Energy optimisation generation within urban water systems

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Intro

The development process of renewable energy (RE) resources in South Africa was spearheaded by the White Paper on Renewable Energy in November 2003. This document established a generation target of 10 000 GWh per annum from available non-coal energy resources by 2013.

The generation output had been envisaged to be extracted primarily from the RE resources namely biomass, solar radiation, wind and small-scale hydropower (<10 MW). The ocean energy exploitation had not been considered at the time. None of the desired RE technology means and products were readily available in South Africa at the time of the WP on RE introduction.

The Electricity Regulation Act (Act 4 of 2006) led to the dissemination of the Regulation on New Generation Capacity. In November 2010 the Department of Energy (DOE) together with NERSA and National Treasury introduced a new Integrated Resource Plan (IRP 2010-2030). The Government promulgated new IRP in May 2011 endorsing thus widely diversified South Africa's future energy generation mix aiming at reducing dependency on the coal-fired energy generation over the next twenty years. At the end of 2011 the DoE and NERSA issued the first order of a 3 725 MW renewable energy capacity, this time entirely allocated to the Independent Power Producers (IPPs).

The RE Independent Power Producers Procurement (REIPPP) programme replaced the internationally adopted REFIT procurement programme, excluding all RE projects below 1 MW in capacity. The REIPPP has been subsequently implemented in three bidding windows and by now the whole RE capacity allotment is fully allocated primarily to the wind, solar PV and CSP large projects. To date the development of RE small-scale projects are not supported by any particular incentives. The banks are reluctant to support small-scale development below 1 MW in capacity. However, so-called embedded generation of hybrid configuration (typically of solar, wind and hydropower) small projects is taking place around South Africa mainly by private developers from their own resources. The research, assessment studies and training in development of embedded generation small-scale projects and technology implementation – specifically focusing on hydropower – are conducted at the University of Pretoria. The university is engaged in the small-scale hydropower research in collaboration with the Tshwane Metropolitan Municipality, Bloem Water and South Africa's Water Research Commission (WRC).

To date the local government authorities and water boards, due to their extensive and demanding functions within the water supply and sanitation chain (i.e. a complex urban water services system), find themselves lacking on the development of renewable energy resources and application of modern technology in their disposal. However the small-scale renewable energy technology options are rather plentiful for most municipalities and water boards as well as interested IPPs.

Energy conservation, efficiency and RE generation programmes

Since 2008 all users of electricity in South Africa and particularly the municipalities were tasked with the implementation of various programmes aimed at the Energy Conservation (EC), Energy Efficiency (EE) and Renewable Energy (RE) technologies implementation.

Energy Conservation (EC) national measures
Conservation measures the in municipal electricity supply and distribution systems have been implemented for a while now. Examples of this include the timing of electricity usage and applying new technological measures. Individual users are tasked with implementing savings measures indoors (e.g. heating, ventilation, air conditioning, lighting, appliances, hot water, fans and pumps) and outdoors (e.g. security lighting, swimming pool, and outbuildings).

Energy Efficiency (EE) measures within the urban water cycle
The efficiency measures are related more to the optimisation of energy usage and application of advanced technology. Specifically within the municipal water-cycle chain, the improvements in energy efficiency are related to the pressure management and leakage reduction, off-peak pumping, baseline energy audit, solar heating and composting, digester mixing optimization, oxygenation capacity and efficiency of algal oxidation ponds, submersible versus self-priming pumps, load shedding, load shifting and water distribution systems optimization). Further substantial improvements in energy efficiency may be obtained from the CHP biogas to electricity, a cost-benefit model for biogas production, energy recovery in desalination systems, recovery from reverse osmosis, fine-bubble diffused air and air injection systems, hydropower generation in pressurised distribution networks, and low-head hydropower generation.

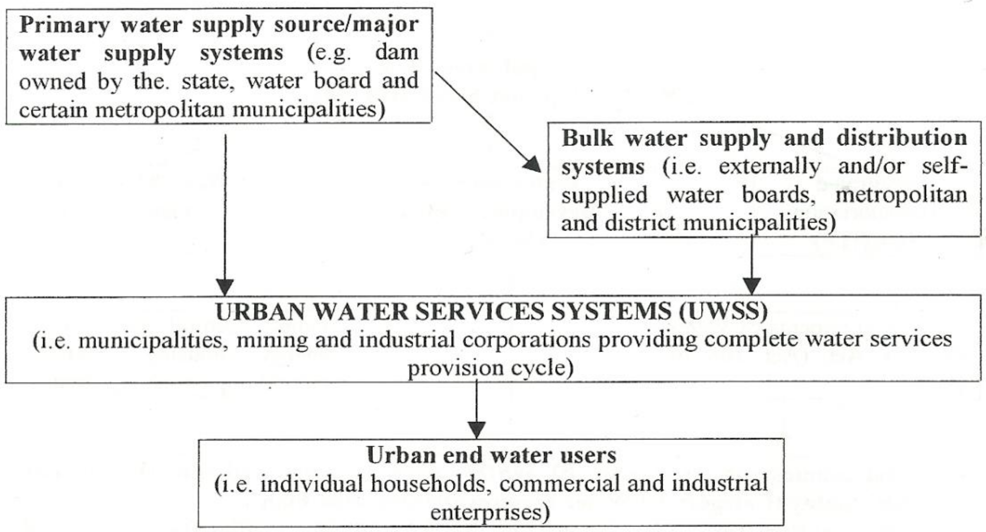
The Second National Energy Efficiency Strategy (NEES) review was instituted in July 2012 introducing the new measures through legislation, incentives, standards and training incentives as given below:

- South African NEES standards
- regulations for allowance on EE savings, Section 12L of the Tax Amendment Law Act, 2013.
- national building codes and regulations (e.g. SANS 204)
- minimum energy performance specifications (MEPS)
- energy efficiency policy recommendations adopted from the International Energy Agency focusing on a 7th priority of Energy Utilities to match the Eskom incentives.

It should be noted that the above listed measures are to enable the key goals of the NEES as energy conservation, energy efficiency and the demand-side management are implementable. The municipalities and water boards should get familiar with the impacts of new measures on their energy usage within relevant supply areas. The EC and EE measures together with implementation of RE technology will reduce the demand for electricity from the national supply if all entities, as well as individual users, will implement such measures on a sustainable basis.

Complex urban water cycle system energy demand and savings

The Department of Water Affairs (DWA) is a custodian of the raw water resources from where water is supplied either directly or via a water board to the local government authorities (i.e. district or local/metropolitan municipalities). The local government authorities overseen by the Water Services Authorities (WSA) looking after the day-to-day operation, maintenance and future development of sustainable water and electricity supplies, as well as sewerage services provision besides other important municipal services, i.e. waste management, roads and storm water, housing, etc. The municipalities and water boards in South Africa are also responsible for the rehabilitation and upgrading of their water supply and wastewater treatment and disposal infrastructural assets. Theoretically, most of such water assets are having besides the demand for energy also a potential for generating energy at various processes and asset locations. The energy demand for pumping within the water supply processes is much larger than for pumping of wastewater. The energy demand from water supply and wastewater processes are proportionally about 52%to 48%respectively. The institutional stakeholders in South African water sector should be concerned about the energy consumption and in-house energy generation issues within the national, regional and municipal water cycle systems.



Institutional hierarchy in South African Water Services Sector

The electricity consumption encountered by a municipality or water board in running the complex water services systems (i.e. abstraction/pumping, treatment/pumping, storage, supply/distribution, collection/pumping/treatment and disposal processes) amounts to a significant cost in the overall municipal or utility budget.

Energy demand and possible gains within complex urban water services cycle

Water supply cycle (chain)		**Energy requiring process**	**Process energy demand**	**Potential energy savings within the processes**
Raw/ potable water	Abstraction	Pumping if not gravity – configuration depending	**max 100 kWh/Mℓ**	Energy efficiency motors and pumps (up to 12%)
	Treatment	Pre-treatment, clarification, filtration, disinfection, etc.	**150 to 650 kWh/Mℓ**	Between 0.014 and 0.021 kWh/m^3 (by refurbishment up to 20%)
	Distribution (consumption)	Pumping if not gravity – configuration depending	**max 350 kWh/Mℓ**	Devices fitted: 0.91kWh/m^3 or 0.05 m^3/day/household
Waste-water (sewage)	Collection	Pumping if not gravity – configuration depending	**approx. 100 kWh/Mℓ**	Heat pumps & in-sewer heat exchanges
	Treatment processes	Screening, grit, sedimentation, aeration, RAS, disinfection, tertiary/advanced	**200 to 1 800 kWh/Mℓ**	ASP Aeration: 0.063 kWh/m^3
				ASP nutrient removal: 0.291 kWh/m^3

		treatment		
	Disposal	Pumping if not gravity – configuration depending	**minor within WWTW**	Energy recovery by hydro-turbines or hydraulic screw (0.018 kWh/m^3)
	Sludge handling	Thickening, dewatering, digestion, drying and disposal	**mainly from belt presses, centrifuges, etc.**	Approx. 0.101 kWh/m^3 (with efficient devices fitted up to 23%)
Sources: British Compendium (UKWIR, 2010) and DWA's Green Drop water chain criteria and assessment approach.				

The amount of electricity required in the operation processes of a water cycle system vary depending primarily on the extent of pumping and treatment requirements. The other factors influencing significantly the electricity requirements are related to the technological status of a system and the quality of water and wastewater being treated.

At present, practically all municipalities and water boards in South Africa are connected to the national grid administered on behalf of the Government by Eskom. Although the situation is changing there are only a few municipal and large industrial/mining electricity users which are capable generating green energy within their own systems. Most existing water services systems in the urban as well as rural areas are having components where the usage of energy can be reduced or even discounted by generating own energy in a whole subsystem or a specific place of the subsystem. Within a complex urban water services system the availability energy generation can be investigated by two approaches: energy conservation (i.e. demand side measures) and/or energy generation (i.e. supply side measures).

Hydro energy potential hidden within the urban water cycle systems

South Africa, as a water stressed country, has developed extensive and complex bulk supply and distribution water-supply infrastructure (e.g. dams, canals, pipelines, service and distribution reservoirs, etc.) where a significant hydropower potential is hidden. If such potential is developed it can discount energy demand on the national electricity grid.

Hydropower in surface and groundwater supply systems

Most of South Africa's municipalities are supplied with the surface water, abstracted from either state-owned or their own dams. There are several municipalities depending entirely on the groundwater supplies. Numerous municipalities are supplied directly with potable water via some twenty water utilities (e.g. Amatola Water, Bloem Water, Magalies Water, Rand Water, Sedibeng Water, etc.).

South Africa has in total some 4 500 dams of various sizes. From the total number, about 260 dams are in the ownership of the local government administration. However there are only some 70 municipal dams having capacity over 1 million m^3 (i.e. 1000 Mℓ). Among those dams are a few with good potential for the hydropower retrofit. Some of suitable municipal dams are listed below.

Municipal dam impoundments with significant hydropower potential

Dam name	River	Municipality (province)	Capacity (million m^3)	Location of hydro-energy potential
Bridle Drift Dam	Buffalo	Buffalo City Metro (EC)	73.5	From river releases
Churchill Dam	Fish/ Tsitsikamma	Nelson Mandela Bay Metro (EC)	33.3	From both river releases and conduit supply
Lake Mzingazi	Mhlatuze	Umhlathuze (KZN)	37.0	From conduit supply
Middelburg Dam	Olifants	Steve Tshwete (MPM)	48.4	From river releases
Ngweba Dam	Fish/ Tsitsikamma	Camdebo (EC)	46.4	From conduit supply
Sol Plaatjie Dam*	Upper Vaal	Dihlabeng (FS)	15.7	Already retrofitted with hydropower generation
Witbank Dam	Olifants	Emalahleni (MPM)	104,0	From both river releases and conduit supply
*Note: The Sol Plaatjie Dam of the Dihlabeng LA had been retrofitted with capacity installation of a 3 MW hydropower in 2009.				

It should be noted that there are other dams owned by entities, as are former irrigation boards (e.g. Impala Water's Bivane Dam) where the small-scale hydropower schemes can be installed. There are also privately-owned dams, where the small-scale hydropower projects being currently developed (e.g. new Bains and Boschendal mini hydropower installations in the Western Cape Province).

Bulk water supply and long conduit water distribution

Many municipalities and some water boards in South Africa benefit from the state-owned inter-basin water transfer schemes (WTSs). There are now some 30 such schemes built to overcome imbalances between geographical water availability and an ever-growing demand for water in the locations without much of natural water available. Typically the raw water is transferred from one river basin to another by means of pumping or gravity via large tunnels. If a municipality is not receiving raw water directly, the raw water will be conveyed by pumping or gravity to one of the water boards (e.g. Rand Water) to be treated and the bulk potable water distributed to the municipalities, industries and mines via the service and distribution reservoirs. Several WTSs have one or more locations where the small-scale hydropower generation plant(s) can be installed, mainly on the gravity pipelines where it is required to reduce the hydrostatic pressure.

The bulk water supply and distribution are the most critical and costly components of the urban water supply system. Thus the savings in these areas through the processes optimization and retrofitting new technology, can offer conservation results in water supply and energy consumption. Most of the operation pumping is taking place within the bulk supply.

Hydropower as pressure reduction in delivery pipelines

The pressurized conduits (at both pumping or gravity) most of them in operation by the water utilities and municipalities are experiencing at certain locations excessive pressures which must be curtailed typically by the pressure reducing valves (PRVs). At such locations the installation of hydro-energy generation devices may be considered. The PRVs are typically installed before the inlet of a reservoir or a breaking point (structure) of a long gravity pipeline. Table below illustrates current hydropower developments taking place at the foremost municipalities and water utilities utilizing this approach in developing available hydro-energy.

Water Supply Systems and potential sites of in-line hydropower development

Water Supply System	Considered hydropower development	Identified sites with hydropower potential
Bloemfontein Water (regional water utility)	Mini hydropower installations on the pressure Caledon-Bloemfontein pipeline	Uitkijk and Brankop reservoirs totaling almost to 1 MW (other options are investigated)
eThekwini Water and Sanitation Department	The installation of six mini hydro sets considered at various reservoirs	Sea Cow Lake, KwaMashu 2, Aloes, Phoenix 1 and 2, Umhlanga 2 totaling to about 750 kW
Tshwane Water Supply Area	A pilot plant of 15 kW has been installed at Pierre van Ryneveld old Reservoir. Several other sites available.	Estimated capacity of 8 MW is envisaged among 10 suitable city's reservoirs
Rand Water (foremost water utility)	In-line hydropower has been identified and evaluated at a 13 MW of hydropower capacity. Another 40 to 50 MW capacity is envisaged to develop	Brakfontein Reservoir. (1.8 MW), Hartebeesthoek Reservoir (2.2 MW), Klipfontein Reservoir (3.4 MW), Zoekfontein Reservoir (5.6 MW)
Source: www.sinotechcc.co.za/courses/workshop.php		

The Pierre van Ryneveld Reservoir Hydropower Plant

According to the WRC/UP K5/2095 progress report dated January 2012 the City of Tshwane MM (CTMM) in collaboration with the University of Pretoria (UP) implemented a pico-hydropower (<20 kW) installation at existing Pierre van Ryneveld Reservoir situated south-east of the Pretoria CBD. The hydro-static pressure available between the Rand Water (RW) service reservoirs and the CTMM's distribution reservoirs is being utilized in generating hydro-electricity for the security lights, alarm and communication purposes. Some 130 MWh per annum can be generated from this installation. The turbine selected for this site, taking in consideration available parameters, is the cross-flow type of local design. The turbine/generator plant is located at the edge of existing reservoir roofing releasing the flows into the atmospheric pressure, which is important in a selection of suitable turbine type. The turbine is equipped with a guide vane to allow for the regulation water consumption patterns. The guide vane is operated by a screw, turned by a removable lever. The turbine/generator unit operates at constant water consumption, which means constant power, normally at full load. A roller type bearing is used on the drive side (pulley) and a ball-bearing type at the drive type at the non-drive end. The latter was selected to obtain an acceptable radial load, which would be too small for a roller type bearing.

Hydropower hidden in water distribution networks

Terminal consumer installations

Theoretically every urban household having an inflow pipe diameter of 20 mm and a flow under at least 10 m head could generate some 50 Watt of electricity during each tap opening. However this energy will have to be stored in a battery system and preferably fed also by a roof solar PV system or any other renewable energy technology application in a hybrid configuration to obtain significant household energy capacity.

Report No. KV 238/10 of the WRC concluded that the flows of potable water passing through the domestic water supply piping during an average day may be utilized for the pico-hydropower (<20 kW) primarily for household energy uses (e.g. charging of cell-phones, security, etc.). The flow exceedance curve can be constructed to assess the availability of the hydropower that might be produced. It is also necessary to determine the pressures in the water supply pipelines.

Residual pressures in urban areas – to obtain the residual head at any point in the reticulation network, such networks should be balanced using instantaneous peak flows (IPF) and fire flows.

Standard head and flow provision at terminal water installations

<table>
<tr><th rowspan="3">Minimum and maximum water head at the house connection</th><th>Type of development</th><th colspan="2">Min head under IPF (m)</th><th>Max head under zero flow (m)</th></tr>
<tr><td>Dwelling house connection</td><td colspan="2">24</td><td>90</td></tr>
<tr><td>Dwelling house yard tap and tank</td><td colspan="2">10</td><td>90</td></tr>
<tr><th rowspan="4">Typical discharge rates for domestic taps</th><th rowspan="2">Tap diameter</th><th colspan="3">Discharge (litres/minute)</th></tr>
<tr><td>5 m head</td><td>10 m head</td><td>60 m head</td></tr>
<tr><td>15 mm</td><td>16</td><td>23</td><td>54</td></tr>
<tr><td>20 mm</td><td>22</td><td>31</td><td>70</td></tr>
<tr><td colspan="5">Source: Municipal Red Book (Chapter 9)</td></tr>
</table>

Potential energy gains from wastewater management

The WRC study undertaken in conjunction with the South African Local Government Association (SALGA) established that there are some 850 municipal wastewater treatment plants (WWTW) of various processing capacities and treatment stages (i.e. from preliminary to advanced treatment). It is essential to any WWTW that it has a sustainable and continuous supply of electricity. If a WWTW is subjected to the power interruptions and pumping stoppages the untreated wastewater is usually spilled directly into receiving river (i.e. ecosystem). Some of the WWTW are having sufficiently large attenuation dams installed. Although some plants, catering for the advanced treatment processes, would be equipped with some kind of stand-by, most small and medium WWTWs do not have any particular back-up. Typically, the existing WWTWs in South Africa are not designed to utilize energy generation potential either at the various processes illustrated earlier, or from the large quantities of treated wastewater released.

Besides energy savings within the wastewater treatment processes the hydro-energy can be recovered on the outfall in front of the plant and/or after the treatment processes on the outfall into receiving river ecosystem. According to available head configuration and the quantities of treated wastewater the type of water turbine can be selected as shown in the table below.

Basic turbine type selection criteria

Turbine	**High head**	**Medium head**	**Low head**	**Ultra-low head**
runner	**> 100 m**	**20 m – 100 m**	**5 m – 20 m**	**<5 m**
Impulse	Pelton Turgo	cross-flow turgo multi-jet pelton	cross-flow multi-jet turgo	water wheel
Reaction		Francis Pump-as-turbine	Propeller Kaplan	Propeller Kaplan
Note: More detailed information on selection of suitable hydro-energy generation equipment for the wastewater outfalls is available from the WRC/UP project K8/1017				

It should be noted that by performance the impulse runner type turbine are more suited to the high head applications where the reaction runner type turbines are most suitable for the low head hydropower installations can function with extremely low heads.

Water conduit hydro-energy availability assessment procedure

The University of Pretoria developed, under WRC/UP Project K5/2095, the conduit hydro-energy assessment Decision Support System (DSS) for the purpose of assessing hydropower availability to assist to the municipalities and water utilities administering water supply systems.

Layout of DSS for assessment of hydro-energy in the water supply conduits

Phase	**Essential inputs**	**Desired outputs**
Phase 1:	Average daily flow	First order power analysis
	Average pressure head (or static head)	Initial estimate of net present

Pre-feasibility		value
	Distance to grid connection (if applicable)	Initial estimate of internal rate of return
	Power demand (if applicable)	Initial estimate of payback period
	Project design life	Optimum design flow and head
Phase 2: **Feasibility**	Measured flow records	Initial turbine selection
	Measured pressure records	Flow rating curve
	Environmental studies	Net present value
	Regulatory assessment	Internal rate of return and Payback period
Phase 3: **Detail design**	Similar to Phase 2, but with additional data	Final turbine selection
	All project costs	Detail drawings
	All expected income	Net present value
	Operational criteria	Internal rate of return
	Detail design of all civil and electro-mechanical components	Payback period
NB: A fourth phase, dealing with operation and maintenance aspects (outside the scope of this study) is also an important phase to consider when designing a conduit hydropower facility.		

Each phase, as illustrated above, has its own process flow diagram linked to the Conduit Hydropower Potential Tool (CHD Tool). Some of the inputs will occur in more than one of the phases. As the project progresses the inputs require to be more detailed.

The DSS that can be used to identify conduit hydropower potential at any system where essential data listed in Table above is available. DSS provides guidance for the development of identified potential sites. A system of flow diagrams and tools is available to enable evaluation of identified site. A systemic approach, consisting of three phases, was developed for the assessment of hydropower potential in a water supply system to ensure that all relevant factors are considered. The three phases, comprising essential input and output parameters, are illustrated below.

Legal and regulatory requirements in developing hydro-energy project

The development of renewable energy resources is relatively new activity and rather untested ground for both public and private sectors in South Africa. In reality there are no firm guidelines for implementation of development stages in creating a renewable energy municipal asset. However, most physical infrastructural assets created in South Africa are developed along the pre-procurement stages as follows:

- project planning/inception stage
- project pre-feasibility stage
- project feasibility stage leading to compilation of a bankable study.

The municipalities have to find their own tendering or PPP implementation approach based on suitable contractual procedure as they will need hydropower consulting services. The hydro-electricity development is rather specialized field in designing of installation and its procurement. There are several options available to the potential IPPs in negotiating with the national departments, parastatals and local government authorities to arrange for an access to the resources and infrastructure which are owned/administered by the state, parastatals and local government authorities.

The general regulatory environment is guided in South Africa by the Constitution via the Parliament, Courts and Tribunals. The key regulatory instruments relevant to the water resources and energy development sectors are to comply with the environmental, water use and disposal and energy generation are:

- National Water Act (Act 36 of 1998)
- Electricity Regulation Act (Act 04 of 2006)
- National Environmental Management Act (Act 107 of 1998).

All three pieces of legislation have a direct influence on the development of renewable energy resources and implementation of technological choice within the urban/rural water services system context. Within the municipal and water board context, the DOE/NERSA standard conditions for small-scale embedded generation within an entity boundaries, allows RE projects to be implemented. The licencing requirements to be observed during the process of renewable energy capacity development at the local government and water board levels are illustrated in table below.

Essential licencing requirements

Regulatory/legal requirements	Usage options			
	Own use	Islanded use	Municipal grid	Eskom grid
	For own use and from grid; but not into grid	Completely independent	Feeds into	Feeds into
Environmental ROD	If <20 MW: Basic assessment (BA) ito S1 activities (GN544); If > 20 MW: EIA ito (amendment to original build's EIA or BA; or new)			
Water Use Licence	• **Repair/rehab/upgrade** (i.e. public or private ownership): Not required unless an increase of a water flow is required • **Augmentation of existing infrastructure** (e.g. pipelines, canals, etc.) Water permit not normally required if not a state's asset • **Retrofitting hydropower to non-powered dams:** Water permit is			

	required subject to possible exemption (i.e. for a community socio-economic/environmental reasons) • **Development of "greenfield" hydropower (not associated with existing infrastructure)** Water use permit is required on all accounts together with a BA or Environment Impact Assessment (EIA)				
Electricity Generation Licence	If < 1 MW none	If for non-commercial none	If < 100 kw none	If > 100 kw yes	Yes (only IPPs through REIPPPP)

Each municipality must match the general legal and regulatory requirements with their local municipal by-laws and regulations integrating the environmental, energy generation and water services legislation. The municipal Integrated Development Plan is perhaps one existing mechanism where the renewable energy development proposals should be incorporated.

Conclusion

The key objective of the IRP 2010-2030 for South Africa is to develop sustainable future energy generation mix producing a significant reduction in the coal-fired generation. The EC and EE programmes together with development of available RE resources (i.e. particularly solar radiation, small-scale hydropower from existing infrastructure, wind and where suitable also ocean energy) became now the national priorities as the margin between demand and supply in electricity from the national grid is very thin. Most of enabling mechanisms are in place to allow for orderly development (refer also to the updated IRP 2010-2030 as published for public comments in late 2013).

On the international scale, South Africa is ranked as the 12th-highest carbon-emitting nation in the world (South Africa's electricity sector contributes by 45% of total emissions). However, the abundance of particularly solar radiation in most regions of South Africa together with the positive implementation results of the REIPPP programme, the country is now widely recognized as future leading renewable energy investment destinations. The RE industry in South Africa is on the *threshold* of significant growth in all spheres of RE technology industries, with the PV market municipal rooftop systems being the strongest component.

Although the energy generation from the solar sources is most suitable for the development in South Africa and particularly within the municipal context, the hydro-energy hidden within the municipal and water board water services systems is another viable renewable and sustainable option open to the owners/administrators of these systems. The future upgrading and optimization of existing water services systems in South Africa to be gravitating primarily to a combination of the solar and hydropower technologies (i.e. as per international tendencies).

The research and assessment tools with development potential, particularly of embedded generation small-scale hydropower supported and financed by the Water Research Commission are being conducted at the University of Pretoria with collaboration with the Tshwane Metropolitan Municipality and Bloem Water board. The University of Pretoria can help to the municipalities and water boards in assessing of energy savings and hydro-energy potential within their water services systems.

References

WRC Report No. KV238/10. *A high level of scooping in the supply of water through pressurized conduits.* April 2010.

WRC Progress Report 1: K5/2095. *Energy generation from water distribution systems.* Pretoria January 2012.

WRC Report No. TT 565/13. Energy Efficiency in the South Africa Water industry: *A Compendium of Best Practices and Case Studies.* June 2013

WRC/UP Project K8/1017. *Energy generation using low head hydropower technology.* August 2013 (draft).