CUVEwaters integrated water resources management

Groundwater Desalination – Implementation Concept

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Abbreviations

ASE	Aqua Services & Engineering
BMBF	Federal Ministry of Education and Research
DME	Deutsche Meerwasserentsalzung e.V.
DRFN	Desert Research Foundation of Namibia
DWSSC	Directorate of Water Supply and Sanitation Coordination (formerly Directorate of Rural Water Supply)
EC	Electrical conductivity
IBEU	Ingenieurbüro für Energie- und Umwelttechnik
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
IFAT	Weltleitmesse für Wasser-, Abwasser-, Abfall- und Rohstoffwirtschaft/ World's Leading Trade Fair for Water, Sewage, Waste and Raw Materials Management
ISE	Institute for Solar Energy Systems, Fraunhofer research organisation
ISOE	Institute for Social-Ecological Research
IWRM	Integrated Water Resources Management
LC	Local caretaker
MAWF	Ministry of Agriculture, Water and Forestry
MD	Membrane distillation
MoF	Ministry of Finance
MSD	Multi-stage desalination
NAD	Namibian Dollar
NamWater	Namibia Water Corporation
NUST	Namibia University of Science and Technology (formerly: PoN)
O&M	Operation and maintenance
PoN	Polytechnic of Namibia (see: NUST)
RO	Reverse osmosis
SEIA	Social-ecological impact assessment
SIJ	Solar-Institut Jülich
TDS	Total dissolved solids
TU Darmstadt	Technische Universität Darmstadt
UNAM	University of Namibia
WPC	Water Point Committee

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Objectives of implementation concept

This implementation concept gives an overview of all the preconditions, procedural issues and results relating to the pilot implementation of groundwater desalination technologies, with regard to technological, institutional, social, economic and ecological dimensions. The document provides some brief information about these aspects and refers to further publications for deeper insights. The fundamental objectives of the implementation concept are as follows:

1. To support communication with partners in Germany and Namibia
2. To ensure strategic planning of future sustainable implementation of CuveWaters technologies
3. To support internal work processes and knowledge management
4. To refer to associated documents, as well as to products and results of the technologies

1. Initial situation

1.1 Problem situation

Arid or semi-arid regions are often characterised by saline groundwater and a lack of perennial surface water bodies; this is particularly true for central-northern Namibia near the Etosha salt pan.

The non-perennial surface water bodies in northern Namibia are called Oshanas (plural: Iishana). They occur during the rainy season and drain towards the Etosha salt pan, while during the dry season they evaporate completely due to the high solar radiation which causes an evaporation rate of more than 2,500 mm per year. The population density – and also the cattle density – is high within the wider area of the Oshana flow regime, resulting in overgrazing. Outside the Oshana flow regime there are no surface water bodies, and the groundwater is saline.

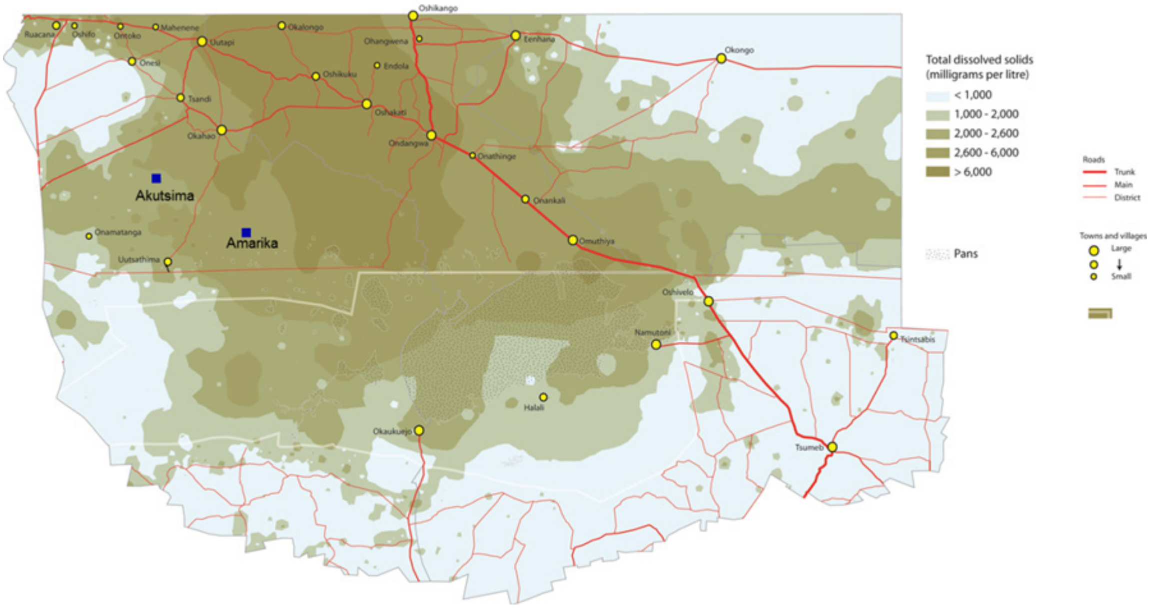

Fig. 1: Salinity of groundwater in central-northern Namibia

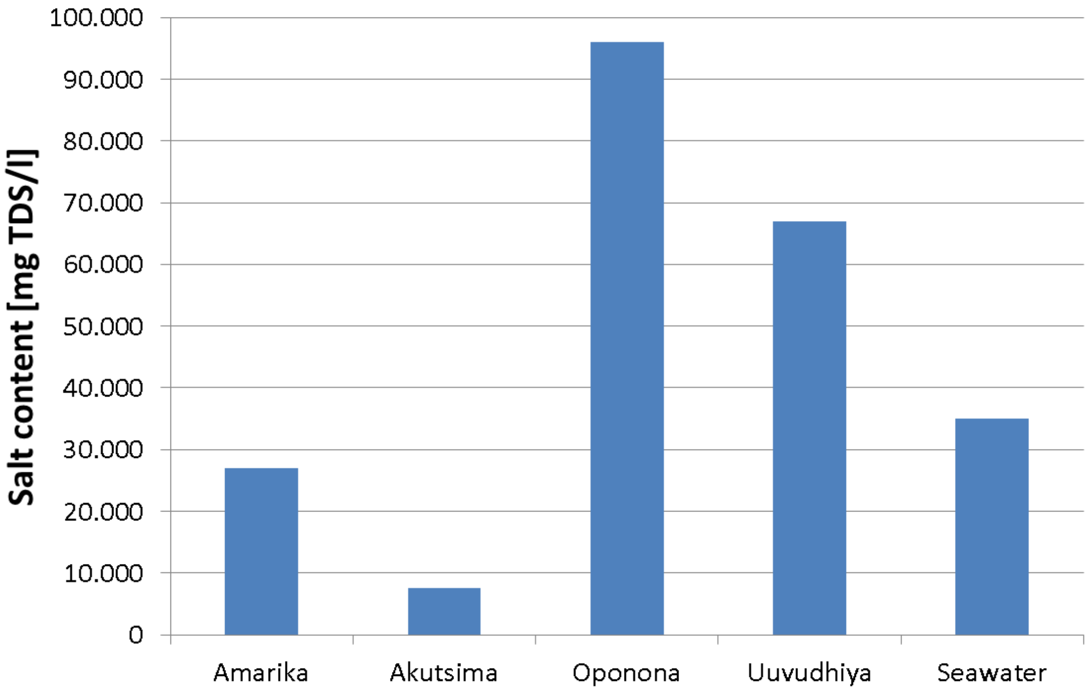

Fig. 2: Salt content from different boreholes in central-northern Namibia (source: CuveWaters)

The salt content of the water from boreholes in the region varies from brackish to seawater quality and above (see Fig. 1). The highest salinity measured by CuveWaters was in 2007 in Oponona, where the salt content was three times higher than seawater (see Fig. 2). The salt content in Amarika (one of the later pilot villages) is slightly lower than seawater (27,000 mg TDS/l) and in Akutsima (the second pilot village) the raw water is brackish (7,500 mg TDS/l).

Northern Namibia has a major water supply scheme which is fed by water from the Kunene River that is taken from the Calueque dam in Angola. The water is transported through an open channel and is purified in four water treatment plants up to potable water (NamWater 1998) before being distributed by a water grid to the population for a large variety of purposes. One third of the Namibian population depends on Angola for its water supply, and this is seen as a major disadvantage. However, this water grid only reaches urban, suburban and peri-urban areas, while rural communities and cattle posts are mostly not served.

The rural population living in such areas is traditionally supplied by hand-dug wells, the so-called *omufinas*. These shallow wells have a very simple construction and fill up with water during the rainy season. The water quality in these wells is poor and the water is biologically contaminated with waterborne pathogenic microorganisms (i.e. by E.coli and coliform bacteria) causing e.g. malaria, diarrhoea, typhoid fever and poliomyelitis. In addition, it is also chemically contaminated (by excess concentrations of total dissolved salts, sulphate, chloride, sodium, fluoride), so it is classified as unsuitable for human consumption (NamWater 1998). The possible health effects of saline and contaminated water have been described in a state-of-the-art review by Sander (2010). The Directorate of Water Supply and Sanitation Coordination (DWSSC) provides chemicals (flocculants with chlorine) for purification of water from the hand-dug wells; nevertheless, the local population suffers from waterborne diseases.

1.2 Political framework, governance and institutions

The DWSSC within the Ministry of Agriculture, Water and Forestry (MAWF) is responsible for the water supply for human consumption and has branches in every region of Namibia. These regional branches are responsible for the construction, operation and maintenance of the water pipelines and boreholes in rural areas, where local Water Point Committees (WPCs) are responsible for the distribution of water and the collection of water fees. WPC members are also members of the local Water Point User Associations, which consist of community members who use a water point for their supply needs. See Werner (2008) for more information on the political and institutional framework of water supply.

The parastatal Namibia Water Corporation (NamWater) constructs, operates and maintains large water supply schemes (e.g. dams and wells, treatment plants, pumping stations, tanks, transmission lines), providing cities with drinking water. However, it usually does not distribute the water itself to the end-user. This is the responsibility of the municipalities or – in rural areas – of the DWSSC.

1.3 Local demand

The villages of Amarika and Akutsima (Omusati region) are located about 40 km away from the existing water grid. There are also no Oshanas in the region, so that the population is obliged to get its water from hand-dug wells. The wells fill up during the rainy season, while during the dry season they become salty and highly microbiologically contaminated. The raw water available from shallow groundwater is thus unsuitable for human consumption, which is shown in more detail by Wanke et al. (2014).

The population density is low in these areas of the Omusati region. The population encompasses about 50 households in each village, with an average of 5 to 9 people living in each household. There is considerable variance, the highest number being 17 people per household. Almost all the water used for human consumption comes from hand-dug wells. A few households are sporadically supplied with tap water brought by lorry from the reservoir of a larger village nearby.

There are no reliable numbers regarding the water demand. Community workshop participants in 2009 estimated that water collected at hand-dug wells amounted to 20 to 25 l per household per day which can be easily measured by the number of carried jerry cans[1] with 25 l content. The main disadvantages of the shallow hand-dug wells are seen as follows by the local residents: fluctuating supply (wells can run dry or overflow); water quality degradation, which is a particular problem for children; fetching water is a risky procedure (accidents can occur when entering the well); insufficient water quantity and quality for cattle during some seasons.

1.4 Analysis of local capacities

The level of education in villages such as Amarika or Akutsima is low. Most of the residents speak the local languages, but no or very poor English. Reading and writing skills are limited. The schools in most of the villages are up to the 4th grade. If children attend secondary schools, they have to leave the village for boarding schools in the region, which is very common.

[1] http://blog.charitywater.org/post/143491921667/the-story-behind-the-jerry-can

1.5 Socio-economic aspects

The following socio-economic data (from a standardised baseline survey undertaken in 2010) describes the population of Amarika and Akutsima (Sander/Deffner 2011). The age structure of households in the two villages is shown in Tab. 1. In both villages, “receiving a pension grant” and “selling various items” are among the two major sources of household income. The third major source of household income in Amarika is “helping others”, whereas in Akutsima it is “receiving a salary”. In addition, more households in Akutsima receive outside assistance (mostly money). If one looks at monetary income, households in Akutsima are thus better off than those in Amarika.

More interviewees in Amarika than in Akutsima report that the householder also owns cattle, although the number of cattle reported is slightly higher in Akutsima than in Amarika. The three main household expenses that were cited in Amarika are food, school fees, and hospital fees. The main household expenses in Akutsima are soap and clothes, while food, school fees and basic needs are in third place. For more details, please see Sander/Deffner (2011).

	Amarika (n = 22)	**Akutsima** (n = 33)	**Onakatili** (n = 7)	**Total** (n = 62)
Percentage of households with children under 1 year old	18% (n = 4)	15% (n = 5)	29% (n = 2)	18% (n = 11)
Percentage of households with children between 1 and 5 years old	68% (n = 15)	49% (n = 16)	86% (n = 6)	60% (n = 37)
Percentage of households with a person aged 60 or over	41% (n =9)	36% (n = 12)	43% (n = 3)	39% (n = 24)

Note: Detailed information on the age structure of the household is not available for three households in Amarika

Tab. 1: Age structure of the households

2. Approach

2.1 Aim of implementation

The purpose of implementing the desalination plants is to ensure that people in rural areas have access to a safe and reliable supply of clean drinking water all year round, thereby reducing the occurrence of waterborne diseases.

The villages of Akutsima and Amarika in the Omusati region were ultimately selected as implementation sites; they were chosen in close collaboration with the Namibian government/ the MAWF. The criteria for selecting settlements as pilot sites were as follows (see final project report for CuveWaters project Phase I delivered by TU Darmstadt):

- Remoteness: the settlement should be far away from the existing water supply network
- Suitability: the raw water should be suitable for desalination
- Sufficiency: the small-scale desalination plants should be able to provide enough drinking water for the population, so only small villages were taken into consideration

The MAWF supported this process by manifesting considerable interest and formulating the demand for small-scale solar-powered desalination plants.

In addition, it was estimated that the total costs for these plants should be within the same range as those for alternative ways of supplying water to remote areas, such as supplying water via tankers or extending the pipeline grid to these areas (see Chapter 4). One foreseeable future risk is that decision-makers will opt for one of the alternatives in the long term, for reasons which are unrelated to costs, e.g. the extent to which each system can be provided by local companies and manufacturers, or the extent to which the necessary investment can be kept in the country.

The main advantage of the desalination subproject, which focusses on small-scale solar-powered desalination, is the suitability of this technology for the decentralised water supply of small remote communities. However, this also constitutes a risk factor: small remote communities are often insufficiently “visible” to decision-makers. In addition, the small absolute numbers of people benefiting from such projects, as well as high expected investment costs and low recovery costs, could push such projects even further down the list of priorities for investors and decision-makers.

2.2 Specification of the technology

Four different desalination pilot plants (prototypes) were installed in the villages of Amarika and Akutsima (see Tab. 2). The four plants were selected on the basis of the following criteria developed by the MAWF and CuveWaters:

- Operation with solar power
- Maximum drinking water production of 5 m^3/d
- Robustness and low maintenance requirements
- Quality of product water has to meet Namibian drinking water standards
- Mobility and ease of relocation when faced with changes to local conditions
- Existence of reference plants in (semi-)arid countries

Based on these criteria, four manufacturers with their specific technological approaches were selected. These manufacturers and the respective types of plants are listed in Tab. 2.

Manufacturer	**Type of plant**	**Location**
pro|aqua GmbH	Chemical-free reverse osmosis (RO)	Amarika
Fraunhofer ISE	Membrane distillation (MD)	Amarika
Terrawater GmbH	Evaporation (E), chemical-free	Akutsima
SIJ/IBEU	Multi-stage desalination (MSD), chemical-free, runs without electrical power	Akutsima

Tab. 2: Desalination plants that were installed

Distillation plants are generally considered to be more robust and have lower maintenance requirements but higher energy demand, so only one reverse osmosis plant was installed.

After construction, the plants’ technical performance was closely monitored for 1.5 years, and adaptations were undertaken as required. Tab. 3 summarises the plants’ most important features during the monitoring period.

For more details, please see the project factsheet on desalination (Liehr et al. 2015).

	pro|aqua	Fraunhofer ISE	Terrawater GmbH	SIJ/IBEU
Technology	Reverse osmosis	Membrane distillation	Evaporation	Multi-stage flush desalination
Start of operation	July 2010	July 2010	July 2010	December 2010
Production of fresh water	Avg: 3.3 m^3/d Max: 4.7 m^3/d	Avg: 0.8 m^3/d Max: 1.7 m^3/d	Avg: 1.4 m^3/d Max: 2.1 m^3/d	Avg: 0.25 m^3/d Max: 0.6 m^3/d
Design capacity	5.0 m^3/d	5.0 m^3/d	4.0 m^3/d	0.6 m^3/d
Conductivity of fresh water	980 µS/cm	480 µS/cm	6 µS/cm	5-10 µS/cm
Raw water demand	14.1 m^3/d	6.7 m^3/d	16.7 m^3/d	1.2 m^3/d
Brine production	10.8 m^3/d	5.9 m^3/d	15.3 m^3/d	0.6 m^3/d

Tab. 3: Key data on the pilot plants, including average values from measurements during the monitoring period (July 2010 to December 2011)

2.3 Profitability analysis

Rough estimates of profitability were made during the planning process for implementation of the desalination plants. Later empirical results from monitoring form the basis for sound cost-benefit calculations with dynamic prime cost analysis; detailed information is presented in Chapter 4.

2.4 Stakeholders

Stakeholders with a defined organisational function in the operation of the plants are the MAWF with the regional DWSSC branch, the WPC, the local caretaker, the service provider, and the plant manufacturers. Please see Chapter 3.2 for details of the operational concept and the stakeholders' roles.

Further stakeholders with important roles in the whole process of implementation and operation are the residents of the two villages, the headman, the regional governor, and the regional council; see also Chapter 1.2.

2.5 Capacity development

Maintenance of the plants was organised at two levels: a local caretaker performs everyday minor repairs, while external professional engineers (service provider) are responsible for regular (major) maintenance work and troubleshooting. The local caretaker (LC) is recruited locally, while the service provider should be a professional working company that is already active in maintaining water infrastructure in the region. The LC and service provider are trained by the manufacturer during the installation of the plants. They subsequently receive support from the manufacturer via satellite phone and data transmission, and from the service provider, particularly when it comes to maintaining the plants.

In addition, handbooks and manuals for the LC and service provider are offered. The service provider handbooks give a detailed overview of the plant and its function, guidelines for regular maintenance, and troubleshooting advice for special cases. Those aimed at the LCs summarise and clearly present their everyday tasks, as well as giving general information on the plant and guidelines for minor repairs.

The two villages still lacked any kind of water infrastructure, so new WPCs needed to be set up. Extension officers from the regional DWSSC (supported by the project) assumed responsibility for this process and for the training.

2.6 Social embedding

Establishing ownership of all the facilities is crucial if one is to prevent misuse and vandalism. The communities of the two villages therefore need to be included in the planning process, as well as in the installation and operation of the plants. The aim here is to increase the likelihood that the communities will adapt to the new water source and assume responsibility for it at a later stage, thereby reducing the risk of vandalism or theft. From a methodological perspective, this can be achieved via the newly developed "demand-responsive approach" (see Deffner/Mazambani 2010), which includes methods drawn from social sciences and participatory planning. This approach was developed by CuveWaters and the DRFN, its aim being to involve stakeholders: residents via community workshops, and local and regional authorities via cooperation and exchange workshops. This process consists of an iterative discussion and adaptation of the technological solutions.

In this way, social aspects are addressed via participatory planning, which begins from the very outset in order to reduce the risk of any misunderstandings. Users' specific needs and opinions are examined in community workshops.

2.7 Impact

The way in which the availability of clean drinking water impacts positively on well-being, livelihoods, and the consumers' state of health in particular needs to be assessed during the pilot phase. This is accomplished via socio-cultural monitoring, health studies, and social-ecological impact assessments in Amarika and Akutsima.

3. Implementation

3.1 Work packages and time schedule

The detailed planning was undertaken in close collaboration with the four plant manufacturers and the seven companies that were involved. It is very important to define the specific requirements and responsibilities at every interface: energy supply, water supply, brine disposal, data transmission, measuring programme, and logistics.

Given the remoteness of the sites and the lack of infrastructure, the installation phase can prove challenging and should be planned well in advance, in conjunction with local companies and authorities. The importation and transportation of the plant and its various parts can also be quite protracted, so enough time should be allowed for this.

The implementation phases and time schedule for the whole process from concept development to the marketing of results are summarised in Tab. 4. These phases can be used in future transfer processes for the comprehensive planning and monitoring of the various activities.

Implementation phase	Principal activity	Time frame
1	Concept development	2006–2007
2	Demand analysis, "demand-responsive approach" and site selection, including community workshops	2007–2009
3	Planning of preliminary works	07/2009–01/2010
4	Construction of preliminary works and desalination plants	01/2010–07/2010
5	Shipping of plants	05/2010
6	Installation of desalination plants and training of service providers and local caretakers	06/2010–07/2010
7	Operation, maintenance and monitoring, including community workshops	07/2010–09/2013
8	Handover of well-running plants to the Namibian government (MAWF)	11/2013
9	Provision of support to the MAWF after handover, including training of the DWSSC to coordinate services, plus preparation of a training concept for technicians and operators	10/2013–12/2015
10	Evaluation, including cost-benefit analysis and study of financing options	10/2013–12/2015
11	Marketing (fairs, conferences, round tables, publications, factsheets)	10/2013–12/2015

Tab. 4: Implementation phases and time schedule for the implementation of the CuveWaters desalination plants

3.2 Operational concept

The operational concept will determine whether or not the plants will run in the future. The roles and responsibilities of the institutions and players involved (and their interactions) are described in Fig. 3. A binding commitment on the roles and responsibilities of all the parties involved will breathe life into the operational concept. Together with the commitments made, this will form the basis for the technology's long-term success beyond formal completion of the project.

According to Fig. 3, the operational concept with defined roles and responsibilities of the key stakeholders are as follows:

The **coordinator (DWSSC)** manages the servicing of the plant. He receives information about any problems that occur (either on the phone from the LC or via the automatic status report from the plants) and decides how to react. The coordinator is also responsible for allocating the budget for servicing, and it is thus up to him to decide whether it is necessary to call the service provider or whether the servicing can be undertaken with internal resources. He receives advice from the plant manufacturers. During the pilot phase, TU Darmstadt coordinated the servicing and maintenance of the plants; after the plants were taken over by the MAWF, this role was assumed by the regional head of the DWSSC in the Omusati region.

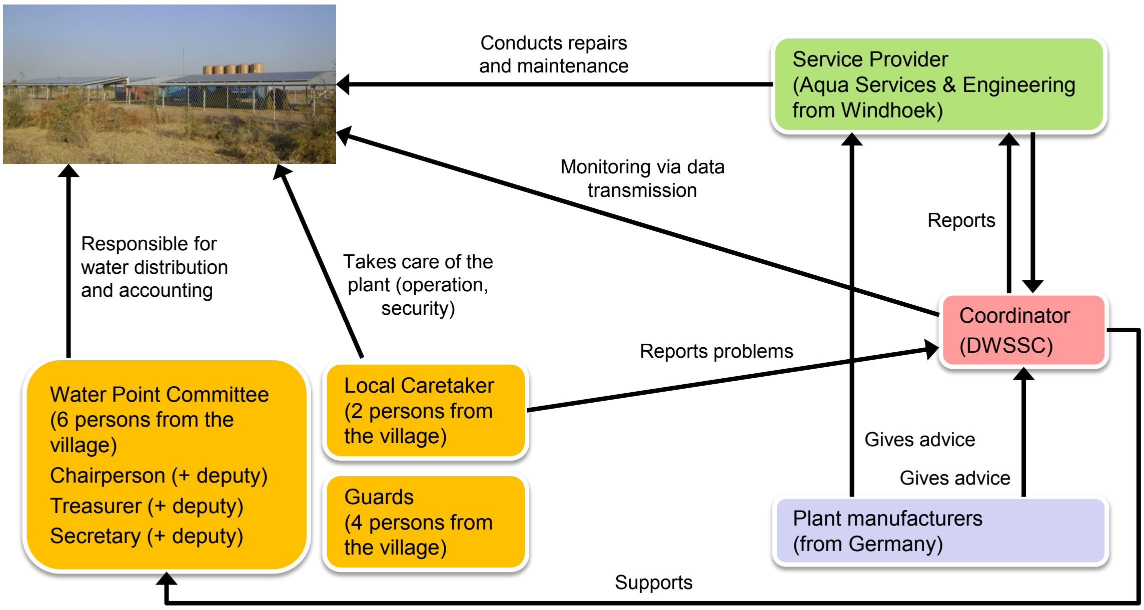

Fig. 3: Summary of the operational concept

The **Water Point Committee (WPC)** is a volunteer but legally installed institution in Namibia, normally managing a water point (e.g. at a borehole or a communal water point of the water grid). It consists of a chairperson, a treasurer, a secretary and their deputies. Similar to the structure at traditional water points, the WPC is responsible for the plant, and especially for distributing and selling the water, as well as deciding how the collected money will be used. The WPC members are usually elected from the community and receive no salary.

Local caretakers (LC) are village residents who are elected by the community. They receive training during the installation of the plants and in subsequent operator training sessions from experts in practice. They are present every day at the plant sites in order to keep them tidy and in good working condition; they contact the coordinator if there are any malfunctions. The caretakers are paid and have generally proved to be very reliable. After multiple trainings and successful applications on site, one of them received a certificate as a purification plant manager from the project. There are also four guards at every site who are responsible for the security of the plants. They are elected by the community and also receive a salary.

The **service provider** plays a key role in the concept. It is a professional company from Windhoek (Aqua Services & Engineering) and was probably the only local company with the expertise to undertake this role when a service provider was chosen. The service provider's staff were trained during the installation of the plants and gained extensive experience of maintaining them during the two years of the pilot phase. The service provider is responsible for ensuring that knowledge about the plants is kept within the company. It also remains in close contact with the plant manufacturers via mobile or satellite phone. A service technician based in Oshakati who can repair and maintain most of the mechanical parts (pumps, leakages, filters etc.) visits the plants every two months. An electrician visits the plants twice a year in order to maintain the electrical equipment (controller, photovoltaic system, data transmission etc.). The service provider also takes water samples for the nationally mandated water analysis.

Additional note: After the handover, the MAWF decided that the intended roles and responsibilities of the service provider will be taken over by trained staff members of the DWSSC. This does not impact CuveWaters' advice, namely to consider a service provider who is well trained with the respective technologies and their maintenance requirements, despite the higher administrative effort of contracting.

The **plant manufacturers** advise the service provider when it comes to identifying faults and possible solutions. During the two years of the pilot phase, the manufacturers monitored the plants via data transmission (satellite or network).

3.3 Framing activities

3.3.1 Capacity development

The partners receive training on implementation of the solar-powered desalination plants. This training deals with the following aspects: know-how relating to analysing possible sites for solar-powered desalination plants; establishing the necessary infrastructure for the plants; transportation from the plant manufacturer to the installation site; on-site installation; commencement of operation and maintenance.

Training of local caretakers and the service provider during installation of the plants – as well as constant support and on-the-job training – were integral parts of the project. Initial operational experience revealed that the training offered was sufficient for the service provider because they gained the skills required to maintain and repair the plants. On the other hand, further training of local caretakers was necessary and additional sessions were conducted in October 2010 with the help of the service provider. The general lack of technicians and operators in Namibia became evident during this training, so a more general vocational course for water and wastewater technicians and operators was designed and carried out in 2011. The training programme with its modules and the duration of this course are presented in Tab. 5.

Module	**Time**	**Location**
Self-management course for students	26.04.-29.04.2011	Hotel Alexander, Windhoek
Process technology: the basics	15.06.-08.07.2011	PoN (NUST), Windhoek
Installing and getting to know the equipment (techniques) – incl. specifics	10.08.-16.09.2011	Water treatment plant, Windhoek
CuveWaters desalination plants	10.10.-04.11.2011	Amarika, Akutsima, Outapi

Tab. 5: Training programme for water supply/wastewater engineering technicians and operators

A total of 12 participants attended this course, including the local caretakers, members of the DWSSC and Outapi Town Council (OTC), as well as employees of ASE (the service provider).

Further framing activities (including participatory planning, assessment of the health situation in the villages, evaluation of the concept's sustainability, and a financial assessment) are presented in other chapters of this document.

3.3.2 Social-ecological impact assessment (SEIA)

The desalination plants are solar powered, so there are no negative ecological impacts due to emissions of greenhouse gases. However, the desalination process produces brine as well as fresh water. Two options are examined for brine disposal: re-injection to aquifers and evaporation within ponds. The most suitable option depends on the hydrogeological conditions.

There are permeable soil layers in Amarika, and the salinity (measured as electrical conductivity EC with the µS/cm unit) increases with depth (see Tab. 6).

Description (borehole depth)	**EC (µS/cm)**
Raw water in Akutsima (50 m)	7,500
Brine in Akutsima	8,500
Raw water in Amarika (50 m)	35,000
Brine in Amarika	43,400
Re-injection borehole in Amarika (90 m)	45,800
Re-injection borehole in Amarika (126 m)	53,300
Re-injection borehole in Amarika (150 m)	62,200

Tab. 6: Salinity (measured as electrical conductivity) in Amarika and Akutsima

The raw water is extracted from a depth of less than 50 m, whereas the brine is re-injected in three boreholes with a depth of 90 to 150 m. The salinity of the groundwater in those deeper layers is already higher than the salinity of the brine. In this case, the re-injection of brine has no negative effect on the groundwater quality. The capacity of the three re-injection boreholes is quite low, so an evaporation pond was also built in case the boreholes failed.

No shallow groundwater was found at the location of the desalination plant in Akutsima; only dry impermeable clay was encountered to a depth of 50 m. Geophysical investigations did not indicate any aquifers nearby. Re-injection is not an option in this case, so an evaporation pond was built. The impermeable layer of clay meant that no expensive lining was necessary to prevent infiltration of the brine.

It is expected that the provision of fresh water in rural areas will attract more people to live there, with a concurrent increase in the amount of cattle. Desalinated water is not recommended for livestock watering, so other sources of water for livestock should be available. This is the case in Akutsima, where the raw water is brackish and people use it for livestock watering, without negative consequences for the cattle. One of the main issues discussed in the community workshops was upgrading the borehole where the raw water for the desalination plants is extracted, but where livestock are watered too.

3.4 Ownership

The German Federal Ministry of Education and Research (BMBF) – and to some extent the manufacturers also – owned the plants during the pilot phase, while the TU Darmstadt was responsible for organisational issues, operation and maintenance, and scientific supervision, including accuracy of the results. At the end of the pilot phase, it was agreed in 2013 that the desalination plants should be handed over to the MAWF free of charge.

The official handover to the Permanent Secretary in the Ministry of Agriculture, Water and Forestry (MAWF), Joseph Iita, took place in November 2013. The MAWF confirmed the handover and assumed responsibility for operation and maintenance as well as the budget allocation with a letter in August 2014.

CuveWaters has made available information gathered during the pilot phase, including technical monitoring results, O&M costs, operational manuals for LCs and the service provider, spare part lists, checklists for plant inspections etc. This information can be used as a guide for the MAWF and the DWSSC. At the same time, CuveWaters has subsequently been supporting the Ministry in the form of additional training on operating and maintaining the plants and the supplying wells on-site; it has also offered technical advice on demand, and has put the MAWF and the DWSSC in touch with the relevant contact people (plant manufacturers, spare part suppliers, maintenance and repair etc.) at all times when required.

The process leading up to the takeover of ownership was accompanied and prepared by a series of participatory activities with the communities which formed part of coordinated action by CuveWaters, the DRFN and the MAWF (see Tab. 7). The results of these activities were used to incrementally modify the concept so that it addressed the local situation, thus supporting the development of the technical concept. The status of the planning and assessment of the situation in the villages was exchanged with the beneficiaries during a series of four workshops at both sites. This took place between the planning and the construction of the plants (2008-2010). The workshops aimed to strengthen the whole community's ownership of the plants. Differences in terms of water usage and the adaptation of the residents in the two villages that had been observed proved to be important aspects for the respective communication and exchange processes with the communities.

Tab. 7 shows the community workshops that were conducted in each village by CuveWaters (in conjunction with the DRFN and supported by the MAWF) during planning, construction and operation in order to guarantee continuous participation and foster ownership by the local population.

Date	Description	Purpose
July–Oct 2008	1st community assessment (workshop)	Needs and demand assessment (qualitative data on population/households, water use, water sources, mapping); introduction of desalination technology; feedback
July 2009	2nd community assessment (workshop)	Site selection, needs and wishes of the community, security issues
July 2010	3rd community assessment (workshop)	Election of the WPC; water tariffs; introduction to monitoring
Oct 2010	Official inauguration	Official inauguration by the Deputy Minister of the

		MAWF
May 2011	Monitoring (community workshop)	Ownership, assessment of the situation, WPC monitoring
Feb–Mar 2012	Monitoring (community workshop)	Ownership, assessment of the situation, WPC monitoring
Nov 2013	Official handover and community workshop	Feedback for optimisation of operational plan, training on health benefits and use of desalinated water

Tab. 7: Community participation activities

In addition, a workshop was conducted in 2007 with regional and national stakeholders (MAWF, DWSSC, CBM etc.) in order to complete the needs assessment. Several stakeholder meetings with the MAWF and the DWSSC took place during the construction phase. DWSSC extension officers have almost always been part of any community meeting relating to the desalination plants.

Further information is provided in the final project reports of TU Darmstadt and ISOE (Phases I and II) and the CuveWaters reports from the DRFN and ISOE on the situation assessment workshops.

3.5 Services (products)

The main aim of the project – namely providing residents with a safe and reliable supply of clean drinking water – was achieved during the pilot phase. Additional services and achievements of the project include the experience gained with small-scale desalination plants under challenging conditions and the enhancement of skills and capacities at the local, regional and national level.

3.6 Sustainability assessment

The key issue with regard to sustainability is operation and maintenance. Phase II demonstrated that the proposed concept works in principle and the next important step is to significantly reduce the O&M costs. This can firstly be done via certified training sessions for water supply/wastewater engineering technicians/operators in conjunction with the UNAM, the NUST, the service provider, and the DWSSC. Secondly, more desalination plants in a specific region would reduce the specific maintenance costs because the cost of travel to reach the plants in Amarika and Akutsima is high.

A more comprehensive assessment of sustainability is still being prepared.

3.7 Variance of implementation and challenges

3.7.1 Technical performance

- In contrast to the original plans, the daily production of fresh water was reduced to ensure operational reliability (see also 3.7.2).
- The evaporation plant, the multi-stage desalination, and the reverse osmosis are operating reliably with the reduced amount of water that is produced.

- The membrane distillation plant could not perform satisfactorily and had to be dismantled (see also 3.7.3).
- The initial assumption (that distillation plants are more robust and have lower maintenance requirements) proved not to be the case for CuveWaters.
- The chemical-free operation of reverse osmosis was initially considered to be insufficiently well developed; nevertheless, the chemical-free reverse osmosis plant from pro|aqua worked well under these harsh conditions during the pilot phase.

3.7.2 Technological design

According to the initial design, the plants should provide 9 to 20 litres per person and day, sufficient for drinking, meal preparation, and to some extent basic hygiene, too. However, the plants actually produce only 4 to 8 litres per person and day, enough for drinking and some cooking but not for other purposes. In particular, the Terrawater and Fraunhofer ISE plants achieved only 35% and 16% respectively of their design capacity during the monitoring period (Tab. 8). This was mainly due to the suboptimal usage efficiency of the energy from the solar collectors in both plants.

Optimisation measures at the Terrawater plant during Phase III of the project aimed at increasing its production rate and energy efficiency.

Manufacturer	**Design capacity [m³/d]**	**Actual average production [m³/d]**	**Ratio of design capacity reached**
SIJ/IBEU	0.6	0.5	83%
pro|aqua	5.0	3.3	66%
Terrawater	4.0	1.4	35%
Fraunhofer ISE	5.0	0.8	16%

Tab. 8: Design capacity versus actual capacity

3.7.3 Dismantling of Fraunhofer ISE plant

In addition to the above-mentioned problem with the solar collectors, several other challenges arose at the Fraunhofer ISE plant. The hardness of the raw water – together with the chemical-free operation – very often led to scaling inside the membrane, which consequently had to be rinsed with acid. This procedure wore the membranes out and caused leakages. For this reason, it was concluded that the Fraunhofer ISE desalination plant could not be successfully adapted to Namibian conditions and it was decommissioned and dismantled in September 2013.

3.7.4 O&M performance: WPC and LCs

During the pilot phase it was found that the institution of the WPC was the weakest link in the operational concept. Its members did not feel responsible for the plants, turnover was high, and the water was mainly sold by the local caretakers. The residents blamed the local caretakers if any issues arose, whereas the WPC members failed to accept any responsibility. The level of education in the villages is low, so accounting is a challenge for almost everyone.

Support for the WPC: we propose that the WPC should receive more support from the DWSSC, for example from the extension officers. The DWSSC should regularly visit the plants to supervise, support, and clarify issues in the community.

Capacity development of the LCs: it turned out that problems or malfunctions were detected more rapidly via data transmission than by a report from the LCs. The data also helps to discover what the problem is, and servicing trips can be organised more efficiently.

3.7.5 O&M performance: service provider

During the initial stages of independent operation of the plants by the MAWF after the handover, it was made clear that the MAWF wished to continue operating them without the help of an external service provider, but by employing personnel from the regional DWSSC instead. At the request of the MAWF, CuveWaters organised a one-week training course on the plants in Akutsima which was attended by several DWSSC employees from across the country. However, regular maintenance of the plants was never really established after the takeover, resulting in them being out of operation for most of 2014 and 2015. Long standing times are further exacerbating the situation of the plants.

Based on the above, it has become evident that regular maintenance of the plants by qualified and experienced personnel is indispensable for their smooth running and the reliable supply of fresh water to the communities. The external service provider gathered valuable hands-on experience and further developed its expertise via regular visits to – and work at – the plants, and through close collaboration with the manufacturers. This first-hand experience cannot really be replaced by individual training sessions. In addition, the DWSSC personnel mainly consist of breaking-in technicians (mechanics), while an electrician is often lacking. This means that DWSSC staff could potentially gradually gather the experience and knowledge necessary to deal with most problems at the plants, although this process would require constant support and advice from either the former service provider or the plant manufacturers. In addition, a biannual check of the plants by an electrician is recommended, and this would probably need to be outsourced.

3.7.6 Social embeddedness

The way in which the beneficiaries have adapted to the new water source is not as expected. The introduction of a fresh water resource actually allows rural residents to practise a multi-resource mix which makes them less vulnerable to low water quality and water scarcity and offers clean and healthy water.

However, one clear finding in this context is that the villagers need more knowledge so that they can choose the right quality of water for each respective purpose. We observed that there are still many residents who will continue to use hand-dug well water as long as it is available, regardless of its quality. The governance of the water point faces similar challenges to those at other WPCs in the Namibian water supply system. Knowledge transfer and capacity development are therefore ongoing tasks.

There are some findings which seem to explain the lower adaptation of water users in Amarika to the new water source. In our view, the main reasons for the lower water consumption in Amarika are as follows: there is less economic stability, so there is less ability to pay for water. There is also greater access to alternative resources, and they are likelier to be valued as being suitable for human consumption. Management of payments is more difficult, because users have to pay each time they buy water. During the end of the investigation period, the water still tasted salty because one technical component needed replacement, and the fresh water is less suitable for brewing traditional drinks. This latter aspect would need further research.

The health effects are difficult to measure. There are some initial signs of improvement in the core indicators such as diarrhoea, and there are clear improvements in terms of subjective health assessments (see Deffner et al. submitted).

3.7.7 Monitoring time frame

The time frame for the technical monitoring scheme began on 17 July 2010 and ended on 31 December 2011, covering a total of 533 days of operation. Initially, some manufacturers struggled with malfunctions and downtimes, as described in detail in the interim report from 2011.

The time frame for the social monitoring began in July 2010 and ended in July 2012; it was extended due to the cost-neutral prolongation of Phase II of the project. Two monitoring and health surveys, several community workshops, and qualitative research undertaken in the context of the vocational school were conducted during these two years (see also Deffner/Mazambani 2010, Deffner et al. 2010, Deffner et al. 2012/2010/2009/2008, Deffner et al. 2012, Nashandi et al. 2013).

3.7.8 O&M input

Operation and maintenance input was much greater than expected in the first months of operation due to malfunctions and downtimes. After adapting the plants, maintenance input could be reduced to the level that was normally expected.

As previously mentioned, the local caretakers' level of education was lower than expected, and this raised the need for additional training as well as much closer supervision and coordination from TU Darmstadt and the field facilitator. The project recommends that the LCs should receive further (ongoing) training so that they become able to perform minor maintenance routines and repairs themselves, which has hitherto not been the case. This kind of training could substantially reduce the O&M costs.

The WPCs proved to be rather inadequate, so the LCs had to undertake most of their work and responsibilities, which proved to be somewhat problematic. The newly created institution of a WPC in each village also needed more supervision and accompanying efforts than originally planned. Additional meetings with the DWSSC, the regional council and others had to be arranged by the coordinator (TU Darmstadt or ISOE).

3.7.9 Handover and ownership

The Ministry of Finance of Namibia was not able to allocate a budget for the maintenance costs of the pilot plants from 2012 onward as expected. In order to ensure the plants' smooth O&M, CuveWaters paid the salaries of the local personnel during the intermediate period until the handover in 2013. Budgeting by the MoF was then possible since 2013.

The process of budgeting via the MoF is a typical problem which can cause major delays to the Namibian state and public institutions assuming responsibility for costs. Communication between the various ministries can only be influenced by the project to a limited degree.

4. Economic considerations

4.1 Investment

Investment costs for desalination are highly dependent on site conditions. Which type (technology, automation etc.) of plant should be built? Is there any infrastructure for a plant, such as a raw water supply? Can brine be disposed of? Are there any tarred roads? Is electricity available, or what other power sources are there etc.?

Tab. 9 gives an overview of the investment costs for implementing the project's desalination pilot plants. For more detailed information, see Liehr et al. (2015) and Pfeiffer (2014).

Position	**Costs [EUR]**
Planning of preliminary work	28,811
Preliminary work (foundations, fencing, pipelines, ponds, tanks, etc.)	578,000
PV solar system and solar pumps including shipping and set-up	193,008
Customs clearing of 13 containers with plants and solar system	11,888
Measuring instruments	14,878
Logistics (overland transport, water supply, tools, sanitation units, crane during installation)	117,750
Alarm system	574
2 satellite phones with 1100 minutes airtime	4,955
Local workers	927
Training of service provider	8,491
Supervision and food supply	22,376
Workshop responsibilities and ownership	4,581
pro|aqua	135,000
Fraunhofer ISE	200,000
Terrawater	142,186
SIJ/IBEU	48,337
Total	**1,511,762**

Tab. 9: Investment costs

4.2 Operation and maintenance costs

In total, the operation and maintenance costs for the four plants during the pilot phase of the project came to 465,860 NAD per year; without the Fraunhofer ISE plant (which was dismantled in September 2013), the costs amount to roughly 340,000 NAD. Tab. 10 gives an overview of these costs.

4.3 Cost-benefit analysis

As previously stated in relation to the investment costs, O&M costs are also highly dependent on site conditions. For example, the maintenance costs are – amongst other things – determined by the distance that has to be travelled by the service provider to the plants, plus the number of plants at each project.

The dynamic prime costs are calculated for investment, servicing (O&M), data transmission and solar energy and for all plants separately. A distinction is made between the pilot case (based on real costs for the pilot phase) and the market case (based on the assumption that any potential investor should be given a realistic quote and assuming similar conditions to Amarika or Akutsima).

	pro|aqua	**Terra-water**	**SIJ/ IBEU**	**Costs [NAD]**
Service electrician from Windhoek				
Number of visits [#]	2	2	0	
Days per visit [d]	2	2	0	
Travel days [d]	1	1	0	
Working hours at the plants (8 h/d) [h]	48	48	0	
Working hours for daily check of data that has been transmitted (0.5 h/working day for all plants) [h]	35	35	0	
Labour costs [NAD]	74,700	74,700	0	149,400
Travel costs [NAD]		24,000		24,000
Total costs for service electrician [NAD]				*173,400*
Service technician from Oshakati				
Number of visits [#]	6	4	2	
Days per visit [d]	1.5	1.5	3.0	
Working hours (8 h/d) [h]	72	48	48	
Labour costs [NAD]	21,600	14,400	14,400	50,400
Travel costs [NAD]		9,840		9,840
Total costs for service technician [NAD]				*60,240*
Operation & maintenance (without service technician)				
Water analysis without biology [NAD]		14,400		14,400
Biological water analysis (4 per year) [NAD]		17,520		17,520
Spare parts [NAD]	16,000	20,000	5,000	41,000
Fees for data transmission [NAD]	10,000	5,000	0	15,000
Local caretaker (2 at each site) [NAD]		6,000		6,000
Guards (4 at each site) [NAD]		12,000		12,000
Total costs [NAD]				*105,920*
Total maintenance costs per year [NAD]				**339,560**

Tab. 10: Overview of operation and maintenance costs per year (in NAD) as incurred during the pilot phase of the project for the three plants still in operation (without Fraunhofer ISE plant)

The dynamic prime costs in the market case (for investment alone) range from roughly 7-10 EUR/m³ (with a useful technical lifetime of 20 years on average and a 5% discount rate, including spare parts and replacement as well as the investment in solar energy and data transmission). The corresponding O&M costs (market case) for the three plants range from roughly 3-7 EUR/m³ additionally.

Sustainable and safe small-scale solar-powered groundwater desalination is an expensive process, so the area of application must be carefully defined. First of all, alternative water supply strategies (especially water grid extension and road tankers) should be considered. There are limitations to the alternatives in remote rural areas, so water desalination becomes an option. The question that has to be answered is: to what extent are alternative water supply strategies more cost-effective than desalination, and in which cases is desalination the better option?

Analysis showed that although the potential dynamic generation costs (market case) for the three desalination plants in Akutsima and Amarika appeared to be high, they fall within the same real cost range as some alternatives for the water supply in that area (Fig. 4).

The cash flow can be derived from calculating the dynamic prime costs. Selling water at regular prices (7-10 NAD/m³) cannot cover all the costs, so one is left with the question as to who will cover them. A private investor can easily compare the costs with the costs of alternative water supply strategies in their specific case, but this question is more difficult to answer when it comes to supplying water to the population in rural areas. In this case, the Namibian government (the MAWF with the DWSSC) is responsible for the water supply as a public service. The project findings provide some evidence that might help to find ways out of this situation.

One important aim is to reduce the high investment and O&M costs.

- Reduction of investment costs: one possibility for pro|aqua or Terrawater is to produce larger quantities of desalination plants. IBEU is searching for suppliers that will manufacture the plants under licence in Namibia. In Germany, the Taprogge company will manufacture and distribute the plants on behalf of IBEU. A local manufacturer should produce and distribute the plants in southern Africa because the specific costs for transport and on-site installation of such small plants are very high. However, the costs could be dramatically reduced if this were to be done by local companies. Fraunhofer ISE is considering using cheaper components from local markets.
- Reduction of O&M costs: having more plants in a given area minimises O&M costs because travel expenses are less. Moreover, the distance that service providers and skilled technicians need to travel is crucial, so nearby towns or cities offering such expertise can be an important factor in reducing costs.

The Namibian sales and distribution department that is envisaged could be a suitable institution to coordinate the entire process, from quotes to planning/installation and right through to operation and maintenance of the desalination plants.

The Namibian government conducted a feasibility study in an area called the Salt Block. Desalination formed part of this study, but no tendering has taken place up to 2015. The results of CuveWaters can support the government in the decision-making process as to which technological option is the best for supplying this region with water.

Please see Pfeiffer (2014) for details of the results and methods used. For further information, see also Liehr et al. (2015).

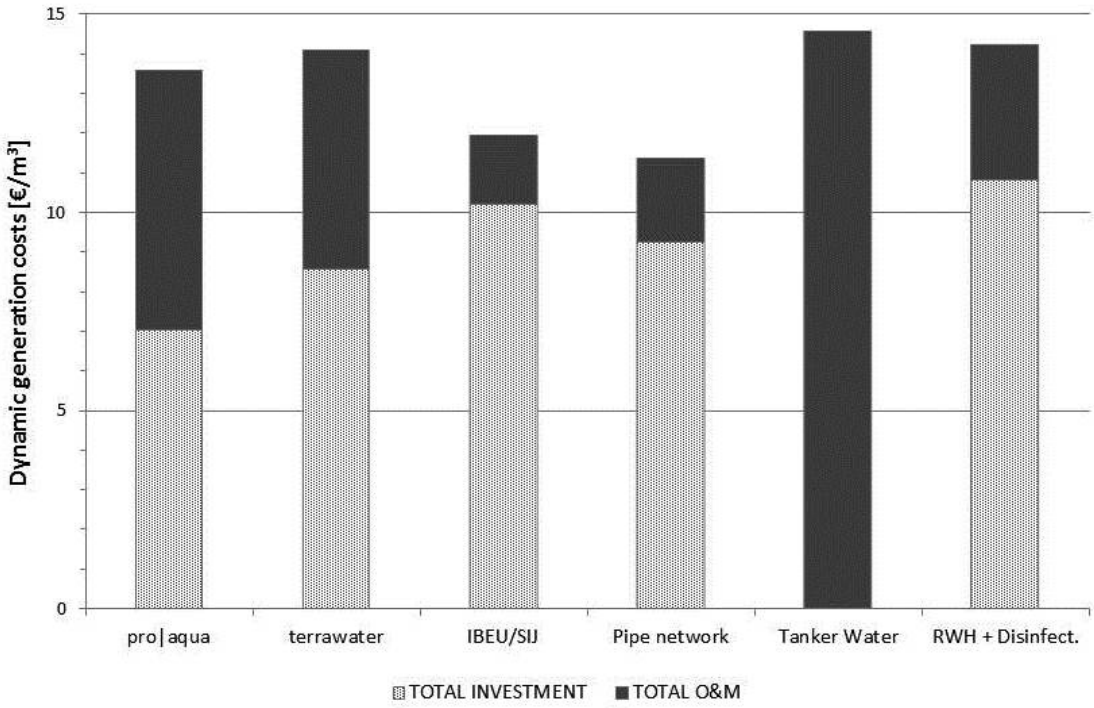

Fig. 4: Comparison of the dynamic generation costs for the three small-scale desalination plants from pro|aqua, Terrawater and IBEU/SIJ, with possible supply alternatives for the region (extension of the pipeline network, supply with tanker water, and rainwater harvesting with disinfection)

4.4 Financing options

Options and instruments for financing the future dissemination of further desalination plants are as follows:

- Development banks (for investment in particular) with loans depending on the specific conditions
- Government and public organisations (for investment and O&M) with budget allocations
- Private investors (for investment and O&M) e.g. for the use of desalination at farms, lodges, mines

See Zimmermann/Lorek (2014/2015) for further information.

5. Transfer/dissemination

5.1 Initial transfer projects

Implementation of the pilot plants has shown that solar-powered desalination plants can be operated under the conditions that prevail in central-northern Namibia.

Further maintenance and optimisation by the manufacturers was executed during Phase III of the project, the aim being to improve the plants' operational reliability. However, due to the long shutdown period of the plants it has not been possible to test the results of these optimisation measures.

Various requests for desalination plants have already emerged for potential future applications:

- 30 desalination plants in the so-called Salt Block in southern Namibia (MAWF)
- Request for a plant from the Olushandja Sub-Basin Management Committee
- At the Water Investment Conference in 2012, various requests for small-scale desalination plants for households came from public and private investors.

5.2 Demand analysis

Manufacturers gave the following responses regarding their experiences of demand and requests relating to the market for desalination technologies:

- pro|aqua: several requests from Asia and Africa for plants similar to the one in Namibia; also requests concerning satellite data transmission. The pilot plant triggered these requests/enquiries. Please contact pro|aqua for more details.
- Terrawater: several requests from Asia and Africa – and one from Namibia – for solar-powered plants (capacity 5-10 m³/d). The pilot plant in Namibia served as a reference. Please contact Terrawater for more details.
- SIJ/IBEU: two requests from Namibia to manufacture plants under licence. Several requests for single modules (50-100 litres/d) at the Water Investor Conference in Namibia (October 2012); several requests from Asia, the Middle East and South America.

Two studies were carried out to identify regions that are potentially suitable for replication of the small-scale solar-powered desalination plants:

The first study by Wende (2015) focused on Namibia and the MSD plant as a suitable solution for implementation at the household level. The potential demand for decentralised water supply (corresponding to limited access to clean water, long distances from the water supply network, and low population density) was analysed along with favourable conditions for the implementation of the MSD desalination plant at the household level (corresponding to high salt content in the groundwater and high groundwater tables that enable water to be extracted via simple manual pumps). The results indicated that regions fulfilling both criteria are very limited in number and surface area, and can only be identified in the Omusati region (where the pilot sites are also located), the north of the neighbouring Kunene region, the Sambesi region, and the north of Karas region in southern Namibia.

The second study by Birkert (2015) aimed to identify suitable regions for the replication of small-scale desalination plants in southern Africa. A set of criteria were developed, including geophysical aspects such as water scarcity and the salinity of groundwater, socio-economic aspects such as the population's access to improved water sources plus incentives for desalination, and socio-cultural aspects that include the size of the rural population and legislative requirements for desalination; the performance of regions in southern Africa was assessed against these criteria. Several regions were identified as potentially suitable, including regions of Namibia, Tanzania, Zimbabwe and Mozambique. More detailed investigations into these regions can offer further insights concerning their suitability when it comes to including small-scale desalination in their water supply system.

5.3 Marketing

The following conferences and trade fairs offer a platform to promote and market the small-scale desalination options:

- IFAT Africa 2015 (Johannesburg, South Africa)
- Viridis Africa: clean technology investment (Johannesburg, South Africa)
- Water Reuse: Blue Resource of the Future (Windhoek, Namibia)
- Windhoek Agricultural Show
- Ongwediva Trade Fair
- Technology round tables in Windhoek as organised and conducted by CuveWaters in 2015

5.4 Networks and partners for dissemination

The following contacts with relevant partners have so far been established because they were already partners in the pilot phase or are potential partners in future transfer processes:

- MAWF (DWSSC)
- ASE
- NamWater
- Lund Engineers
- UNAM, NUST and University of the Western Cape, South Africa
- GIZ (initial contacts at a stakeholder workshop in Ongwediva, October 2012)
- DME Deutsche Meerwasserentsalzung e.V.

5.5 Intellectual property rights management

Intellectual property rights should be discussed directly with the plant manufacturers.

5.6 Success factors

The following aspects have been identified as critical success factors when implementing desalination plants in similar contexts and situations to the Namibian case that we have presented here:

- Successful operation and maintenance needs a multi-level responsibility structure that is embedded into the existing structures, processes and routines.
- A strong sense of ownership of the plants needs to be developed at the operating institution (here: the DWSSC) in order to avoid a feeling that the plants are too high-tech, too sensitive, or too “alien”.
- Maintenance requirements have to be addressed in a timely manner (identification of faults as well as subsequent reaction); this is because the plants are remote and spare parts are often not stocked by local providers.
- In order to support demand, technical implementation needs to be accompanied by awareness-raising within the communities about the benefits of the desalinated water.
- Utilisation of the revenues from the sale of water needs to be transparent by means of a viable scheme which is communicated to the community. In addition, non-revenue water should be kept at a low level.

See also Liehr et al. (2015).

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