Chapter 14
Fog Collection and Participatory Approach for Water Management and Local Development: Practical Reflections from Case Studies in the Atacama Drylands

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Abstract The Atacama drylands are characterized by a high level of aridity and water scarcity, abandonment of rural areas by the population and loss of biodiversity, where some areas never get any rainfall. The advection fog is a daily phenomenon and a local resource that can be used by means of a simple low-technology called "Atrapaniebla" (Fog Collector), providing water for human consumption and irrigation. Some case studies offer different scenarios in terms of this technology's purpose:

- to fulfil the water needs of small isolated communities;
- allows activities like proximity agriculture and reforestation for the rural population;
- to support biodiversity's preservation and scientific research.

The effectiveness of these projects depends on important factors that are not to be taken for granted, like the communities involvement, the presence in the territory of

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an active institution and the role of the planned management. This paper analyses different case studies in the Atacama drylands, showing the need of stakeholder involvement and participatory approach. A participatory framework is proposed for project implementation and funding for successful and reliable fog collection and water management.

Keywords Fog water collection · Rural communities · Local management · Participatory planning

Introduction

Arid landscapes cover 41% of the surface of the planet. They include both urban and rural areas and people face problems connected with the growth of the population and with tensions in the environmental context, from the over-exploitation of soil and supplies to the lower availability of resources, water in particular. In the Atacama drylands, the most hyperarid region in the planet, the non-sustainable use of land and water and the impact of climate change are the main causes of the general deterioration of the arid landscapes.

The essential function of water is to maintain life on the drylands because all the human settlements are closely tied to its presence, and therefore water becomes a vitally important economic and eco-social resource. Improved availability of water would facilitate the lives of the local population, supporting rural settlements and reducing the exodus of the population to the cities usage (Marzol and Megia 2008).

As a key component of the water cycle, fog is a crucial factor in driving landscape structure, function and dynamics of coastal, high-altitude, and arid or semi-arid regions. The concept of Fogscape (Salbitano et al. 2010), i.e. fog-dependant landscapes, is definitively applicable to Atacama drylands where the frequency, pattern and intensity of fog events is highly influencing the functioning and dynamics at landscape ecology level (Fig. 14.1). Indeed, the social component of fogscapes is very linked to fog water collection that can represent a sustainable drinking water resource for rural communities with low per capita water usage (Domen et al. 2013).

The Chamanchaca (advection sea fog) in the Atacama drylands is a local resource that can be directly used by means of a simple technological device called Atrapaniebla (Fog Collector), which intercepts and captures fog moisture.

The fog collector device has been developed and used for many years in Chile: from the 60s this low-technology has been established in northern Chile, and in the 80s and 90s it started being used for water-collection programmes. It has been successfully tested also in other parts of the world, not only for human consumption but also for forestry and agricultural use (Schemenauer and Cereceda 1991, 1994a, b).

The purpose of the article is to describe past and current fog collection projects in the Atacama drylands and to review the sustainable freshwater use practices. In particular, the main objective is to focus on the methods and management

Fig. 14.1 Advection Fog, Alto Patache, Atacama mountains coast (courtesy of *Cereceda P*, CDA—Centro del Desierto de Atacama)

approaches, underline the strengths and weaknesses of ongoing projects and reflect on the development of design and management innovation and improvement for future applications.

Fog and Fog Water Collection

Fog moisture is a fundamental water source in many coastal ecosystems of the world (Dawson 1998). Fog appears in various shapes and places: advection fog is often generated over the ocean, where humid air passes over cooler water and forms low clouds, which are blown in the coastal areas by winds (Hiatt et al. 2012). Due to morphological factors, the formation of advection fog occurs more often in mountainous coastal areas.

The advection fog in the Atacama's coasts allows the existence of fog oases where ecological communities can periodically activate life cycles and relationships initiating temporary and fragile ecosystems. The patches of fog oases usually cover few hectares, fragmented in a continuous matrix of hyperarid ecosystems. The fog oases temporary patches constitute habitat for endemic or highly adapted plant and animal species.

The relics of forest stands in the semiarid coastal mountain ridge in Chile also attest the role of advection fog in sustaining regional ecosystems. The average annual precipitation in these area does not overtake 150 mm of annual rainfall while fog-derived water can contribute to additional 200 mm per year so enabling the existence of forests in fogscapes. The biodiversity of these ecosystems is definitively higher as compared to drier zones hosting species that developed various forms of adaptation to hyperaridity.

Nevertheless, both fog oases and forest of fogscapes are under risk of degradation, loss and desertification. The ecosystem services associated to fogscapes are fundamental for the future of the region. Support services as biological diversity and habitat complexity; regulating services as climate change mitigation, carbon sequestration, micro-and meso-hydrology; provisional services as water, food and wood will be highly dependent, in the next future, on the conservation and restoration of fog-dependent ecosystems.

Thanks to fog collectors, bare areas once dependent on fog can be reclaimed to ecological restoration and the ecosystem services ensured, with great benefits for the local people.

Sustaining tree plantations by fog water is an action that can initiate easily a secondary succession towards ecosystem recovery. Once the planted trees grow to the size of being able to capture fog by the canopy, they become natural fog collectors and, in absence of anthropogenic disturbances, the succession moves towards more biodiverse and complex habitat while reducing definitively the risk of local erosion and desertification, contributing to groundwater recharge (Domen et al. 2013), and initiating soil evolution (Salbitano et al. 2010).

Fog can be directly used by means of a simple technological device. A plastic net is exposed to the action wind that pushes the fog through the net. Fog droplets are captured and combine to run down the mesh into gutters and tanks for storing and purification. Actually there are some experimentation on size, shape, mesh design and materials, depending on the fog quality and site characteristics.

The standard fog collector (SFC) is a small device used in investigative studies to evaluate the amount of fog water that can be collected in determined sites. The SFC consists in a standard 1 m $\times$ 1 m metal frame usually covered in polyethylene Raschel mesh, set at 2 m high (Fig. 14.2).

Fig. 14.2 SFC—Standard Fog Collector, Alto Patache, Atacama (photo: *Martino Correggiari, 2012*)

The large fog collector (LFC) mesh areas typically range from 40 to 48 m2. The net is anchored to two poles, forming a natural concave surface in the wind. The SFC and LFC should be oriented perpendicular to the main wind direction for obtaining optimal performances (Schemenauer and Cereceda 1994a, b).

Fog water is collected not only in the Atacama drylands but also in various locations throughout the world (Fig. 14.3). The fog collection is then possible in many mountainous coastal arid areas (Chile, California, Morocco, Peru, South Africa) but it is also present in some islands (Canary Islands, Dominican Republic), and in some particular inland sites with scarcity of water or precipitations (Ethiopia, Guatemala, Yemen, Tanzania). In this context, a natural phenomenon and a simple technological device can concretely influence the dynamics of a certain territory and its population.

Many differences in the fog water collection potentials have been determined for a variety of locations around the world. Collection rates range from 1 to 10 l/m^2/day, but they are known to be as 20–30 l/m^2/day1 in some regions (Schemenauer and Cereceda 1994a, b).

The collection rate depends on both environmental factors and fog collector design. The factors that determine the collection rate are the wind speed, the liquid water content of fog, the size distribution of the fog droplets and the design of the mesh material. The collection efficiency is most influenced by the role of the wind, with regard to both speed and direction. Schemenauer and Cereceda (1994a, b) and Marzol and Megia (2008) have shown that the optimal wind speed for collecting a good amount of water is between 3.5 and 9.0 m/s.

Figure 14.4 shows the collection rates for different locations in the world.

The evaluation of sites using SFC for fog collection projects is the first fundamental phase. The evaluation time must be at least a year long, to describe the water potential in the location and the seasonality of the phenomenon. It is necessary to distinguish rainfall from fog collection rate in the provision of water for human use;

Fig. 14.3 Fog collection projects using SFC and LFC around the world

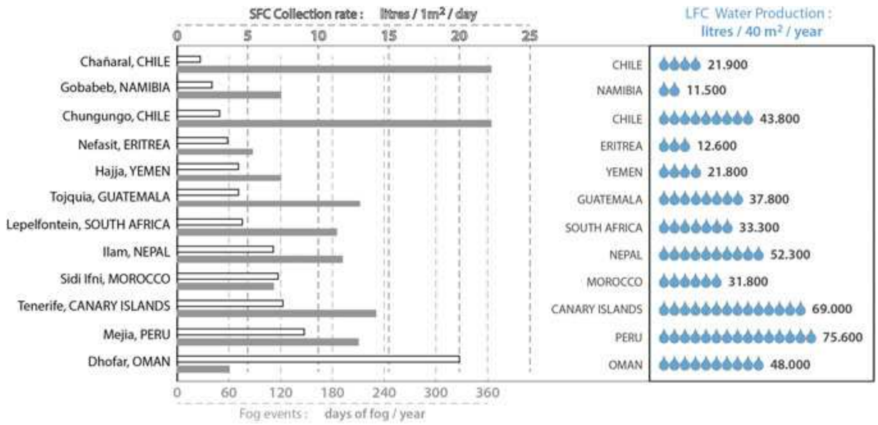

Fig. 14.4 Collection rates and fog water production for selected locations in the world

therefore, the installation of a weather station can be important to give accurate and contemporary data for all meteorological parameters.

The quality of fog water has been proved acceptable for human consumption (Schemenauer and Cereceda 1994a, b). This water is affected by both the surrounding air and the build-up of particles trapped in the mesh: however, most of the fog water harvesting installations around the world meets the WHO standards for metals and ions in drinking water (Abdul-Wahab et al. 2007; Klemm et al. 2012).

In Latin America the fog frequency is very high throughout the year, while in other regions there is less frequency but more collection capacity (Morocco, Canary Islands), still making efficient the use of water fog. In other areas where fog only occurs a few months in the year, such as Oman, Yemen or Eritrea, the storage of fog water for use as drinking water throughout the remainder of the year may be impractical (Schemenauer and Cereceda 1994a, b).

Case Studies

In the drylands, this technology offers an opportunity of sustainable development for small communities, villages or local ecosystems, whose basic needs are highly vulnerable. Moreover, the positive effects could be multiple, as for example the reduction of migration of people away from rural areas, the conservation of traditional activities, the support to local hydrology and ecosystem recovery, etc.

Our interest in research on fog water collection lies in some factors that can determine the success or failure of a fog collection project. For this reason, we have collected different case studies in the Atacama drylands to analyze and compare their development processes. First of all, they show that fog water is a valuable source of fresh drinking water for human consumption, gardening, and even for reforestation. These case studies reflect the features of other ongoing projects that have various elements in common. One of the main elements is the interaction and collaboration, on different levels, between the local communities and one or more active institutions/organizations, which can be a university research centre, an NGO or a government institution.

Therefore, particular attention should be given to the implementation factors for long-term success in community fog collection projects.

Chungungo—El Tofo—Chile

The fog water project in the village of Chungungo (La Serena, 29°26’52.0”S 71° 17’54.5”W) began in 1987 with the evaluation phase (Fig. 14.5). The work was run by a collaboration between the IDRC, International Development Research Centre of Canada, the investigators of the Pontifical Catholic University of Chile, and the National Forestry Corporation (CONAF).

In 1992, the research group installed 50 fog collectors and the Canadian Embassy provided funds to build a pipeline from the collection site to the village of Chungungo on the coast. The Chungungo Water Committee (CWC) was established as a local organization that included the whole community as partners.

The system grew until there were about 100 fog collectors, 7 km of buried pipeline, a storage tank and a distribution system in the village. An average of 15.000 l of drinking water was provided each day of the year, with peak water production exceeding 100.000 l per day (Cereceda et al. 1997). The Side by side

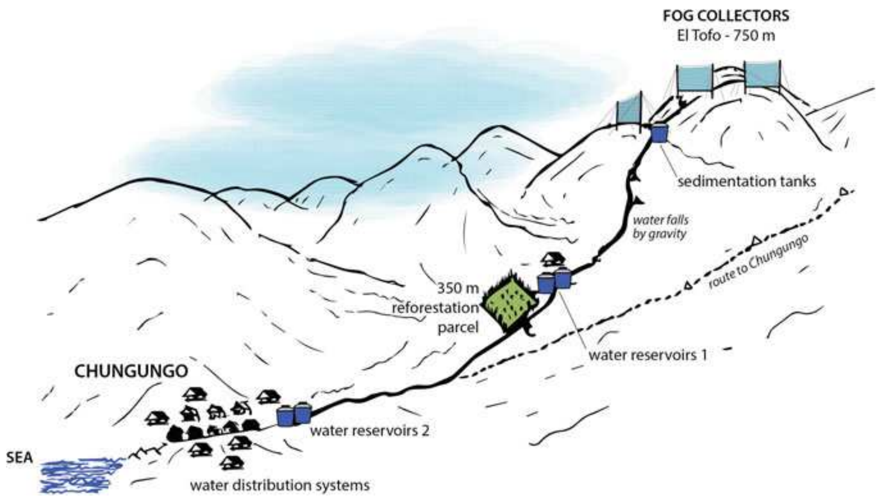

Fig. 14.5 Chungungo fog collection system scheme

with the FCS development, some projects were carried out, like the establishment of forest plots, a fish manufacturing plant and an agricultural orchard.

In the following years the community and the CWC were no longer supported in the management of the project, as a consequence administration problems began because the CWC failed to resolve different issues regarding water distribution, fog collector damages and operational maintenance (Edwards 2005). The maintenance of the fog collectors implied funds that were not available and the pressure of the community, which grew from 300 to over 600 permanent residents, determined the end of the project. In the early 2002, there were about 25 operating fog collectors and in 2003 there were none. Water began once again to be requested at a high cost through the tank trucks, as the community had done before the start of the project.

Chañaral—Falda Verde—Chile

The project began in 2001 to provide water to the coastal location called Falda Verde (Copiapò, 26°17’57.6”S 70°37’24.4”W), 5 km north of the city of Chañaral. The Atacama Fog Collection Group, a group of local fishermen, ran the project and installed 6 large fog collectors of 48 m^2, after 2 years of studies and measurements, supported by the FogQuest organization and the Pontifical Catholic University of Chile.

Fog collectors initially provided about 600 l of water daily to a greenhouse and an agricultural area in the coast. The greenhouse had tomato plants and the group started an Aloe Vera plantation in the field. A number of organisations provided the necessary funds through donations from the first installation to later additions, like the Rotary Club in Canada, the Australian Embassy and the AngloAmerican Company in Chile. In 2005, four new LFCs as well as some infrastructure to pipe and store the water were installed: this has increased the average daily water production to about 1000 l.

The group members have also built a path that starts from the cultivations and gets the fog collectors on the tops of the first range of mountains, connected with the network of trails of the nearby National Park of “Pan de Azucar”, attracting some tourists.

Actually, the Atacama Fog Collection Group manages the maintenance activities and sells the Aloe Vera produced (Fig. 14.6). The project has slowly developed over the years and has found its balance, managed entirely by the Group, producing alternative profits for the community.

Mejia—Lomas de Mejia—Peru

The first experimental campaign in Mejia (Arequipa, 17°03’46.5”S 71°53’19.7”W) was carried out from 1995 to 1999 in the framework of an EU project, with the aims

Fig. 14.6 Aloe Vera plantation in Falda Verde (courtesy of *Cereceda P*, CDA—Centro del Desierto de Atacama)

Fig. 14.7 Fog collectors in the Mejia Lomas (photo: *Elena Bresci, 1997*)

to reintroduce vegetation on the Lomas ecosystem and to investigate the effectiveness of fog collection technology (Fig. 14.7). Five Universities were involved, the San Augustin University of Arequipa from Peru, the Pontifical Catholic University from Chile and others from Europe, Padua, Florence and Toulouse.

In the experimental site of Las Cuchillas, located on the coastal hills close to Meija (Dept. Arequipa, South Peru) trees of native species (*Caesalpinaea spinosa* and *Prosopis pallida*) and exotic species (*Acacia saligna, Casuarina equisetifolia, Parkinsonia aculeata*) were planted in 1996, in order to check the rehabilitation potential of the degraded “lomas” ecosystems. The main project’s installations were 20 large fog collectors (with 6000 l average daily water production), three reservoirs, the drip irrigation system, an experimental station and plot.

After the end of the EU project, the tree plantation was monitored over a period of 14 years (2010). Among indigenous species *Caesalpinea spinosa* shows the highest rate of survival. The exotic *Acacia saligna* shows the maximum height, diameter and crown volume increments. The habitat conditions, both in term of diversity/frequency of plant and animal populations, and plant cover have changed substantially over the years. Overall, the tree-covered soil retained much more of both elements than the non-forested areas, thus demonstrating the efficiency of the intervention carried out in terms of combating the greenhouse effect. The various tree species planted, however, showed greatly variable capacity to promote carbon sequestration at soil level.

The water collected by the fog collectors was used not only for plant cultivation, but also for livestock water supply and small-scale farming. But once the goals were achieved, the project slowly ended because of the lack of involvement of the local people in monitoring and maintaining it.

Atiquipa—Lomas de Atiquipa—Peru

This case study is located in Peru, in the southern Lomas, vegetal formations similar to the Fog Oasis in Chile. The residents of the rural community of Atiquipa (Arequipa, 15°47’40.4”S 74°21’47.0”W) are the owners of the Atiquipa’s Lomas, extending across 30.000 hectares of land.

The first phase of evaluation with SFC started in 1995–97, developed by the investigators of the San Augustin University of Arequipa, in collaboration with the Atiquipa villagers. Then, they installed 28 fog collectors divided into two mountain sites, and different ponds thanks to the high water capture (Fig. 14.8).

Water was used essentially in the reforestation of 400 hectares with a plant of great importance to the community’s economy: the “tara” (*Caesalpinea tinctoria*) whose fruits are quoted in the local and international market.

The community involvement has been a key factor to achieve the restoration of a part of this ecosystem; currently the “Environmental Management Plan: 2005–2020” is active. It is overseen by the Atiquipa inhabitants, and the Lomas have received the recognition of “Private Conservation Area”.

These results show that it is possible to capture water enough to recover ecosystems and make subsistence farming through the irrigation of species with little water requirement and resistant to drought.

Fig. 14.8 LFC—Large Fog Collectors in the Atiquipa Lomas (reproduced from *González SM and Torres J* 2009)

Evaluation Criteria

Leaving aside the technical data for individual projects, our attention has shifted to the relationship between the stakeholders involved, and the social and economic aspects. Inside these aspects, which have a wide range definition, we can find the key criteria for the implementation of future fog collection projects.

From the point of view of management processes, past and ongoing projects have shown some limits in the methodological approach. Therefore, priority must be given to the effectiveness of participation processes and management tools, and in any case on the will of all the stakeholders involved.

From the point of view of the community involvement and perspectives, the analysis allowed us to identify some essential factors in the development of a fog collection project, among which the most important are the long-term and active presence of a local organization, the community participation and training and the continuous participatory redesign of the project with all the stakeholders involved.

Methodological Approaches—Participatory Processes

The interest in research on fog water collection does not only lie in the technical aspect because there is enough literature that considers the issues of technical improvement, mesh technology, water sanitation and every aspect to be taken into account in the evaluation of a potential fog collector site. The real interest is in future applications, and what really matters is that water resource will be essential to improve the quality of life of rural communities (Marzol and Megia 2008) and their surrounding arid landscapes.

The first step is to identify a social need for water. There must be a community with a requirement for more water or cleaner water while conventional means are not able to satisfy their demand (Batisha 2015). In this case, there is a critical point to be solved at the beginning of every type of intervention: the commitment of the community to be an active partner of the project.

Another point of particular importance at the beginning is the identification of a local non-governmental organization (NGO), or other organizations, who work directly in the territory. The organization will have the task to provide training, education and the on-going support for the participation of the community. It is important to have the local population participate in decisions on the water applications, participate in the construction of the system, and, as far as it is practical, take over the maintenance and operation of the system (Batisha 2015).

Therefore, the first phase of the evaluation of fog water potential must be carried on in parallel with the analysis of the community´s social, cultural and economic status. The social impact of this type of project and the possibility of a new source of freshwater should be managed by means of a series of community meetings and specific meetings with the women of the village who may be excluded from the village organizational structure. The elders and community councils usually manage community organizational and social structures. Considering these structures, another fundamental factor is the creation of a specific committee for the water management. In this way, the community is empowered and in a legal position to seek out financial and project assistance from different sources. Membership rests on the belief in their founding principles, commitment to the group and collaborative participation (Rosato et al. 2010). The role of the local organization is to ensure the water committee activities and an appropriate and functional water management programme.

In fact, a project that involves the use of new resources and the involvement of the local population must consider a management methodology in the form of an integrated management plan. This implies that the first decision to proceed with the project is made by all the stakeholders involved: the community, the local organization, the sponsors, the institutions. Then the respective skills come into play in a continuous participatory redesign of the project, where technical adjustments and goal corrections must be agreed with community members.

Some projects end when the management passes to community responsibility, because of some common causes: operating costs, poor maintenance, administrative difficulties and lack of involvement. For example, in the Chungungo project only a half of the community members know that the fog collector system was a donation from the institution involved. The village was located 7 km from the LFC and local population had no connection with the fog resource environment resulting in poor knowledge of fog behaviour. All these factors were reflected in a low overall involvement with FCS, resulting in low community participation. This resulted in a low community commitment with the CWC and thus in an inappropriate maintenance of the fog collectors, affecting the efficiency of the FCS.

In the case studies and in other fog collection projects, the population of the communities ranged between 100 and 500 people. High levels of independence were reported in communities with few inhabitants. The belonging to small communities makes the individual person more responsible for the project. Particularly, women need to be involved starting from planning to the implementation stage as they are the primary users and direct beneficiaries of the collected water (Fessehaye et al. 2014).

It is important to understand that the community members are not only the beneficiaries of the project, but in particular they are the main players who will manage the project and the future social impacts. The more the people are encouraged, permitted and willing to invest (within their means of possibility), the more convinced they will be of the project and the higher the likelihood of long-term success. Strong enough long-term commitment to the project is essential to a successful transfer of technology and active, ongoing management by the community. Continuing to support and facilitate this local capacity development has been identified as a crucial objective in the next phases of the project.

To ensure the economic management, during all the development project steps, exit options must be taken into consideration. That may happen very early, before any test measurements are being started, before the decision of construction of large collectors, or after the LFC production phase with limited success (Klemm et al. 2012).

Methodological Approaches—Funding and Costs

In the economic evaluation of fog collection projects, it is preferable to adopt a planned management rather than a process of cause-effect. The latter choice would be the simplest, consisting in the birth of a project idea, fundraising, and the achievement of results: but the focus must be shifted from the result to the method (Fig. 14.9).

An economic study, undertaken to ensure that the projected water costs will be favourable in comparison to other alternatives such as tanker trucks or water pipelines.

The beginning of a project of collecting fog water has to follow the phase of consultation between the stakeholders. Then Initial funds and expertise typically originate from outside.

These funds must be raised from a sponsoring agency with an interest in the territory, from donors who are willing to support the proposed project, or from organizations with a focus on supporting water projects in developing countries.

Typical funding agencies are private and corporate donors, NGOs, UN agencies and the European Union. In many cases, there is a lack of information about potential money sources. For example, in the Atacama region, belonging to Chile and Peru, funds are offered by governmental organizations the local municipalities,

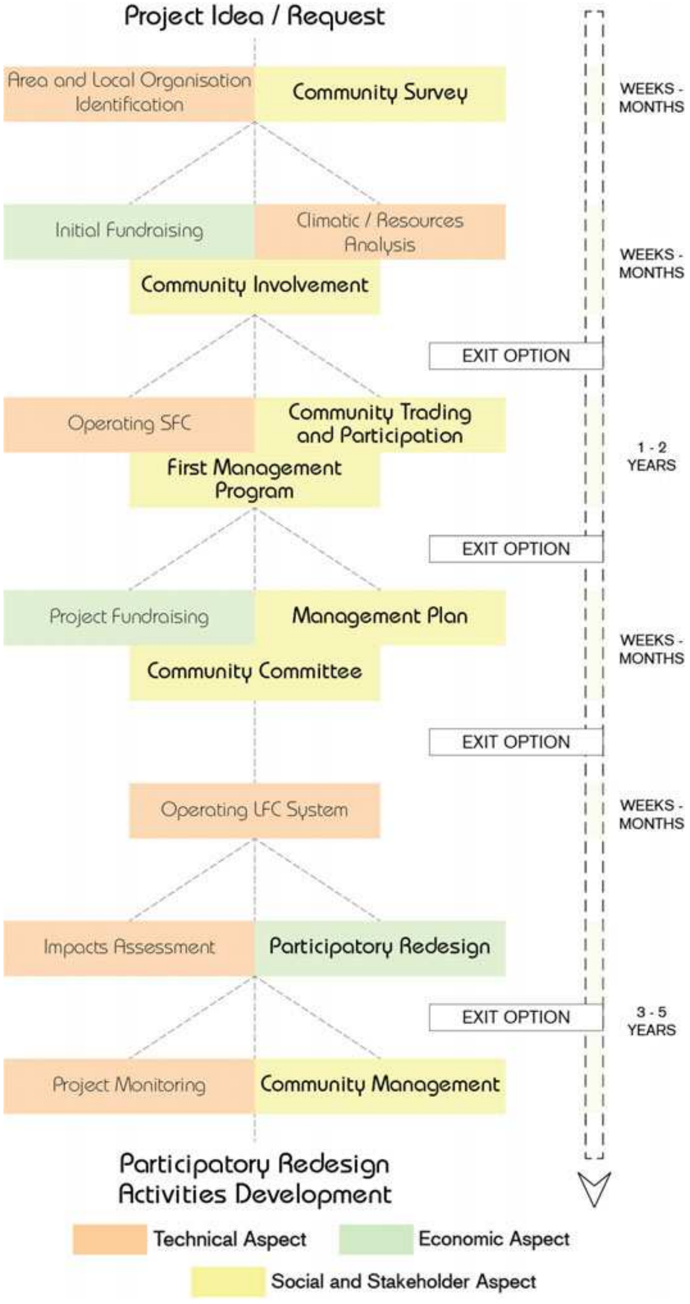

Fig. 14.9 Methodological approaches: hypothesis of a management programme for a fog collection project

private companies and foreign embassies, but local people are not aware of these funds.

The private sector, represented by many industrial companies and mining industries which operate in the Atacama drylands, can be interested in projects of environmental compensation to make up for the pollution they produce and to take advantage of financial opportunities. Environmental compensation is compulsory in Chile, like in many other countries.

One vital source of funds is the community interested in the water project. Not because they have a lot of money to provide, but because their monetary commitment shows their serious involvement in the project. It shows they are not simply looking for a gift but they are rather an active partner in the project.

A complete SFC setup costs around 150 USD, depending on the local market situation. If a field programme with a complete meteorological station is required, then an additional 2.500 USD in instrument and travel costs may be involved plus time for data analysis (Klemm et al. 2012). The estimated start-up cost for an installation of a complete LFC system for a rural village of 150 people on the Atacama coast is of around 75.000 USD, assuming no costs for salaries in external NGOs (Klemm et al. 2012). The cost includes collectors, pipes, storage tanks and, distribution system for an installation with a target goal of 30 l/capita/day, requiring approximately 20 large fog collectors, or around 750 m^2 of mesh, considering an average collection rate of 6 L/m2/day. A fog collector project in Lima that considers 100 LFC at 350 USD per collector and 500 USD for annual maintenance, shows how an investment of 35.000 USD being paid back after a period of 8 years. Obviously, the funds required depend on the scale of the project and its location.

The integrated management plan of the project should include strategies and funding for ongoing support, unanticipated expenses and repairs and it must require the necessary participation and involvement of the local community in maintaining and managing the installations. The availability of time may be the best possible investment from the community because maintenance requires monitoring, regular tightening of support cables and mesh, immediate repairs to any minor tears, inspections of reservoirs and distribution systems, etc.

Through participatory redesign, it is thus possible to monitor activities and financial aspects, allowing the direct users and potential new investors or sponsors to be informed and given awareness on new project goals and interventions.

As the case studies shown, there are advantages to fog collection projects when they provide benefits and profit for local populations, besides increased water availability (Fig. 14.10). Therefore, local populations could consider their participation as an investment, regarding themselves not only as a marginalised group of neighbours trying to improve their livelihood, but as a group of investors starting their own business (Batisha 2015; Klemm et al. 2012).

Fig. 14.10 Fog collector system and community members in Falda Verde, Chañaral, Atacama (courtesy of *Cereceda P*, CDA—Centro del Desierto de Atacama)

Conclusions

Fog collection, as an alternative source of freshwater, does not represent a global solution for the problem of water availability in drylands, but it allows intervene in a specific way in local situations, usually neglected by the infrastructural innovations that are applied to the most densely inhabited and productive areas of a territory.

A good number of projects show the opportunity to perform various activities: drinking water for human consumption, reforestation and agricultural production. These activities can generate small business and social initiatives and have positive effects on the territory, at an ecological and cultural level. In a holistic landscape framework, these positive effects are reflected on the arid lands' safeguard and local development, thanks to research, educational activities and sustainable tourism. Ecological factors should be considered because fog collectors does not require on-going energy inputs and could be useful for carbon sequestration in connection with reforestation (Batisha 2015).

From the point of view of management processes projects have shown their limits in the methodological approach. The analysis of some different case studies in the Atacama drylands shows that community participation is vital for the elaboration of plans and activities, which improves monetary income and at the same time can provide fund and labour for FCS operation and maintenance. Real sustainability will be reached when the beneficiaries are themselves managers of a fog water collection system. Capacity building, awareness motivation, education and training of the local people are key success factors (Rosato et al. 2010).

The role of a local organization, aiming to implementing all aspects of technology and management, is much more appropriate to offer a long-term role promoting fog collection projects than a foreign-sponsored institution who might withdraw from that territory.

This work reviewed, compared and discussed experiences and theoretical materials, with the purpose of exchanging information and underlining some critical aspects of fog collection project management. Starting from practical experience, we propose an operative framework for stakeholders involvement and a participatory approach based on the redesign concept, with the objective of facilitating future fog project implementation and support the translation of this alternative technology to various local situations in drylands.

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