Chapter 4
Eco-infrastructures, Feedback Loop Urbanisms and Network of Independent Zero Carbon Settlements

Carlos H. Betancourth

Abstract More than half the world's population now lives in cities, and the rate of urbanization is accelerating. Cities are major sources of greenhouse gas (GHG) emissions. They are vulnerable to climate change. The limited success of the December 2009 Copenhagen climate negotiations heightens the urgency of cities' efforts to adapt and mitigate to climate change. Urban growth in the developing countries of Latin America, India and China is fundamentally changing the lives of hundreds of millions of people. So far, these urbanization processes have dramatically increased developing countries' environmental damage and vulnerability to climate change. This paper aims to show that urbanization can be a sustainable process capable to create secure urbanities through an eco-infrastructure approach for reducing urban vulnerabilities that explores a series of strategic responses in a weave of eco-infrastructures, feedback-loop urbanisms and networks of zero carbon settlements powered by renewable energies.

4.1 Introduction

Climate change impacts such as increases in global temperatures, loss from flooding and hurricanes accompanied by rising sea levels are becoming an all too frequent occurrence in many countries, particularly in cities where people and assets are concentrated. This is generating uneasiness over the environmental security to maintain and enhance economic growth at the national scale. In a context of resource constraints and climate change, questions of environmental, social and economic reproduction become strategically entangled at the city level. It is expected that increasing concerns over the environmental security of cities will give rise to attempts to protect their critical infrastructures. Cities need to actively engage in developing strategic responses to the opportunities and constraints of

C.H. Betancourth (✉)
Independent International Consultant
e-mail: chbetanc@msn.com

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climate change and resource constraints. This means that urban centres must be prepared with a knowledge base of climate projections and specialized tools to deal with these impacts to look after their critical infrastructures through the protection of flows of ecological resources, infrastructure and services at the urban scale.

Moreover, given the potential devastation associated with future climate change-related disasters, it is vital to change the way we build and manage our cities, through new strategies to reconfigure them and their infrastructures in ways that help secure their reproduction. The spatial planning of cities requires the consideration of climate change impacts as vital components of urban development. In order to start to build up the case for the strategic relevance of the city in generating responses to climate change, it is important to design tools for local governments and their communities to better understand the concepts and consequences of climate change and resource constraint; how their impacts generate urban environmental in-security; and what needs to be done to build ecological secure urbanities. In this paper, we begin to put together a framework for a tool-based process that takes into consideration the limited resources that characterize cities in developing countries (as well as the uncertainties and risks that characterize the complexity of climate change), and start to build a knowledge base that will inform and support the design of strategies to protect cities through comprehensive adaptation programs and plans.

Based on the case of Latin America in general and in particular on the case of informal settlements in the city of Cartagena (Colombia), I outline the challenges posed and the responses required by the environmental security of cities. I propose an eco-infrastructure approach for reducing urban vulnerabilities and start to explore a series of strategic responses which I characterize as a weave of eco-infrastructures which points in the direction of a new logic of infrastructure provision. It is critical that the definition of urban infrastructure must be expanded from just basic services to include climate change impact and hazard management investments for a secure built environment. The argument is developed in five sections.

The second section following the introduction presents the case of climate change impacts in Latin America and how these ongoing changes are already affecting ecosystems and social systems. The third section provides an overview of the concept of environmental security and formulates the need for new planning and design tools. The fourth section elaborates and presents the tools and their components. This section makes the case for the strategic involvement of cities in addressing climate change. It provides a preliminary evaluation of impacts on ecosystems and eco-infrastructures at the regional scale. It maps information regarding potential hotspots of vulnerability at the regional scale. It introduces some of the steps necessary to create a knowledge base for the city and its citizens, and explores responses for secure urbanities through eco-infrastructures, enclosed spaces, and networks of zero carbon settlements. The final section summarizes the key findings of the paper and makes some general suggestions for further research and investigation.

4.2 Climate Change Impacts in Latin America

The observed changes in the global climate suggest that warming of the climate system is undeniable (IPCC 2007, Stern 2008). 2010 is becoming the year of the heat wave, with record temperatures set in 17 countries. The recorded temperature for Colombia, in January 2010, was, 42.3°C (Guardian 2010a). The rise in global temperatures is impacting Latin America's cities including low-lying cities located in the Colombian Caribbean coast. Temperatures in Latin America increased by about 1°C during the twentieth century, while sea level rise reached 2–3 mm/yr since the 1980s. The IPCC's Fourth Assessment Report predicts that under business-as-usual scenarios, temperature increases in Latin American countries with respect to a baseline period of 1961–1990 could range from 0.4 to 1.8°C by 2020 and from 1 to 4°C by 2050 (Magrin et al. 2007). The effects from a rise of two degrees-modifying weather patterns, which in turn affect temperatures, precipitation patterns, sea levels, storm frequencies and floods will be felt by every town and city, especially those in coastal zones. Changes in precipitation patterns have been observed, with some areas receiving more rainfall, and others less. Extreme weather events have become more common in several parts of the region, including more and/or stronger storms (Raddatz 2008, Hoyos et al. 2006, Webster et al. 2005).

Climate change is likely to cause severe impacts on ecosystems and species such as the bleaching of coral reefs; the damage of wetlands and coastal systems and the risk of forest degradation in the Amazonan basin as well as on socio-economic systems and cities of the Latin American region (Milly et al. 2005, Ruiz-Carrascal 2008, Coundrain et al. 2005). It is expected that the agricultural sector will suffer direct and large impacts from gradual changes in temperatures and precipitation (Mendelsohn 2008, Medvedev and van der Mensbrugghe 2008). Cities and localities will also suffer serious economic and social impacts: the expected increase in the frequency and/or intensity of hurricanes and tropical storms will impact coastal cities, their livelihoods, infrastructures and biodiversity (Curry et al. 2009, Toba 2009); the expected disappearance of tropical glaciers in Los Andes (Bradley et al. 2006) and changes in rainfall patterns will have economic consequences on water supply and the availability of water for use and consumption in Andean cities, in agriculture, and in hydroelectric production. The increase in the rate of sea level rise will economically damage coastal areas and cities through the loss of land, of tourism infrastructure, of buildings (UNFCCC 2006, Dasgupta et al. 2007). Climate change could also have multiple impacts on health (Confalonieri et al. 2007), such as increase in malnutrition and mortality, cardio respiratory diseases from reduction in air quality, and an increase in water-borne diseases-such as malaria in rural areas and dengue in urban areas.

The evidence indicates that climate change and resource constraints will impose significant costs on Latin American cities and eco-systems (De La Torre et al. 2009). However, current efforts to address climate change focus mainly on attempts to *mitigate* climate change and on reducing GHG emissions of greenhouse gases as well as on endeavors to *adapt* through reducing the vulnerability of communities at risk by improving and building hard and grey infrastructures. This paper attempts to move beyond adaptation and mitigation and aims at long-term climate resilience (the physical and the institutional capacity to absorb the long-term trends and near-term vagaries of climate while maintaining risk at socially acceptable levels) of cities and their critical infrastructures, and sets out an argument for including an eco-infrastructure-based approach in strategies to address climate change. As these ecosystems have a critical role to play in building resilience and reducing vulnerabilities in cities, communities and economies at risk, the enhanced protection and management of ecosystems, biological resources and habitats can mitigate impacts and contribute to solutions as nations and cities strive to adapt to climate change. This proposal for an informal settlement located in the Delta City of Cartagena Colombia proposes an eco-infrastructure approach to climate change as a supplement to national, regional and local strategies. Such eco-infrastructures based strategies can offer sustainable solutions contributing to, and complementing, other national and regional adaptation strategies, and facilitate a transition of informal settlements from "a slum condition" to a living laboratory of eco-infrastructure landscapes for low carbon growth and development. This requires a transition from mono-functional grey infrastructures to a network of multi-functional eco-infrastructures and living spaces that all work together as a connected system to conform an integrated habitat.

In a context of resource constraints and climate change risks (floods, droughts, heat stress, diseases, loss of infrastructure and lives, displacement of people), a series of new environmental, socio-economic and political problems (energy security, scarcity of water resources) is forcing issues of environmental security up the agenda of national governments (UNEP 2007, Pirages and Cousins 2005, Hodson and Marvin 2009, Giddens 2009). Major and emerging environmental changes (such as depletion of fresh water supplies, fisheries, biodiversity, agriculture lands, food and health safety, stratospheric ozone and global warming) can lead to environmental conflicts (Betancourth 2008a), and to short and long term decreases in environmental security. Resource constraints and climate change can be characterized as problems of environmental security. This in turn invites to rethink the concept of security. Addressing environmental insecurity requires collective and preventive action (through re-design) and a transition to alternative models of development and economic growth where the sustainable use of natural resources and joint efforts to protect the environment can contribute to environmental security and conflict prevention.

4.3 The Need for New Tools

This issue of environmental security can be formulated at different but interrelated spatial scales: global, national, sub-national, regional, urban, metropolitan and local. The implementation of the mitigation and adaptation policies necessary to successfully address the climate change challenge will only be achieved, and sustained, through involvement and commitment at all these levels of decision-making. In particular, the full engagement of the sub-national scales is important to move the climate change and alternative development agendas forward. Their decisions can influence GHG emissions and most site-specific adaptation initiatives as well as to promote long-term planning and to incorporate climate change considerations into decision-making. Adaptation to climate change is very site specific, and local planning decisions will be critical to tailor almost every single adaptation action to the conditions in which it will take place. The relevant questions at this local scale are: how do cities and regions prevent their reproduction in conditions of environmental insecurity? Which are the strategic responses and which insights, capacities and new tools are needed for successful decision-making? To elaborate on these questions requires formulating a new agenda for urban development.

4.3.1 The Agenda

This agenda is built around the following problems and themes:

1. the problem of the environmental security of cities as protecting flows of environmental resources at the regional and urban scales;
2. the strategic importance of cities in developing responses to climate change and resource constraint for the production of secure urbanities;
3. the reorientation of the management, growth, and development of the city to climate change and resource constraint; by building on the synergy and interdependence of ecological and economic sustainability;
4. the reconfiguration of the city and its infrastructures in ways that help to secure their environmental, social and economic reproduction, around the following responses:
   (a) improving the strategic protection of cities through:
   - the redesign of layers of eco-infrastructures (the environment as infrastructure);
   - enclosed and autonomous urban spaces (feedback loop urbanisms); and
   - networks of zero carbon settlements.

   (b) reducing the sensitivity of citizens to climate hazards by using the sustainable management of ecosystems and of eco-infrastructures to:
   - expand livelihood assets; and
   - enable economic development through enterprise development related to ecosystems management.

   (c) improving adaptive capacity through eco-infrastructure governance that builds:
   - adaptative/mitigative planning;
   - flexible and coordinated institutions; and
   - learning and dissemination of knowledge needed to empower people in planning and decision-making related to adaptation.

In order to gather social actors around this agenda, we need to offer them new insights, guidance and tools as they seek to take steps to adapt and mitigate to climate change. In what follows I will briefly present some of these tools.

4.3.2 The Tools and Their Components

4.3.2.1 Constraints of Key Local Institutional Players

There are a number of barriers that need to be recognized and overcome to enable key local actors to play a critical role in addressing climate change. First, there is an increasing body of scientific literature on global climate change impacts but a lack of knowledge at the local level. Second, in a new field like climate change, local public authorities may have limited technical and financial capacities. Third, knowledge sharing is limited by the varying roles and responsibilities of regions and cities. If local authorities are to succeed in their efforts to address climate change, effective partnerships must be formed with a variety of social actors – their constituencies, the national government, international donors, the academic community, technical centres of excellence, and the private sector, who share common interests in addressing climate change. Fourth, the preparation of integrated urban and regional climate change plans can remove some of these barriers above. Such plans will require a rethinking of the development processes and the formulation of strategic approaches and innovative policy development and planning instruments to promote long term planning and to incorporate climate change considerations into decision-making (UNDP 2009).

4.3.2.2 Changing Needs and Uncertainty

Climate change is unequivocal. Less certain is the timing and magnitude of climate change. Climate change represents a dramatic increase in uncertainty and new decision-making methods will be required to cope with it. Many infrastructure investments and planning decisions, such as water and transportation infrastructure, building design and urban/land-use planning, require substantial lead-time for conception and implementation. By the end of this century, investments may have to cope with climate conditions that will be radically different from current ones, otherwise they risk to be obsolete or sustaining damages due to the impacts of climate change. Different climate change models could predict a full range of possible future climates for one and the same region and city. These entails that infrastructures could face different and opposite climate change scenarios.

Water infrastructure could, over its lifetime, face a significant drying, a progressive wetting, or even an initial wetting period followed by a significant drying. Water engineers can easily design water infrastructure adapted to a progressive drying or wetting but it will be more difficult to design infrastructure adapted to a full range of possible future climates. Thus, infrastructures would need to be designed and re-designed so that they can be adapted not just to one scenario or the other, but to a full range of possible future climates. While it is known that our climate will change over the long-term, decision-makers are confronted with a situation where the direction of change is not fully clear at this stage. The chain of causality between emissions today and the future impacts of climate change has many links, and there is a great deal of scientific uncertainty involved in moving from each one to the next. Yet decision-makers will still need to make investment decisions today, with incomplete and imperfect information to estimate both the costs and benefits of such decisions. It is very hard to quantify the probabilities associated with specific climate impacts. Thus, policy makers are confronted not only with risk-randomness with known probabilities, but also with uncertainty (Knight 1921).

The risk of simply reacting to changes in the short- or medium-term could result in poor investment decisions, the cost of which could exceed the direct costs of global warming. These considerations of risk and uncertainty may make it prudent for policymakers to adopt an approach based on precaution, in which a large weight is assigned to the objective of avoiding such events. Addressing environmental insecurity requires acting preventively through re-design and a transition to alternative models of development and economic growth. Therefore, it is important to design strategies which can cope with climate change uncertainty regardless of how the local climate will change. In what follows, I will be exploring strategies for risk-informed mobility, multiple land use planning and risk informed water management through the concepts of eco-infrastructures; of feedback loop urbanisms and of networks of zero carbon settlements. But we will present first some preliminary prospective techniques and scenario based approaches that can help us overcome some of the constraints posed by the lack of information and help local and regional decision-makers deal with climate uncertainty and complexity.

4.4 Evaluating the Vulnerability of Ecosystems and Eco-infrastructures

Adaptation to climate change calls for a new paradigm that manages risks related to climate change by considering a range of possible future climate conditions and associated impacts, some well outside the realm of past experience, trends, and variation. This means not waiting until uncertainties have been reduced to consider adaptation actions. Mobilizing now to increase the city's security and adaptive capacity can be viewed as an insurance policy against an uncertain future. Reducing vulnerability to climate change requires to consider a combination of: (a) the nature and magnitude of the changes experienced and reduced exposure to hazards; (b) underlying social, cultural, economic, geographic, and ecological factors that determine sensitivity to climate change, and reduced sensitivity to the effects of climate change; and (c) the city's ability to prepare for, and respond to impacts on ecological, economic, and human systems, and increased adaptive capacity (See agenda cited above in Section 4.3). This process can be described as a series of stages: a first step is to identify current and future climate changes relevant to the city under consideration; the second step is to assess the vulnerabilities and risk to the system; the third step is to develop an adaption strategy using risk-based prioritization schemes; the fourth step is to identify opportunities for co-benefits and synergies across sectors; the fifth step is to implement adaptation options; and the sixth step is to monitor and re-evaluate implemented adaptation options. This preliminary exercise on adaptation planning that is presented in Table 4.1 as a linear progression is a cyclical, iterative process incorporating at least six steps (Fig. 4.1). This tool stimulates discussion and investigation, and allows social actors and stakeholders to make connections at different spatial scales between and among eco-infrastructures, the ecosystem services they provide, the local impacts, vulnerability, and responses to adaptation and mitigation. Due to time and space limitations, we will only be dealing here with steps 1, 2 and 3.

4.4.1 The Increase in GHG Concentration and Atmospheric Warming

In this first step (first and second column), we begin to identify current and future climate changes relevant to the territory under consideration. The warming of the climate system and the rise in global temperatures is already affecting Latin America's climate and its cities. Temperatures in Latin America increased by about 1°C during the twentieth century, while sea level rise reached 2–3 mm/yr since the 1980s. Changes in precipitation patterns have also been observed. Extreme weather events have become more common in several parts of the region, including more periods of intense rainfall and consecutive dry days.

4.4.2 The Impacts of Climate Change on Eco-infrastructures

Relying on climate projections one must next identify eco-infrastructure vulnerabilities (the third column), determine which risks are likeliest and which could have the biggest impacts, develop adaptation strategies, and prioritize them. As indicated above, some climate projections entail large uncertainties, and sorting matters out can be very hard. An example is whether to construct storm surge barriers in the city harbour to protect the city from flooding. This calls for caution against erecting hard infrastructures. The storm-surge barrier question raises the need to look at both the impacts of climate change not just on the environment, but to the environment as eco-infrastructure for responding and providing solutions to climate change adaptation. Once an inventory of these eco-infrastructures has been completed, the second step the assessment of vulnerability focuses on gaining an understanding of how climate change will impact the goods and services (column 4) provided by natural resources and eco-infrastructures (column 3); human-built infrastructure (column 5) and coastal communities (column 6) at different spatial scales. Vulnerability assessment for climate change in a coastal city-region also considers two other factors: the

Table 4.1 Impacts of climate change on eco-infrastructures at different spatial scales

Relating climate change to eco-infrastructures ecosystem services and impacts		Eco-infrastructures (Large Scale LA/Caribe)	Affected assets/ associated ecosystem services regional/local scale	Localized/sector impacts local scale	Hotspots of vulnerability	Strategic responses to reduce vulnerability to climate change
		Melting andean glaciers/paramos	Paramos: store/provision water for use downstream; energy	*Lower water availability* for irrigation, industry, energy, cities *Flooding; mudslides*	Mountains, rivers; cities	*Reduce exposure to hazard/strategic protections:*
Climate change		*Bleaching of coral reefs (Caribbean)*	Food; Protection of shorelines from storms	Lower food availability, lower protection shorelines Fisheries, tourism	Small islands	• Repair eco-infrastructures • Create autonomous urban spaces
		Damage Coastal wetlands-mangroves	Regulation of hydrological regime; protection from flood/storm; habitats; livelihoods	Destruction productive ecosystem: shrimp, oyster, fish production	Coastal cities	• Create networks of zero carbon towns
Increases in ghg con-centration	Consequences Sea level rise Temperature increases	*Sea level rise*	Ecosystem wetlands/mangrove Natural buffer against flooding; high winds, erosion	*Coastal cities inundation and erosion* *Increased flooding* Mangrove forest Agriculture Migration to cities Beachfront Tourism transport	Low lying delta	*Reduce sensitivity to effects* of cc: • Increase livelihood assets and • Increase opportunities *Increase adaptative capacity:* • Flex multi-actor institutions • Disseminate knowledge needed to deal with uncertain future events and
Atmospheric warming	Change in precipitation patterns	Rainfall patterns weather-related natural disasters Hurricanes Flood mudslides storms	Ecoinfrastructure Engineered infrastructures Protection coastal cities	Tourism Beachfront Transport Health	Drylands	• Empower people in planning and decision-making about adaptation
	Extreme vents	*Biodiversity* Decay of the Amazon rainforest		Loss of cultural bio-diversity heritage		

Source: Compiled by author

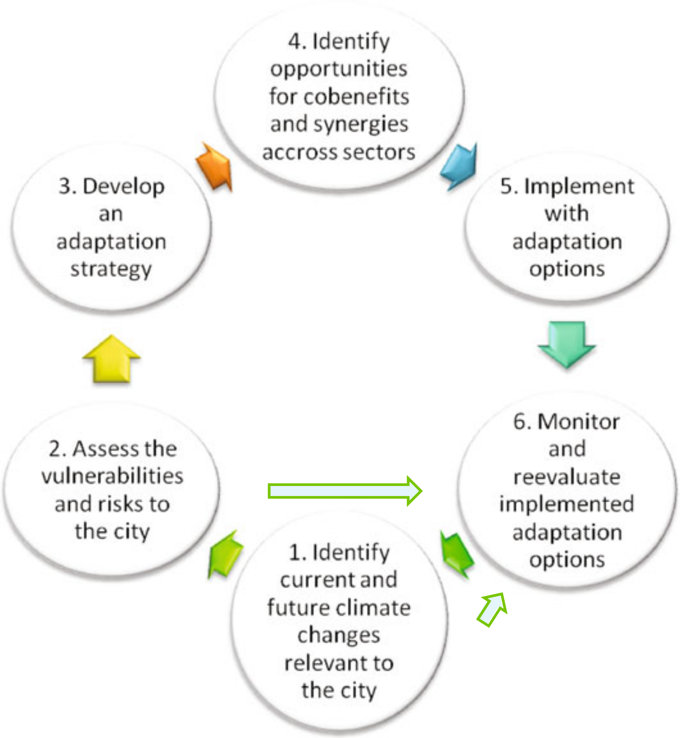

Fig. 4.1 Six-step adaptation planning as a cyclical, iterative process. *Source*: Compiled by author

natural assets and the human capital that will be exposed to and impacted by climate change (and that combined define hotspots of vulnerability (column 6); and starts to evaluate the capacity of communities and ecosystems to adapt to and cope with climate impacts (column 7).

Climate change will impact the health, function and productivity of ecosystems, thus impacting the health and welfare of communities and the people that depend on these natural resources. The main Latin American eco-systems that are already suffering negative effects and impacts from ongoing climate change are outlined in Section 4.2 above

4.4.3 Eco-infrastructures, Eco-system Services and the Affected Assets and Functions

High mountain eco-infrastructures including glaciers and high altitude wetlands (*paramos*) provide numerous and valuable environmental goods and services. They are eco-infrastructures that store and release water for use by downstream populations working in agriculture and living in cities. Large numbers of people in Latin America are dependent on glacier water. The fast melting of the Andean glaciers would deny major cities water supplies and put populations and food supplies at risk in Colombia, Peru, Chile, Venezuela, Ecuador, Argentina and Bolivia. Large cities in the region depend on glacial runoffs for their water supply. Quito, Ecuador's capital city, for example, draws 50% of its water supply from the glacial basin, and Bolivia's capital, La Paz draws 30% of their water supply from the Chacaltaya glacier which is expected to completely melt within 15 years if present trends continue. In Bogota, Colombia, 70% of the city water supply comes from an alpine paramo (a fragile sponge of soil and vegetation), which could dry up under higher temperatures. The volume of the lost glacier surfaces of Peru is equivalent to about 10 years of water supply for Lima (Bradley et al. 2006, Environment News Service 2008, Kaser et al. 2003).

The drastic melt forces people to farm at higher altitudes to grow their crops, adding to deforestation, which in turn undermines water sources and leads to soil erosion and putting the survival of Andean cultures at risk (NEF 2006). The entire range of the tropical Andes, and host to the vital global biodiversity, will be affected. Without this natural storage, more construction of dams and reservoirs would be needed. Power supplies also will be affected as most countries in the Andes are dependent on hydroelectric power generation (Bradley et al. 2006, Francou et al. 2003). Accelerated urban growth, increasing poverty and low investment in water supply will contribute to water shortages in many cities, to high percentages of urban population without access to sanitation services, to an absence of treatment plants, high groundwater pollution and lack of urban drainage systems (IPCC 2007).

Coral reefs eco-infrastructures are an integral part of the Caribbean fabric, threading along thousands of kilometres of coastline. Rich in life and beauty, they serve a multitude of purposes to the Caribbean people. Their fisheries provide food for millions of people, their structure protects shorelines from tropical storm swells; as they bleach, the reefs disintegrate and thus eliminate this protection. Reefs are also a tourism attraction and as they bleach and disintegrate, they lose their aesthetic value (Buddemeier et al. 2008). Coastal wetlands eco-infrastructures provide many environmental services, including the regulation of hydrological regimes, human settlement protection from floods and storms, sustenance for many communities settled along the coast, and habitats for waterfowl and wild life. These wetlands possess the most productive ecosystem and is one of the richest on Earth. Floods, mudslides and hurricanes could have serious impacts on eco-infrastructures and engineered infrastructure along the coastal cities and on the tourism industry, for example, in the form of loss of valuable beachfront. Coastal flooding will negatively affect the ecosystems of mangroves, a plant which is crucial in providing a natural buffer against flooding, high winds, and erosion (IPCC 2007). This may accelerate migration to urban centres (Gleditsch et al. 2007).

4.5 Mapping Potential Hot Spots of Vulnerability at the Regional Scale

On the basis of the first tool – an assessment exercise (Table 4.1), we can elaborate a second tool – a mapping exercise where we start to downscale the information to the regional level and define potential hot spots of vulnerability at the city-region scale and where the impacts of climate change on the eco-infrastructures and their ecosystems may be most dramatic. These hot spots of vulnerability (column 6 of Table 4.1, Fig. 4.2) are locations and places where susceptibility to adverse impacts of climate change is high because of exposure to hazards such as floods and drought or storm surges and because of sensitivity to their effects. These hotspots are the highest priority locations for adaptation, and include:

- The mountains and their rivers where the retreat of glaciers and reduction in the size of snow packs will increase disaster risk and shift the volume and timing of downstream water availability for irrigation, industry and cities. This is the case of La Sierra Nevada de Santa Marta (32 streams of water have disappeared in the last years).
- Small islands where sensitivity to coastal erosion, inundation and salt-water intrusion is high at community levels. This is the case of The Archipelago of San Andrés, Providencia and Rosario islands.
- Lowlying deltas and coastal cities where higher frequency of flooding and coastal inundation will have the most acute impacts. This is the case of the entire Colombian Caribbean coast and of cities such as Cartagena, Barranquilla, and Santa Marta.

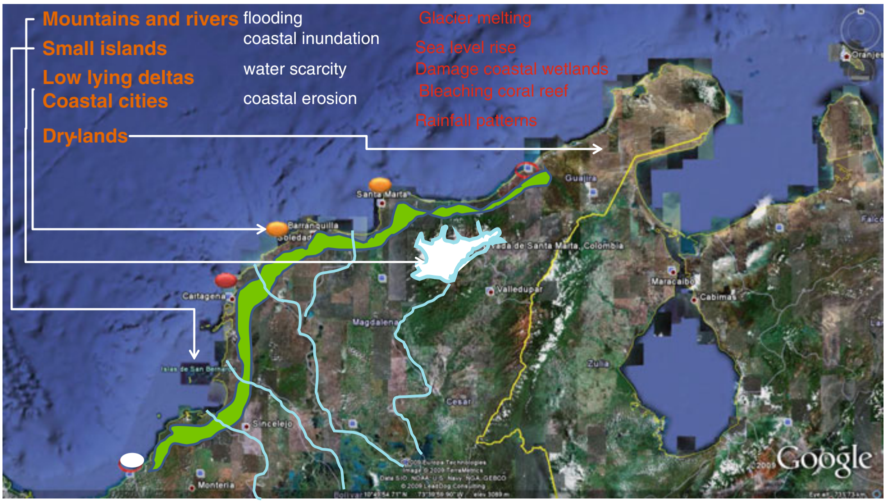

Fig. 4.2 Assessment exercise: defining hot spots of vulnerability at the regional scale. *Source*: Compiled by author http://maps.google.com/maps?t=h&hl=en&ie=UTF8&ll=10.411323,-75.495731&spn=0.027098,0.033002&z=15

- Drylands where susceptibility to more severe or more frequent water scarcity is high because of threats to food security, health and economic development. This is the case of La Guajira, but also of the Monteria-region

As Fig. 4.2 suggests, we find all these hotspots in the Colombian Caribbean coast. Before we move into the formulation of the next question, let us open a parenthesis here and note the following: (1) the regional and the territorial scale of the map is the scale of the ecosystems; (2) it is important to draw climate plans at this territorial scale; (3) it is at this scale where we find the potential to harness revenue streams from regional ecosystem services that could be invested in urban programmes. At this point the critical question to be addressed is: how can vulnerability to the hazards be reduced in the case of each hot-spot on the map? To elaborate on this question requires zooming-in on one of these hotspots where vulnerability is high for the poor and where climate change exacerbates exposure to climatic hazards.[1] This requires to down-scale the information to the city level, and the design of a third tool; a knowledge base for the city and its citizens. This tool is elaborated in the next section.

4.6 Creating a Knowledge Base for the City and Its Citizens

4.6.1 The Localized Impacts of Climate Change: The Case of Colombian Coastal Cities

As allued to earlier, Colombian coastal zones are highly vulnerable to sea-level rise, to coastal erosion, and flooding of low-lying areas. Seven critical zones have been identified: The Archipelago of San Andrés, Providencia y Santa Catalina in the Colombian insular area of the Caribbean; the cities of Cartagena de Indias, Barranquilla, and Santa Marta in the Caribbean continental coast; and the cities of Tumaco and Buenaventura in the Colombian Pacific coast. In the case of Cartagena, neighbourhoods located in the southern border of the *Cienaga de la Virgen* (Fig. 4.3) exhibit high socioeconomic and biophysical vulnerability (Invimar 2005, 2007).

The objective of this more localized assessment of Cartagena de Indias and its ecosystems is to identify the main vulnerable and at risk areas at the city scale. This knowledge is critical for defining priority actions to create secure urbanities. The assessment is not a quantitative tool for ranking cities nor is it intended to be a scientifically rigorous assessment.

Cartagena de Indias is a large seaport, economic hub, as well as a popular tourist destination on the north coast of Colombia. Cartagena faces the Caribbean Sea to the west. To the south is the Bay of Cartagena, which has two entrances: *Bocachica* in the south and *Bocagrande* in the north. The principal water bodies within the urban area are the *Bahía de Cartagena*, *Ciénaga de la Virgen* and *Ciénaga de Juan Polo* that are connected by a complex system of lakes and channels (Alcaldía de Cartagena 2000). Cartagena is also a divided city. It contains a series of antagonisms strong enough to prevent its ecological, social and economic reproduction.

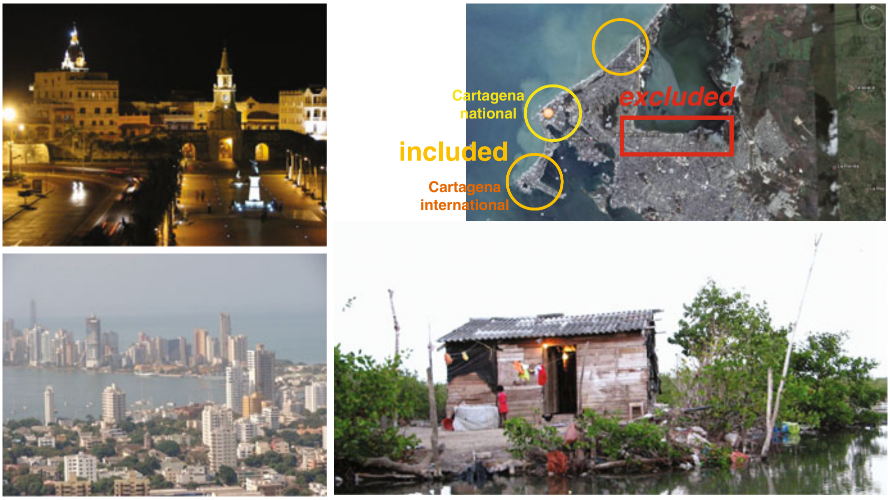

Fig. 4.3 Main antagonisms: Cartagena as a divided city. *Source*: Compiled by author. http://maps.google.com/maps?t=h&hl=en&ie=UTF8&ll=10.411323,-75.495731&spn=0.027098,0.033002&z=15

Three possible antagonisms present themselves: the threat of ecological risks; the inappropriateness of an illegal process of urbanization through which public lands and their ecosystems are privatized; new forms of social exclusion such as new slums and shanty towns (Fig. 4.3). While the threat of ecological risks means that the entire city is in danger of losing everything and of vegetating in an unliveable urban environment, the antagonism between the included and the excluded is a crucial one. Thus, the ethico-political challenge is for all the inhabitants of the city to recognize themselves in this figure of the excluded. In a way, today we are all potentially excluded from nature through climate change impacts, and the only way to avoid actually becoming so is to act preventively through re-design in the form of collective action.

4.6.2 Identifying the City's Eco-infrastructures and Ecosystems and Some of the Forces that Are Degrading Them: The Workbook

The following are some of the most productive and biologically complex ecosystems localized in the Caribbean coastal zone of Cartagena and in its lagoons (Fig. 4.4):

Sandy beaches occupy 90% of the coastal line of the district. The biggest hazard for the preservation of this ecosystem comes from the intense process of urbanization (CIOH 1998). The Rosario islands coral-reefs are endangered by the use of

CITY KNOWLEDGE BASE

Eco-infrastructures	Associated Ecosystem Services	Process that degrades eco-infrastructures and ecosystem services	impact	Strategic Responses to reduce vulnerability to CC
Sandy beaches and dunes	Natural buffer; filtration of seawater; biodiversity	Population growth; coastal development	Degradation of eco-infrastructures and their ecosystem services increase vulnerability to climate change impacts (sea level rise)	
Bleaching of coral reefs (Caribbean)	Food; Protection shorelines from storms	Uncontrolled tourism		
Coastal wetlands (estuaries, deltas, coastal lagoons) Mangroves	Regulation of hydrological regime; protection from flood/storm; habitats; livelihoods	Illegal process of creation of new land for urban expansion		
Sea grasses	Fishing grounds	Sewage disposal		

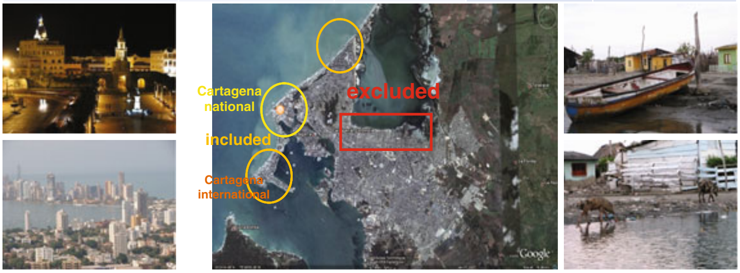

Fig. 4.4 Eco-infrastructures at the city scale. *Source*: compiled by author http://maps.google.com/maps?t=h&hl=en&ie=UTF8&ll=10.411323,-75.495731&spn=0.027098,0.033002&z=15

dynamite as a fishing method, uncontrolled tourists, increase in sea surface temperature and sediment discharge due to dredging of the dike channel (Díaz et al. 2000, Charry et al. 2004). The Cartagena Bay's 76 ha of sea grasses are connected to the open beaches and 58 ha are inside the bay; they are threatened mainly by untreated sewage disposal (Diaz et al. 2003). The biggest coastal lagoon in the area is the *Cienaga de la Virgen*, which has a length of 22.5 km and a mean depth of about 1.5 m. It is separated from the sea by *La Boquilla's bar* and is surrounded by mangrove areas (Alcaldia de Cartagena 2000). The south and west flanks are impacted by urban expansion, as this area is home to several of the city's shanty towns (Niño 2001). The interconnections between the *Cienaga de La Virgen* and Cartagena's Bay are currently interrupted as a result of unplanned urban expansion and garbage accumulation. Unplanned urban and industrial development in the *Cienaga de la Virgen* and Cartagena's Bay has resulted in a lack of sewage treatment that has deteriorated the environment in these areas.

There are several forces that contribute to the process of degradation of urban ecosystem services at the city and regional level; two of them deserve particular mention here: the illegal process of urbanization and coal mining for global markets and their associated logistics. The city of Cartagena is growing and there is scarcity of land. The low-lands around the lagoons of the *Bahía de Cartagena*, *Ciénaga de la Virgen* and *Ciénaga de Juan Polo*, are public lands inhabited by valuable eco-infrastructures such as mangrove forests. These public lands are privatized through an illegal market for urban land: poor people invade illegally the public lands, destroy the urban mangrove forest, fill in the lagoon, create new plots of land, and sell them in the illegal market. These land plots will be later legalized. Ecosystems are being privatized for use as new lands for urban development. Neither the national nor the local government has taken any serious action to protect these eco-infrastructures and their services.

The other important process impacting these eco-infrastructures at the scale of the city-region is the exploration of coal mining for global markets. The logistics of coal mining is degrading the ecosystems and landscapes of the city of Santa Marta such as the development of five coal mining ports (and associated train and truck infrastructure) along 39 km of beautiful beach front (McCausland 2009). These two cases suggest that the synergies and interdependencies of ecological and economic sustainability cannot be assumed as given. This economic model of illegal urbanization negates the ecological component of the synergy-equation (the mangrove forest is destroyed in order to fill in the lagoon and create new land for urban development). These combined process and forces (slum formation and exclusion; coal mining impacts and privatization of public lands through illegal urbanization; etc) have the potential to jeopardize the social reproduction of cities and generate new urban environmental conflicts between different social groups and their values regarding the environment, eco-infrastructures and their ecosystem services; climate change impacts and adaptation responses. Thus, the synergies between the ecological and the economic city still need to be constructed through a process of mediation of these new urban environmental conflicts.[2]

Degradation and destruction of the eco-infrastructures (coastal-wetland and its mangrove forests, Fig. 4.5) and ecosystems leads to loss of these ecosystem services. Of vital importance is the undeniable fact that human well-being can be damaged when these services are degraded, or else costs must be borne to replace or restore the services lost.

To illustrate, exposure to hazards can be reduced through eco-infrastructures and their ecosystem services. The risk of drought can be minimized by eco-infrastructures which store water for use during dry spells in wetlands and groundwater recharge areas, lagoon floodplains, and aquifers. The risk of flooding (Fig. 4.6) can be lessened by floodplains that reduce and control flood by giving water the space needed to dissipate flows. The risk of coastal erosion can be reduced by mangroves, barrier reefs and islands that protect against storm damage, and tidal or storm surges, as witnessed in the Asian tsunami of 2004, where damage from coastal inundation was reduced where mangroves were intact (UNEPWCMC 2006).

Drainage and infilling of wetlands through the process of illegal urbanization means natural water storage is lost and recharge of groundwater reduced, reducing dry season flows and the options available for coping with drought. This process is increasing the city's vulnerability to climate change (Figs. 4.5 and 4.6) by destroying the eco-infrastructures and ecosystem services, needed to reduce exposure to these risks and hazards. The implication is that where ecosystems are lost or degraded, so are the services from them that people use. Without this natural eco-infrastructure, people lose benefits and are exposed to hazards and vulnerabilities they would otherwise be able to avoid or have protection against.

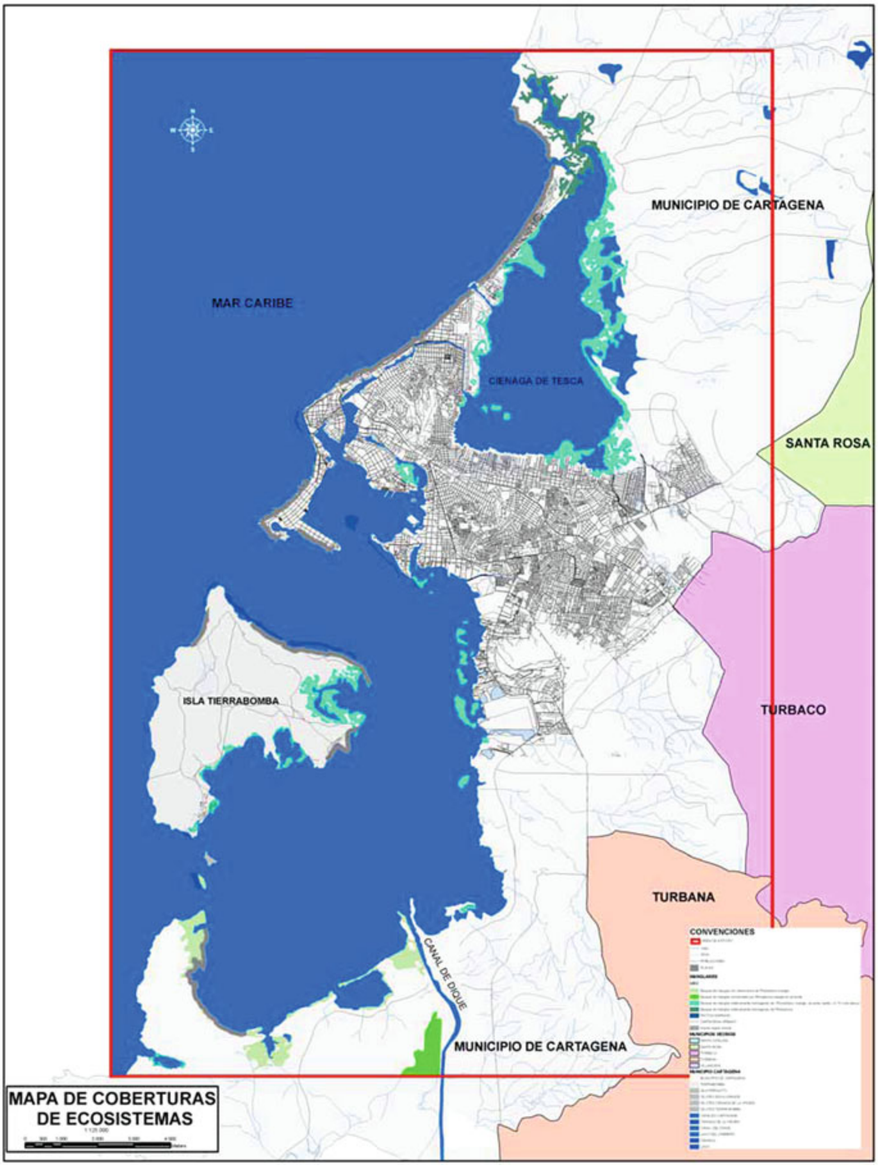

Fig. 4.5 Eco-infrastructures at the city scale: map showing ecosystem land cover in study area. *Source*: INVEMAR-Instituto de Investigaciones Marinas y Costeras "José Benito Vives De Andreis". 2005

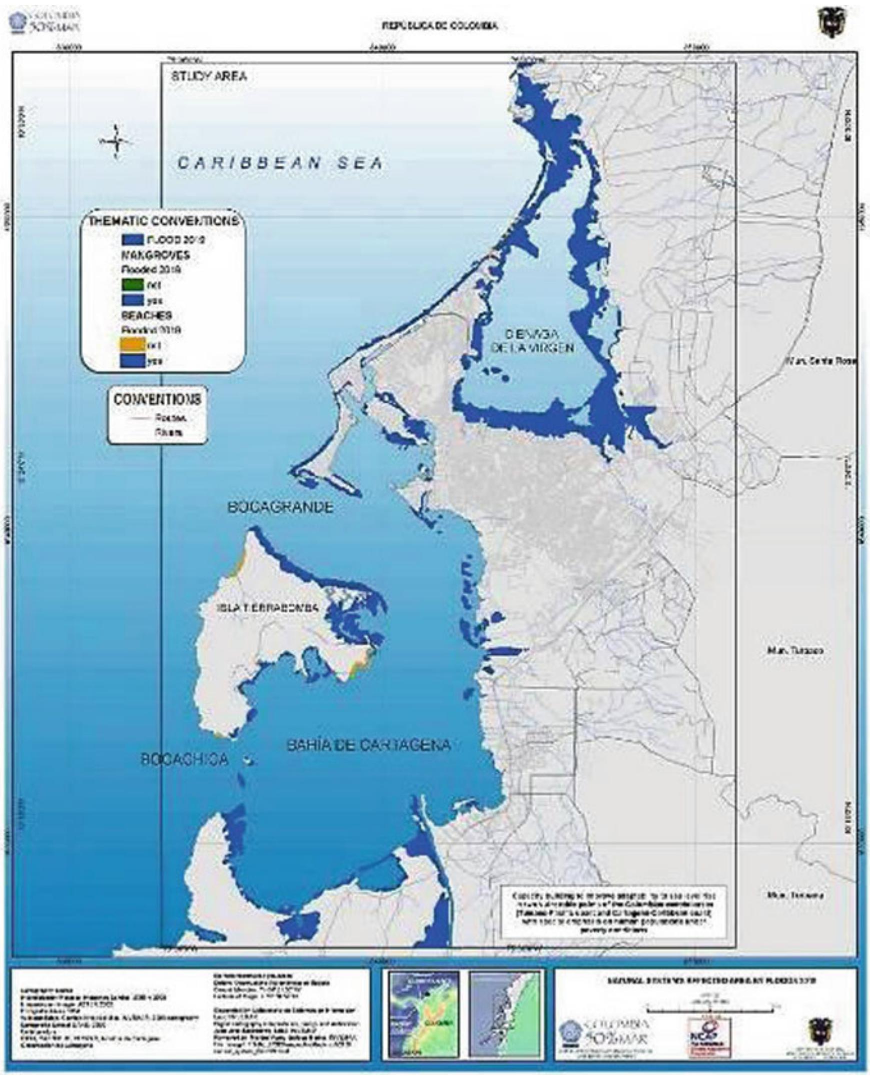

Fig. 4.6 City-knowledge base. Mapping the impacts of climate change (sea level rise scenario). *Source*: Adaptación costera al ascenso del nivel del mar. *Martha P. Vides Ed.* 01/04/2008; Invemar

4.6.3 Conclusion Regarding This Preliminary Assessment Exercise

The preliminary assessment exercise shows that all the ecosystems services and eco-infrastructures in the area needed for adaptation have been seriously threatened and damaged by the mismanagement of the process of urbanization and resource exploration. The natural infrastructure of the lagoons has been damaged, and as a result communities living with these hazards are less able to cope. The adaptive capacity of the ecosystems, eco-infrastructures and communities of Cartagena has become fragile, just when resilience is most needed. Sea level rise will only bring a higher risk of coastal inundation and erosion and lower the resilience[3] of its communities. This coastal city is becoming a hot spot of vulnerability where higher frequency of flooding and coastal inundation will have the most acute impacts.

Put simply, the effects of climate change mean that Cartagena and the *Cienega de la Virgen* will be at greater risk from flooding in future years. Furthermore, many flood risk areas are undergoing development and regeneration, meaning that more people, buildings and infrastructure are likely to be exposed to the risk of flooding in the future. This is the case of *La Cienega de Juan Polo* north of *La Cienega de La Virgen* (Fig. 4.7). Eco-infrastructures are thus needed to reduce the vulnerability of the city to climate change. They need to be integral to portfolios of adaptation measures and strategies. If eco-infrastructures are overlooked, opportunities to reduce vulnerability and increase resilience will be missed. The combination of all these eco-infrastructures and their ecosystem services could reduce exposure to climatic hazards. The focus on reducing vulnerabilities brought by climate change requires that there is new explicit recognition given to the role of eco-infrastructures. This is what our next tool proposes to do.

Fig. 4.7 Cienega de Juan Polo. *Source:* Compiled by author http://maps.google.com/maps?t=h&hl=en&ie=UTF8&ll=10.411323,-75.495731&spn=0.027098,0.033002&z=15

4.7 Securing Urban Space Through Eco-infrastructures: Self-Enclosed Spaces and Coastal Networks of Zero Carbon Settlements

Latin American countries and their cities have a "comparative advantage" in pursuing a low-carbon growth path and mitigating climate change. These cities could play an important role in developing responses to the challenges of climate change and resource constraints. To realize this potential requires developing new styles of eco-infrastructures around the protection of the city, redesign of self-enclosed urban spaces, and the creation of networks of zero carbon settlements. In this way they will be integrating adaptation, mitigation measures and non-regret options and thus reduce the city's emissions at low cost, while at the same time reaping sizable development co-benefits (Tol and Yohe 2006, Lal 2004, Landell-Mills 2002, Vardy 2008, Baker 2008). This is a *prudent approach* based on *precaution and re-design* as a form of collective action (Schneider et al. 2007, Yamin et al. 2006).

4.7.1 First Set of Strategies for Adaptation Planning: A Tapestry of Eco-infrastructures

Based on this approach, a style of spatial planning of cities that considers climate change impacts as vital components of urban development, that requires cities to act cross-sectorally in a holistic rather than sectoral engagement in climate change is proposed. This planning requires in turn, the concept of a multidimensional system of infrastructures that weave together at least six strands of infrastructures: the first layer of blue eco-infrastructures (the flood control function; the sustainable urban drainage system); the second layer of urban forest (mangrove) eco-infrastructures; the third layer of green eco-infrastructures (linked greenways and habitats); the fourth layer of grey infrastructures (the engineering infrastructure and sustainable engineering systems); the fifth layer of human-habitats (the built systems, hard-scapes and regulatory systems); and, the sixth layer of renewable energy infrastructures (solar, wind, biomass, etc) (Fig. 4.8). This web of infrastructures and habitats is the first step of a progressive infrastructure redesign where adaptation planning recognizes the ecosystem services and the climate change adaptation function of these eco-infrastructures.

4.7.1.1 Blue Eco-infrastructure: The Creation of Room for the Water

Coping with floods, drought, storms and sea-level rise will depend on water storage, flood control and coastal defence. In response to climate change, many countries and cities are likely to invest in even more grey-infrastructures for coastal defenses and flood control to reduce the vulnerability of human settlements to climate change. However, providing these functions simply by building grey infrastructures – such as dams, reservoirs, dikes and sea walls – may not be adequate (Palmer et al. 2008). It is here where the blue eco-infrastructures have a critical role to play (Fig. 4.9).

Natural ecosystems can reduce vulnerability to natural hazards and extreme climatic events and complement, or substitute for, more expensive infrastructure investments to protect coastal and riverine settlements. Exposure and the risk to flood is reduced by restoring the function of the floodplains in combination with sound land-use planning, parks and other open public spaces that could function as safety reservoirs in case of floods, and also barrier islands and wetlands. By given space back to the water, the goal is to restore the lagoon's eco-infrastructures

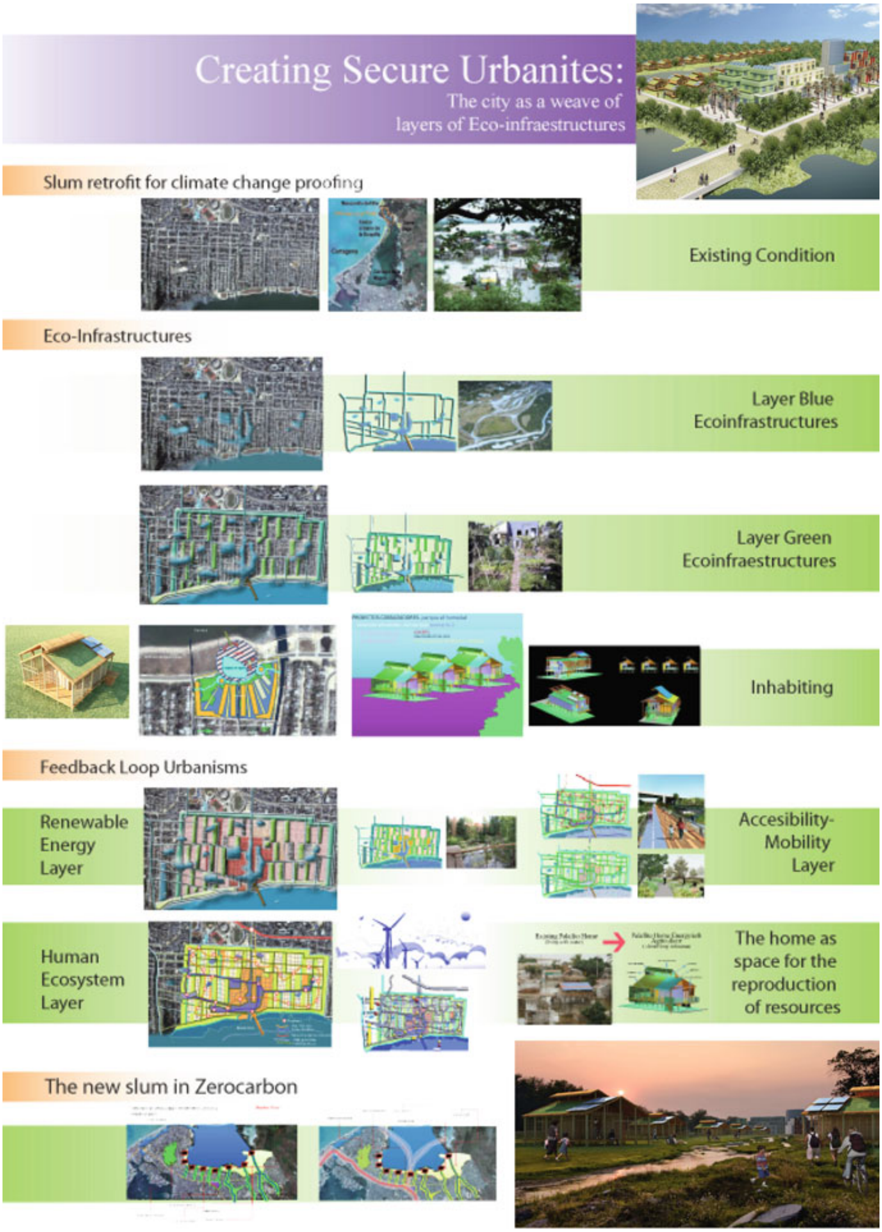

Fig. 4.8 Secure urbanities: strategic protection through eco-infrastructures. *Source*: Compiled by author

Fig. 4.9 Eco-infrastructure: reuse public space for rainwater storage connected through canals. *Source*: Compiled by author http://maps.google.com/maps?t=h&hl=en&ie=UTF8&ll=10.411323,-75.495731&spn=0.027098,0.033002&z=15

as a source of adaptive capacity and renewed resilience. The layer of blue eco-infrastructures incorporates flood risk into urban (re)development and increases adaptive capacity towards future flood impacts. Investing in the conservation of these blue eco-infrastructures provides storm protection, coastal defenses, and water recharge and storage that act as safety and control barriers against natural hazards. The environment becomes an eco-infrastructure for adaptation.

In Fig. 4.8, we propose to restructure and reconstruct a "shanty town" area, so that more space may be created for storage of excess rainfall through water plazas. Traditional engineered solutions often work against nature, particularly when they aim to constrain regular ecological cycles, such as annual river flooding and coastal erosion, and could further threaten ecosystem services if creation of dams, sea walls, and flood canals leads to habitat loss. The idea is to design a flood control project that utilizes the natural storage and recharge properties of critical forests (mangroves) and wetlands (the lagoons) by integrating them into a strategy of "living with floods in water plazas" that incorporate forest protected areas and riparian corridors and protect both communities and natural capital (Fig. 4.10).

4.7.1.2 Green Eco-infrastructure: Restore the Mangrove Urban Forest

The risk of coastal erosion can be reduced by protecting mangroves (Danielsen et al. 2005, Kathiresan and Rajendran 2005). The strategy is to use the potential for mitigation of the urban mangrove forest to reduce emissions at a low cost through

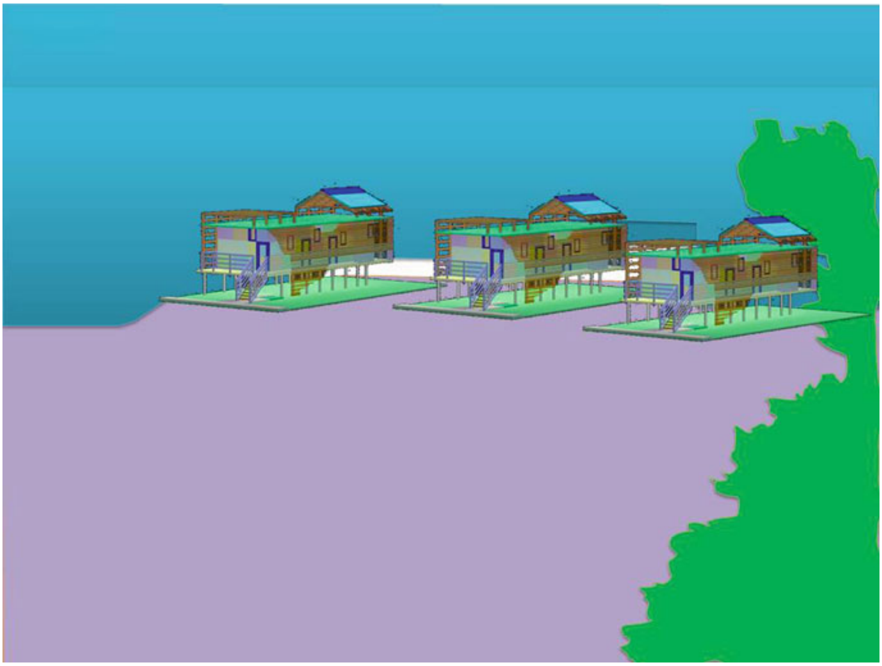

Fig. 4.10 Living around a water plaza. *Source*: Compiled by author

afforestation and reforestation (A/R, REDD Web Platform 2010). The restoration of the mangrove swamp ecosystems can be successful, provided that the hydrological requirements are taken into account, which means that the best results are often gained at locations where mangroves previously existed; which is the case in Cartagena and her *Cienegas*.

The restoration of mangroves can also offer increased protection of coastal areas to sea level rise and extreme weather events such as storms while safeguarding important nursery grounds for local fisheries. These reforestation activities could generate carbon credits for the voluntary market that will be used to finance sustainable livelihood activities in the area, such as fruit tree gardens (see below, green eco-infrastructures), aiming at increasing urban farmers' income, while at the same time reducing pressures on native forests. The opportunity to earn future carbon finance payments can increase the value of the informal and squatter settlement and its marginal lands (Lal 2004, Landell-Mills 2002, Harris et al. 2008, Betancourth 2009a). This will amount to the transformation of the shanty town into a *new "extractive protected area"* (Allegreti 1994), that will reduce emissions from deforestation and degradation of native forests in the city and the region. This mangrove urban forest eco-infrastructure will be a regional park of interconnected networks of natural areas and other open spaces that conserves natural ecosystem values and functions, and sustains clean air and water (Fig. 4.11).

Fig. 4.11 Network of zero carbon settlements within a regional park (the mangrove green-belt). *Source*: Compiled by author http://maps.google.com/maps?t=h&hl=en&ie=UTF8&ll=10.411323,-75.495731&spn=0.027098,0.033002&z=15

The park will enable the urban area of the informal settlements to flourish as a natural habitat for a wide range of wildlife, and deliver a wide array of benefits to people and the natural world alike, such as providing a linked habitat across the urban landscape that permits bird and animal species to move freely. In addition, this urban forest eco-infrastructure can also provide the following services: cleaner air; a reduction in heat-island effect in the urban area; a moderation in the impact of climate change; increased energy efficiency; and the protection of sources of water. In Cartagena we are proposing to re-create and reconstruct the mangrove forest that once covered the *Cienega de la Virgen* plain under a new park concept (Fig. 4.8). The idea is to give the city of Cartagena a big protective mangrove peri-urban forest that can function as a bio-shield against sea level rise, and climate change. The mangrove greenbelt can also provide significant coastal protection from erosion. The mangrove forest will be connected to a network of urban open space lands to preserve a high quality of life, carbon sink creation, and city beautification. The forest will clear the air and treat the water that runs into the lagoon (*Cienega de la Virgen*), re-naturalize the territory and increase its biodiversity, create a living laboratory of environmental monitoring, provide an area for recreation, revitalize the historic/natural memory and strengthen the city identity.

Introducing eco-tourism has the additional benefit of making the forest accessible to citizens, promoting goodwill among the people, and demonstrating the importance of maintaining and improving the forest. It will thus be the community who will begin planting the trees. As part of this urban forestry proposal, all major roads in the area will be provided with green medians and above all, green corridors (Betancourth 2007). The distributed greenery ensures that the roads have high CO_2

absorption capacity in close range of the emission source. The roadside greenery aids in reducing the heat island effect and atmospheric pollution. The urban forest can help mitigate and adapt for temperature changes due to climate change.

4.7.1.3 Green Eco-infrastructure: Urban Agriculture

By re-creating, improving and rehabilitating the ecological connectivity of the immediate environment, the green-infrastructure turns human intervention in the landscape from a negative into a positive. It reverses the fragmentation of natural habitats and encourages increases in biodiversity to restore functioning ecosystems while providing the fabric for sustainable living, and safeguarding and enhancing natural features. Urban forestry and urban agriculture strategies for climate change mitigation are integrated into this green eco-infrastructure This new connectivity of the landscape with the built form (see orange and grey infrastructures) can be both horizontal and vertical (Figs. 4.12 and 4.13).

4.7.1.4 Orange Infrastructure

This layer represents the human community, its built environment (buildings, houses, hardscapes and regulatory systems such as laws, regulations, ethics, etc). Homes are clustered around blue and green eco-infrastructures. The design proposal

Fig. 4.12 Green eco-infrastructure-ecological corridors. *Source*: Compiled by author http://maps.google.com/maps?t=h&hl=en&ie=UTF8&ll=10.411323,-75.495731&spn=0.027098,0.033002&z=15

Fig. 4.13 Orange eco-infrastructure: diversity of homes around a diversity of eco-infrastructures. *Source*: Compiled by author http://maps.google.com/maps?t=h&hl=en&ie=UTF8&ll=10.411323,-75.495731&spn=0.027098,0.033002&z=15

for the individual urban-home/farm extends the ecological corridor (around which homes are clustered (Fig. 4.14) vertically from the ground up to the green gardens on the living roof tops. Thus the blue and green infrastructure network can be used to define the hierarchy and form of the habitats and natural green spaces within a community (see living around a water plaza, Fig. 4.15).

4.7.1.5 Grey Infrastructure

The grey infrastructure is the usual urban engineering infrastructure such as roads, drains, sewerage, water reticulation, telecommunications, energy and electric power distribution systems. This is also the infrastructure of mobility and accessibility. These mobility systems should integrate with the green and blue infrastructures rather than vice versa, and should be designed as sustainable accessibility systems (Fig. 4.16).

4.7.1.6 Renewable Energy Infrastructures

Finally, it is the layer for renewable energies (Fig. 4.17). These last three layers of infrastructures bring us into the second main set of responses and strategies, namely the redesign of feed-back loop urbanisms (a cycle of behavior in which two or more

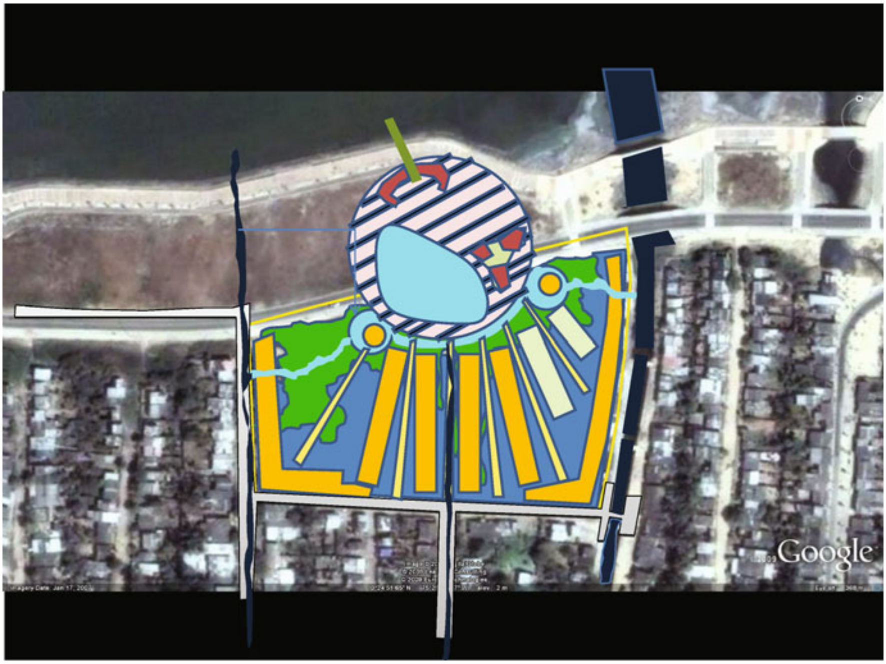

Fig. 4.14 Water plaza. *Source*: Compiled by author http://maps.google.com/maps?t=h&hl=en&ie=UTF8&ll=10.411323,-75.495731&spn=0.027098,0.033002&z=15

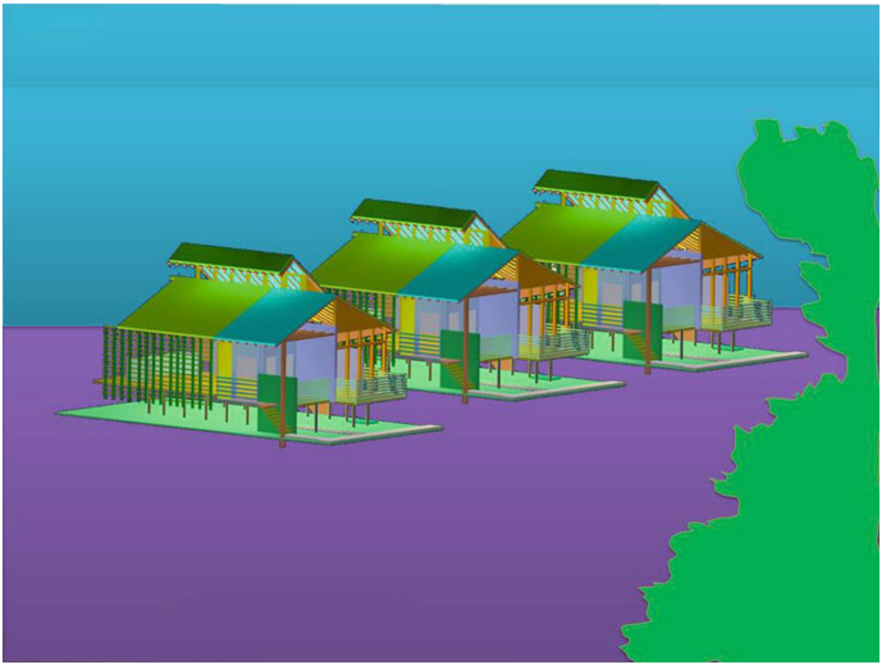

Fig. 4.15 Living around a water plaza. *Source*: Compiled by author

Fig. 4.16 Grey infrastructure: multimodality and accessibility. *Source*: Compiled by author http://maps.google.com/maps?t=h&hl=en&ie=UTF8&ll=10.411323,-75.495731&spn=0.027098,0.033002&z=15

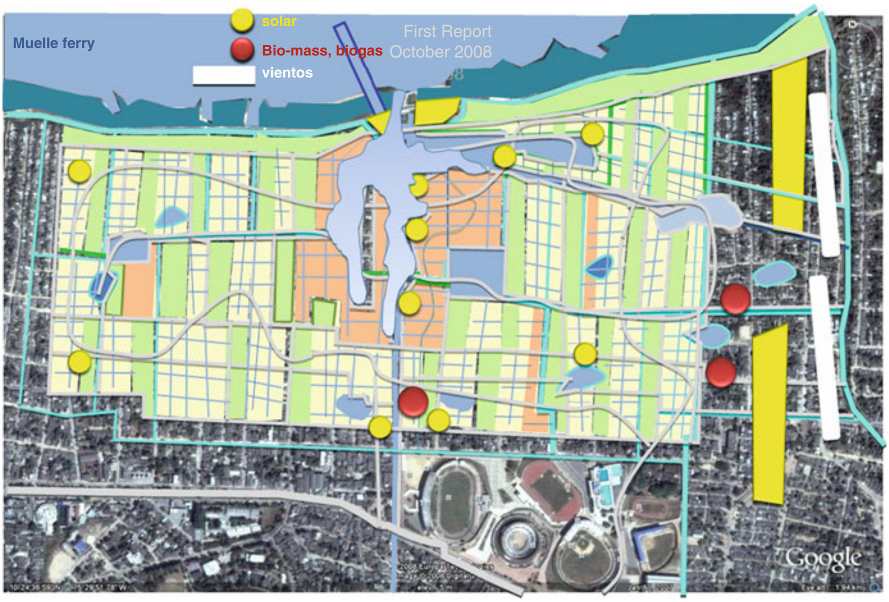

Fig. 4.17 Renewable energy infrastructures. *Source*: Compiled by author http://maps.google.com/maps?t=h&hl=en&ie=UTF8&ll=10.411323,-75.495731&spn=0.027098,0.033002&z=15

infrastructures act to reinforce the other's action) and self-enclosed spaces. But let us first look at the layer of the home.

4.7.1.7 The Home

As it is the case in Cartagena, the urban poor are typically at the highest risk in the event of natural disasters due to the location of low-income settlements. Ensuring that cities continue to drive growth in a sustainable manner is fundamental to development and poverty eradication. An important adaptation strategy for local governments is to provide new shelter options for the poor to avoid the creation of new settlements and slums on marginal land. But, population retreat, a most workable strategy against highly risk areas, generates strong cultural resistance. Despite natural phenomena like earthquakes, subsidence and tsunamis threats, people will not leave their "informal settlements" to start paying for public basic services on a safer house. It is in this regard that the housing tradition of the Pacific coast is relevant. Pacific coast meso-macro tidal regime is subject to a medium to low wave regime associated to wind's influence. Tidal amplitude reaches up to 5 m in some areas, which is 10 times greater than the Caribbean (Invimar 2005, 2007). This natural condition has allowed the development of *palafitic* housing, a dwelling built on a platform over the sea, an autonomous adaptation strategy towards sea level changes. This proven ancient adaptation strategy can be used in areas where rising temperatures due to climate change are becoming a problem. The idea is to transfer this technology from the Pacific coast to the Caribbean and implement this solution for the case of housing around the *Cienega of La Virgen* (Fig. 4.18).

4.7.2 Second Set of Strategies for Adaptation Planning: Nested Closed Urbanism and Decoupling from National Infrastructure and Building Enclosed Self-Sufficient Cities

The last three layers of infrastructures above (mobility, multiple land uses and renewable energies) will be weaved together to conform with nested feedback loop urbanisms. Nested feed-back loop urbanisms are urban developments that can be created to deal with their own infrastructure needs on site, including water supply, storm-water control, sewage treatment, thermal demand for (heating and) cooling and electrical demands. Creating these nested systems will buffer the demand on centralized infrastructure and add system robustness and resilience; all necessary in a world with increased uncertainty in climate effects on infrastructure.

Cities usually seek out resources from locations ever more distant and connected through networks. Developing responses to climate change requires challenging this traditional approach and build greater self-sufficiency by a dual strategy of both decoupling from external reliance on national and regional infrastructures and building up local and decentralized systems for water and energy supply, waste disposal and mobility systems; that is, by building more "self-sufficient" infrastructures of

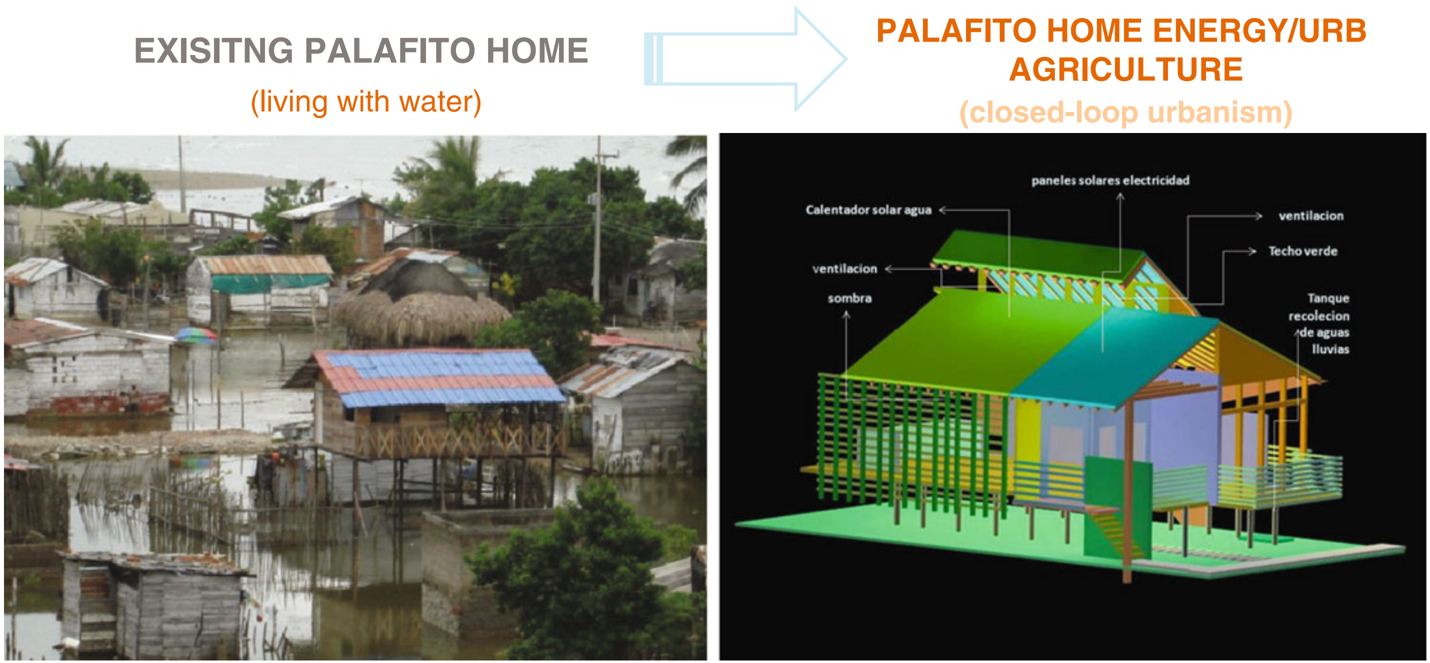

Fig. 4.18 From palafito home to the house as a unit for the production of renewable energy, water conservation and urban agriculture. *Source*: Compiled by author

provision on a city scale. It is important to design a suite of infrastructure strategies for energy, waste and water to minimize the consumption of resources and production of wastes; to consider reuse, develop decentralized energy production and waste treatment technologies; and reduce reliance on external infrastructure to increase the relative self-sufficiency of the city (Fig. 4.18).

4.7.2.1 The Transport Sector

In dealing with the mobility of citizens, the top policy priority in the Latin American region in general and in Colombia in particular, is to slow down the rapidly rising rate of emissions from light vehicles by providing incentives for more efficient cars and for reduced car use. This can only be attained with the integration of mobility services (mobility planning and integrated transport strategies that span across different transportation modes) multiple land uses and development of renewable energies through urban design. There is already in place a mass transit system for Cartagena (Trans-caribe). In order to avoid the pitfalls of the Trans-milenio system in Bogota, we propose to supplement this system with a maritime transport system in the Cienega de la Virgen. Thus, pollution-free buses, and water taxis, powered by fuel-cells or other zero carbon technologies, will run between neighbourhoods. We propose to have only green transport movements along the Cienega de la Virgen's coastline. People will arrive at the coast by boat, traveling along the shore as pedestrians, cyclists, or passengers on sustainable public transport vehicles. What is now a highway will become a trail system along the shore and within the regional mangrove park proposed above (see Fig. 4.11 urban forest).

The mass transit system for Cartagena (Transcaribe) and the city at large will be linked to the Cienega de la Virgen coastline, by a network of pedestrian walkways. The adjacent communities will inhabit and transform these non-regret investments in transport infrastructures through a series of supplementary projects that include: an urban village with multiple uses along the walkway (with a water-canal illuminated by light-emitting diodes (LED)) that connects the terrestrial and maritime system of mass transit (zero carbon vehicles will be allowed only within the walkway such as the already in the area existing *bici-taxis*); a regional commercial node at the intersection of the walkway and the system of mass transit, a Trans-Caribe Station that generates renewable energy (Betancourth 2003); and a market and festival square where the families living in homes that produce urban agriculture and renewable energies along the walkway will trade their products (see below, the home as production system of agriculture and renewable energy products) and thus add and capture value to and from the flow of commuters moving between the terrestrial and maritime system of mobility. Thus the transport system goes beyond being merely a line on a map to rapidly connect two points in the possible shortest way; and, becomes a habitat (Betancourth 2003, 2007) (Fig. 4.19).

High quality densification along the mass transit system would reduce the impact on the environment, while contributing to making Cartagena greener, more sustainable, more livable, and more affordable (Betancourth 2003). The zero carbon

Fig. 4.19 Integration of transport and land use planning along the mass transit corridor. *Source*: Compiled by author http://maps.google.com/maps?t=h&hl=en&ie=UTF8&ll=10.411323,-75.495731&spn=0.027098,0.033002&z=15

settlement proposal for la Cienega de la Virgen (Figs. 4.8 and 4.11) explores increasing density in a variety of contexts: in lower density areas, along transit routes and nodes, and in neighbourhood centres. Of key importance is to support density that is high quality, attractive, energy efficient, and respectful of neighbourhood character, while lowering the city's GHG emissions. The energy efficiency of this transport system will be improved by retrofitting traffic signals and street lights (replacing incandescent fixtures with light-emitting diodes (LED)) as well as by the conversion of outdated lighting to modern, efficient technology in public sector facilities, parking structures, police substations, fire stations, and community centres, resulting in energy savings and in financial savings.

4.7.2.2 Renewable Energy

Wind conditions, high solar radiation levels, geothermal resources, bio-mass, are excellent in many Latin American countries and cities, as well as in Cartagena and La Cienega de la Virgen. Compared to costly grid extensions, off-grid renewable electricity typically is the most cost-effective way of providing power to isolated

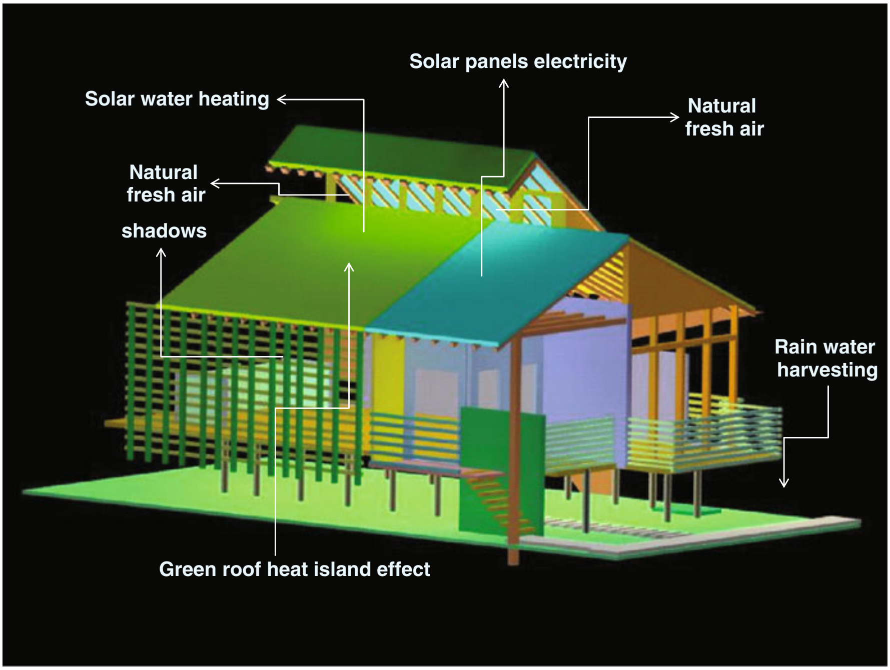

Fig. 4.20 The home as a system for the generation of renewable energy, water collection and urban agriculture. *Source*: Compiled by author

urban, periurban and rural populations (ESMAP 2007). We are proposing the concept of a Zero Carbon settlement for La Cienega de La Virgen (Fig. 4.17). Zero carbon means no net carbon emissions from all energy uses in the home. Key features of a zero carbon development could include technologies such as passive solar energy, thermal solar panels and the conversion of solar energy to electricity in photovoltaic cells. The home is conceived as a system for the generation of renewable energy closely connected to urban agriculture, combining water collection (rainwater harvesting), roof-top living gardens to reduce the impact of urban heat island effect, and recycle building materials (Fig. 4.20).

4.7.2.3 Urban Gardening at Home

Urban agriculture can be defined shortly as the growing of plants and the raising of animals within and around cities (Fig. 4.12). There is an incipient form of urban agriculture already at work in the neighbourhoods around the *Cienega de la Virgen*. It is important to strengthen this initiative by better integrating it with the urban economic and ecological system. This is the most striking feature of urban agriculture, which distinguishes it from rural agriculture. Such linkages include the participation of urban residents as farmers, use of typical urban resources (like organic waste as compost and rain water for irrigation), and direct links with urban consumers. Urban agriculture is an integral part of the urban system: the residential unit allows for collection of rainwater for irrigation (Fig. 4.18); the market in the proposed pedestrian walkway that connects the Cienega de la Virgen with the system of mass transit allows for a direct link with urban consumers (Fig. 4.19). Urban agriculture could help address the problems of food scarcity, unemployment, as well as urban waste and waste water disposal.

4.7.3 Third Set of Strategies for Adaptation Planning: Creating Networks of Zero Carbon Settlements Along the Coast Connected Through Regional Eco-infrastructures

The proposal for La *Cienega de La Virgen* described above is aiming to show that urbanization can be a fundamentally sustainable process, and, that we must rethink the means by which we urbanize. We envision de *Cienega de La Virgen* not as a dormitory town, a single-use housing development, but as an ecologically sustainable, and commercially sustainable zero carbon settlement; a settlement that will run on renewable energy, recycle and re-use waste water, protect the wetlands and mangrove forest by returning land to a wetland state creating a “buffer zone” between the city and the mud flats of La *Cienega de la Virgen*, and protect air quality by creating a system of multimodal mobility integrated with a dynamic layer of multiple land uses; small villages that meet to form a city sub-centre, where all housing is situated within seven minutes’ walking distance of terrestrial and maritime public transport. This not only lowers the consumption of energy, but also enables transport to be run on renewable energy to achieve zero carbon emissions. Having compact, efficient, and walkable settlements spread along a landscape of eco-infrastructures, that recognize human relationships with nature and secure their long-term sustainability, is an important mitigation and adaptation measure. This is a settlement as an urban landscape of multifunctional eco-infrastructures where living roofs, large trees and soft landscapes areas absorb rainfall; where a network of street swales and unculverted meadows safely manage large volumes of water.

This is an urban landscape of eco-infrastructures that provides flood protection, that does not waste water but stores and recycles it for irrigation, that saves energy. It is also a landscape where living roofs insulate buildings, and trees shade homes and offices which reduces the need for air conditioning, cleans and cools the air, provides green spaces to encourage exercise and socializing, where you can work or cycle to school or to work through car-free greenways, where meadows run alongside offices and shops, and where you can see food being grown in the park. The idea is to develop this prototype through a demonstration project and then to replicate it along the coast to form a network of such settlements connected through a system of sustainable mobility and of regional eco-infrastructures (see Figs. 4.8 and 4.11, 4.19). This is a vision to help address the climate change challenges that we hope will become a prototype in the implementation phase.

4.7.4 Fourth Set of Strategies for Adaptation Planning: The Impacts of Restoring and Repairing the Eco-infrastructures on Sensitivity and Adaptive Capacity

Expanding livelihood assets and enabling economic development sensitive to climate hazards will assist sustainable management of the blue and green eco-infrastructures proposed above.

Eco-infrastructure governance Adaptive capacity will be built through flexible and coordinated institutions in learning and the dissemination of knowledge needed to empower people in planning and decision-making related to adaptation. Restoring the lagoon's natural eco-infrastructure could become a source of adaptive capacity and renewed resilience.

Community action: participatory and community action for redesigning and restoring the eco-infrastructures can increase resilience to current disasters, for example, by building houses on stilts (*palafito* homes), replanting coastal lowlands (urban mangrove forest), digging and maintaining drainage ditches within the settlement (blue eco-infrastructure). However, city-level commitment is needed for city-wide eco-infrastructures to effectively complete the adaptation for climate change.

4.7.5 The Model to Finance Investments to Repair the Eco-infrastructures

Carbon offsets and carbon credits may be an opportunity for carbon markets to make cities less dependent on national government for financial support. The access of funds through carbon markets could be recognized as an important adaptation initiative (Betancourth 2009a). Bio-rights are also innovative financing mechanisms for reconciling poverty alleviation and environmental conservation. They may offer a novel approach to linking conservation with development. By providing micro-credits for sustainable development, the approach enables local communities to refrain from unsustainable practices and be actively involved in environmental conservation and restoration. Micro-credits are converted into definitive payments upon successful delivery of conservation services at the end of a contracting period. Bio-rights offers an approach in which global stakeholders pay local communities to provide ecosystem services such as carbon sequestration, fresh water supply and biodiversity (Guardian.co.uk 2010b). The approach unites the conservation and development aspirations of NGOs, governments, the private sector and local communities alike. It accomplishes community involvement in the preservation of environmental assets that are of global importance (for example, the mangrove forest).

4.8 Conclusion

This paper has focused on the role of the environment in providing solutions to climate change. There are links to resilience, which accord the environment a critical role in climate change adaptation. We need to recognize the benefits of ecosystem services in strategies for climate change adaptation and improve resilience to climate change impacts on cities through investments in nature's eco-infrastructures. The restoration of the eco-infrastructures of the Cienega de la Virgen lagoon will rebuild ecosystem services that help to reduce exposure to climatic hazards, but especially, it will help to ensure people have more of the assets needed to make urban fishing and farming livelihoods less sensitive to climate change. It will support livelihoods and economic development that reduce sensitivity to hazards, especially for the most vulnerable. Just as important, the learning, flexible institutions and investment that underpin effective management and restoration of the coastland's natural eco-infrastructures provide vital adaptive capacity that is based on resilience.

The case we have presented here demonstrates how adaptation that is based on resilience could reduce exposure to hazards, to impacts and increase in adaptive capacity. In the hot spots of vulnerability along the Colombian Caribbean coast, citizens will cope better with climate change impacts where eco-infrastructures are intact or restored than where they are degraded. Where climate change has led to weakening capacity to cope with shocks and stresses, the key is to increase resilience. With resilience as a goal, the eco-infrastructures, the feedback loop spaces, and the network of zero carbon settlements, must form the heart of effective strategies for climate change adaptation.

The tools drafted above are intended to initiate a learning process for local governments. They look at the issues of climate change, and its potential consequences that can affect ecosystems and cities. The tools recommend a thorough city self-assessment and a comprehensive information base as starting points; they offer strategic responses (eco-infrastructures; enclosed spaces and network of zero carbon settlements) that a city can use as follow-up to building its programs for resilience. The tools aim to generating public awareness and engaging stakeholders as well as to motivate city officials to take actions.

Notes

1. Vulnerability to climate change is high if changes in climate increase the exposure of populations to events such as drought, floods or coastal inundation, because of higher frequency or severity where the ability of people to cope is limited. Capacity to cope is most limited, and thus sensitivity is highest where livelihoods and the economy are based on a narrow range of assets that are easily damaged by climate hazards, with few alternate options or means of managing risk. Vulnerability is therefore especially high for the poor in those "hot spots" where climate change exacerbates exposure to climatic hazards.
2. The analytical framework proposed by the Eco2Cities program tends to assume these synergies as given. Therefore this program needs to be supplemented with strategies to mediate these new urban conflicts (Betancourth 2008a, b). New tools such as the mapping of the social tensions,

their impacts on eco-infrastructures, the construction of consensus starting from those impacts, need to be added to this framework (Launch: Ecocities2. World Bank 2009).

3. Resilience is the amount of disturbance that can be withstood before a system changes its structure and behaviour – before, for example, it breaks down (Folke et al. 2004).

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