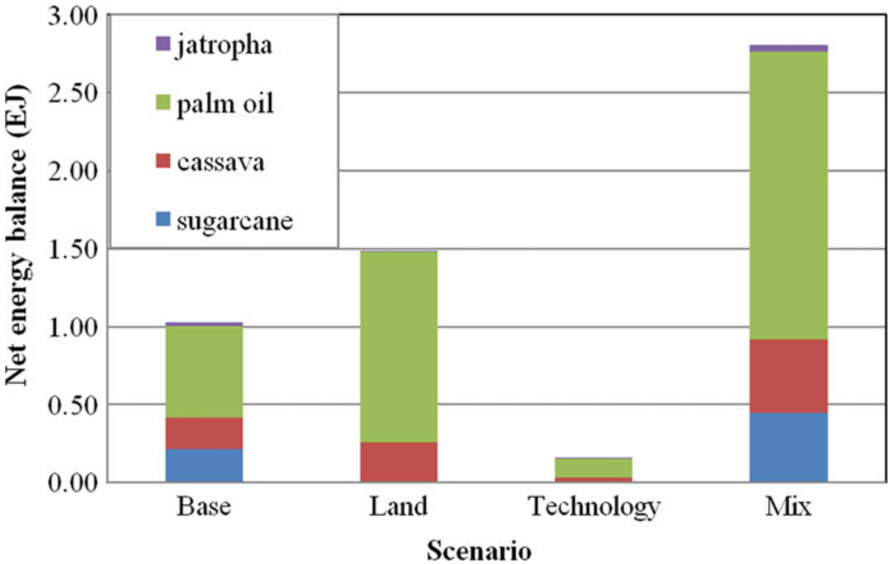

Fig. 19.3 Net energy balance in 2025

compared with domestic demand. In the "land and technology" scenario, biodiesel production achieves 53,800 million liters in 2025, far exceeding domestic demand of 3,500 million liters. The "land" and "base" scenarios respectively result in excess production of 30,600 and 14,200 million liters in 2025.

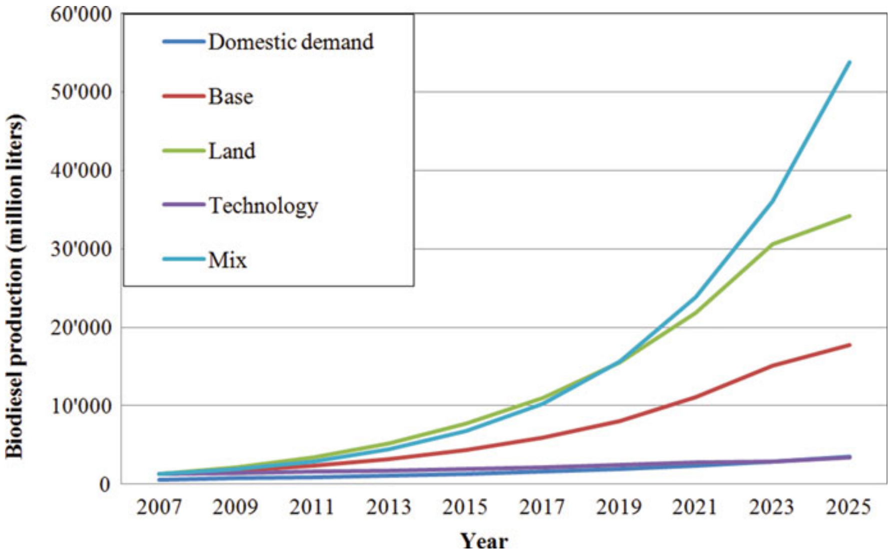

Fig. 19.4 Biodiesel production output

The "technology" scenario can fulfill domestic biodiesel demand except in 2025, with production of 3,400 million liters. Figure 19.5 demonstrates the oil equivalent of biofuel replacement of transportation fuel in Indonesia. In 2007, biofuel replacement equals 54.4 and 559 million liters for bioethanol and biodiesel, respectively. Due to a higher growth rate of bioethanol compared to biodiesel in 2021, bioethanol demand surpasses biodiesel demand. In 2025, bioethanol and biodiesel demand equals 7,700 and 3,300 million liters of gasoline and diesel fuel, respectively.

19.3.2 Economic Impact Assessment

Another major driving force behind biofuel development in Indonesia is poverty alleviation by producing added value from existing local resources, empowering local communities by creating jobs, saving foreign reserves, and generating income by exporting biofuels. With oil prices of US$ 60 per barrel, replacement of oil with biofuel could save US$ 4.1 billion in domestic transportation, in 2025. In terms of export, in 2025, biofuel production could generate income of 1.22 to US$ 21.93 billion, depending on the scenario chosen. Table 19.3 presents the export value of biofuel products in 2025 for all the scenarios. The "land" scenario shows lower income than the "base" scenario due to a higher volume of biodiesel produced, as biodiesel has a lower production cost than bioethanol.

Figure 19.6 illustrates the profit from biofuel production in all the scenarios. The highest profit is achieved in the "land and technology" scenario at US$ 3.75 billion, which is 2.6 times the profit in the "base" case. The lowest profit is in the "technology" scenario with forecast profit of US$ 190 million in 2025. Table 19.4

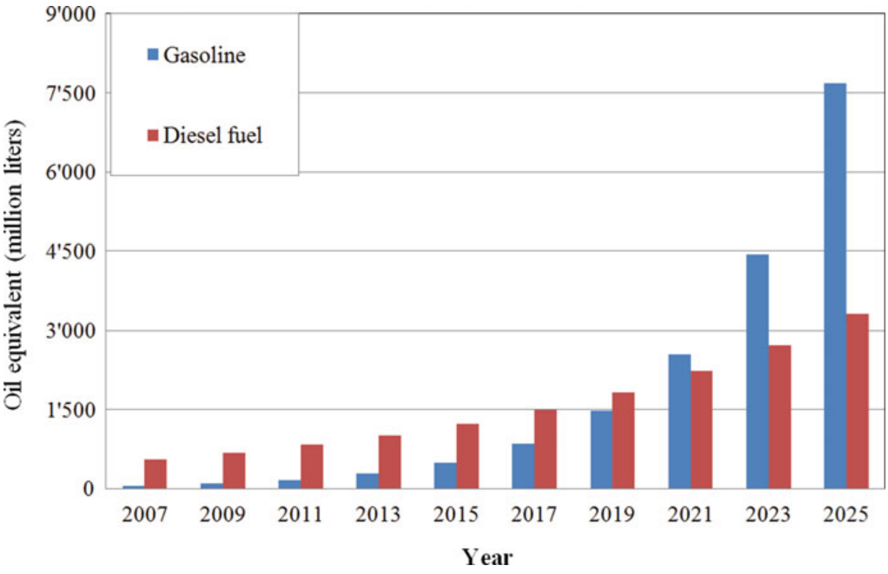

Fig. 19.5 Oil equivalent of biofuel domestic demand

Table 19.3 The export value of biofuel in 2025

Scenario	Export value (million US$)		
	Bioethanol	Biodiesel	Total
Base	5.9	5.8	11.8
Land	0	12.568	12.6
Technology	0	0	0
Land and technology	27.441	20.636	48.1

shows the labor requirements for all scenarios in 2025. The highest labor requirements are in the "land and technology" scenario due to land expansion and increasing biofuel production as a result of the yield growth rate. In contrast, the "technology" scenario shows the lowest labor requirements as there is no land expansion, and labor requirements are measured based on land allocated either to agriculture or biofuel production.

19.3.3 Environmental Impact Assessment

In addition to the conflict over land for food and fuel, sustainability of biofuel production is a concern. This study looks at biofuel production considering conservation and protection of natural resources. The extension of 0.5–10 million hectares from 2007 to 2025 could be achieved mainly by allocating unutilized or nonproductive land, such as that on the Sumbawa and Lombok Islands (National Team for Biofuel Development 2006). As a result, biofuel production could have a positive

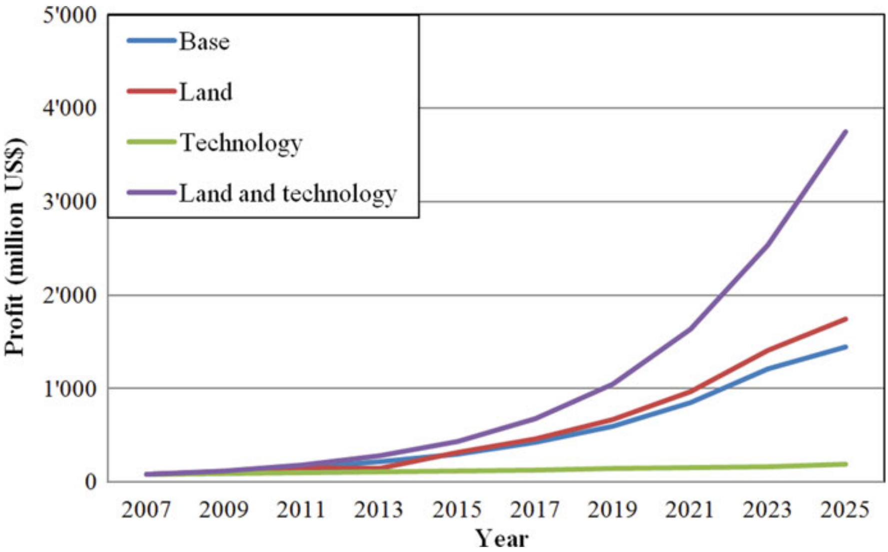

Fig. 19.6 Profit for biofuel production

Table 19.4 Labor requirements in 2025

Scenario	Labor (persons)
Base	6,897,700
Land	6,941,900
Technology	343,200
Land and technology	7,140,500

effect on the greenhouse gas emission balance. Figure 19.7 shows net emission balance of biofuel production for all the scenarios. Due to the higher output, the highest carbon saving is achieved in the "land and technology" scenario and amounts to 168 million ton CO_2 equivalent (MtCO_2eq) in 2025. The other scenarios incur much lower carbon savings, at a maximum of only 50% of that achieved in the "land and technology" scenario.

19.3.4 Technology Assessment

Use of biofuels as transportation fuels has reasserted the links between energy and agriculture. Biofuels procure multiple benefits related to energy security, socioeconomic factors, and climate protection. Biofuel, which is mainly used as an energy source for transportation, can improve the energy autonomy of an economy, reducing dependency on fossil oil and gas. Use of biofuel shows fast growth because it can curb greenhouse gas emissions by replacing fossil fuels. Most of the crops used for biofuel production are originally grown for food consumption.

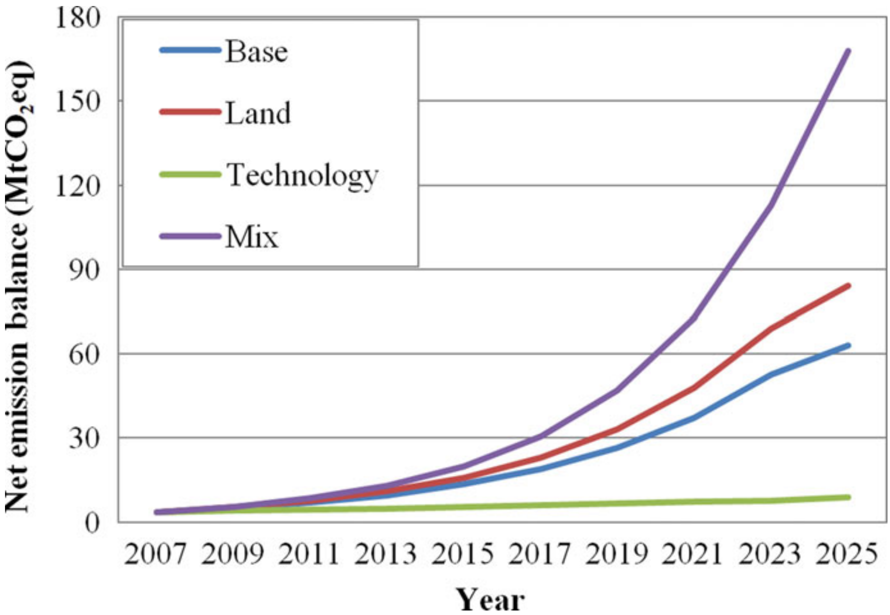

Fig. 19.7 Net emission balance

Nevertheless, the boom in biofuel demand for the transportation sector has incurred negative consequences. Expanding cultivation of fuel crop plantation has promoted land clearing in forests. In fact, deforestation and land clearing have been identified as the largest source of CO_2 emissions according to Wetlands International (2006). Sustainable production must attend to this issue in biofuel production development by preventing deforestation. In addition, competition between crops for energy and food has resulted in increasing food prices. This situation is often referred to as the "food versus fuel" dilemma (OECD-FAO 2008). To avoid this, there is intense pressure to strive for higher yields and minimize fossil fuel consumption in production with technology improvements.

One of the parameters used to measure how effective biofuel is in replacing fossil fuel is the energy ratio, that is, the ratio of energy contained in biofuel, related to the fossil fuel energy used for its production. The energy ratio from sugarcane ethanol has a value of 4.9 in this study, while palm oil biodiesel has a value of 3.6. Sugarcane processing technology is already fully developed compared to palm oil processing However, net energy balance, which is the difference between energy output and energy input during production, has the highest value for palm oil compared to all other biofuel crops. Another problem that needs solving is balancing the supply and demand of crops for food and fuel. This can be achieved by channeling excess supply of food into fuels and vice versa.

Biofuels are at present produced in large quantities in other regions such as the USA, Brazil, and Western Europe. In the future, restrictions on allocation of land and higher feedstock costs in these regions will shift biofuel production to other regions that have more land available and have lower feedstock costs, such as Indonesia, Malaysia, and Thailand. First-generation biofuels have already reached a competitive price in some regions, due to economies of scale and technology learning such as in Brazil, where the price of bioethanol is US$ 0.23 per liter compared to oil prices of US$ 0.25 per liter (Coelho et al. 2006). Second-generation biofuels will be produced from nonfood materials such as cellulosic biomass, which includes wood, rice straw, and grass. Another nonfood biofuel are third-generation biofuels produced from algae. This type of biofuel has even more advantages, as product yield is higher than that of first- and second-generation technologies. Increasing fossil oil prices will improve the competitiveness of biofuel.

In addition, biofuel must also compete with other renewable resources and low carbon technologies, such as hydrogen fuel cells and hybrid vehicles. At a later stage, second- and third-generation biofuel may be available on a large scale, offering much better prospects and competitive fuel prices in the long term, between 2020 and 2030. In terms of policy, it should be pointed out that in other countries, the introduction of biofuels in the transportation sector is predominantly promoted by means of subsidies and tax incentives.

The Indonesian government fosters development by assigning millions of hectares of land for plantations and for opening up of the energy sector to private and foreign investment. The opening of a plantation can provoke conflict between the plantation companies, the workers, and the local community. The conflict with workers is over labor rights, in particular, wages and working conditions. Plantation development is likely to lead to a change in the ecosystem (available water sources and biodiversity), which affects the communities.

19.3.5 Limitations of the Model

The complexity of building a bioenergy model is undeniable. The uncertain cost of feedstock crops, the different yields due to land, water, and climate conditions, and the methodology of data collection are several aspects that influence reliability of the outcome of models. Discrepancies between a model and reality are to be expected. In Indonesia, biofuel was first produced in 2006, and so far, there is no existing scientific data regarding biofuel life cycle assessment. Our model uses different data sources, deploying different methods to collect input data. Energy input data is derived from different countries: Brazil for sugarcane, India for *Jatropha curcas*, and Thailand for cassava and palm oil. Cost data is obtained from Thailand for sugarcane and cassava and Indonesia for palm oil and *Jatropha curcas*. Emission data is obtained from Brazil, Thailand, Indonesia, and India for sugarcane, cassava, palm oil, and *Jatropha curcas*, respectively. Biofuel crop yield in these regions could be different from Indonesia's biofuel crops, considering the different cultivation methods, land output, harvesting methods, production processes, plant capacities, and distribution channels.

The model could yield more reliable results by using life cycle assessment of Indonesian crops and considering several other aspects: the "food and fuel conflict," benefits gained from by-products, land use change (direct and indirect), and deforestation and ecosystem changes (due to biofuel development). Utilization of coproducts as energy carriers, for example, will procure greater savings in energy and greenhouse gas emissions. Nonetheless, the outcome of the model provides a direction for the optimum value of biofuel production, which is useful for the stakeholders to achieve the best results under land and technology constraints.

19.4 Conclusions

Based on the modeling results in this study, several conclusions can be drawn. In Indonesia, biofuels can reduce dependency on oil by partially replacing fuel demand in domestic transportation, empower local communities by creating jobs in agriculture and industry, generate income by exporting excess production, and lead to carbon emission savings. For sustainability reasons, land allocation for biofuel must not lead to deforestation.

This study is based on increasing land allocation and technology development (yield growth) as a dynamic function to increase biofuel production. The results can be summarized as follows:

- In terms of energy output, the "technology" scenario, which relies on technology improvement without land allocation, can only fulfill domestic demand for bioethanol and biodiesel up to 2015 and 2023, respectively.
- From an economic perspective, with oil prices of US$ 60 per barrel, biofuel replacement of oil in domestic transportation could save US$ 4.1 billion in 2025. Export is possible until 2025 and earns US$ 49 billion at a maximum level in the "land and technology" scenario.
- With sustainable production, carbon emission savings could be achieved of up to 167.8 $MtCO_2eq$. The other scenarios only show 5.3%, 37.5%, and 50% of these carbon savings in the "technology," "base," and "land" scenarios, respectively.
- Production cost may decrease due to economies of scale, and production output could increase due to technology development and development of next generation technologies.
- Development of biofuel production in Indonesia is still in its infancy. Development potential must be carefully assessed considering all the parties concerned: the biofuel industries, workers, local community, and government. Involving the local community by hiring and training local people to plant biofuel crops in a sustainable way and buying the crops from local farmers could be an option for the biofuel industry.

Acknowledgments This chapter was based on the author's Ph.D. research work at the Department of Management Science and Technology, Tohoku University with financial support from Japan's Ministry of Education, Culture, Sports, Science and Technology (Monbukagakusho). The information supplied by Dr.-Ing. Evita H. Legowo of Indonesia's Ministry of Energy and Mineral Resources is acknowledged.

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Chapter 20
Selling Hours of Solar Lighting in the Evening

Leon Gaillard and Andreas Schroeter

20.1 Country Background

The Lao People's Democratic Republic (Lao PDR) features in the group of least developed countries (LDCs), with a UNDP Global Human Development Index (HDI) rank of 131 (out of 177 countries) (UN Lao PDR 2009). Significant improvements are primarily impeded by geographic and demographic conditions: 70% of the country is mountainous and thickly forested (Mongabay 2009), with highly dispersed and ethnically diverse population (82.9% of approximately 5.6 million) (Messerli et al. 2008) living in rural and remote areas lacking access to basic social infrastructure, communication, transport links, and professional opportunities, and where poverty tends to be more acute (Government of Lao PDR/UN Country Team 2006).

20.1.1 Access to Energy

In terms of energy, the utilization is still at low levels of technique and technologies, and the use of fuel wood still dominates and is supplemented by the use of fuel oil, charcoal, and electricity. It is worth noting that Laos imports all of its petroleum products (ADB 2006). Electricité du Laos (EdL) is the state-owned electricity provider and owner of the national grid. Hydropower plants provide 99.8% of grid electricity – due to many rivers and streams crisscrossing the country (EdL and Ministry of Energy and Mines 2008). At present, 58% of all households

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have access to electricity with only 50% connected to the national grid and 8% depending on isolated mini-hydropower plants and solar photovoltaic (PV) systems, as well as generators and car batteries (Messerli et al. 2008).

20.2 Project Overview

20.2.1 Sunlabob Renewable Energy Ltd.

The focus of this study is a project developed by a Lao commercial company, set up in 2000, licensed in 2001, and operating as a profitable, full-service renewable energy provider selling hardware and providing commercially viable energy services. It acquired unrivaled knowledge and experience of the local market and stakeholders, largely through solar home systems (SHS), comprising its first rural electrification efforts, which consisted in providing SHS to rural households, on a rental basis.

The success of a rural market PV rental business depends on a wide distribution network, which must be very cost effective and meet a very high standard of service. In order to achieve nationwide coverage, Sunlabob developed an extensive network of franchisees, who were all rigorously and thoroughly trained by the company to be responsible for the commercial development of the rental operation, the installation of PV systems, and the provision of maintenance services. Offering fast and reliable maintenance has always been core to the company's mission and interventions, as the systems' sustainability and longevity largely depend on this "after-sales" service. This independent distribution network, which plays an important role of developing new business, collections and maintaining a servicing network and commercial presence at the provincial level, only reinforced a belief that involving local individuals, loyal and empowered, is crucial for any rural electrification initiative.

The main lesson learned from the SHS was that, even on a rental basis, only the top third of village households on average could afford the systems. Second, systems must be adapted to the existing consumer behavior. For the SHS, money was collected by the franchisee from the end users on a monthly basis. This turned out to be difficult, as most rural households on the one hand do not have regular monthly incomes (largely depending on agricultural output) and on the other hand are not used to putting money aside on a monthly basis for their expenses. This gave rise to the idea of smaller but more regular expenses for lighting and paved the way for the development of the solar lantern rental system (SLRS).

According to the company director, a key lesson learned from the SHS project was that training village energy committees (VECs) is not a commercially viable activity, hence the need to involve other sources of funding for projects that have a large capacity-building component. Having said that, this is where the company acquired its expertise in providing training, both technical and administrative, which is now used for the VECs and village technicians (VTs) who are involved in the SLRS.

Finally, the SHS program enabled the company to develop a strong relationship with the government of Laos and provincial and district representations. Due to difficulties mentioned above, the system is now gradually being phased out.

Based on its experience, the company believes that responsible, long-term-oriented entrepreneurship is the driving force for sustainable economic development and for providing the managerial, technical, and financial resources needed to meet social and environmental challenges.

Starting with a team of three people, operations in the Lao PDR grew from strength to strength into a company with a team of 42 full-time staff and offer a full range of renewable energy solutions, such as solar water pumps and heaters, water purification systems, street lighting solution, cooling units for health posts, and solar lanterns. The company is constantly developing new ways to promote renewable energy technologies in Laos and recently launched an Energy Efficiency department, responsible for conducting energy audits and advising customers on ways to save energy thereby reducing their environmental impact.

20.2.2 Institutional Arrangements, Project Partners, and Funding

Unlike foreign enterprises, companies licensed in Laos have permission to conduct rural electrification initiatives nationwide without the need for lengthy planning applications on a case-by-case basis. However, each individual initiative must be approved by the authorities of the province and district concerned. Generally in Laos, any electrification project below 100 kW is under the supervision of provincial authorities, and project over 100 kW requires central government authorization (EdL and Ministry of Energy and Mines 2008).

Arrangements with other partners are illustrated in Fig. 20.1.

The division of public and private ownership of assets is an important factor for the proliferation of the SLRS. The movable assets are a more feasible investment for the private investors. The private energy provider makes the "private investments" to own and operate the movable assets, namely the solar charging station, that is, the generating equipment. The public side, in this case the village, is responsible for the "public investments," namely providing lanterns to the village franchisee or users.

This innovative operational arrangement then leads to an innovative financial arrangement that allows for mutually leveraging opportunities. Consistent with a public-private partnership arrangement, the financing of the SLRS will be a combination of public funds to finance the public assets and private funds to finance the private assets. This arrangement allows public money to comfortably finance a project that 100% directly benefits the public and leverages the private sector. Private funds are able to leverage public funds to pursue a market that would otherwise be very difficult to operate successfully in. This concept can open markets and opportunities that would otherwise remain closed for a very long time.

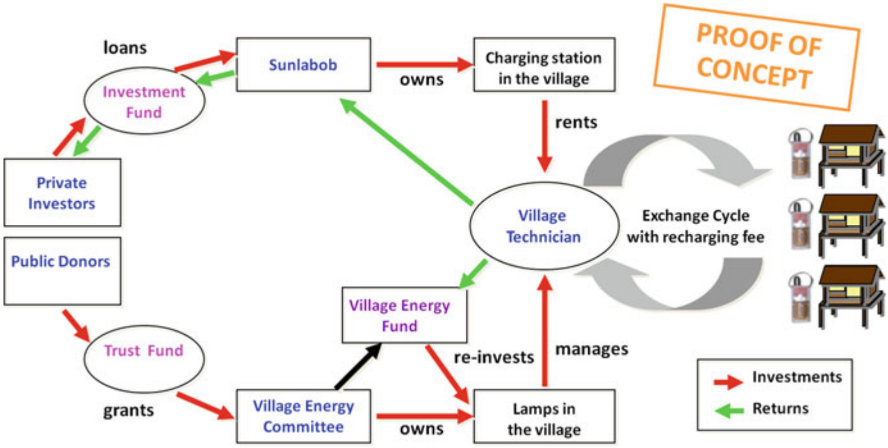

Fig. 20.1 Financial arrangements and partners for SLRS public-private partnership model (Source: Sunlabob Renewable Energy Ltd. 2008)

After the initial investment by the public, the launched village enterprises are expected to generate sufficient income to expand and continue their operations through the revolving fund without any further public investment, thereby ensuring sustainability of project.

20.3 Implementation Strategy

20.3.1 Delivery Method

To implement the SLRS, it is first necessary to identify a village entrepreneur who is interested in renting the SLRS and can be trained as a technician. The company will install the solar charging station at a central place in a village and will also be responsible for regular servicing of the station. The VT pays a fee to rent the solar charging station, but purchases the portable lantern units (with the help of public funds if necessary), which are then rented out to the village households interested in buying lighting. The village households pay a fee to the VT for renting a charged lantern or, viewed differently, for simply buying lighting.

The technician will operate on a franchise arrangement with the company. In return for a regular monthly fee on the charging station and for purchasing the lantern units, the franchisee is provided the following:

- Installation, regular servicing, and maintenance of the charging station
- Initial business and operational training, as well as ongoing advice and support
- Regular training for maintaining quality of equipment and data

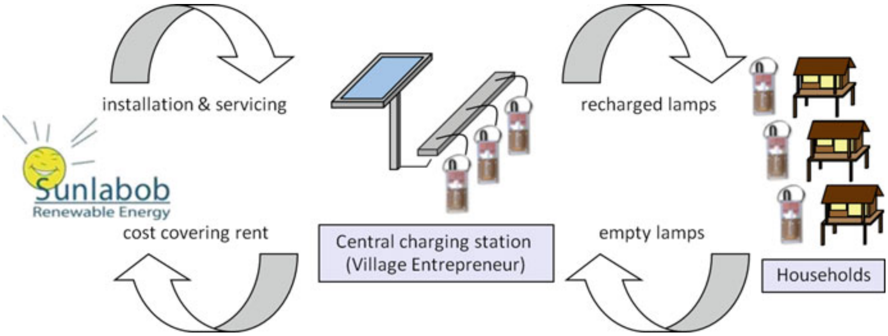

Fig. 20.2 Operational model for the solar lantern rental system (*SLRS*) (Source: Sunlabob Renewable Energy Ltd. 2008)

- Assistance in local marketing, through public relations (PR) materials, demonstrations, and campaigns
- Assistance in accessing soft loans if necessary

Figure 20.2 gives an illustrative representation of the operational flow of the SLRS model.

20.3.2 Project Activities

20.3.2.1 Present Status

The design and development process for the SLRS took over 1 year, including research and development on the components. Field trials played an important role, and at the time of writing, several pilot projects were being conducted in Laos, Uganda, and Afghanistan.

One of the objectives of the first pilot projects in Laos was to get a sense of how villagers would accept the solar lantern, focusing on ease of use, design, and types of usage. Another objective was to simulate the actual implementation of the SLRS to determine user behavior.

20.3.2.2 Product Package

The product and intervention package has been designed to replicate the behavioral patterns of rural households in terms of spending on kerosene. For the households, the recharging fee is a small regular expense, comparable to the established behavior of purchasing small amounts of kerosene regularly from the village outlet. The routine cycle of household expenditure therefore remains unchanged. Even the act of going to the recharging station to "buy light" mimics the act of buying kerosene at the shop. As explained above, the operations result in the sale of hours of light, as opposed to the sale of equipment, which also emulates the service provided by grid connection.

The design of the SLRS is based on the idea of keeping construction as simple as possible, while still providing versatility, robustness, and ease of use. This is achieved by reducing the number of technical components to a bare minimum, placing most of the system's "intelligence" in the external system control unit (SCU). The system is entirely modular, and additional charging stations can be operated if required.

The Lantern Unit

The lantern unit comprises an energy efficient lamp, battery, and control electronics. These are designed to be portable and can be taken home, hung up, stood on a surface, or carried while illuminated. A robust tamperproof casing protects the internal components. Controlled use is ensured by an integral microprocessor, which records the total hours the lantern has been active since charging. The use of lanterns is carefully constrained while rented to a user. The lantern units are disabled after 10 h and cannot be turned on again by the customer. If used as a power supply, for example, to charge a cell phone and a low voltage condition is detected (flat battery), the integrated low voltage protection feature also results in the disconnection of the power outlet, and the lamp is switched off.

During the entire period between charges, the lantern unit's power output receptacle cannot be used to charge the unit's battery, ensuring that no unauthorized charging can occur. In order to prepare for charging, the lantern unit is connected to the SCU and can only be unlocked then. The SCU also reads the number of hours the lantern unit has been used since the last charging and writes it to the charging log, along with the lantern unit's unique identification and the current date and time. The lantern unit can then be connected to the battery charging unit until fully charged. While in charging mode, the internal controller prevents switching on the lamp and any attempt to extract power through the receptacle exceeding a set period. This approach ensures that only fully charged lantern units are handed out, but does not interfere with the operation of modern charge regulators that may probe the battery by discharging it for short periods of time.

Once the battery is fully charged, a lantern unit can be prepared for handing out to the next household, ordinarily in exchange for a spent one. It must be reconnected to the SCU to activate the lantern unit for lighting operation and record the lantern unit's ID to the activation log, along with the date and time. The integrated system is represented schematically in Fig. 20.3.

In addition to providing lighting, the lantern unit can be used as an unregulated 12-V power supply for small electronic devices. Possible uses include mobile phone charging or powering portable radios or mini-TVs. Any power extraction through the power outlet is measured, converted into an equivalent number of

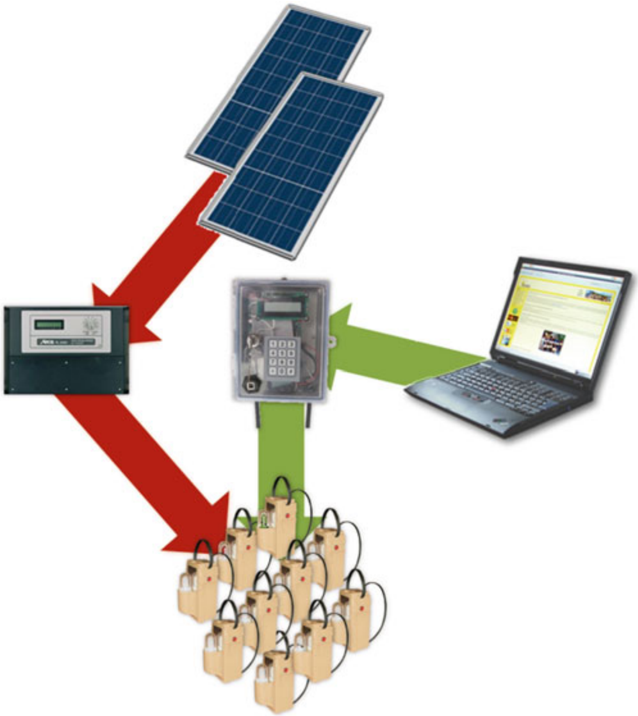

Fig. 20.3 SLRS control and supply schematic (Source: Sunlabob Renewable Energy Ltd. 2010)

lighting hours, and the operating time of the lantern unit is reduced accordingly. This ensures that the users get the exact amount of energy they pay for, whether they use the lantern unit for lighting, as a power supply, or both.

The System Control Unit (SCU)

The SCU is located at the charging station. It is used to activate the lantern units for either charging mode or for lighting mode by the households and to collect any data acquired since the last recharging. The SCU currently uses an integrated solid state (secure digital) storage module to store the log files and firmware updates of the associated lantern units. It is also used to store the SCU's firmware updates and configuration data. The size of this storage module can be increased to accommodate the needs of system setups with large numbers of lantern units per SCU.

Management Software

To facilitate the handling of data collected by many SCUs in many villages, the solar lantern recharging system comes with a management software complete with a graphical user interface. The data collected can be analyzed in many ways, that is, number of charges and fluctuations in time, lamp distribution, intensity of usage in various areas, frequency of switching on and off, and average time of switched on light. The management software also enables firmware updates and is used to modify configuration settings of the SCUs.

20.3.2.3 Operational Details

The village entrepreneurs and the company enter a franchise agreement, which encompasses:

- The installation of the charging station, including the SCU
- The regular servicing of the charging station
- The sale of lantern units and of spare parts
- Regular training to maintain quality and introduce technical upgrades
- Operational and business advice
- Assistance in local marketing: PR materials, demonstrations, campaigns
- Assistance in accessing soft loans and financing opportunities

The rental income usually pays for these services, although various programs funded by public agencies may pick up some of the costs, for example, training.

20.3.2.4 Responsible Supply Chain

Laos is a largely agricultural country and has very few industries. This implies that the high-tech components of the SLRS have to be imported. Solar panels and batteries come from China, light bulbs from Singapore, and microprocessors and charging stations from Germany. However, in order to maximize the impacts of our activities on the country's development, the company purchases as much material as possible from local suppliers, which includes all the SLRS accessories (cables, outer box, straps, etc.) (COPE 2009).

20.4 Financing Mechanisms

In order to be adopted by the poorest rural households, the solar lantern must be competitive with the price of kerosene. Kerosene prices vary from country to country, but in Laos, households typically spend US$ 4–6 per month for lighting. In order to offer its system at low cost, the company has had to develop collaboration with public donors, thereby creating a public-private partnership for providing solar lighting to poor households in remote villages. There is a strong case to be made for public involvement in launching such ventures. However, public financial involvement must be designed to encourage private investments into commercial operations. Subsidies, if badly designed, can be counterproductive. Public and private investments can offer mutual leverage, in circumstances where one alone may not achieve the intended effect. For the SLRS, private investors are to invest in the charging stations to be rented out, whereas publicly launched revolving funds provide the first batch of lanterns to start up the businesses of the village entrepreneurs.

Following the initial public investment, the system and models are designed in such a way that the village entrepreneur is expected to sustain his newly created business with the recharging fees alone and without any further investment.

Based on kerosene prices and rural households' incomes in Laos, the recharging fee for the solar lanterns has been set to 4,500 LAK (about US$ 0.53). The income from each recharging fee is to be split into four parts as follows:

- 1,900 LAK (42% of the recharging fee) is set aside in a maintenance fund managed in conjunction with the VEC, which is to be used for the purchase of replacement components.
- 1,100 LAK (25% of the recharging fee) is retained by the VT as a salary.
- 1,000 LAK (22% of the recharging fee) goes to the company as the rent for the charging station (paid by the VT).
- 500 LAK (11% of the recharging fee) is to be shared among the members of the VEC as remuneration for their time administering the system.

20.5 Capacity Development

The SLRS model makes full use of the existing institutional structures found in rural Laos. The development of a VEC, responsible for this service naturally fits in with the way in which villages traditionally manage their community-level affairs. Similarly, in terms of the VT, it is common to find one key competent individual in a community who is already identified by villagers as a focal point for technical issues or with an incline for commercial activities or providing access to material and hardware.

This project has the potential to create jobs for technically versatile people who are disadvantaged in rural areas because they cannot apply their skills there and often leave the village as a result and are lost from the local village economy.

Working on this existing structure, the company adds specific training and capacity building in order to enable these communities to manage SLRS.

Training for the VEC members includes:

- Energy service management
- Basic bookkeeping
- Maintaining transparency
- Community communications

Training for the VTs includes:

- System operation
- System maintenance
- Keeping records of the usage

For each village, the cost of capacity building is about US$ 500. This comprises the initial training sessions as detailed above and three coaching visits, over a period of 18 months. Capacity building costs in Laos are high because existing skills are relatively low, due to an underdeveloped education system. As an indication, the literacy rate in rural regions without road access is 41.1% for women and 67.6% for men, and nationwide, only 15.5% (14.6% female; 16.3% male) of the population aged 6 and above have completed primary education and 6.1% (5.4% female; 6.9% male) have completed lower secondary education (Messerli et al. 2008). In addition to a low level of skills, the technology brought to rural communities is very new, hence the need to spend a lot of time and money on capacity building. In the case of the SLRs, this is mitigated by the fact that the solar lanterns mimic existing behaviors with kerosene. However, in order to reduce training costs, the company trains VECs and VTs in groups of five to eight people from neighboring areas at the same time.

20.6 Impacts

In its current form, the impacts of the SLRS project show that it contributes largely to the efforts being made to achieve, in particular, three Millennium Development Goals (MDGs):

- MDG 1: Eradicate extreme poverty and hunger
- MDG 7: Ensure environmental sustainability
- MDG 8: Develop a global partnership for development

20.6.1 MDG 1: Eradicate Extreme Poverty and Hunger

The project improves the economic situation of poor households in several ways. First, most of the funds collected as charging fees remain in the village: the VT and VEC are remunerated in return for managing the service, and the rest of the money is retained in a maintenance fund, which is used for the benefit of the community and to buy replacement components or additional lanterns for the village households. Second, the SLRS is cheaper than kerosene per hour of light so end users spend less on lighting. The quality of light provided by the SLRS lanterns is also considerably better than that of traditional kerosene lanterns; one solar lantern can replace several kerosene lanterns, and the light of a single unit is sufficient to accomplish household chores or income-generating activities in the evening.

A study in Ban Phonlek shows that half the total number of households who are participating in the project are using the lantern for income-generating activities. Among them, half sell animals, a quarter sell handicraft products, and the other quarter sell general items. By increasing the number of productive hours, the system thus further improves the wealth of a household. Lastly, the SLRS dramatically increases energy security for poor households, since the price of kerosene fluctuates erratically, whereas the price of the SLRS is controlled. This makes household finances much easier to plan. Periodic price updates are planned based on the country's consumer price index (CPI). On a national level, locally produced renewable energy sources reduce the reliance on imported fossil fuels (100% for Laos) and further increase energy security by removing potential threats, such as political instability of energy-producing countries, manipulation of energy supplies, competition over energy sources, attacks on supply infrastructure, as well as accidents and natural disasters (ASPI 2007).

The SLRS project generates jobs both directly and indirectly. At the company's head office in Vientiane, the system creates the jobs involved in assembling the lanterns and providing the systems to rural areas. At village level, jobs are created for those providing the service to the end users, namely the VECs and the VTs. Finally, by increasing the number of productive hours in the day, the system indirectly, but purposely, creates income-generating opportunities.

The system itself introduces the need for local services with the creation of a small business run by the VT. The company's activities encourage a local technician to constitute his/her own microenterprise, technically and operationally safeguarded through a franchise arrangement with the company providing experience and competence. VTs are trained to correctly service and maintain both the charging station as well as the rechargeable lanterns in order to ensure longevity. The concept combined with the skill improvement allows them to run their own sustainable business, supplementing other income sources. With a single charging station (50 lamps), the VT receives a net income of around US$ 400 in the first year of operation. Compared to a gross national income (GNI) per capita of around US$ 600, which includes the higher-income urbanized communities, the SLRS microenterprise provides the VT with a decent income.

The SLRS also introduces the concept of fee-for-service in rural communities, which could result in other local enterprises using it as a model for their business. In addition, through contact with the company, rural households gain awareness of other renewable energy technologies and services that they may wish to develop in the village and run as a microenterprise, for example, TV/Video or even projector with screen, coolers, a laptop with GPRS Internet connection, or UV-sterilized bottled drinking water.

In terms of access to telecommunication systems and information, in Laos, the information and communication technology (ICT) sector is still emerging (UNCTAD 2007), but many people demand more information to expand their knowledge and reduce poverty (Vientiane Times 2009). Access to information and knowledge has been identified by the Government of Laos, during the eighth Party Congress in 2006, as a crucial prerequisite to alleviate poverty in rural areas and boost the country's socioeconomic development (Vientiane Times 2009). The Government is currently working to develop useful information in print, radio, and TV formats for rural households on topics that concern them, such as agriculture, public health, income generation, and poverty reduction (Vientiane Times 2009). In addition, the government sees the media as "an important nation building asset [. . . and . . .] a tool to disseminate the Party's policies, laws and regulations" (Vientiane Times 2009).

20.6.2 MDG 7: Ensure Environmental Sustainability

The main aim of the project is to reduce fossil fuel consumption for lighting. It is estimated that fuel-based lighting such as kerosene lamps consumes 77 billion liters of fuel annually throughout the world, equivalent to 1.3 million barrels of oil per day (LBL 2005). The average daily burn time of one kerosene lamp per household is 3–4 h, which sums up to around 40 L of kerosene consumed per year.

Furthermore, the light provided by a kerosene lamp is inefficient in terms of useful lighting. Theoretically, more than one kerosene lamp per household has to be used for sufficient lighting which further increases the kerosene consumption. The kerosene used for domestic lighting can also find its way into vehicles with additional environmental consequences (Mills 2000). In addition, the SLRS also reduces the amount of fossil fuels used for the transport of the lighting fuel.

Energy use and production affects local, regional, and global environments. According to Lawrence Berkeley National Laboratory (2005), the single greatest way to reduce greenhouse gases associated with lighting energy use in developing countries is to replace kerosene lamps. Nearly 100 kg of carbon dioxide (CO_2) are emitted per year by each kerosene lamp (Mills 2003). As part of the SLRS, the actual usage of each lantern is recorded in detail by the internal microprocessor, and data is collected and aggregated at charging stations. By basing its calculation directly on the offset of kerosene, the company will be able to precisely quantify the emission reduction achieved. Sunlabob is currently working on strategies to enter the carbon trading market using the clean development mechanism (CDM).

In terms of affordability, the SLRS is directly competitive with kerosene. It is sustainable due to the equipment lifecycle being carefully included in the operational model so that high-quality service can be provided to the lantern users on a long-term basis. Finally, in terms of environment, by using solar energy to power the charging stations, the SLRS has a low impact.

By eliminating the use of kerosene lanterns, the solar lanterns solve two serious problems associated with the usage of kerosene lamp. First, many homes have poor ventilation so that burning kerosene lamps causes indoor air pollution resulting in health hazards such as lung and eye infections and respiratory problems. The light is so poor that the users can only work or read if they are almost directly over or nearby the flame inhaling even more of the toxic fumes. Second, kerosene lamps as flammable liquids have more probability of causing burns and fires than all forms of electric lighting, primarily due to overturned or toppled lamps. Each year, many homes and even entire communities worldwide burn to the ground (Pode 2008). The solar lantern in fact neither has an emission of any kind nor poses any technical risks to the user. SLRS offers rather an affordable, clean, healthy, safe, and sustainable energy source.

The SLRS increases energy efficiency by providing high-quality light compared to kerosene lamps. The light output of a kerosene lamp, measured in lumens, is 45 lm compared to the SLRS's 4-W compact fluorescent light bulb with 120 lm. The lanterns also promote efficient use of energy as a flashing LED which clearly indicates the number of remaining hours of light (out of the initial 10 h), enabling villagers to manage and plan their energy usage efficiently.

20.6.3 MDG 8: Develop a Global Partnership for Development

The SLRS projects bring to Lao villagers a sense of being part of the global scene by exposing them to international products with state-of-the-art technologies, new organizational approaches, and global actors. A learning process with VECs and VTs is initiated with long-term potential. The establishment of VECs also has numerous positive impacts on communities in terms of management issues, responsibility, or social cohesion.

The concept has been extended beyond the boundaries of Laos, by engaging into South-South cooperation initiatives, as illustrated by the current projects in Uganda and Afghanistan. Three representatives of African enterprises came to Laos to learn about the company's range of products and practices. The delegation visited several implementation villages, where technicians explained their role, and the benefits they saw to their own households and their community. The event was a rare encounter of people from African nations and rural Laos and represented the coming together of two different peoples that face some common challenges for development. Indeed, it is the similar needs in some developing nations, and moreover the firsthand understanding of those needs that can be an advantage for South-South exchanges over the historical North-South dissemination of technology.

20.7 Project Sustainability

20.7.1 Ensuring High (Robust) Quality of Product

An analysis of the market revealed a market gap. Indeed solar lanterns have been widely propagated as a solution for lighting in remote villages away from the grid. Standard solar lanterns, however, have shown to fail much earlier than expected. One reason is that low-quality components are often used to reduce costs of manufacturing to make the lanterns more affordable. Another is that batteries are often irregularly charged, or households engage in "hotwiring" to use the batteries for operating other equipment, resulting in early battery failure. The result is that solar lanterns have not made a broad breakthrough in poor rural areas and that kerosene still rules the off-grid lighting market.

The challenge for the company was therefore to find an operational scheme for solar lanterns that could:

- Use advanced charging equipment and tamperproof units to exploit the full life expectancy of components
- Tightly control the use and charge status of the lanterns, and monitor the life cycle of their components, thereby increasing their real on-site efficiency
- Reduce costs per hour of light to be commercially competitive with kerosene lanterns on a household level.

With such innovations, it is hoped that solar lighting can make a significant impact in thousands of low-income rural households in the developing world.

20.7.2 Matching the Product with Consumer Behavior

The SLRS product was specifically developed in response to a direct consumer demand. During the course of its previous solar panel rental scheme, villagers in the areas reached by installation teams frequently asked for a cheaper alternative to the SHS. The SLRS fills a gap in the market, namely the need for reliable lighting and low-power charging (e.g., for mobile phones), for low-income households.

Another advance in the service arrangement from SHS to SLRS was to move away from a monthly rental fee to instead a fee based on the level of use. Moreover, by introducing monitoring features to indicate the state of charge in a lantern, users are directly in control of their energy consumption.

Certain features of the lanterns have also been strongly affected by consumer choice. Examples of this include the use of compact fluorescent light bulbs instead of LEDs and the placement of straps to enable the units to be both carried and hung.

As described in preceding sections, SLRS mimics conventional behaviors associated to the use of kerosene for lighting purposes. This is a significant design choice in the system to improve its sustainability, as it has a minimal impact upon existing supply chains within the village.

Finally, since the SLRS is operated and maintained locally by the VT and VECs, consumers are in direct contact with their service providers. Consumer satisfaction is highly visible and has an immediate effect upon those responsible for the systems.

20.7.3 Local Ownership

Local ownership is another essential element of the project's sustainability. At the end-user level, it is crucial that the community wishes to adopt the system and have ideas about how they might effectively use the new technology. It is also important that they pay a small fee to charge the lanterns because the company's experience has shown that when such technology is provided for free, there are few incentives for end users to look after the equipment. In this configuration, the fees also allow to remunerate villagers to look after the system on behalf of the community. The VT is chosen to maintain the system and replace components when they have reached their end of life, using the money set aside for that purpose. This ensures that the system continues to function independently of external technicians going to the village to carry out repairs. Finally, the VEC guarantees that the money is collected and allocated properly so that a high-quality service can continue to be delivered to end users. It is therefore in the interest of all community members to look after the system and ensure its longevity.

20.7.4 A Profitable Business for Everyone

As detailed above, the SLRS concept was designed in such a way that all stakeholders involved benefit from the system. End users get safer and brighter lighting at a price equivalent to their traditional kerosene expenses. VTs run the SLRS charging as a small business, and as such have interest in selling as many "recharging fees" as possible, and hence ensure that the charging process and lanterns function properly. In addition, they gain an employment opportunity, additional skills, and access to potential new business ideas. VECs safeguard the sustainability of the project and thereby reassert their role as a governing entity and actively contribute to the development of their communities.

Beyond the initial investment, the village is empowered to operate the SLRS with minimal technical support from the company. Over three quarters of the money generated by the system stays within the community and the largest fraction of this is used by the village to maintain the system. It is also important to ensure that the fee structure is transparent and well understood in the villages. The income generated for the community supports the sustainability of the SLRS through its effect upon the level of buy-in by the villagers, since it generates a good perception that continued use of the SLRS is serving to bring wider development of the community.

20.8 Conclusions

Experience gained before and during the development and implementation of the SLRS has shown that technical expertise is essential but needs to be combined with a robust operational and financial model offering economic sustainability, in order for rural electrification programs to have long-lasting benefits for populations in developing countries.

By taking a fee-for-service approach, high quality can be ensured in terms of both hardware and operation with the lifetime and status of components being continuously monitored through the rental and return cycle.

The systems benefit from the support structure of a competent private enterprise external to the village while still being run very much as local businesses. Strong commitment and buy-in of local populations is therefore decisive in the success of the systems.

Finally, by purchasing hours of light instead of hardware, end users gain considerably more control over their energy expenses and greater flexibility in managing their energy consumption. Moreover, by empowering rural communities to be responsible for their power supply, the SLRS contributes to wider community development.

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Chapter 21
Technological Developments Appropriate to Local Context: Lessons Learned from the Decentralized Rural Electrification Project in Ouneine (Morocco)

Benjamin Michelon and Ali Nejmi

21.1 Introduction

Born from collaboration between the Ecole Polytechnique Fédérale de Lausanne (EPFL), the Institut Agronomique Vétérinaire Hassan II (IAV) in Rabat, and the Targa-Aide Association, the purpose of the Decentralized Rural Electrification Project for remote settlements in the Ouneine Valley (Moroccan High Atlas) is to provide isolated populations with a decentralized electricity generation microgrid using several renewable energy sources, eventually connected to the national electricity grid. Although both these aspects fostered siting of the project in this valley, this choice can mainly be explained by repeated requests from the population in this territory for electric power, whereas the region was not scheduled for any electrification project by the Office National d'Electricité (ONE) until 2015. The valley was therefore designated to host real decentralized experimentation on known terrain. This project, undertaken in the form of research-action, contributed to gradual improvement of the inhabitants' living conditions and generation of widely applicable and shareable knowledge. At local level, this project aimed to promote sustainable development in the Ouneine Valley, by providing a group of villages with quality electricity supply from a decentralized microgrid, supplied by renewable energy sources (two small hydropower plants connected to the grid). At global level, this involved gathering fresh knowledge in the field of rural electrification, both in technical and sociological terms (Michelon et al. 2010).

However, during project implementation, the protagonists had to face up to a certain number of trials and tribulations which affected and cast doubt on the

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starting premise, especially in terms of technical choices and adaptation of technology to local society. Unexpected installation of the ONE grid and resistance of the population to the adaptations required for setting up of the system incessantly reminded the project promoters of the need to adopt an approach integrating local factors in the implementation of electrification. In this chapter, we propose, based on the lessons learned from the Decentralized Rural Electrification Project financed by the Swiss Agency for Development and Cooperation (SDC), the identification of psychological, social, economic, technical, and political factors which interact on choice, development, and rolling out of the techniques. This observation analyzes the way in which technical and social issues overlap and merge and the method used by the Decentralized Rural Electrification Project to try and factor local cultural and institutional aspects into definition and deployment of the technology.

This chapter first of all presents the aims of a technological innovation project in the south. This involves emphasizing the importance of adapting technical innovations so that they fulfill social demand. We will then compare these theoretical aspects, which we studied prior to project start-up, to the Moroccan Decentralized Rural Electrification experiment by analyzing the project implementation phases. On this basis, we will then make an assessment of this experience and identify areas for improvement to be studied for future projects: innovation, cultural adaptation, and the combining process.

21.2 Adapt the Technique to Fulfill Social Demand: Aims of a Technological Innovation Project in the South

In order to talk about overlap of social and technical issues of a development project, we have opted to approach the matter with the question of standards, which may be both technical and social. The different human societies are governed by a multitude of standards, otherwise known as the rules to be applied, generated in the various fields (economic, technical, environmental, and social standards) on different scales (national, continental, or even the world). The coexistence of standards produced by the different participants (local population, project promoters, financial backers, etc.) in the different fields is located on the development project scale. The purpose of this type of action is to provide, within a predefined territorial scope, social change also based on technical progress driven by its promoters.

In social terms, use of the word standard is justified by the fact that this notion enables no prior moral judgment to be made of the society in which we are working. Social standards are not laws, obligatory rules that assume an external requirement that is to be obeyed. By definition, they group together rules of conduct incorporated by individuals and models of behavior stipulated by the society. Derived from customs and traditions, the value systems progressively developed within this society guide individual behaviors from the inside. Challenged and supplied by inputs from other societies on a regular basis, they are continuously reviewed and renegotiated between the different strata of society, and they are born of negotiation, permanent compromise between the protagonists who use them. This need for standards is apparent in the relationships that individuals forge and maintain with their peers, regardless of the type of relationship – family, hierarchical, and so forth. This need is related to the very nature of human relations, based on an implicit social contract, which does not describe in detail all the interactions between individuals in the society and thus leaves room for opportunism, uncertainty and acts of deviance morally and ethically prohibited.

From a technical point of view, the need for standardization is born with the appearance of human technical activity. The place afforded by modern vocational organizations to knowledge of the ground rules and development of standards continues on from the role played by the trade guilds in the Middle Ages. A technical standard is defined as a set of rules for usage, requirements concerning characteristics of a product or a method, enacted in order to guarantee good working order, ensure usage, and prevent risks. It aims to establish a common language which facilitates communication and discussions and constitutes a tool for exchange between product suppliers or service providers, users, experts, laboratories, and so forth. These standards reflect the status of knowledge at their time of drafting. Established by consensus between the various participants concerned by a given subject, they constitute optimum compromise between status of the technique and economic and social requirements. The main criteria for validation and use of a technical standard are based on its degree of proficiency and the advantages that it procures for its users.

The latter point challenges the cooperation and development project operators. How can the two types of standards – social and technical – be practically combined to create innovation? Within the framework of a development project, the acute problem of interrelations between the different cultures arises, thus reflecting this dialogue between sciences and societies greatly fuelled since the post-war period. This question of sharing and ownership by the local population of knowledge and technical progress thus refers back to the issue of transfer of technologies in development projects. There is thus a relationship between the project concept and that of development, both stemming from a civilization conditioned by the myth of inevitable progress, and also by the optimism of technological culture (Boutinet 2004). This issue has long been forgotten within the framework of development policies: faith in progress and theories of economic boom (Rostow 1963) have eluded any consideration of this matter. With the oil crisis in the mid-1970s, western society started to be intensely worried about the effects of urbanization, industrialization, and demographic growth. The Club of Rome and the Meadows report (Meadows et al. 1972) thus insist on zero growth, indispensable in their opinion so as to limit both use of resources and risks incurred by societies. Such analyses started to rally the politicians, decision-makers, and citizens around the war cry of "think global, act local." At the same time, certain authors (Wisner 1979) observed the virtual failure of transfer of technologies to industrially developing countries. This trend largely spread by the media results in global awareness of the need to reflect on the future of the planet and its implications in terms of societies' choices. The methods of transfer, practiced in a sudden and brusque manner, are immediately challenged (Geslin 2002). This encourages the development of innovative, flexible, and adaptable approaches to adopt a real social, cultural, and technological partnership.

21.3 Stages of the Decentralized Rural Electrification Project

21.3.1 Initial Definition of the Generation, Transmission, Distribution, and Consumption System of the Decentralized Rural Electrification Microgrid

The Decentralized Rural Electrification Project coordinator decided as an initial approach to assess the recommended technical options and the methodology developed for electrification with the aim of guaranteeing ownership by the population and developing a management system able to free up the revenue required for autonomous regional development actions. It thus affects both social standards and technical standards.

The purpose of setting up of the decentralized microgrid is to develop an electricity generation technique using primary renewable energy sources supplying remote settlements with small isolated consumer networks and possibility of interconnection. In order to do so, technical standards based on the principle of international standards (such as specifications and performance required by the grid), not yet recommended in Morocco, were incorporated with the arrival of electricity generation. Right from the start, the aim of supplying the consumer, using renewable energy sources on an isolated microgrid, with quality electric power with a certain number of guarantees, in compliance with the international standards and recommendations issued by the International Electrotechnical Commission (IEC), was confirmed. This involved ensuring human protection, equipment reliability, constant frequency and voltage despite load variations, and security of supply at any time. Achievement of this objective was made all the more difficult due to not as good decentralized microgrid rigidity[1] for voltage and frequency as the major interconnected grids. This problem was magnified by the length of the network to be covered, as certain villages are separated by several kilometers (specific adjustment of frequency and voltage has to be carried out to fulfill grid quality and safety requirements).

[1] Degree of grid sensitivity (voltage, frequency, and stability) to disturbance, such as sudden variations in load or spurious faults, such as short circuits.

A conventional technological approach of the generation, transmission, distribution, and consumption system in the Ouneine Valley was adopted by factoring in local requirements stipulated according to on-site investigations:

- Low revenue of the rural and mountainous population
- The different categories of population covering households that are relatively well off and those that are very hard up
- Use of renewable energies only
- Need to use turbine-driven water for irrigation
- Consumption of large quantities of wood (especially in the community centers, such as mosques and hammams)
- Conservation of the mountain landscape
- Lack of technical knowledge of the inhabitants
- Absolute need for ownership by the inhabitants
- Planning of future connection of the decentralized microgrid to the national grid operated by the ONE

Static and dynamic operating conditions of such generation, transmission, distribution, and consumption system, using hydropower sources operating in parallel, were simulated[2] prior to construction, according to different scenarios, to check feasibility of each solution. Concerning the consumption system, composed of 8 villages, representing around 300 households to which community buildings and areas, such as mosques and hammams, should be added, consumption was determined based on minimum lighting and audiovisual needs for the poorest households, whereas purchase of a refrigerator and small domestic appliances was counted for the richest households. Trends in consumptions were determined based on a period of 10 years with two hypotheses (minimum and maximum) of demographic growth rate and average increase in revenue. Given the lifestyle of the population, peak demand occurs between noon and 1 o'clock in the afternoon and between 7 and 11 o'clock in the evening. This results in surplus electricity supply at certain times in the day which can then be used to run electric water heaters in the mosques instead of wood.

In terms of internal equipment, specific attention was paid to safety by incorporating the relevant Swiss standards: separation of lighting systems and sockets and installation of 30-mA differential circuit breakers on the sockets.

Concerning the distribution system, all the infrastructure is built for low voltage 400 V supply: generation and transformer outgoing feeder, supply of village incoming feeders, and distribution to each household. In order to conserve the village landscape, underground distribution was opted for as much as possible for cable routing, in compliance with the IEC standards. Given the distances between villages (minimum 2 km), the type of connection selected for the transmission system was medium voltage level of 22 kV adopted by the ONE throughout the

[2] The SIMSEN software (simulation of energy and drive systems) developed at EPFL by the Electrical Machines Laboratory (LME), under the guidance of Prof. J.-J. Simond.

country. This was the natural choice given the fact that, right from the start, it was planned to connect the Decentralized Rural Electrification Project microgrid to the national grid operated by the ONE, at some point in the future.

In order to find the best match between generation and consumption, given the different technical and social requirements, a decision support tool needed to be developed. The latter called OPTELDEC (Keller et al. 2007) was developed at EPFL. This tool models consumption loads (household consumption), generation facilities (hydropower, solar, and wind power plants) and storage facilities (batteries and basins), and a diesel generator for backup so as to ensure consumer supply at any time. The purpose of this approach is to first of all provide the scheduler with plenty of operational leeway in grid design. Then the requirements specified enable more realistic grid configurations to be gradually focused on by preventing the waste of time incurred by simulations of not very advantageous variants.

A system of priorities was then set up as it was impossible to handle all the requirements at the same level. In the case of the Decentralized Rural Electrification Project, priority was given to the cost. Each solution adopted was simulated with the SIMSEN tool (operation, stability, and short circuit current).

21.3.2 Local Implementation: Negotiation with the Population

During the negotiations held by EPFL-Targa-Aide team with the heads of the households in one of the project douars for siting of the generation, transmission, distribution, and consumption system (that of Tinsemlal, the first village concerned by the project), a certain number of problems, mainly related to socioeconomic impacts, were raised. For a long time, these issues constituted the main obstacle to concluding an agreement with the village inhabitants. Use of water as an energy source had significant consequences in an area where its use is limited by quotas. Construction of an electricity generation system, using hydropower turbines, resulted in streamlining of water supply for farmlands. This factor constituted a significant economic and social impact as it conditioned the good level of crop yield. In addition, water sharing had been established for generations (according to complex informal regulations) and constituted common law.

A certain number of conflicts of interest related to water consumption rapidly sprang up, mainly concerning:

- The fate of nine watermills built along the initial seguia (open irrigation channel): they should not be removed.
- Survival of the walnut trees previously irrigated by the water source: they constitute a significant source of revenue for the village.
- In addition to these initial requirements, the villagers also expressed their wishes to:
- Neither change nor interrupt water flow rate so as not to disturb the irrigation towers for crop cultivation.

- Ensure sufficient electricity supply over time (adjustments, ease of operation, and maintenance, etc.) with adequate storage.
- Generate and distribute quality electricity in the same way as the major grids (constant voltage and frequency and absence of harmonics). In order to do so, the adjustment system for each power plant shall incorporate operation with (1) decentralized interconnection on the microgrid considered, (2) fine control if need be, and (3) interconnection on the national grid, assumed as being constant.

For the project, this involved overcoming the difficulties incurred by the small hydropower plant project using the village water source. Induction needed to be carried out for the setting up of new water distribution methods guaranteeing permanent operation of the farmers' irrigation system. This new practice nevertheless challenged ancestral practices demonstrating the power of the households concerned.

The arrival of electricity also posed a problem of test of strength between the different villages in the valley where intervillage relations are highly complex, further strengthened by the phenomenon of being enclave. Over the course of time, complicity and rivalry have been forged between the villages (trade, kinship, etc.). These relationships were particularly heightened by the coming of the electrification project, which involved certain collective management aspects. Within this framework, sharing of the electricity generated by a single source had a significant impact vesting one of the villages, Tinsemlal (where the power plant was sited), with a strategic position for electricity supply. The location also posed a problem for common intervillage management of the infrastructure. The villages had to be made to accept the fact that it was impossible to provide each one with a source due to prohibitive costs. However, that does not mean that the village selected for construction is the owner of the power plant. It had to be understood that risk management is shared between the different communes consuming the electricity. In the event of failure, all the villages concerned have to pay.

In addition, this especially involved proposing new electrification solutions and modes more in keeping with specific socioeconomic contexts, like the rural mountain environment in Morocco, providing everybody with access to power. Within this framework, for example, conservation of the site and its environment was considered as very important for future development of the valley, and conditioned the choice of the standards applied. This mainly resulted in burying the low voltage cables and supporting the medium voltage line with wooden posts on the edge of the hillside. This approach was not however understood by the local population. A part of the inhabitants challenged the installation of underground cables preferring overhead lines. The fact of being able to see the lines, and therefore being able to observe any breaks in the cable, represented visual guarantee of electricity routing for them. It was still necessary to discuss with the beneficiaries about these technical choices, so as to make them aware of long-term development considerations, namely conservation of the landscape and economic development of the valley with ecotourism intent on environmental conservation must prevail over a way of thinking that responds to immediate problems. It was then necessary to argue in favor of general interest, as part of an initiative which far outweighs the immediate aims and interests of the local community.

21.3.3 Unexpected Arrival of the ONE: Comparison of the Standards Between the National Operator and a Local Integrated Project

Right from its conception, the Decentralized Rural Electrification Project responded to the request of the Ouneine Valley population. It was all the more justified as electrification was only planned by the ONE in the long term. The low population density and remote settlements (and therefore low profitability) encouraged the electricity supplier to fit out more economically viable areas as a priority.

After the ONE managers inspected the project site in March 2003, and due to the effect of local impetus generated by the Decentralized Rural Electrification Project, but certainly also out of fear of competition between the two types of electrification, the ONE undertook the installation of low and medium voltage lines in the valley. Faced with the ONE terms of implementation, project impetus was adversely affected. The ONE, with the installation of its own grid, then asked the project designers to comply with its own technical standards. This was a complete reversal of the situation for the project promoters, who had previously consulted the national electricity generation company so that implementation of the Ouneine Valley project could be green-lighted, along with approval of the technological standards proposed.

This request made by the ONE managers replacing the previous spokesmen who had validated the project approaches when it was set up in the year 2000 challenged the application of project-specific standards. The latter had been incorporated to respond to local impacts (socioeconomic impacts, such as local consumption and technical impacts, such as grid power capacity). The project also supported connection of the population to the supply by proposing microcredit so that everybody could benefit from the system.

After 2 years of negotiations, a partnership agreement was concluded between Targa-Aide, the SDC, and the ONE in August 2005. It stipulates the position of the latter institution concerning the valley and the Decentralized Rural Electrification Project and defines the nature of relations between the different partners. This document enabled the different actions to be better coordinated and project experimentation to be continued. This agreement mainly resulted in the application of new rules, both regarding grid management (especially concerning pricing as the cost of the kWh was set at national level by law) and technical standards during installation of the national grid and interconnection between the national grid and the local microgrid. Technical standards were the subject of discord and heated discussions between the project technicians and the ONE inspectors. The ONE engineers dismissed out of hand the idea of burying the low voltage cables at a depth of 80 cm and also contested the fact of supporting the line over a length of 2 km, with wooden posts at the edge of the hillside and household protection, and requested the removal of the 30-mA differential circuit breakers installed in each household as a safety measure. They forced the project team to upgrade these project standards (nonetheless based on international regulations) to adapt them to the ONE standards in force. They are based on the fact that in the General Rural Electrification Program, the ONE only uses metal pylons for medium voltage, overhead LV stranded cables, and 300-mA circuit breakers for household protection. And the pylons thus made their appearance in the valley.

Lastly, the work of the Decentralized Rural Electrification Project seeking to develop appropriate technical standards was nearly stopped by a national institution able to invoke double legitimacy on the institutional and technical front. In addition to the purely institutional question, the issue of definition of standards was raised. This coexistence of two rival and even opposing strategies on the same ground required finding technical and institutional compromises enabling each of the parties to justify their own legitimacy. In addition, the project had to make the requisite adaptations related to expectations and reticence on a permanent basis. Based on all these experiences, we can propose a summary of more general remarks highlighting the factors to be incorporated to implement technological projects in southern countries. Its purpose is to notify future operators and provide avenues to be explored for new technological development projects.

21.4 Assessment and Avenues to Be Explored: Innovation, Cultural Adaptation, and the Combining Process

21.4.1 Innovation Required

One of the first lessons to be learned from the experience of the Decentralized Rural Electrification Project is that it is always necessary to innovate within the framework of technological development projects.

This innovation shall first of all be technological. The fact of challenging the nationally accepted standards may be considered as a stalemate reached by the project for which it then paid a heavy price. However, this innovation was deemed necessary to take up the gauntlet in a difficult environment. In addition, the Ouneine Valley is inhabited by a poor population with only few resources mainly coming from a farming economy. It was therefore important to consider the economic factor to provide improvement that did not weigh too heavily on the valley household economy. On the other hand, the fact of providing a source of electrification in a remote valley with few natural resources required significant adaptation to these restrictive environmental factors.

In addition, this innovation must be incorporated in local society. Technical standard authors shall be careful with the quality of participation of the locals and approval of the technical innovations by the project beneficiaries as this is the basis of the authority, legality, and quality of the standard to be compiled. Within the framework of the Decentralized Rural Electrification Project, these are the leaders, representative to varying extents, which sway general opinion in favor of acceptance or refusal of something new, innovation, defined as being something that changes the traditional standard and thus transgresses the rules.

This approval process may be represented as a dynamic model where innovation may be implemented at any time and is not bound to come out of the creative mind of the genius inventor (Callon and Latour 1991). Further to a series of transformations (understood as successive reinterpretations by the different intermediaries related to the technique and simultaneous resulting adaptations), it managed to rally an increasing number of allies. It is the scope and solidity of the social network, and not just the technical solution, to which successful innovation can be attributed.

21.4.2 Weight of Local Factors

The Decentralized Rural Electrification Project enables us to reconfirm the fact that to understand and take action for development project implementation, local cultural and organizational factors contributing to the definition of the type of technical standards to be applied should be incorporated. Thus, the Decentralized Rural Electrification Project promoters are completely part of the trend, validating the fact that technical aspects are inextricably linked to culture (values, signs, symbols, and knowledge), social and political organization, and the natural environment (Debresson 1993). The local microgrid thus had to be incorporated in the valley by factoring in these different aspects. The action of the Decentralized Rural Electrification Project confirms the fact that deployment of science and technology in society should not be reduced to a simple transplant of knowledge, know-how, practices, and techniques in a social fabric where the ground has not been prepared in advance. There are not two separate camps, science and technology on the one side and society on the other side. The opposite shall apply, the first should be deeply rooted in the second and their development should depend on physical, social, economic, cultural, historical, and political reality (Bassand et al. 1992). Technology shall thus be firmly anchored in local development dynamics. However, there is no magic recipe, but rather the need to propose new practices by distrusting the hypothesis that confirms the fact that incorporating the participants on all fronts in the analysis of decision-making processes, highlighting local and sectoral specificities for technological ownership, does not automatically vest the tangible results for this process, namely the ensuing technologies, with a necessarily social nature, defined as socially acceptable, to not go as far as saying sustainable development (Rossel et al. 1999).

This type of decentralized rural electrification project is part of the local environment where the inhabitants' capacity to contribute is quite low. A certain number of local factors which are as much the conditions of collective action, development of collective rules, and legitimate authorities should thus be built into design of standards, as they are essential to successful implementation (Appolin et al. 1999). This work of adaptation to local context during transfer of technology is known as anthropology-technology, defining the veritable adaptation of technology to the population which, in the same way as ergonomics, gathers together knowledge derived from human sciences to improve design of technical systems, as the scale is different, with other sources being required (Wisner 1979). This is mainly based on incorporation of the inhabitants' capacity to contribute and the project promoters' aim to generate power for everybody.

Another significant factor to be incorporated in project implementation is that of time. Very often according to the strategy of development awaited with impatience by the population, the projects are implemented with short lead times (as the short term fulfills the urgent need of the local population). Faced with requirements for results, a simple, pragmatic approach then represents the best means of preventing delays and stumbling blocks. This minimizes the room for negotiation and orients project choices, thus losing the creative and innovative dimension even though it was validated within the framework of a research-action project, such as the Decentralized Rural Electrification Project.

21.4.3 Combining of Technological Development Project Standards: From Concept to Action

Prior to the project, there was a real social demand for electricity. The project was therefore entirely legitimate and fulfilled real social demand and not just the aim of external experts. However, one of the project aims defined by the promoters (advocating an approach oriented by northern thinking) stipulates that this involves development of overall approach methodology, for decentralized electricity generation and distribution using several renewable energy sources (optimum simulation, design, and management). The choice of energy sources is thus focused right from the start on finding a technical solution for the setting up of a specific electrification grid, sourced from natural local resources.

This framework raises the question of what purpose is served by involving the local population in technical choices, if not just to further complicate the matter. The population thus only confirmed this major principle with the expectation that the project would fulfill a strongly expressed need. The question is then couched in these terms: who should produce the technology and the related technical standards? In the case of this transfer, the technology should be actually transformed to be owned, as defined by Callon and Latour (1991), but also combined. The other underlying question is: How can this technology be jointly produced?

The real turning point of the question is located at the end of the 1980s. The question of technological transfer was brought to the forefront of the international scene during the Rio Conference which officially announced this transfer as an action principle (United Nations 1992). Recent awareness of local technical culture (mainly initiated by the World Bank's indigenous knowledge program unveiled in 1998) reveals this fresh impetus. Recognition of local traditional know-how and validation in development projects attest to endogenous representation of technical and developmental aspects. This process aims to incorporate existing technologies and related know-how for the transplant of technology and amendment of local techniques so as to carry out positive combination in quest of continuous technical improvement. This approach shall incorporate both the existing social standards and local technical practices.

Figure 21.1 illustrates the problem of being able to involve southern country societies in production right from the development phase. Technical knowledge transferred from the north stems from western society, conveying a certain number of specific values and standards to this society. Transfer of this modern technology is thus often imposed and takes the place of local techniques in developing countries, considered as less effective do-it-yourself (Akubue 2000; Pascon 1980). In addition to these multiple criticisms, other terms have been in use since the 1990s to cover the global issues raised by this concept. The notion of sustainable technology, factoring in environmental and social effects, thus provides a dynamic approach covering all the aspects designated by the term appropriate. This consists of combining the two technological models (those from the north and those from

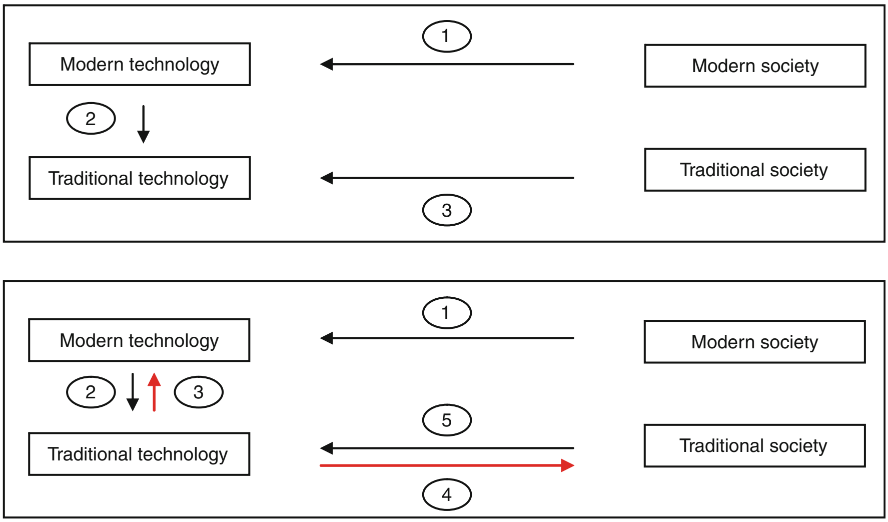

Fig. 21.1 Process for combining standards: changeover from a conventional scheme to technological reinterpretation

the south) in order to expand on the techniques and understand the real social, economic, and environmental needs of southern societies, resulting in appropriate technologies, for which the beneficiaries can take possession, understand the operation, and develop the mechanisms.

However, this appropriate technology concept, created in the 1970s (Schumacher 1973), seems to have been all too quickly abandoned. Still today, the significance of this term lies in the fact that it provides a critical view of interrelations between science and society, to prevent us from stumbling blindly into a hypertechnical society and highlighting growing interactions between northern and southern societies. The latter point is fundamental: Both societies continue to mutually challenge each other, openly and without preconceptions, on the role and future of technologies in our societies. This thus involves development and confirmation of political speeches and awareness of the impact of technologies on our daily life and the future of our planet.

21.4.4 Technical Mediation: Know-How to Be Developed

Lastly, one of the lessons learned from the Decentralized Rural Electrification Project is that this transformation process defended by Callon and Latour (1991) shall be supported by technical mediation, namely liaison between technical and environmental aspects. This mediation aims to render technological requirements socially acceptable and influence technical decisions by factoring in social requirements. Also, technological innovation incurs fundamental disruptions that need to be supported. The protagonists, like the natural elements and technical systems, come out transformed from these different trials: innovation as the process produced from knowledge, technical systems, and forms of organization (Akrich 1993).

In order to support this change, the project promoters shall adopt a holistic vision, involving a multidisciplinary team capable of incorporating all the project components. Setting up of technology in a local developing environment only has meaning if it fulfills demand but also if it creates active response negotiated between man and his environment. This is the very purpose of technical mediation and creation of combined forums involving all the project protagonists, regardless of their origin and their diversity, places of exploration of the identities of the participants in the projects, exploration of problems, possible options, and learning from controversy (Callon et al. 2001).

In order to implement technological innovations, within the framework of appropriate technology, adopting a mediative approach seems to be a prerequisite. This involves placing man at the center of his preoccupations, by anticipating the sustainable consequences incurred by the new methods, related to technology, and living together, related to incorporation of technology in society.

21.5 Technological Developments to Help Social Revolutions

As we have already mentioned, the intentions of the Decentralized Rural Electrification Project were ambitious. On the one hand, the project challenged the development project practices by adopting an integrated approach factoring in environmental, technical, social, and economic aspects at the same time. On the other hand, this ambition was also sustained by the application of two other precepts.

First of all, this is an appropriate technology project implemented according to a process which questioned each stage by repeating rounds of analysis or a cycle of operations. If the project is retrospectively analyzed, it seems that it has been through three essential stages: the first one corresponded to definition of the needs and technological offer proposed to the inhabitants by factoring in local parameters; the second one aimed to set up technical training (to organize transfer to local employees) and socioeconomic training (to foster appropriate management and appropriable by its rural beneficiaries); and the last one was a phase of installation and measurement of technology impacts. Transition between these different phases was carried out according to an iterative process, constantly challenging the project promoters as to the merit of the action and casting doubt on the results expected by interaction with the different local and national participants, such as the ONE. The project promoters had to advance sometimes by trial and error, analyzing successes, obstacles, and partial failures to grasp the cause, meaning, and repercussions, so as to keep on track and achieve the initial objectives (Piveteau and Billaud 1999).

Second, it was implemented with close involvement of the population. Although this was not always easy, local population participation and action remain one of the positive points of the project. If we limit ourselves to just considering this single objective, the project already represented an undertaking of immense scope: this involved fostering social, environmental, and economic change in a geographically marginalized region, in favor of inclusive collective action concerning disadvantaged social groups.

During the project, this participation took on multiple forms enabling real collective dynamics to be created in the Ouneine Valley: Participation in discussions was accompanied by physical participation in the works and financial contribution enabling the inhabitants to own their new electrification system and ensure its maintenance and sustainability. The population, desperate for electricity, accepted these conditions and played the game. In order to achieve these aims, methodology facilitating compatibility between technical and social imperatives needed to be deployed. This encouraged participation from all layers of the population (including women) and saw the emergence of new leaders from the younger generation of the valleys committed to management of their territory, with most of the elder sons expatriated to the large Moroccan cities or abroad.

Going beyond a technological electrification project using renewable energy sources, as complex as it was, it is thus a project of society which was progressively built up in the Ouneine Valley. The arrival of the project considerably altered the position and role of players in this territory, even if this meant that the promoters were themselves pressured by fresh expectations emerging as and when the project progressed. In addition to the design and application of appropriate technology, projects of this type bring about political and social rebirth, making the inhabitants rethink their ways of living together and restate their expectations of the state, local authorities, and society as a whole. Current sociopolitical revolutions in the North African countries show that much more time and further dialogue are needed to help these populations, hoping to rapidly benefit from better living conditions. Providing scientific progress is adapted and adjusted to the expectations of societies in full swing; technology confirms its legitimacy by helping these processes to be achieved.

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